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Strain-hardening during compression of closed-cell Al/Si/SiC + (TiB_2 & Mg) foam

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ABSTRACT

Three sets of Al–Si alloy closed-cell foams, i.e. Al7Si + (3SiC), Al7Si3SiC + (3 Mg), and Al7Si3SiC + ($3TiB_2$) were produced. The deformation behaviors of the foams were then studied by means of compression test. The load–displacement curves showed that foam containing 3 wt.% Mg had considerable stress oscillations. However, the plateau stress and the dissipated energy increased more than 100% for foam with 3 wt.% TiB_2. Accordingly, microstructural investigations displayed that compressive responses of foams were dependent on bonding mechanism of SiC and TiB_2 particles to the matrix and their distributions. Then, a technique was developed for determination of crushing start point regarding to absorption energy-stress curves. It was found that the hardening for foam with 3 wt.% Mg cannot be described by a simple power-law function, while an asymptotic function is proposed for properly determination of the hardening behavior of foams.

1. Introduction

In the last few decades, utilization of aluminum alloy foams witnessed a rapid growth in a variety of industries, due to their unique combination of properties [1–3]. Metal foams as advanced materials are categorized in two groups, based on their cellular structure: i) open cell foams, and ii) closed cell foams. Industrial applications of open cell foams are in the field of filtration, and thermal or ionic exchangers. However, the closed cell foams have applications such as impact, sound, and vibration energy absorbers. Today, the closed-cell foams as energy absorbers, crash boxes and bumpers in the automobile industry are commercially available [4,5]. The closed-cell metal foams can be manufactured through either casting or powder metallurgy. In powder metallurgy, TiH_2 or $CaCO_3$ powders as a foaming agent are mixed with the metal powder. Then the powder mixture is consolidated into a precursor by hot extrusion. Finally, the precursor will be foamed by heating in a furnace. However, in the casting route, after melting of base metal, blowing agents of TiH_2 or $CaCO_3$ are added to the liquid which is stirred by using an impeller. Then the liquid with a numerous bubble nuclei is poured into a hot metallic mold and is held in the foaming temperature for a few minutes for bubbles growth. In the next step, the liquid foam is cooled rapidly. With regard to the fabrication methods, aluminum and aluminum alloys are best candidates for metallic foams due to their excellent mechanical and physical properties. Al-foams are considered as suitable materials for energy absorption thanks to their cellular structure. Al-alloy foams demonstrate a plateau of almost constant stress in the uni-axial compressive stress–strain curve with the densification strain value up to 75%, which indicates a high energy absorption capacity [1]. It is known that a typical compressive stress–strain curve of the metal foam has three regions including the following: i) elastic deformation, ii) full plastic deformation together with cells crushing and partial strain-hardening up to the densification strain, and iii) hard plastic deformation with large strain-hardening after the densification similar to dense materials deformation. As compared to bulk metals, metal foams exhibit larger deformation in compression testing. Then, it is reasonable to ignore the elastic deformation range in comparison to the plastic deformation range. Johanson and Mellor have presented several experimental equations for plasticity of materials such as $\sigma = a(1-\exp(-n\varepsilon))$, $\sigma = c(a+\varepsilon)^n; 0 \le n \le 1, \sigma = Y\tanh(E\varepsilon/Y)$, and $\sigma = Y + H(\varepsilon)^n$ [6]. However, the best approximations for large strain values in stress–strain behavior of materials include the following [7,8]: 1) perfect plastic material, 2) linear strain hardening material, and 3) nonlinear strain. If a material has a very small strain hardening rate, then its behavior can be approximated by an ideally plastic material with no elastic range and a zero strain hardening rate ($\sigma = \sigma_0 = \text{etc.}$). For materials with a nearly constant strain hardening rate, a linear approximation of strain hardening is useful. If the elastic region is ignored, a rigid-linear strain hardening describes as equation ($\sigma = \sigma_0 + k\varepsilon$) (with σ_0 being the stress at the onset of plastic deformation) [9,10]. However, in many materials including metals, the stress–strain behavior for large strain deformation can be approximated by $\sigma = k\varepsilon^n$. Values of K and n depend on the material characteristics and describe the strength

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