JMEPEG (2012) 21:985–987
DOI: 10.1007/s11665-011-9976-2

1059-9495/$19.00

Influence of Cell Shape Anisotropy on the Compressive Property of Closed-Cell Al-Si Alloy Foam

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(Submitted January 7, 2011; in revised form April 16, 2011)

Closed-cell Al-Si alloy foams have been prepared by melt route. The cell shape anisotropy ratio of Al-Si alloy foams specimens in relative density range of 0.11-0.39 were measured. The quasi-static compressive tests show that Al-Si alloy foams have higher plastic collapse stress in the longitudinal direction (LD) than in the transverse direction (TD). The plastic collapse stress ratio increases with cell shape anisotropy ratio, which is basically in agreement with Gibson and Ashby model. Moreover, energy absorption capacity of Al-Si alloy foams was investigated. The results show that the energy absorption capacity in the LD is higher than that in the TD.

Keywords mechanical testing, metal-matrix composites, non-ferrous metals

1. Introduction

Metal foams, offer lightweight, high specific strength and good energy absorption property, are a relatively new and uncommon group of engineering materials (Ref 1). The compressive behavior have been received much attention in recent years for metal foams due to their potential applications (Ref 2-7). However, the anisotropy of cells was rarely taken into account. Metal foams, like most polymer foams, are anisotropic. Anisotropy can arise in two quite different ways: structural anisotropy and material anisotropy (Ref 8). The more obvious for metal foams is structural anisotropy: direction-dependent foam properties attributable to the shape of the cells. Kitazono et al. (Ref 9) pointed out that the Al-Mg alloy foams manufactured through accumulative roll-bonding process usually have elongated pores in transverse directions (TDs). Despite the frequent reports of anisotropy, there is little information on the comparison between mechanical properties and theory model.

In this work, Al-Si alloy foams have been manufactured through melt route using TiH_2 foaming agent. During the melt foaming process, especially in the cooling stage, the pores were elongated in rise direction. For this reason, aluminum foam may become stiffer in the rise direction than in the other two. The purpose of this work is to study the compressive behavior of axisymmetric Al-Si alloy foams in two directions.

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2. Experimental Procedure

The raw materials for preparing foams were Al-Si alloy (6.5-7.5 wt.% Si, 0.25-0.45 wt.% Mg), high purity metal Ca and the powder of TiH_2 (with granularity of 45 μm). Ca about 3 wt.% was used as thickening agent. TiH_2 powder in the size range of 40-50 μm of about 1.5 wt.% was used as foaming agent. Al-Si alloy is used as virgin alloy. The method involves number of steps: (1) Al-Si alloy and Ca were melted to 850 °C in crucible furnace, (2) the TiH_2 foaming agent was added into the melt at 680 °C, the stirring rate 2000 rpm, (3) after holding for a certain period at 660 °C, the crucible was taken out of the furnace, and (4) the melt was cooled to room temperature in air. The density, ρ^*, of the foamed specimen, is measured by Archimedes' principle. The relative density is defined as ρ^*/ρ_s, where ρ_s is the density of the matrix of which it is made. The measured specimens were cut in both the TD and the longitudinal direction (LD). Figure 1 shows the anisotropic cells morphology of Al-Si alloy foam. It is clear that cells in the LDs were elongated.

The cell shape anisotropy ratio, which was defined as the ratio of the longitudinal dimension to the transverse dimension, was obtained from the Image-Pro system by counting of 400 cells on the surfaces of a typical sample. The dimension of compression test specimens was 30 × 30 × 45 mm. Quasi-static compression tests were conducted in CMT5105 material testing system with a rate of 1 mm/min, i.e., with a strain rate of 5.6×10^{-4} in the specimens.

3. Results and Discussion

The anisotropy ratios of 19 specimens in relative density range of 0.11-0.39 were measured and the results were shown in Fig. 2.

At least three tests were conducted for each specimen to guarantee the reliability of the results. It can be seen that the anisotropy ratio increases first and decreases afterward with the relative density. The anisotropy ratios are higher in the relative

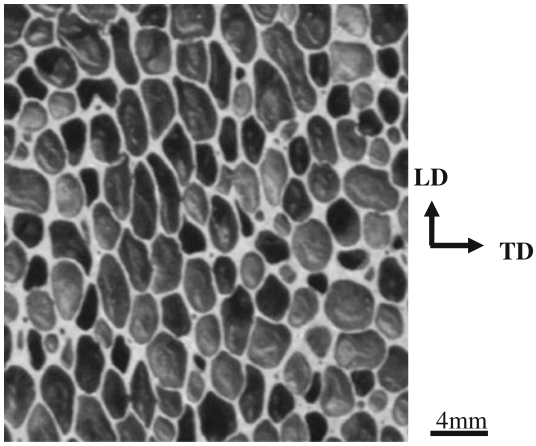

Fig. 1 The anisotropic cells morphology of Al-Si alloy foam: $\rho^*/\rho_s = 0.136$ (LD and TD in the figure indicate the loading directions during quasi-static compression tests

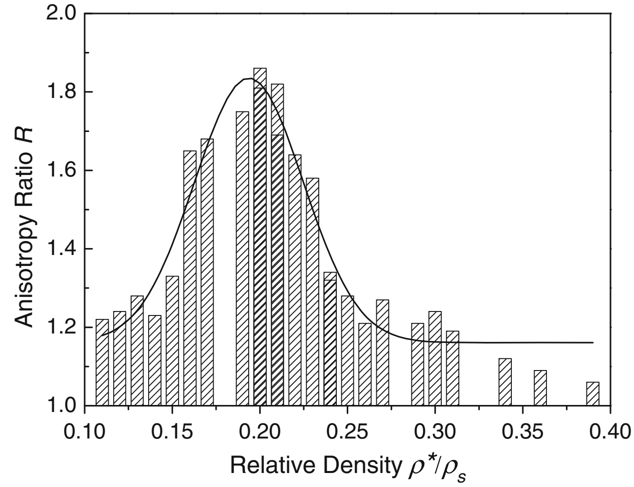

Fig. 2 The anisotropy ratios of specimens in relative density range of 0.08-0.31

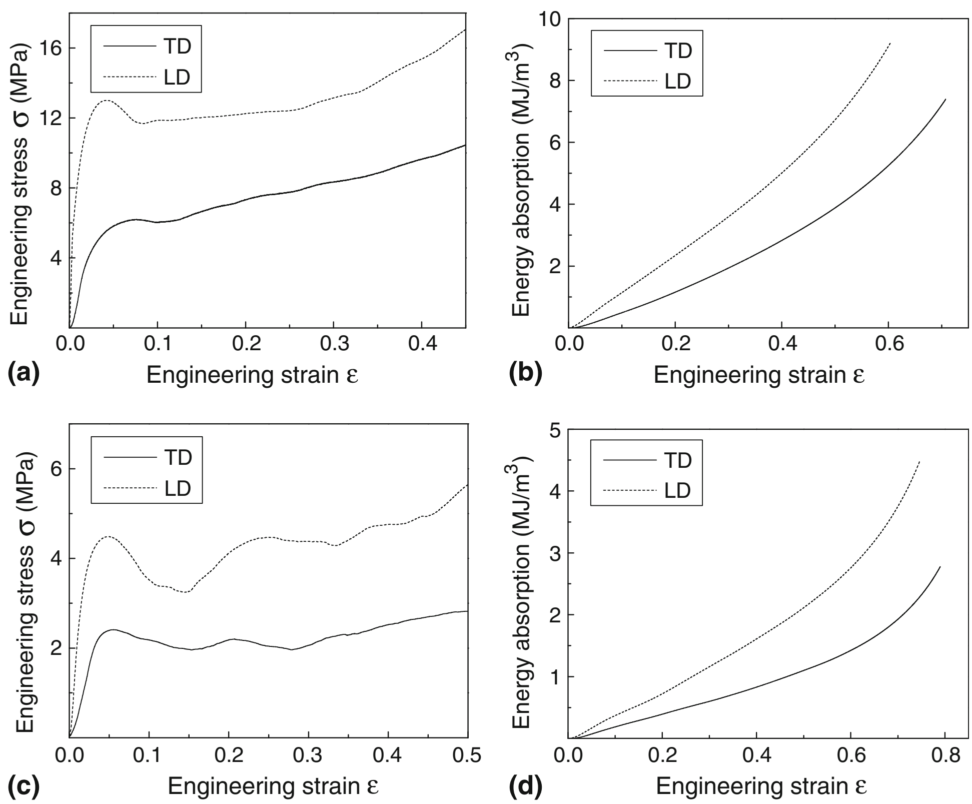

Fig. 3 The engineering stress-strain curves (a, c) and the energy absorption curves (b, d) in the TD and LD specimens. (a) $\rho^*/\rho_s = 0.21$, $R = 1.78$; (c) $\rho^*/\rho_s = 0.13$, $R = 1.51$; (b) energy absorption of specimens in a; (d) energy absorption of specimens in c

density range of 0.18-0.22. When the relative density is above 0.25, most cells of Al-Si alloy foams are spherical or roughly spherical, with the result that the anisotropy ratio approximately equal to 1.

The typical anisotropic engineering stress-strain curves and the energy absorption curves in the TD and LD for Al-Si alloy foam specimens with relative density of 0.21 and 0.13 are shown in Fig. 3. Since the densities of the two kinds of specimens (TD and LD) are almost identical, the effect of the porosity can be ignored.

The energy absorbed per unit volume (W) can be obtained from the area under the stress-strain curve (Ref 10), namely:

$$W = \int_0^{\varepsilon} \sigma(\varepsilon) d\varepsilon, \qquad \text{(Eq 1)}$$

where $\sigma(\varepsilon)$ is the stress as a function of the strain.

As shown in Fig. 3(a) and (c), it is obvious that the Young's modulus E^* and yield strength σ^* of LD specimen is greater than that of TD specimen. The finding corresponds to the

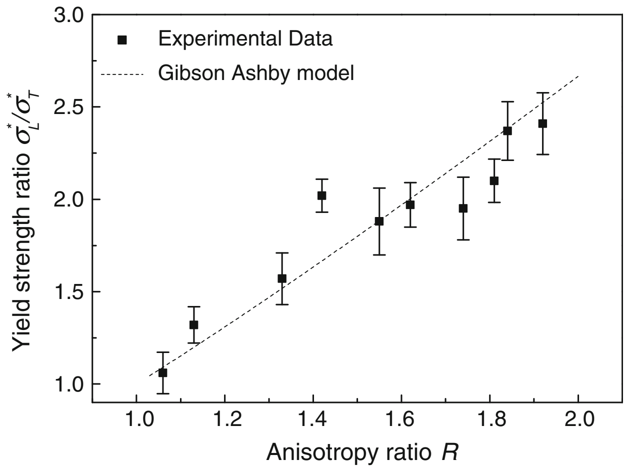

Fig. 4 The relationship between the plastic collapse stress ratio and anisotropy ratio

results of literature (Ref 9). In addition, Fig. 3(b) and (d) shows that the LD specimen has higher energy absorption capacity due to higher stress plateau than TD specimen. Compared with TD specimens, the energy absorbed by LD specimens in Fig. 3(b) and (d) was 7.80 and 2.41 MJ/m^3, respectively, at the strain of 55% while that absorbed by TD specimens was only 4.51 and 1.25 MJ/m^3, respectively. Figure 3 indicates that Al-Si alloy foams with cell shape anisotropy exhibit great disparity on the stress plateau and energy absorption even though they have about equal density.

The plastic collapse stress ratio σ_L^*/σ_T^* was introduced to quantitatively describe the relationship between plastic collapse stress and anisotropy ratio, where the subscript L and T denote the LD and TD, respectively. The results were shown in Fig. 4.

The relationship between plastic collapse stress and anisotropy ratio have been deduced (Ref 8), namely:

$$\frac{\sigma_L^*}{\sigma_T^*} = \frac{2R}{1 + 1/R} \qquad \text{(Eq 2)}$$

In the present study, the experimental data in Fig. 4 is closely in agreement with the Gibson and Ashby model. Experimental results in Fig. 4 show that the plastic collapse stress ratio rises with increasing anisotropy ratio.

4. Conclusions

The compressive behavior of Al-Si alloy foams in the transverse and LDs was studied. The cell shape anisotropy ratio of Al-Si alloy foams specimens in relative density range of 0.11-0.39 was measured. The anisotropy ratios are higher in the relative density range of 0.18-0.22.

The plastic collapse stress of Al-Si alloy foams in the LD were higher than that in the TD and Al-Si alloy foams can absorb more energy in the LD. Moreover, the plastic collapse stress ratio rises with increasing anisotropy ratio.

Acknowledgments

Financial support from the Natural Science Foundation of China (Grant No. 50704012) is gratefully acknowledged.

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