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Effect of Fly Ash Particles on the Compressive Properties of Closed-Cell Aluminum Foams

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The closed-cell aluminum foam reinforced by 1.5 and 3.0 wt.% fly ash particles were manufactured by molten body transitional foaming process. The backscattered electron image shows that fly ash particles distribute uniformly in the cell wall. The quasi-static compression tests were conducted. Results show that Al/Fly ash foams have stable compressive property and the sudden stress drop was not observed. The plateau stress increases nearly linearly with relative density. Moreover, the addition of fly ash particles improves the plateau stress. Also, the energy absorption property of Al/Fly ash foams increase with relative density and fly ash content. These can be attributed to the contribution of the compression of cell gas and the membrane stress in the cell wall.

Keywords fly ash, foams, mechanical properties, metals and alloys, porosity

1. Introduction

In the past few years, metallic foams, especially aluminum foams have received great interest. Foam structure usually contains more than 70% of volume as cells (Ref 1). The special structure gives Al foams high specific strength, high specific stiffness, and high energy absorption capacity. Metallic foams, therefore, were used as protective materials in traffic and packing industries, the automotive, railway and aerospace industry (Ref 1-4).

So far a lot of researches have been done on the mechanical properties of Al foams which are manufactured through various processes (Ref 5-9). In order to improve the strength of Al foams, various particles and fiber were added into the matrix (Ref 10-12). Results show that the addition enhances the strength indeed. Fly ash, the waste generated in coal-based thermal power plant, is cheaper than other thickening agents (e.g., calcium). In addition, the fly ash particles contain the ceramic particles such as Al_2O_3 and SiO_2 which could increase the viscosity of the melt and stabilize the cell wall (Ref 12, 13). Therefore, the fly ash particles were added into the melt as thickening agent to replace part of calcium and stabilizing agent.

In the present work, closed-cell aluminum alloy-fly ash particles composite (Al/FA) foams were prepared by melt route. The current research focused on the compressive properties and energy absorption characteristic of closed-cell Al/FA foams with different FA content.

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2. Experimental Procedure

Al/FA foams were prepared by molten body transitional foaming process. The raw materials for preparing foams were Al-Si alloy (6.5-7.5 wt.% Si, 0.25-0.45 wt.% Mg), preprocessed fly ash (with granularity of 20 μm), high purity metal Ca and the TiH_2 powder. Ca about 0.5 wt.% was used as thickening agent. TiH_2 power in the size range of 40-50 μm of about 1.5 wt.% was used as foaming agent. Fly ash particle about 1.5-3.0 wt.% was used as reinforcement. The method involves number of steps (Ref 14): (1) moltening Al-Si alloy (Si: 6.5-7.5; Mg: 0.25-0.45), preprocessed fly ash (20 μm; 1.5 wt.%, 3.0 wt.%), and calcium metal (0.5 wt.%) in industrial electrical furnace at 850 °C; (2) adding foaming agent TiH_2 (40-50 μm; 1.5 wt.%) to the melt at 660-700 °C, the stirring rate 1500-2000 rpm, the stirring time 120-240 s; (3) transferring the molten to the bubbly case at 660 °C; (4) pushing bubbly case to the maintaining furnace and foaming in it for 240-360 s; and (5) cooling the melt to room temperature in the air.

Closed-cell Al/FA foams with 1.5 and 3.0 wt.% of FA content were produced by this technique. Density values in the range of 0.15-0.8 g/cm^3 can be achieved. 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 cell wall material.

After cooling, the resulting foamed pieces were cut by electric sparking machine and the dimension of compressive specimens was Φ 30 by 30 mm. Quasi-static compression tests were conducted in CMT5105 material testing system with rate of 2 mm/min, corresponding to a nominal strain rate of 1.1×10^{-3} in the specimens.

3. Results and Discussion

The macrostructure of typical Al/FA foam sample is shown in Fig. 1(a), where the cells range in size from 3 to 6 mm. Figure 1(b) shows that fly ash particles distribute uniformly in the cell wall and the agglomeration was not observed.

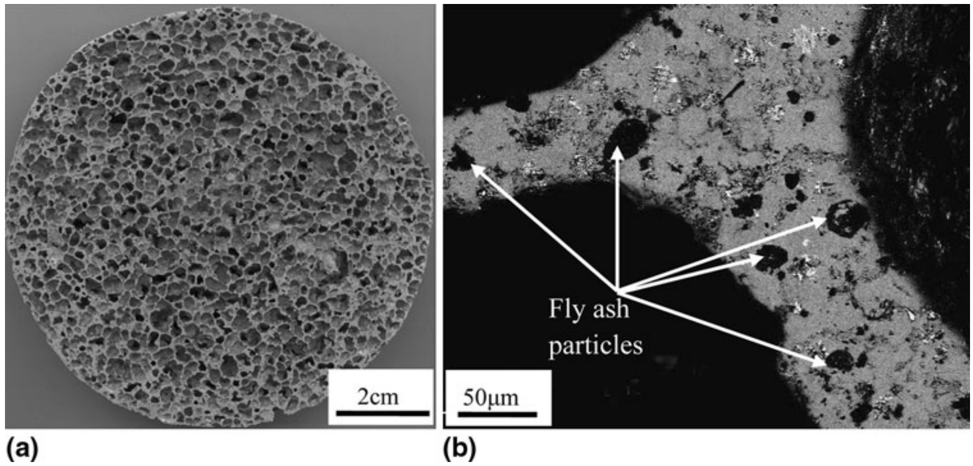

Fig. 1 Macrostructure of closed-cell Al/FA foam with FA content of 1.5 wt.% (a) and (b) the distribution of FA in the cell wall

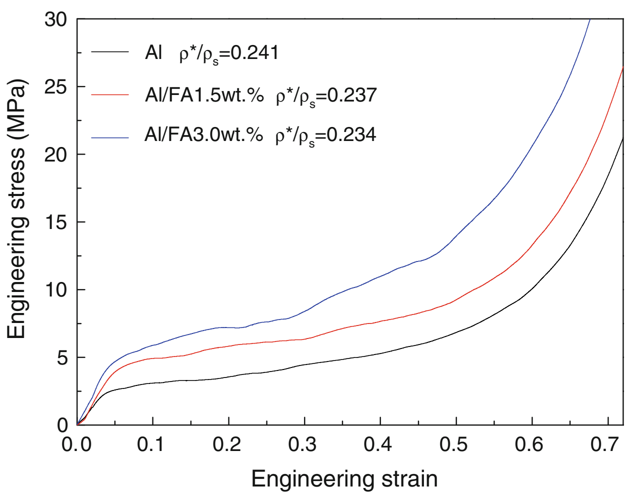

Fig. 2 The compressive stress-strain curves for Al foam and Al/FA foams with approximately similar relative density

The typical compressive stress-strain curves for Al foam and Al/FA foam with various FA content were measured. The results were shown in Fig. 2. Three specimens have similar relative density. Three distinct regions were observed in these curves: a linear-elastic region at a strain of less than 0.05; a plastic plateau region up to a strain of 50%; and final a densification region where the stress increases rapidly with strain. The compressive stress-strain curves were smooth and sudden stress drop was not observed, which indicated a stable compressive process. Compared to the Al foam, the Al/FA foams exhibit high plateau stress rather than short plateau. In addition, the strain hardening in Al/FA3.0wt.% foam is more compared to the other two. The compression of cell gas (Ref 15) and the membrane stress in the cell wall (Ref 16) are responsible for the phenomenon. Figure 3 shows the cell morphology of Al/FA1.5wt.% foam and Al/FA3.0wt.% foam. It is clear that foam with 1.5 wt.% FA particles exhibits more imperfection (e.g., fractured cell walls, corrugate cell walls, and irregular cell shape), the contribution of compression of cell gas and membrane stress in the cell wall to the plateau stress, therefore, is decreased during the compression.

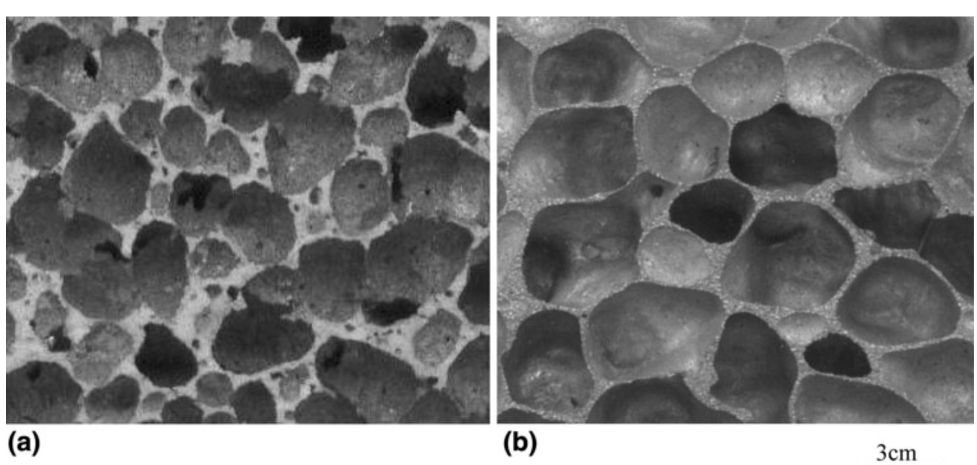

Fig. 3 The cell morphology of closed-cell Al/FA foam (a) with FA content of 1.5 wt.% (b) with FA content of 3.0 wt.%

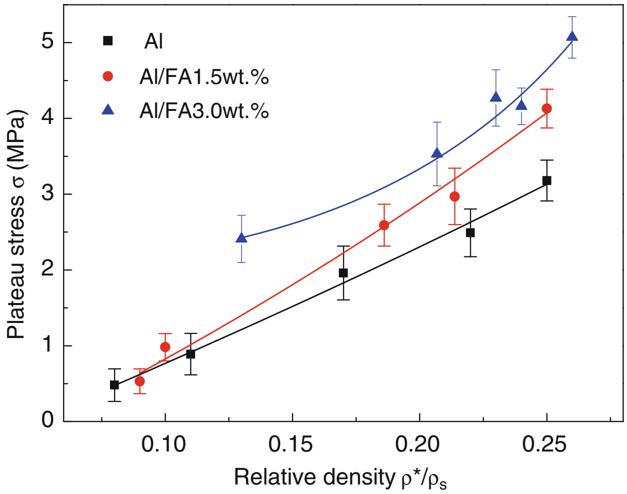

Fig. 4 The relation between plateau stress and relative density for Al foam with various FA content

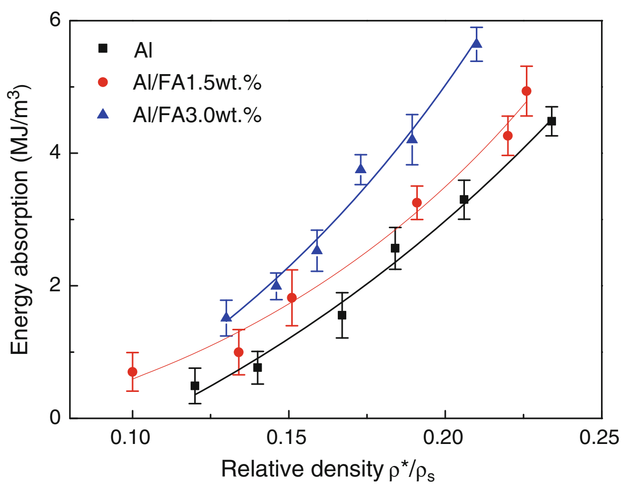

Fig. 5 Energy absorption capacity of Al foam with various FA content

More compressive measure was conducted to investigate the relation between the yield stress (defined as the stress at the strain of 0.05) and relative density. The results were shown in Fig. 3, where the yield stress increases with relative density. The finding corresponds to the Gibson & Ashby model. Moreover, the strength of Al/FA foam rises with the FA content due to the addition of FA particles.

Absorbed energy per unit volume, W, is simply the area under the stress-strain curve, namely:

$$W = \int_0^{\varepsilon} \sigma(\varepsilon)dx \quad \text{(Eq 1)}$$

where σ is the compressive stress and ε is the compressive strain. The densification strain was taken as 0.6 in the present work. The energy absorption capacity of Al foam and Al/FA foams with various FA content was plotted against the relative density. As shown in Fig. 4, the absorbed energy increases with the relative density and the FA content. For Al/FA foams, the fly ash particles distribute in matrix as particle reinforcement, which can produce higher strain hardening to improve the plateau stress during the compression test (see Fig. 2). The addition of FA particles decreases the imperfection of cells. The bending and bucking of the cell walls and the presence of gas within the cell increase the energy absorption capacity (Fig. 5).

4. Conclusions

The closed-cell aluminum foams reinforced by 1.5 and 3.0 wt.% fly ash were manufactured by molten body transitional foaming process. Fly ash particles can distribute uniformly in the matrix. Three regions were observed in the stress-strain curve and good compressive stability during the compression tests was presented. The aluminum foams reinforced by fly ash particles show higher plateau stress and more energy absorption. It can be attributed to the compression of cell gas and the membrane stress in the cell wall.

Acknowledgments

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