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Compressive properties of closed-cell aluminum foams with different contents of ceramic microspheres

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ABSTRACT

In this paper, closed-cell aluminum foams with different kinds and contents of ceramic microspheres are obtained using melt-foaming method. The distribution and the effects of the ceramic microspheres on the mechanical properties of aluminum foams are investigated. The results show that both kinds of ceramic microspheres distribute in the foams uniformly with part in the cell wall matrix, some in adhere to the cell wall surface and part embed in the cell wall with portion surface exposed to the pores. Ceramic microspheres have an important effect on the yield strength, mean plateau stress, densification strain and energy absorption capacities of aluminum foams. Meanwhile, the content of ceramic microsphere in aluminum foams should be controlled in order to obtain good combination of compressive strength and energy absorption capacity. The reasons are discussed.

1. Introduction

Closed-cell aluminum foams are a class of novel materials with continuous metallic matrix being separated by equally distributed gas bubbles. Compared with commercial available bulk alloys, they have many excellent properties, such as ultra-low density, good energy absorption property, high electromagnetic shielding effect, excellent sound-absorbing property and good damping performance [1]. Many kinds of metallic foams (e.g. aluminum, magnesium, titanium, nickel and steel) have been developed for energy-absorbing applications as they have a distinct advantage over solid metals in this respect, the related energy-absorbing characteristics of these materials have also been widely researched [2,3]. Among these kinds of metallic foams, aluminum foams, due to their lightweight and good energy absorption performance, have been drawing much attention in construction, automotive and aerospace applications. Meanwhile, with the development of preparation methods, aluminum foams have been widely used as structural and functional materials. However, in these fields commercially pure aluminum foams were rarely used because of their lower mechanical properties [4,5]. A few researchers have focused on this phenomenon and Huang et al. investigated the effect of Sc elements on the quasi-static compressive behaviors of Al foams and the results showed that minor Sc additions and subsequent proper heat treatment could dramatically improve the compressive yield strength of Al foams [6]. In our previous research Mn particles was introduced into commercial pure aluminum foam to improve its compressive properties [7]. These are useful and effective ways to obtain high-strength aluminum foams. However, as it is known that Al–Sc alloys are expensive, resulting in increased production costs. Although Mn particles are much cheaper than Al–Sc alloy, they need an intermediate preparation process, leading to energy consumption. Recently, ceramic microspheres, by-products of pulverized coal combustion in thermal power plant boiler, have been drawing a lot of attention in the respect of metal matrix syntactic foams (MMSFs) [8,9], owning to their low density, insulating heat, saving energy, good flowability and high mechanical features. Millions tons of ceramic microspheres powder are generated in coal based thermal power plants every year and only a small portion is being utilized [10]. Metal matrix syntactic foams (MMSFs) using ceramic microspheres as pore generation agent or thickening agent have been proved to possess excellent compressive properties compared with conventional aluminum foams [8–12].

Metal matrix syntactic foams (MMSFs), mainly fabricated through melt infiltration of technique, resulting in confined foam dimensions and the porosity of the foams fabricated through melt infiltration is less than 65% [13–15], to the best of our knowledge. Researchers have investigated the micro-architecture and compressive deformation behavior of Al-alloy and microspheres hybrid Al-foam prepared through stir casting technique using $CaCO_3$ as foaming agent [12]. 30 vol.% of cenospheres were added into the melt mixture as thickening agent, it was confirmed that the

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closed-cell foams possessed higher plateau strength and energy absorption capacity than conventional aluminum foams [12]. It is significant to produce hybrid metal foams through conventional casting method which is widely used in the industrial production of aluminum foams and the products have a greater range in respect of the dimensions. However, we should note that only fixed percentage of microspheres was added into the melt as thickening agent. While, from the engineering application view point, the effect of ceramic microspheres contents on the variation of compressive properties, the distribution of the ceramic microspheres and the optimal content in the foam have to be investigated and found. Unfortunately few literatures focused on this region and further research is needed.

In the present experiment, closed-cell aluminum foams containing different kinds and contents of ceramic microspheres were prepared through melt foaming method. The effects of ceramic microspheres on the compressive properties were investigated experimentally and the optimal contents of the ceramic microspheres were found.

2. Experimental methods and materials

Melt foaming method was applied to fabricate closed-cell Al foams with different types and contents of ceramic microspheres. The raw materials used in the present experiment were commercially pure aluminum ingots (with the purity of 99.5%), Ca granules (commercially pure, granularity between 1 and 2.5 mm, thickening agent), TiH_2 (commercially pure, 300 ± 20 mesh, foaming agent) and two types of ceramic microspheres QK150 and QK300, with the compositions of SiO_2 ~60 wt%, Al_2O_3 ~40 wt% and Fe_2O_3 ~0.5 wt% (supplied by Sun Microsphere Co., Ltd., China). The size ranges of QK150 and QK300 are 45–150 μm and 150–300 μm respectively. In addition, the compressive strengths are 17.24 and 14.48 MPa, respectively. Detailed preparation process mainly includes the following steps: (1) melting certain quantity of commercially pure aluminum (~1 kg) in a low carbon steel crucible to a fixed temperature; (2) adding certain quantity of Ca granules (thickening agent, 2 wt%) with the stirring speed of 450 rpm for 6 min and different contents (0%, 2.5%, 5.0%, 12.5%

Table 1
Detailed specimens structural parameters.

Types	No.	Length/mm	Width/mm	Height/mm	Volume/mm^3	Weight/g	Porosity (%)
QK150	2.5–1	25	25	25	15,625	10.9917	0.7395
	2.5–2	25	25	25	15,625	11.4574	0.7284
	5.0–1	25	25	25	15,625	10.5438	0.7501
	5.0–2	25	25	25	15,625	10.7994	0.7440
	12.5–1	25	25	25	15,625	10.8164	0.7436
	12.5–2	25	25	25	15,625	10.6876	0.7467
	20.0–1	25	25	25	15,625	12.2705	0.7091
	20.0–2	25	25	25	15,625	12.4959	0.7038
QK300	2.5–1	25	25	25	15,625	9.0889	0.7846
	2.5–2	25	25	25	15,625	9.1023	0.7842
	5.0–1	25	25	25	15,625	9.2763	0.7801
	5.0–2	25	25	25	15,625	8.9086	0.7888
	12.5–1	25	25	25	15,625	8.5124	0.7982
	12.5–2	25	25	25	15,625	8.8920	0.7892
	20.0–1	25	25	25	15,625	8.9926	0.7868
	20.0–2	25	25	25	15,625	9.1691	0.7827
Original	O-1	25	25	25	15,625	10.6302	0.7480
	O-2	25	25	25	15,625	10.9997	0.7393

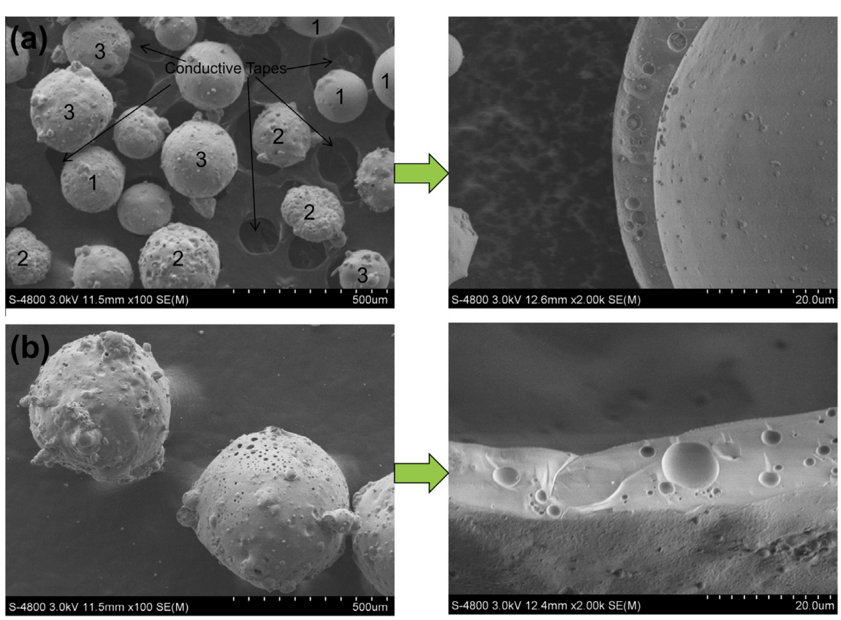

Fig. 1. Macroscopic and fracture morphologies of QK150 (a) and QK300 (b) ceramic microspheres.