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Enhancement of open cell aluminum foams through thermal evaporating Zn film

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ABSTRACT

Relatively low mechanical properties of open cell aluminum foams have become a restrictive factor to their applications in engineering fields. To overcome this shortcoming, a surface enhancing method was investigated in the present study to coat a zinc film on the cell strut surface through thermal evaporating technology. The results show that the coated film obviously makes the foam enhanced and the compression yield strength is increased one order of magnitude higher than that of uncoated material. On the other hand, the mechanical characteristics of the foam has changed from ductile to brittle after the coating, represented by pronouncedly serrated stress-strain curves. This demonstrates that the mechanical behavior of the coated foam is to a great degree dominated by the film and the surface coating does be an effective way to modify the overall mechanical behavior of aluminum foams.

1. Introduction

Open cell aluminum foams with a 3-D net structure are a special material with a series of excellent functional properties including sound absorption, heat dissipation, chemicals support etc. [1]. While the high porosity and permeability contribute to excellent functional properties, they make the mechanical properties of foams obviously decayed, being typically lower than 1.0 MPa in compression strength [2]. This may lead to premature failure of relevant structures or devices so that their applications are greatly limited in many situations [2]. If reliable applications are expected for the open cell aluminum foams, increasing the strength as largely as possible is necessary, particularly for those where a harsh mechanical environment is met [3–5]. In most application conditions, such as sound insulation, heat transfer and fluid filtration etc., the open cell metal foams usually undergo a compression loading. The typical failure mode is bending-dominated deformation or fracture of cell struts [6]. In such situations, even a thin film on the struts could have a significant enhancing effect on the foams because the surface films are far away from the neutral bending axis of the struts and have a high second moment of area [7]. From this viewpoint, efforts have been made to enhance the open cell aluminum foams by depositing a film on the strut surface, such as electrodeposition [3–5], anodizing [8] and plasma electrolytic oxidation and so on [9,10]. However, due to the complicated cell channels, the passage of charges through the foam is very difficult and the distribution of electric field will be changed when the electrolyte fluid penetrates the cells. This results in inhomogeneous coating even no coating within the inner cells, and thus the enhancing effects are often unsatisfactory [7]. In order to avoid this shortage, thermal evaporating technique was tested and optimized in the present study to coat a zinc film on the strut surface of open cell aluminum foams. The microstructure of the film and the mechanical behavior of coated foams were examined and correlated to give guidelines for related studies and applications.

2. Experimental

2.1. Preparation of foam samples

Open cell aluminum foams used in the present study were fabricated using commercially pure aluminum through an infiltration method [11,12]. The cylindrical samples with the dimension of 20 mm in diameter and 20 mm in height were cut from the foam blocks by an electrical discharge machine. The cell size is 15 ppi (pores per inch) and the relative density is about 6%.

2.2. Thermal evaporation coating

Fig. 1 schematically shows the thermal evaporation apparatus used in the present study. Zinc powder with a purity of 99.9% (Alfa Aesar) was used as the source material and placed on Chip A. An open cell aluminum foam sample to be coated was placed on Chip B. The quartz tube was evacuated to 10^{-1} Torr first, and then

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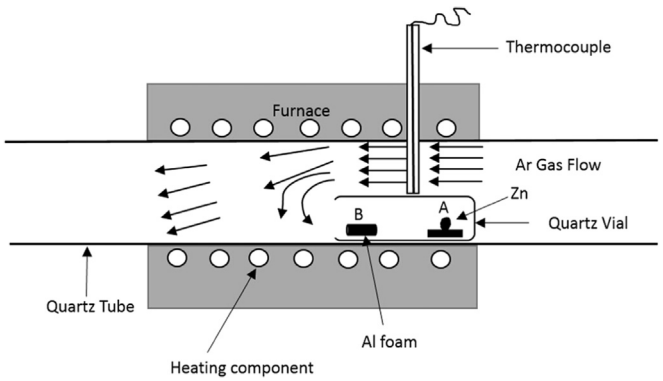

Fig. 1. Schematic diagram of thermal evaporating apparatus.

purged with argon gas flow until an atmospheric pressure was established. Subsequently the furnace was heated to set temperature, i.e. 600 °C, with a stable argon gas flow of 100 sccm. To examine the effect of coating time on the formation of film, the aluminum foam samples were held in the furnace for 30, 60 and 90 min, represented by treatment 1, 2 and 3, respectively. After that the sample was taken out from the furnace and cooled naturally.

2.3. Characterization of microstructures and mechanical properties

X-ray diffraction meter (XRD, X'Pert Pro MPD), energy dispersive spectroscope (EDS), scanning electron microscope (SEM, FEI Sirion 200) and optical microscope (Imager.A1m, Zeiss) were employed to characterize the phase, composition and microstructure of coated film. A material measuring system (Instron 3369, Load cell 2530-445) was used to measure the mechanical properties of the foams. The measurements proceeded at a compression rate of 3 mm/min until the obvious densification of fracture of the samples arisen. At least three samples were tested in compression for each coating condition and the arithmetic mean value was used as the representative value of mechanical properties for each sample group. The compression strain was obtained by the recorded cross-head displacement. The density of coated foams was calculated by the measured weight and dimensions, while elastic modulus and compressive strength were determined from the engineering stress–strain curves. Vickers microhardness of samples was measured at a load of 0.5 N and a holding time of 15 s.

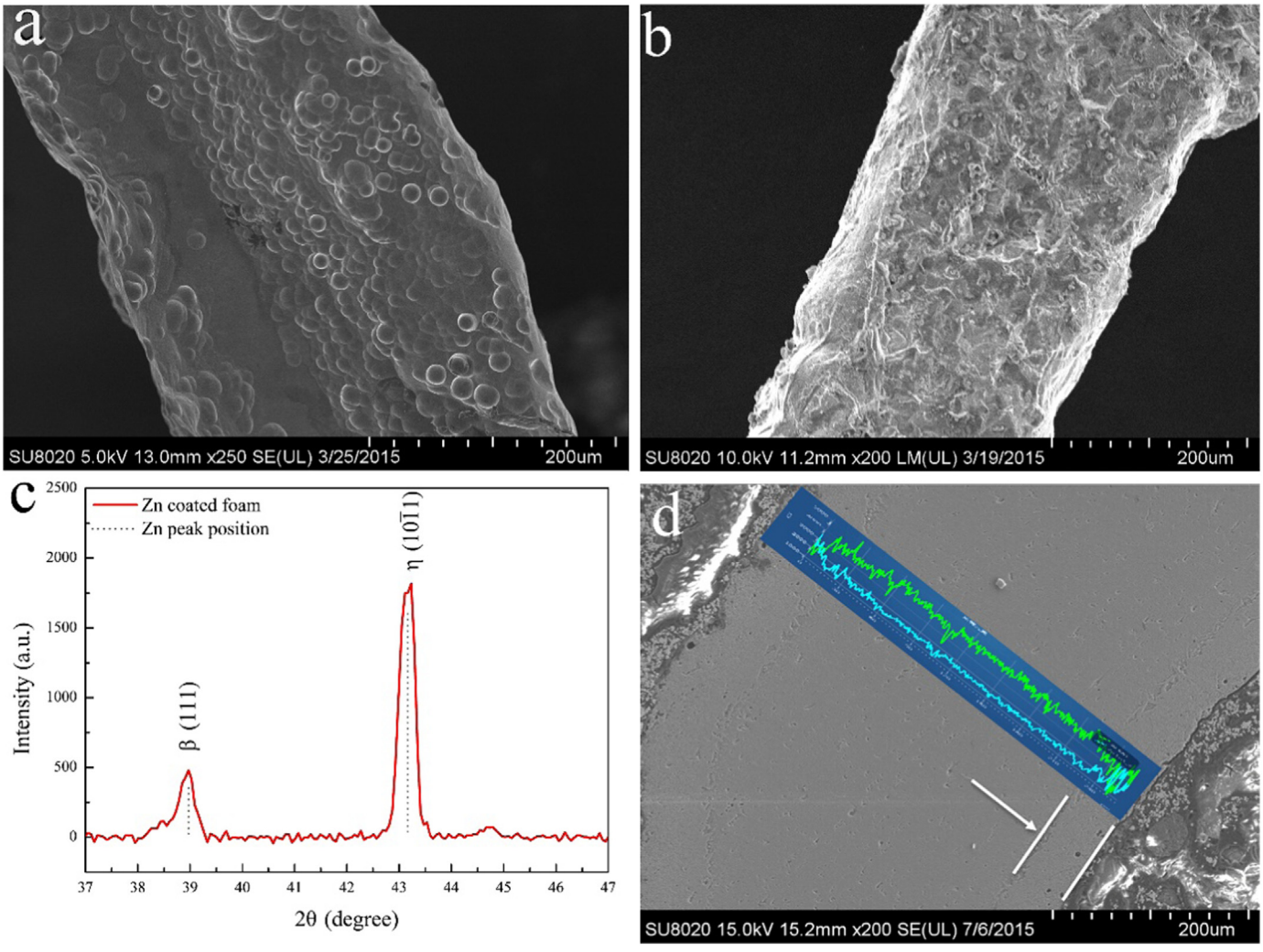

Fig. 2. Cell strut surface morphologies of original (a), coated foam sample (b), XRD pattern of film (c) and EDS elemental mapping (d) in the cross-section of strut for the sample after the treatment 2 (the blue line represents the concentration of zinc).