Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Composite Structures 71 (2005) 191–198
COMPOSITE STRUCTURES
www.elsevier.com/locate/compstruct

Evaluation of compressive mechanical properties of Al-foams using electrical conductivity

A. Kim [a,*], M.A. Hasan [a], S.H. Nahm [b], S.S. Cho [c]

[a] Division of Mechanical Engineering, Kongju National University, Shinkwan-dong 182, Kongju, Chungnam 314-701, Republic of Korea
[b] Korea Research Institute of Standards and Science, PB Box 102, Yusong, 305-600 Daejeon, Republic of Korea
[c] School of Materials Engineering, Chungnam National University, Daejeon 305-764, Republic of Korea

Available online 30 November 2004

Abstract

Al-foam filled composite panels have enormous potential for application as light weight structural members as well as the energy absorber during crushing. In such applications the mechanical properties of foams are of paramount importance. In this study, Al alloy foams of composition Al–3 wt.%Si–2%Cu–2%Mg were produced using powder metallurgical method. Mechanical properties of foams of different density were measured using the uni-axial compression test and the measured properties such as elastic modulus and strength were compared with those of other existing commercial foams. The newly produced (Al–3%Si–2%Cu–2%Mg alloy) foams showed the elastic modulus and strength similar or sometimes higher than those of the other existing commercial foams. The electrical conductivity of the foams was measured and was found to follow a power law relationship, with an exponent value of 1.5, with the relative density. A set of mathematical relationships were deduced between electrical conductivity and various compressive properties of Al-foams with an aim to propose a nondestructive method for obtaining the elastic modulus, the compressive strength and the densification strain of foams using electrical conductivity. The curves obtained from derived relationships fit very well with the experimental results.

Keywords: Aluminum foam; Powder metallurgy; Elastic modulus; Plateau stress; Densification strain; Electrical conductivity

1. Introduction

Metal foam is one of the latest inventions in the field of engineering materials. However, due to its various attractive properties such as super light weight [1], good energy absorption [2], high strength, high stiffness and outstanding damping capability [3], it has already emerged as one of the most appropriate solutions for many structural and functional uses in such diverse fields as automotives, transports, ships and aerospace applications. Particularly Al-foam filled composite panels are widely being considered these days for structural use in aircrafts and satellites, and functional use in automotive bumpers, roofs and door beams for improving the crashworthiness of vehicles which will ultimately reduce the damage of the vehicles and increase safety of the passengers during crushing. Industrial production of foamed metals is now established for applications like sandwich structures [4], panels, foam-filled crash absorbers [5], heat exchangers and so on. Since industrial exploitation of a new material is always determined by the possibility to reproduce its mechanical and physical properties, these days many of the researchers in the field of metal foam are working with an aim to propose quality control methods for the development of reliable foam products and in this attempt, many of them are considering various nondestructive testing and

* Corresponding author. Tel.: +82 41 850 8616; fax: +82 41 854 1449.
E-mail address: amkee@kongju.ac.kr (A. Kim).

0263-8223/$ - see front matter
doi:10.1016/j.compstruct.2004.10.016

inspecting techniques for both during production and post-production evaluation of mechanical properties of foams.

Degischer and Kottar [6] studied the applicability of various nondestructive testing methods for characterizing Al-foams. Their work showed that eddy current and conventional ultrasonic testing are not fruitful for characterizing Al-foams, however the X-ray computed tomography (CT) enables a detailed structural analysis of the foam. Cornelis et al. [7] and Grote et al. [8] also performed study on foams using X-ray computed micro-tomography. Very recently Anwarul Hasan et al. [9] studied the evaluation of the mechanical properties of Al-foam cell wall material using nanoindentation technique where they found that the cell wall material of Al-foams shows higher hardness and elastic modulus than the solid material from which foams are produced.

In this paper we have proposed a nondestructive method, based on measuring the electrical conductivity, for evaluating mechanical properties of Al-foams. The Al–Si–Cu–Mg alloy foams were produced using powder metallurgical method. Compressive mechanical properties of the produced foams were experimentally measured. Equations have been established between electrical conductivity and mechanical properties bridging the existing relationship of these properties with foam density and introducing some empirical modification so that the applicability of these equations can be extended to real foams. Mechanical properties of the foams obtained from experiment were plotted against electrical conductivity along with the plot of proposed equations. It was found that the proposed equations fit very well with the experimental results.

2. Experiment

2.1. Material and specimens

The aluminum alloy powder of particle size 150–900 μm were produced by melting the elements in required proportion (Al–3 wt.%Si–2%Cu–2%Mg) and using centrifugal atomization. 99% (weight) of Al-alloy powder and 1% TiH_2 were mixed in a rotating V-mixer with a velocity of 300 rpm for 30 min. The mixture was then consolidated by cold compaction at a pressure of 4 MPa and hot extruded at a temperature 430 °C with an extrusion ratio of 20:1 in a uni-axial extrusion machine.

Foaming of the extruded precursor material was performed by keeping them inside a close mould and heating them in a pre-heated furnace. The pre-set furnace temperature was 700 °C and the foaming time was 15 min. The foam density was controlled by varying the amount of precursor material in the mould. Foaming process was terminated by simply removing the moulds from the furnace.

Skin was removed from these foams and specimens were cut to the appropriate dimension (35 × 35 × 40 mm) using a band saw with a guide to ensure that the cuts were made accurate and straight. Such a dimension was chosen so that the edge length of the compression test specimens in all cases be at least seven times the cell diameter. This is the minimum required size to avoid edge effects which may reduce the measured values of elastic modulus and compressive strength [10].

2.2. Compression test

The uni-axial compression test was performed on the specimens using an MTS 830 machine. Fig. 1 shows an Al–Si–Cu–Mg alloy foam specimen used for the compression test and electrical conductivity measurement. During compression test the load and displacement were monitored by a computer, equipped with a data acquisition system. All stresses and strains used here are nominal stresses and nominal strains deduced from the recorded load–displacement data. In this work, load was applied at a constant displacement speed of 0.02 mm/s and the specimens were compressed between parallel steel platens to ensure perfect axial loading. Compression was stopped when 85% strain was reached.

2.3. Electrical conductivity

The electrical conductivity of the foams was measured using a set up based on an upgraded design of four-probe resistivity measurement apparatus. It was found that the conventional four-probe resistivity measurement method cannot be used in this case. Because in conventional four-probe method, four equi-spaced probes placed in a line are to be kept in contact with

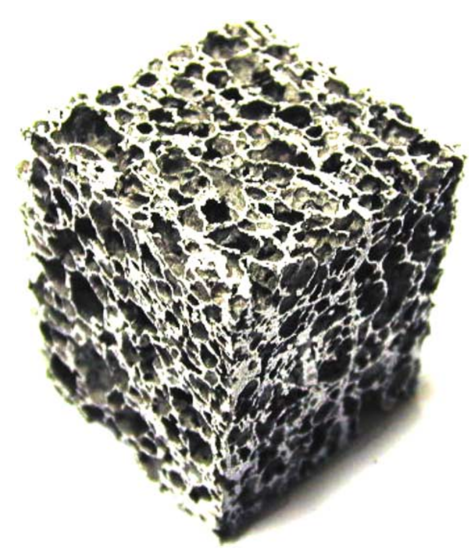

Fig. 1. Al–Si–Cu–Mg alloy foam specimen ($\rho^*/\rho_s = 0.23$) used in the experiment.