Acta Astronautica 128 (2016) 243–250

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/aa

Effect of cell-size on the energy absorption features of closed-cell aluminium foams

S.K. Nammi [a,*], G. Edwards [b], H. Shirvani [a]

[a] Anglia Ruskin University, Bishop Hall Lane, Marconi 215, CM1 1SQ, UK
[b] Department of Electronic & Electrical Engineering, University of Chester, Pool Lane, Chester CH2 4NU, UK

ARTICLE INFO

Article history:
Received 29 April 2016
Accepted 25 June 2016
Available online 2 July 2016

Keywords:
Aluminium foam
Cell-size
Energy absorption
Repeating unit-cell
Micromechanical

ABSTRACT

The effect of cell-size on the compressive response and energy absorption features of closed-cell aluminium (Al) foam were investigated by finite element method. Micromechanical models were constructed with a repeating unit-cell (RUC) which was sectioned from tetrakaidecahedra structure. Using this RUC, three Al foam models with different cell-sizes (large, medium and small) and all of same density, were built. These three different cell-size pieces of foam occupy the same volume and their domains contained 8, 27 and 64 RUCs respectively. However, the smaller cell-size foam has larger surface area to volume ratio compared to other two. Mechanical behaviour was modelled under uniaxial loading. All three aggregates (3D arrays of RUCs) of different cell-sizes showed an elastic region at the initial stage, then followed by a plateau, and finally, a densification region. The smaller cell size foam exhibited a higher peak-stress and a greater densification strain comparing other two cell-sizes investigated. It was demonstrated that energy absorption capabilities of smaller cell-size foams was higher compared to the larger cell-sizes examined.

1. Introduction

Cellular solids are widespread in nature. They are made of arrays of small enclosed spaces that are also referred to as cells. Examples include a bee's honeycomb, cork, sponge, and trabecular bone. Closed-cell Al foams are man-made artificial cellular solids that have many applications in aerospace, automotive, biomedical and engineering industries in general [1–3]. Al foams can be used in the area of blast energy absorption, crashworthiness and protection against Micro-Meteoroid and Orbital Debris (MMOD) particle impacts in space engineering [4]. They have the ability to absorb kinetic energy from impact and can delay and attenuate stress waves in a typical explosion [5,6]. Al foams have the ability to undergo plastic deformation at a nearly constant stress level, over a wide range of strain. This makes them ideal for energy absorption. Sandwich panels made of Al foam core can be used as lightweight crash pads.

Cellular structures of real Al foams are complex; each individual cell is different to others in size and shape forming a disordered solid on the mesoscale. Additionally, material distribution within an individual cell is non-uniform. Typical cellular geometry of real closed-cell foam is shown in Fig. 1. Note that the terminology *real* will be used throughout in this work to represent manufactured foams. It is far too challenging to model three-dimensional representations capturing all cell features of real Al foam. Numerical modelling techniques that involve complex features such as corrugations, curvature and voids require impractical computational effort. Thus, idealization of geometry is carried-out to minimize computational effort. Simplified micromechanical models consider the geometry to be homogeneous, akin to a crystalline lattice, making it possible to characterize and quantify behaviour. Cellular solids characterization is mainly carried-out in three length scales (viz: macro-, meso-, and micro) [7]. Modelling at the macro level examines global behaviour (or collective characteristics of material) of whole system of foam cells. Al foam is described with a homogeneous material behaviour. i.e. a constitutive law is employed to generate yield criterion for foams [8]. On the other hand, at micro-scale modelling, the behaviour of the individual cell constituents such as voids, corrugations, plateau edges and imperfections etc. need to be accounted for. The macro and microscale characterizations are also referred to as phenomenological and micro-mechanical modelling respectively. The meso-scale modelling is intermediate between the aforementioned. Repeating Unit-Cell (RUC) based modelling is often used in both micro and meso scales [9].

The foam specimen dimension relative to the cell-sizes is important in order to apply the constitutive models effectively; the overall specimen size has to be at least greater by order of 10 than

* Corresponding author.
E-mail address: sathish.nammi@anglia.ac.uk (S.K. Nammi).

http://dx.doi.org/10.1016/j.actaastro.2016.06.047
0094-5765/© 2016 Published by Elsevier Ltd. on behalf of IAA.

Nomenclature

Al	Aluminium
MMOD	Micro-Meteoroid and Orbital Debris
RUC	Repeating Unit-Cell
SEM	Scanning Electron Microscope
TKD	Tetrakaidecahedra
ρ^*	Density of foam
ρ_s	Density of intrinsic material of foam
σ	Nominal stress
ε	Nominal strain
ε_d	Densification strain
σ^*_{pl}	Plateau stress
t	Cell-wall (pore) thickness
l	Cell edge-length of TKD foam
3D	Three-dimensional
L_x	End-to-end distance in global x direction of TKD foam
L_y	End-to-end distance in global y direction of TKD foam
L_z	End-to-end distance in global z direction of TKD foam
E^*	Elastic modulus of foam
E_s	Elastic modulus of intrinsic material modulus of foam
E_V	Energy absorbed per unit-volume
S	Surface area of foam
V	Volume of foam

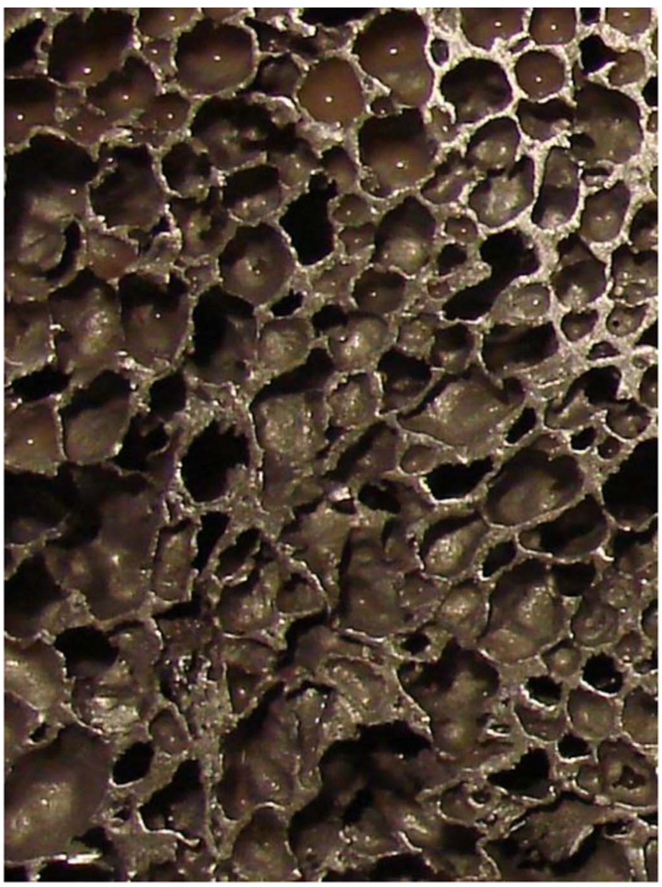

Fig. 1. Cellular structure of Al foam.

the dimensions of a single foam cell [10]. On the other hand, micromechanical models are the only solutions available to predict general foam behaviour when some dimensions of Al foam section are of a few cell diameters. Thus, the micromechanical models are mainly used for identifying optimum conditions for best mechanical properties. In this respect, the work described here will go some way in the design of microstructure for better energy absorption. Specifically, investigations are focussed here on Al foams of three different cell-sizes with the same density.

2. Problem statement

Cell-sizes of real Al foam can be controlled to a certain extent. Begging the question on how cell-size effects the energy absorption features of same density Al foam. The issue to be considered is whether smaller cells (with thin cell-walls) or larger cells (with thick cell-walls) have better energy absorption characteristics. From materials design view point of view, this knowledge is precursor in the design of a blast resistant casing that uses Al foam as a sacrificial energy absorber as shown in Fig. 2. A strip (end-to-end thickness 25.4 mm) of real Al foam of density (ρ^*) 0.17 g/cm^3 is sandwiched between two steel layers as shown in Fig. 2. The thickness of outer layer of steel (i.e. facing blast load) can be varied whilst the inner layer is made of 18 gauge steel body. Depending on the foam cell-size, a thickness of 25.4 mm cross-section of foam can be filled with between 2 and 4 cell diameters. It is obviously possible to increase the number of cells if the Al foam is filled with smaller cells. However, cost considerations and technological challenges mean that between 2 and 4 cells are practical. From the design point of view, the sandwiched Al foam must absorb the blast energy without damaging the contents in casing.

Fig. 2. Al foam reinforced casing.

3. Compressive response and energy absorption features

Closed-cell real Al foam of density 0.17 g/cm^3 were obtained from CYMAT Corporation [11]. Intrinsic Al material was assumed to have a density (ρ_s) 2.7 g/cm^3. An experimental stress (σ)–strain (ε) plot of this Al foam under compression is shown in Fig. 3. The compressive response of Al foam consists of three regions (Linear-elastic, Plateau