Polymer Testing 32 (2013) 1538–1544

Contents lists available at ScienceDirect

Polymer Testing

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

Material behaviour

Characterization of irregular open-cell cellular structure with silicone pore filler

Matej Vesenjak [a,*], Lovre Krstulović-Opara [b], Zoran Ren [a]

[a] Faculty of Mechanical Engineering, University of Maribor, Smetanova 17, 2000 Maribor, Slovenia
[b] Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split, R. Boškovića 32, 21000 Split, Croatia

ARTICLE INFO

Article history:
Received 31 August 2013
Accepted 9 October 2013

Keywords:
Open-cell cellular structure
Irregular topology
Aluminium foam
Silicone pore filler
Mechanical properties
Experimental study

ABSTRACT

The paper presents the results of studying the influence of silicone polymer pore filler on the macroscopic quasi-static and dynamic compressive behaviour of aluminium foam with irregular open-cell structure. The study is based on a mechanical experimental testing programme, where the deformation mechanism and mechanical energy absorption capacity of aluminium foam with silicone pore filler have been observed for the first time. As plastic yielding is accompanied by significant heat energy dissipation, this study was additionally supported by thermal imaging, which enables visualization of plastification to better understand the deformation process of observed specimens. The influence of specimen size on the behaviour of aluminium foam specimens has also been investigated. The results show that introduction of silicone pore filler considerably increases the energy absorption capacity at almost unchanged densification strain under both quasi-static and dynamic loading conditions. The silicone pore filler also significantly influences the deformation behaviour of aluminium foam specimens, which is manifested in a different stress distribution and a significant transverse deformation with conical plastification front. However, only a minor difference in response of different size specimens has been observed.

1. Introduction

Cellular materials are attractive engineering materials due to their wide ranging application and various advantageous mechanical, thermal, electrical and acoustic properties [1–4]. The mechanical behaviour of cellular materials mainly depends on the porosity, base material [1,5], morphology [6,7], topology [8,9] and pore filler [5,10–12].

This paper presents an upgrade to previous studies of open-cell regular polymer cellular materials and the influence of silicone pore fillers showing a brittle collapse mechanism and unsteady stress plateau [6,10]. Previously published results [6] have shown that laser sintered polyamide cellular structures with regular pore topology exhibit a layer-wise collapse mechanism, regardless of the cell shape. It has been proven by experimental testing that a circular cell shape provides higher structural stability of the cellular structure and higher capability of mechanical energy absorption. It has been observed that the energy absorption is highly strain rate dependent, especially for structures with rectangular cells, which makes them very attractive for use in the field of crash/impact applications, e.g. armour or protection materials. The other experimental study [10] was focused on mechanical characterization of an regular open-cell cellular structure made of photopolymer FullCure M840. The response of the photopolymer cellular structure was highly erratic due to a brittle, layer-wise collapse mechanism of the structure, resulting in high stress oscillation regardless of the loading velocity. A silicone rubber was used as pore filler material to remedy

* Corresponding author. Tel.: +386 2 220 7717; fax: +386 2 220 7994.
E-mail addresses: matej.vesenjak@um.si (M. Vesenjak), lovre.krstulovic-opara@fesb.hr(L. Krstulović-Opara), zoran.ren@um.si(Z. Ren).

0142-9418/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.polymertesting.2013.10.005

such behaviour. The compressive experiments on silicone filled cellular structures have shown significant change in their macroscopic behaviour. The original brittle behaviour with high stress oscillations was strongly dampened by the silicone filler, resulting in a more predictable and reliable mechanical response. Furthermore, the silicone filler has significantly improved the mechanical energy absorption capacity.

The advantages achieved by using silicone pore filler in regular open-cell cellular materials provided a further motive to investigate the influence of pore filler material on conventional irregular open-cell cellular structures, e.g. aluminium foams, to determine its influence on the macroscopic quasi-static and dynamic compressive mechanical behaviour (Fig. 1), as well as the mechanical energy absorption capacity, by means of a mechanical experimental testing programme. The results of this study are reported in this paper together with investigation of the size effect on the behaviour of metal foam specimens.

As plastic yielding is accompanied by heat energy dissipation, this research was additionally supported by thermal imaging to trace strain localization and propagation of localization bands and densification in metal foam specimens. It is shown in [13–15] that, under dynamic loading, local densification propagates depending on the moving deformation front or the motion of the specimen. The densification itself is characterised by a clear moving front line. The low strain rate deformation (i.e. quasi-static loading), where strain localization in the form of bands is defining the yielding plateau, is described in [16]. The phenomena of formation of a yield plateau and localization bands are experimentally and numerically described in [17]. The local buckling and bending, with self-contact of open-cell cellular material struts, define the stress plateau (Fig. 1, region (iii)). The stress plateau is finalized with densification of the foam specimen, resulting in increased macroscopic stiffness (Fig. 1, region (iv)).

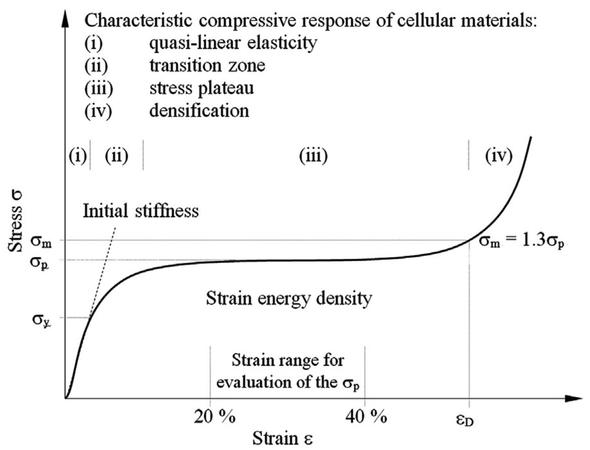

Fig. 1. Characteristic behaviour of cellular materials under compressive loading.

2. Aluminium foam and silicone filler

2.1. Open-cell aluminium foam

The aluminium foam specimens to be studied were manufactured by m.pore GmbH using an investment casting process [18]. The base material was Al99.7%. The aluminium foam manufacturer prepared two types of samples, which have been extensively studied [19]:

– 20 mm cubes (small specimens) with relative density of 6.1% (porosity is 93.9%) and average pore size of 2.3 mm (approx. 20 pores per inch) and
– 40 mm cubes (large specimens) with relative density of 7.8% (porosity is 92.2%) and average pore size of 4.5 mm (approx. 10 pores per inch).

8 small and 16 large aluminium foam samples have been experimentally tested in this study.

2.2. Silicone rubber

The filler material used in this study was a quasi-elastic silicone polymer rubber (2K-Z010) [20,21] which allows for easy application. The silicone filler is chemically stable, having the advantage of very low friction and adhesion to the aluminium foam structure. The silicone rubber is a 3-component composition comprising 100 g of component A ($\rho = 1260$ kg/m^3, $\mu = 25-30$ Pa·s), 5 g of component B (catalyst) and 20 g of component C (silicone oil). The purpose of component C is to adjust the stiffness of the silicone rubber. Increasing the amount of component C makes the silicon rubber softer and assures that the silicone does not stick to the surface after hardening. Consequently, it allows for easy de-bonding as shown in Fig. 2. Low-friction and low-adhesion silicone behaviour reduces the conservation of elastic energy that could cause spring-back, leading to lower mechanical energy absorption capability [22].

Material characteristics of the silicone filler have been previously determined with standard compressive tests [5,10].

2.3. Aluminium foam with silicone pore filler

The silicone filler is very effective for intercellular filling of an open-cell cellular structure by treatment in a vacuum chamber during the silicone curing process.

Fig. 2. De-bonding of silicone filler from compressed metal foam.