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MEASURING OF ELASTIC PROPERTIES OF METAL FOAM BASED ON COMPRESSION TEST AND DIGITAL IMAGE CORRELATION

P. ZLAMAL[1] D. KYTYR[2] T. FILA[2] P. KOUDELKA[2] O. JIROUSEK[2]

Abstract: *From a mechanical point of view the most important ability of metal foam is absorption of large amounts of strain energy. This advantage is based on the cellular structure with high ratio of porosity (75-95%). The aim of this study is determination of stress-strain measurement protocol for closed-cell aluminium metal foam Alporas® during a compression test using in-house loading device. Changes in structure were observed and strain was calculated based on Digital Image Correlation (DIC) technique. For the assessment of overall compression elastic modulus a new software tool based on the Matlab toolkit was developed.*

Key words: *Alporas, compression test, DIC, metal foam.*

1. Introduction

Metallic foams have become increasingly used in many applications for their unique properties. From a mechanical point of view the most interesting is the ability to absorb large amounts of strain energy. The ability is enabled via cellular structure with high ratio of porosity (75-95 %). From stress-strain curve of compression it is obvious that after the initial linear elastic region (corresponding to cell edge bending or face stretching) is the point of yield strength followed by wide plateau of constant stress (corresponding to cell collapse, plastic yielding, etc.) in extensive range of deformation [1]. Understanding of the deformation behaviour (i.e. strain and stress distribution) of metal foams is important for design of components (bumpers, deformable elements of vehicles etc.). Foams from biocompatible materials (i.e. titanium) can be suitable for implants in the future. Currently, the PlivioPore implant system (Synthes GmbH, Switzerland) for lumbar vertebrae based on open-cell titanium foam is commercially produced and tested [2]. Application of open-cell metal foams as the bone implant evokes its structural similarity to trabecular bone. For this substitution it is necessary to compare the deformation behaviour of the artificial and natural cellular structure. Uniaxial loading test is widely used method for

[1] Czech Technical University in Prague, Faculty of Transportation Sciences, Department of Mechanics and Materials, Na Florenci 25, 110 00 Prague 1, email: xzlamal@fd.cvut.cz
[2] Academy of Sciences of the Czech Republic, Institute of Theoretical and Applied Mechanics, v. v. i., Prosecka 76, 190 00 Prague 9, email: {kytyr, fila, koudelka, jirousek}@itam.cas.cz

investigation of material properties and compression test can be performed for determination of Young's modulus and yield stress of metal foams [3].

The aim of this study is to determine the stress-strain measurement protocol for the compression test of the metal foam using the in-house loading device. Strain of the sample is measured based on DIC technique. Evaluation of the mechanical properties of the sample is performed using the custom tool based on the Matlab toolkit.

2. Materials and Methods

2.1. Sample preparation

For the compression test aluminium metal foam Alporas® (Shinko Wire Co. Ltd, Japan) was used. Alporas is a light-weight cellular material with closed-cell internal structure industrially produced since 1986. Structure of this material is typically constituted by large inner pores of polyhedral shape with a mean cell size 4.5 mm. Cell walls are typically 100 µm thick with overall porosity approximately 90%. Alporas is manufactured using special alloy containing 97% of aluminium, 1.5 % of calcium and 1.5 % of titanium [4].

Cuboid shape (30x30x60 mm) samples (n=9) were cut from slab of the metal foam and sides were grinded using silicon carbide abrasive papers with P240 and P600 grit sizes. Grinding was performed in order to achieve smooth surface with the intact microstructure of cell walls. Surface with clearly-visible microstructure is necessary for precision strain measuring using DIC. For investigation of the influence of the end artefact [5], the ends of three samples were embedded approximately 5 mm into the epoxy resin.

2.2 Compression test

Prepared samples were inserted into home-built loading device [6-7] equipped with 2kN force sensor (U9b, HBM GmbH., Germany). Before the final compression (up to 2 % total deformation) series of loading cycles were performed for elimination of the end artefact of the sample. During the experiment a deformation of each sample was acquired using two cameras (see Figure. 1.).

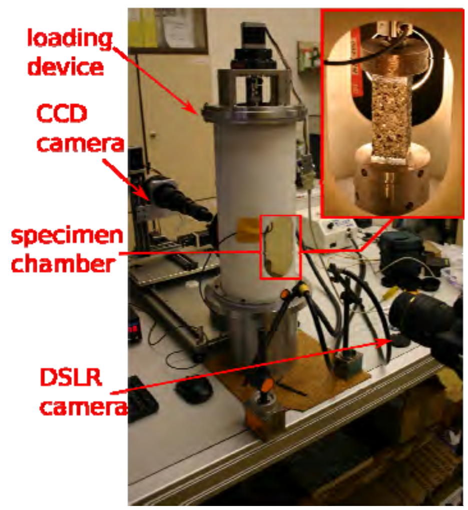

Fig. 1. *The experimental setup*

In the first case, a DSLR CMOS camera (EOS 550D, Cannon, Japan) with 3456x5184 px resolution equipped with a macro lens (105mm F2.8 EX DG Macro, Sigma, Japan) was used. Measurement of the microstructure deformation on opposite side was performed by a grayscale CCD camera (CCD 1300-F, VDS Vosskuhler GmbH, Germany) with 1280x1024 px resolution attached to an optical microscope (Navitar Inc., USA). The frame rate of the DSLR camera and the CCD camera were 0.4 fps and 5 fps, respectively. Acquired images from both cameras were compared with regard to their suitability for evaluation of the displacement of the DIC markers.

The rectangular fields of markers were selected in the captured data and their positions were tracked using DIC toolkit [8] based on Lucas-Kanade algorithm. From the displacements of the markers in an upper and a bottom layer the strain values were determined for the each captured image, i.e. - for each loading state. Force values corresponding to the loading states were selected from the force log. Stress values were calculated based on selected force values and cross-section of the sample. Young's modulus was obtained from the slope of the elastic part of the stress-strain curve. The flowchart of the developed measuring protocol is shown in Figure 2.

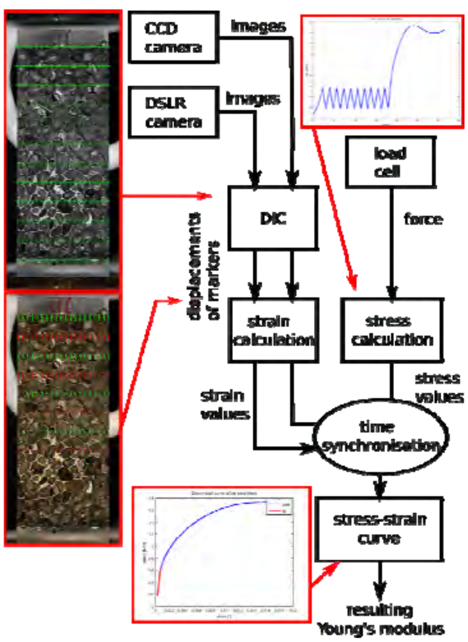

Fig. 2. *The flowchart of the developed measuring protocol with examples of the processes in the function blocks*

3. Results

Strain values were calculated from the movement of the DIC markers during the compression test. Image data were captured using two cameras on the opposite sides of each sample. Imaging using CCD camera was performed in a limited area because attached microscope lens (0.25 x magnification) did not provide for observation of the entire sample. The CCD observing area is shown in Figure 3 and for comparison, the CCD observing area is shown on the same side as the DSLR imaging area.

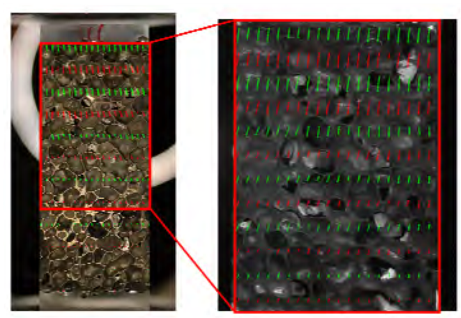

Fig. 3. The *movement of DIC markers and sizes of the observation areas: DSLR camera (left), CCD camera (right).*

Although these cameras have different acquisition properties (size of the observing area, resolution, frame rate, lens etc.), the resulting Young's moduli were approximately equal (e.g. E_{CCD}=1.669 GPa and E_{DSLR}= 1.698 GPa in the case of the same sample). Established overall Young's modulus for samples (n=6) without embedded ends and samples (n=3) with embedded ends were E_{pure}=1.33±0.147 GPa and $E_{embedded}$=1.52±0.202 GPa, respectively.

4. Conclusions

In this work the novel stress-strain measurement protocol for the compression test was developed. The functionality was tested using compression test of the aluminium foam specimens. From obtained stress-strain curves the overall Young's modulus E_{pure}=1.33±0.147 GPa of Alporas was determined. In comparison to elastic modulus E=40 GPa [7] of Al-rich zone (97% of the solid material of the sample) measured by nanoindentation, the high porosity (91%) gives the excellent deformation behaviour under loading. During the compression test, image data were captured using two cameras: (i.) grayscale CCD and (ii.) commonly available DSLR camera. From results it is obvious that overall Young's modulus was independent on the choice of camera because strain calculation was a lmost the same (E_{CCD}=1.669 GPa and E_{DSLR}= 1.698 GPa). For investigation of influence of the end artefact, the ends of three samples were embedded into the epoxy resin. Measured stiffness increase (E_{pure}=1.33±0.147 GPa, $E_{embedded}$=1.52±0.202 GPa) is due to the imperfect embedding process because the part of the epoxy resin penetrated through the pores deeper into the sample and reinforced the m icrostructure. These samples were excluded from the overall Young's modulus calculation. On the other hand, these measured data could be used for the toolkit evaluation. A correct determination of the elastic properties of the metal foam obtained from the experiment will be essential for validation of numerical modelling in further work.

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