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Deformation Mechanisms of Auxetic Microstructures for Energy Absorption Applications

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Abstract: In this work parametric modelling was utilized to design and produce two types of porous microarchitectures with auxetic compressive properties suitable for deformation energy mitigation applications such as blast and bullet protection. The samples were directly produced from acrylic material using a high resolution 3D printer and their compressive mechanical characteristics were tested. Two different structures exhibiting in-plane negative strain dependent Poisson's ratio were selected for the analysis: i) two-dimensional inverted (re-entrant) honeycomb and ii) two-dimensional cut missing-rib. Stress-strain relationships were established from a set of quasi-static compression experiments where the strain fields were evaluated using digital image correlation applied to measure the full-field displacements on the samples' surface. From the displacement fields true strain – true stress curves were derived for each sample and relative elastic moduli were evaluated.

Introduction and methods

Recently much effort has been concentrated on development of advanced materials providing high impact energy absorption capabilities for applications where weight is a crucial factor. One of possible solutions are porous solids (i.e. open or closed cell foams) which are advantageous by their low specific weight and thus high specific stiffness. However usage of most foam types including metallic foams is impossible for certain applications (including blast protection) as it may be necessary to use materials with relatively high compressive strength [1]. One of possible approaches how to deal with absorption of enormous amounts of deformation energy during blast and impact loading of structures is to produce a highly optimized porous structure taking advantage of negative Poisson's ratio of its skeleton [2].

In this paper two microstructures utilizing in-plane negative Poisson's ratio were produced by direct 3D printer Pro Jet HD3000 (3D Systems, USA) utilizing multi-jet modelling technology. Samples were produced from VisiJet EX200 (3D Systems, USA) UV curable acrylic material suitable for high resolution 3D printing with resolution $328 \times 328 \times 606$ DPI (x, y, z) and layer thickness 0.036 mm. In this mode accuracy of printing was approx. $0.025 - 0.05$ mm and the production process took 11 hours. Two different structures exhibiting in-plane negative strain dependent Poisson's ratio were selected for the analysis: i) two-dimensional inverted (re-entrant) honeycomb (porosity 73.2 %, Fig. 1 left, upper) and ii) two-dimensional cut missing-rib (porosity 72.8 %, Fig. 1 left, lower).

Quasi-static uni-axial compressive experiments were performed using in-house developed loading setup based on a novel modular compression/tension loading device suitable for both optical and X-ray observation of deformation processes equipped with U9b force transducer (HBM, Germany) with nominal force capacity 2 kN. Deformation of the samples was optically observed using a CCD camera and digital image correlation (DIC) method was used for strain-field evaluation [4] and calculation of true strain - true stress relationships.

Results and conclusion

True stress – true strain diagrams from experimental quasi-static compression tests were plotted for both microstructures as shown in Fig. 1 right. It can be seen that cut missing-rib microstructure exhibits

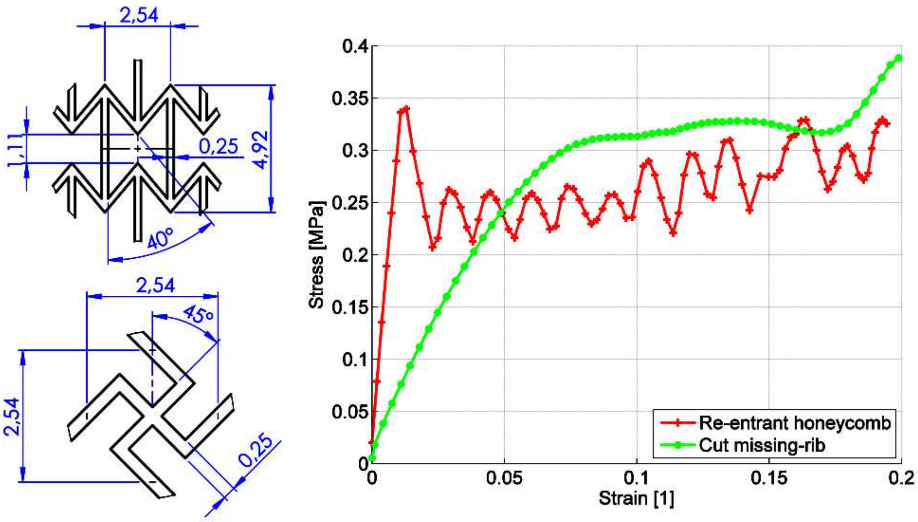

Fig. 1: Schematics of investigated microstructures (left) and true stress - true strain relationships determined using DIC (right).

initial compressive behaviour very similar to a closed-cell porous solid [3]. The initial linear elastic part is followed by apparent yield point and compaction region with constant stress plateau. These parts are then at approx. $17.5\,\%$ strain followed by region of localized densification due to negative Poisson's ratio of the unit cell and repeated decreases of stress that can be attributed for ruptures of beams due to excessive bending. Response of the re-entrant honeycomb microstructure to compressive loading is significantly different. After the initial linear elastic region $30\,\%$ drop of stress is followed by cyclic increases and decreases of stress levels in the specimens with apparent progressive trend. Following visual inspection of individual projections during deformation the occurrence of cycles can be attributed to collapse of individual layers of unit cells in the microstructure. From the elastic parts relative elastic moduli were evaluated resulting in $E_{\text{r,cut}} = 4.46 \cdot 10^{-3}$ for the cut missing-rib structure and $E_{\text{r,inv}} = 2.37 \cdot 10^{-2}$ for the inverted honeycomb structure. It has been shown that DIC method is suitable for characterization of deformation and mechanical characteristics of auxetic constructs produced by direct 3D printing.

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References

[1] Y. Sugimura, J. Meyer, M. Y. He, H. Bart-Smith, J. Grenestedt, A.G. Evans, On the mechanical performance of closed cell Al alloy foams, Acta Materialia, 45 (1997) 5245–5259.

[2] M. Grujicic, J. Galgalikar, J. S. Snipes, R. Yavari, S. Ramaswami, Multi-physics modeling of the fabrication and dynamic performance of all-metal auxetic-hexagonal sandwich-structures, Materials & Design, 51 (2013) 113–130.

[3] O. Jiroušek, T. Doktor, D. Kytýř, P. Zlámal, T. Fíla, P. Koudelka, D. Vavřík, Journal of Instrumentation, X-ray and finite element analysis of deformation response of closed-cell metal foam subjected to compressive loading, 8 (2013) C02012.

[4] I. Jandejsek, J. Valach, D. Vavřík, Optimization and Calibration of Digital Image Correlation Method, in: P. Šmíd (Ed.), Proceedings of Experimental Stress Analysis 2010, Univerzita Palackého v Olomouci, Olomouc, pp. 121–126.