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Material Behaviour

Cell shape effect evaluation of polyamide cellular structures

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A B S T R A C T

The paper describes an experimental investigation of regular open-cell cellular structures, where the influence of cell shape on cellular structure behavior under uniaxial compressive loading has been studied. Cellular structures with circular and quadratic cells have been manufactured with the laser sintered rapid prototyping technique using polyamide PA-12 as the base material. An advanced approach for Poisson's ratio evaluation is proposed, which is based on the three-dimensional laser scanning technique. The experimental results have shown that the same layer-wise collapse mechanism, commonly observed in irregular open-cell structures, can be observed also in regular open-cell structures. The energy absorption characteristics show advantageous performance of cellular structures with circular cells in comparison to the quadratic cells.

1. Introduction

Cellular structures have become very popular engineering materials in recent years due to their wide applicability and various advantageous mechanical and thermal properties [1–3]. One of the disadvantages of the cellular structures is their irregularity and inhomogeneity [4]. However, with modern production technologies the degree of regularity as well as cell size control drastically increase, e.g.. lotus-type porous materials, hollow sphere structures [5]. With the newer production techniques, even the cell shape can be controlled to produce a cellular structure designed to fulfill unique properties for individual engineering applications. Since the cell shape influence on the mechanical properties of cellular structures has not yet been fully addressed, this experimental study focuses on its characterization and evaluation at quasi-static and dynamic uniaxial compressive loading conditions. The polyamide specimens have been produced with a laser sintering procedure, allowing easy production of different cell shape types, where the base material properties have been additionally characterized using a three-dimensional laser scanning technique.

2. Evaluation of the base material mechanical properties

To better understand the behavior of manufactured cellular structures, the mechanical properties of the base material, polyamide PA-12 (EOSINT P/PA2200), have been determined [6,7]. Cylindrical specimens of diameter $2r = 20$ mm and height $h = 20$ mm have been manufactured for this purpose by the laser sintered rapid prototyping technique. The specimens have been subjected to quasi-static and dynamic uniaxial compressive loading using a servo-hydraulic testing machine (INSTRON 8801), achieving strain rates up to $\dot{\varepsilon} = 10\,s^{-1}$. During the compressive loading a significant strain hardening plastification zone has been observed. The derived stress-strain response of the cylindrical test specimens (Fig. 1) allows the polyamide to be characterized as a ductile material with a stable dynamic response. The Young's modulus for the quasi-static ($E_{stat} = 1944$ MPa) and dynamic ($E_{dyn} = 2023$ MPa) loading cases were obtained from the stress-strain diagram (Fig. 1). The derived Young's modulus corresponds well with the data provided by the

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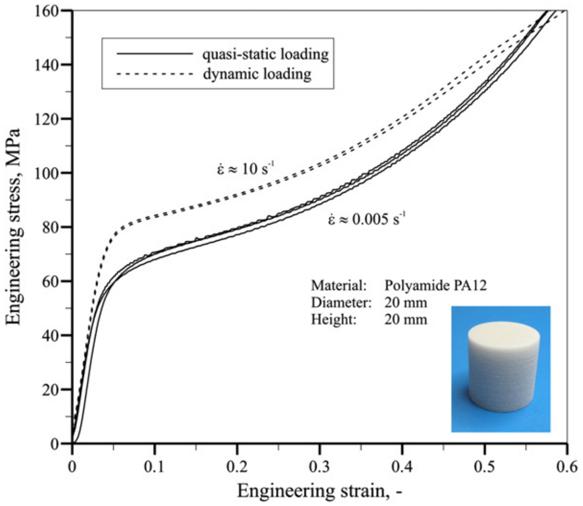

Fig. 1. Behavior of the polyamide under quasi-static and dynamic compressive loading.

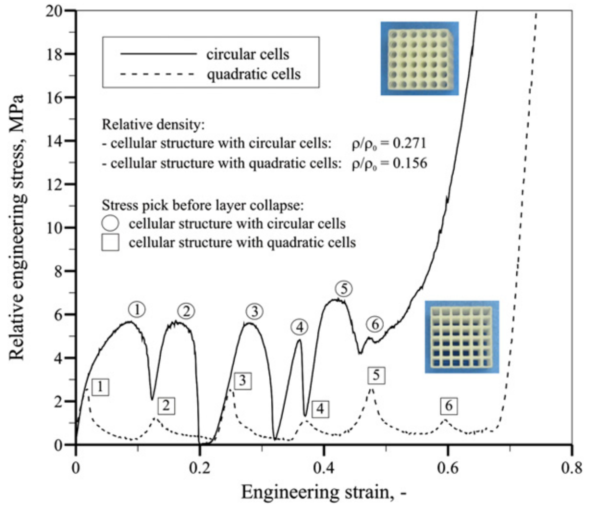

Fig. 3. Comparison of compressive behavior between circular and quadratic cells (quasi-static loading).

material producer [6]. The yield stresses for the quasi-static and dynamic loading case are $\sigma_y = 47$ MPa and $\sigma_y = 62$ MPa, respectively. The initial plastic region can be described with a plastic modulus of $E_{pl} = 95.5$ MPa.

The Poisson's ratio has been precisely evaluated from cylindrical specimen volume changes during the compression tests with a three-dimensional laser based NextEngine scanner. The volumetric deformation is

$$\varepsilon_V = \frac{\Delta V}{V_0} = \frac{V - V_0}{V_0} = \frac{\pi r^2 h - \pi r_0^2 h_0}{\pi r_0^2 h_0} = \frac{r^2 h}{r_0^2 h_0} - 1 \qquad (1)$$

where r is the specimen radius, h is its height and index 0 refers to the undeformed specimen. If small changes in geometry are defined as Δr and Δh, higher order terms can be neglected and relation (1) reduces to

$$\varepsilon_V = \frac{r^2 h}{r_0^2 h_0} - 1 = \frac{(r_0 + \Delta r)^2 (h_0 + \Delta h)}{r_0^2 h_0} - 1 \approx 2\frac{\Delta r}{r_0} - \frac{\Delta h}{h_0} = 2\varepsilon_r + \varepsilon_l \qquad (2)$$

where ε_r and ε_l are the radial and longitudinal deformations. The relation between the radial and longitudinal deformations is defined by the Poisson's ratio, where $\varepsilon_r = -\nu\,\varepsilon_l$. By inserting this relation into (2), the volumetric deformation and Poisson's ratio can be expressed as

$$\frac{\Delta V}{V_0} = \varepsilon_l(1 - 2\nu) = \frac{\Delta h}{h_0}(1 - 2\nu) \Rightarrow \nu = \frac{1}{2}\left(1 - \frac{h_0 \Delta V}{V_0 \Delta h}\right) \qquad (3)$$

According to equation (3) and geometrical data obtained by the three-dimensional scanning during the deformation process, a Poisson's ratio of $\nu = 0.204$ has been evaluated for the polyamide PA-12.

3. Characterization of the open-cell cellular structure

With the purpose of studying the influence of cell shape on macroscopic behavior of regular polyamide cellular structure, two cases have been considered: (i) structure with circular cells ($\rho/\rho_0 = 0.271$) and (ii) structure with quadratic cells ($\rho/\rho_0 = 0.156$). The specimens were manufactured by the laser sintered virtual prototyping technique, allowing for easy production of different cell shape types. The global specimen's dimensions were $24 \times 24 \times 24$ mm, containing $6 \times 6 \times 6$ cells. The circular cell diameter was 3 mm and the

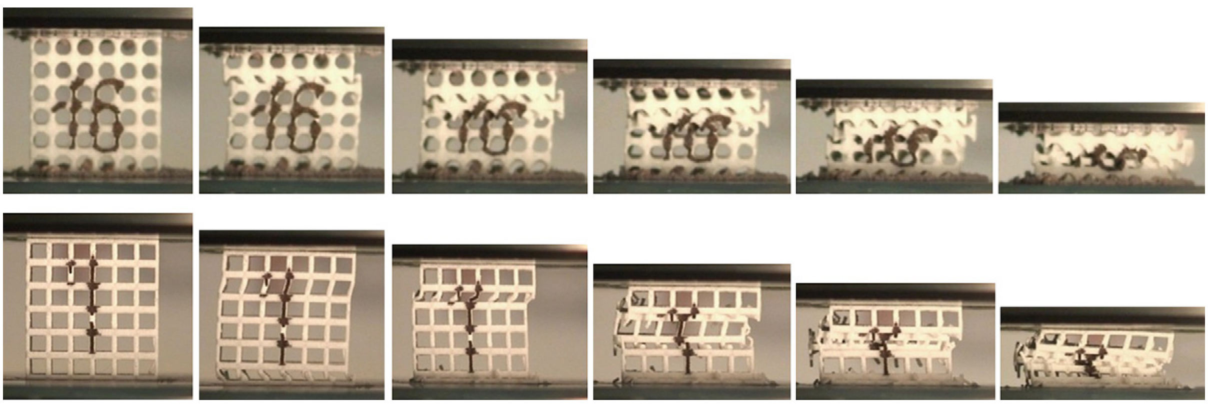

Fig. 2. Layer-wise collapse mechanism of the circular (upper raw) and quadratic (lower raw) cell structure.