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High Strain Compression Behaviour of Nano-structured Hierarchical Irregular Honeycombs

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The nano-structured irregular honeycombs are assumed to be hierarchical and self-similar and of a number of structural hierarchy, as shown in Fig. 1. This paper aims to study the effects of cell irregularity on the nonlinear compression behaviour of nano-structured hierarchical honeycombs.

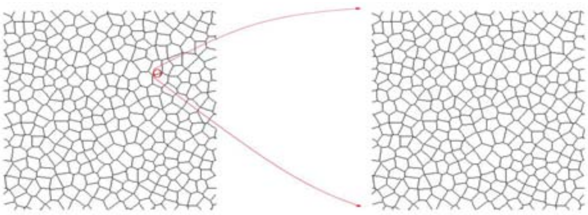

Fig. 1. A nano-structured hierarchical and self-similar irregular honeycomb.

We developed a software to construct periodic random irregular nano-sized honeycombs with different degrees of cell regularity α [1, 2], as shown in Fig. 1, and then used the commercial software ANSYS to perform finite element simulations on the nonlinear compressive behaviour. Each of the cell walls is partitioned into a number of Timoshenko beam elements. At the nanometer scale, the bending, transverse shearing and axial stretching rigidities of the cell walls are size-dependent [3-5] and given as

$$D_b = \frac{E_S bh^3}{12(1-\nu_S^2)}[1+6\frac{l_n}{h}+\frac{\nu_S(1+\nu_S)}{1-\nu_S}\varepsilon_0^L], \tag{1}$$

$$D_s = \frac{G_s bh}{1.2}\cdot\frac{[1+\frac{6l_n}{h}+\nu_s\frac{1+\nu_s}{1-\nu_s}\varepsilon_0^L]^2}{1+\frac{10l_n}{h}+30(l_n/h)^2}, \tag{2}$$

and

$$D_c = E_s bh(1+2l_n/h) \tag{3}$$

Where the width of the cell walls, *b*, is assumed to be a unity and much larger than the thickness *h*, $l_n = S/E_S$ is the intrinsic length of the material at the nano-meter scale, *S* is the surface elasticity modulus, E_S and ν_S are the Young's modulus and Poisson ratio of the solid material. $\varepsilon_0^L = \frac{\sigma_0^L}{E_S}(1-\nu_S) = -\frac{2\tau_0}{E_s h}(1-\nu_S)$ is the initial strain of the cell walls in the length direction,

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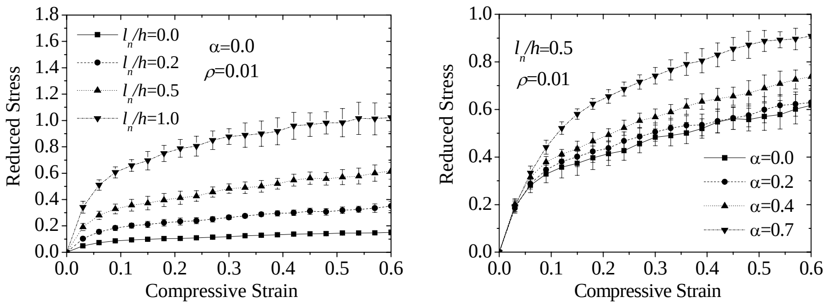
τ_0 is the initial surface stress, and both of them can be controlled to vary over a range from negative to positive. We incorporate the size-dependent effects (Equations (1-3)) into the finite element simulations by using a programmed user subroutine.

The finite element simulation results show that for the first order nano-structured hierarchical honeycombs with a low relative density ($\rho = 0.01$), the dimensionless compressive stress increases with the compressive strain; the thinner the cell walls (or the smaller the cell size), the larger the dimensionless compressive stress (Fig. 2a); the higher the degree of cell regularity α, the larger the dimensionless compressive stress (Fig. 2b). Cell wall thickness has negligible effect on the Poisson ratio, while higher the cell regularity, the larger the in-plane Poisson ratio, and the Poisson ratio is always very close to 1.0 when the deformation is small and reduces with the increase of the compressive strain.



(a) (b)

Fig. 2. Relations between the compressive strain and the dimensionless (reduced) compressive stress: (a) effects of cell wall thickness; and (b) effects of cell regularity.

The nonlinear compression behaviour of the nano-structured hierarchical honeycombs is related to that of the first order nano-sized honeycombs. It was found that nonlinear mechanical properties of both the first order nano-honeycombs and the nano-structured hierarchical honeycombs are tuable and controllable over a large range [6]. Thus random irregular nano-structured hierarchical honeycombs can be used as the activating materials in practical applications.

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