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Finite Element Analysis of Thin-Shell Microlattices: Towards Ultralight and Tight Structural Materials

• Motivation

A microlattice is an ultralight shell-structure which consists of bcc-like elementary cells with thin-walled, cylindrical Ni struts.

– Mechanical Properties

(i) Ultralight: $\rho \geq 0.9$ mg/cm^3.

(ii) Unique scaling of effective elastic modulus: $E \sim \rho^2$.

(iii) Almost full recovery of initial shape after unloading from 50% compression for thin shells, $t = 150$ nm, [2, 3].

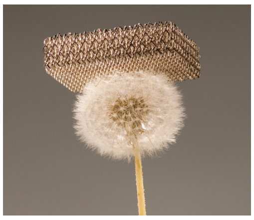

Fig. 1. Ultralight. [1].

– Multifunctional Applications

Desirable for thermal insulation; battery electrodes; catalyst supports; acoustic, vibration, or shock energy damping.

• Fabrication and Experiments

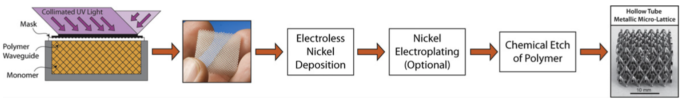

Fig. 2. Fabrication from polymer templates, [2].

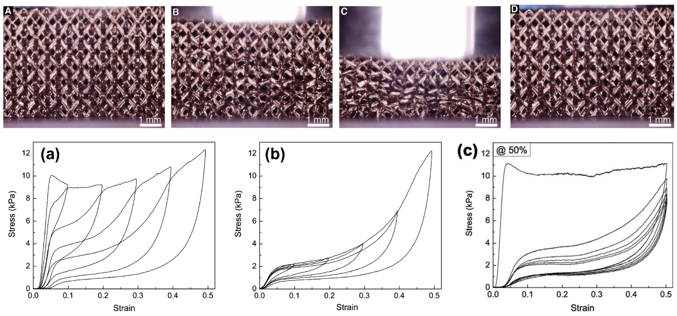

Fig. 3. (top:) Compression up to 50 % and unloading for wall thickness $t = 150$ nm, slab length $l = 4$ mm, diameter $D = 0.5$ mm, from [2]. (bottom:) Hystereses, from [3].

• Elasto-Plastic Finite Element Analysis

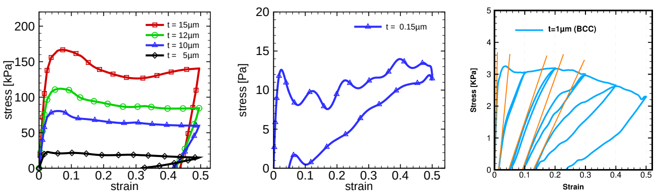

Fig. 4. Stress-strain curves (Ni) for (left) one loading-unloading cycle for various t ($l = 4$mm, $D = 0.5$mm), (centre) for $t = 150$ nm there is almost full elastic recovery even after 50% compresssion, in agreement with the experiment, see Fig. 3 (c), (right) for cyclic loading with an increase of compressive strain: note the gradual decrease of stiffness.

• Deformation Analysis (FEA)

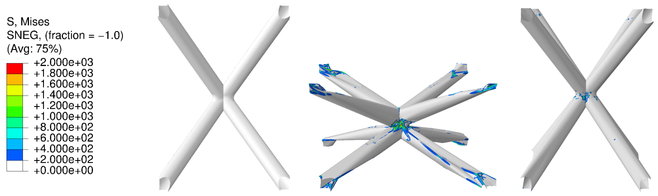

Fig. 5. Unit cell compression for $t = 150$ nm with von-Mises stress at (left) initial state, (centre) at maximum compression of 50%, and after unloading.

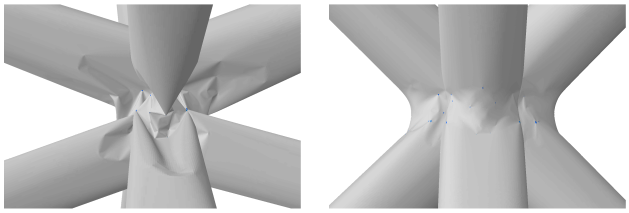

Fig. 6. Nodal *folding* mode for $t = 150$ nm (left) at 50% compression and (right) at complete unloading.

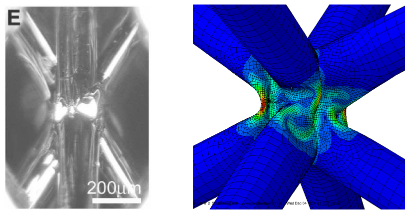

Fig. 7. Nodal *buckling* mode in (left) experiment [2] and (right) simulation for $t = 3\mu$m.

• Scaling Behavior (Ashby-Diagrams)

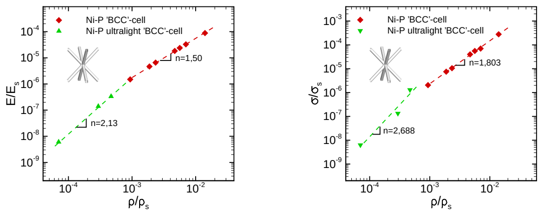

Fig. 8. Ashby diagrams for (left) nominal elastic stiffness and (right) strength.

$$\frac{E}{E_s} = C\left(\frac{\rho}{\rho_s}\right)^n, \qquad \frac{\sigma}{\sigma_s} = D\left(\frac{\rho}{\rho_s}\right)^m$$

The scaling behavior for the nominal elastic stiffness n and the strength m is in agreement with the experiments, [2].

References:

[1] http://www.cnet.com/news/breakthrough-material-is-barely-more-than-air/

[2] T.A. Schaedler et al., *Science* 334 (2011)

[3] A. Torrents et al., *Acta Mater.* 60 (2012)

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