The Mechanics of Lattice Materials

Norman A. Fleck

Engineering Dept., Cambridge University, Trumpington St.,Cambridge, CB2 1PZ, UK
NAF1@eng.cam.ac.uk

ABSTRACT

This talk reviews recent advances in the mechanics of lattice materials. The overall goal is to combine material, topology and length scale in new ways in order to develop new combinations of thermal-mechanical properties, such as high strength and low thermal conductivity at low density. Thereby, gaps in material property space can be filled, see Fig. 1(a). There remains a significant challenge to design lattice materials with a prescribed set of properties: such properties are not entirely arbitrary but are subject to cross-property bounds. The mechanical properties of lattice materials are largely dictated by nodal connectivity, with imperfection playing a minor role.

The bounds on some properties (such as strength) are much closer together than those for other properties (such as fracture toughness): in fact, no satisfactory bounds have been obtained on toughness to the author's knowledge. Recently, the macroscopic fracture toughness K_{IC} of a number of isotropic 2D lattices has been determined by finite element calculation. It is assumed that the lattice, of strut length L fails when the local stress anywhere in the struts attains a critical tensile stress σ_f. The fracture toughness is sensitive to topology and is the greatest for the Kagome lattice: this can be traced to the fact that this lattice has a transition value of nodal connectivity equal to 4: the lattice is at the transition between a stretching-dominated lattice and a bending-dominated lattice. Calculations of fracture toughness have also been performed for ductile lattices, whereby failure is dictated by a critical local strain criterion.

Buckling response of lattices. Lattice materials have found most application in the cores of sandwich panels, due to the fact that they can be designed to be stiff and strong in shear, and also under normal through-thickness compressive loadings, as encountered in blast loading. Under such dynamic loadings, the compressive, buckling response of the lattice is influenced by material inertia and strain rate sensitivity.

Topology and material inertia have a major effect upon the elastic-plastic buckling response of a lattice. Recently, the buckling strength of hollow lattices has been explored and buckling maps developed in order to show the sensitivity of buckling load to topology, see Fig. 2. An additional strategy is to increase the wall strength of the struts by surface hardening treatments: this delays the onset of plastic buckling. The sensitivity of buckling strength to dynamic effects has been explored theoretically and experimentally, and used to determine the resistance of lattice-cored sandwich to blast loading (water blast and sand blast).

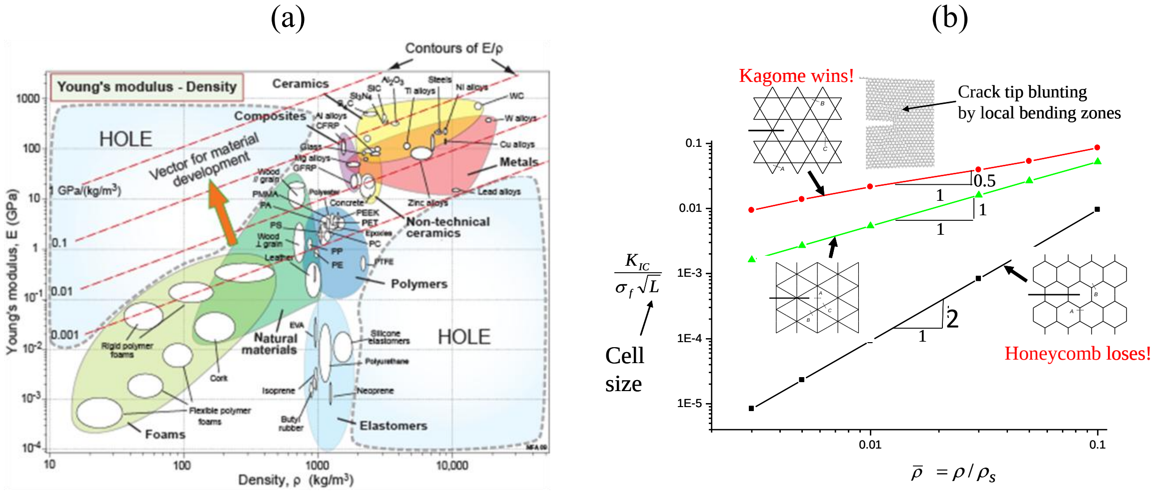

Figure 1: (a) Gaps (holes) in material property space: an example is shown for a plot of Young's modulus versus density; (b) the dependence of fracture toughness upon relative density $\bar{\rho}$.

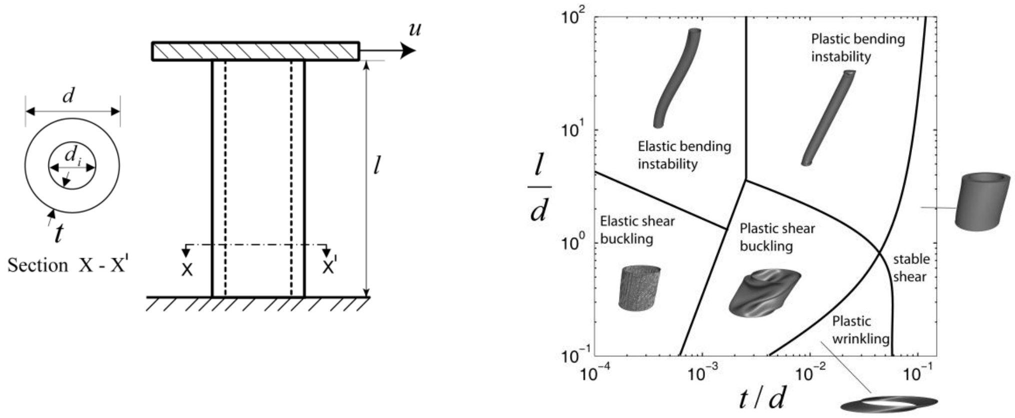

Figure 2: A buckling map for hollow tubes in shear, made from type 304 stainless steel.

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