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Design, fabrication and mechanics of architectured micro-/nanolattices

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ABSTRACT:

For nearly all structured materials, there exist several pairs of inevitable conflicts, such as high strength vs. large deformability/ductility, high strength vs. low density, and high strength vs. good recoverability, which restricts the applications of the structured materials in energy storage/absorption and mechanical actuation. Designing and synthesizing materials that are simultaneously strong and stiff, substantially deformable (i.e. >10%), and lightweight remains a long-standing and unsolved challenge. Here we first present the fabrication and mechanical characterization of 3D high-entropy alloy (HEA)-polymer nanolattices. These composite nanolattices are made up of a HEA-coated (14.2-126.1 nm in thickness) polymer strut (approximately 260 nm in the characteristic size). In-situ mechanical testing inside a SEM showed that these composite nanolattices exhibit a high specific strength of 0.027 MPa/kg m3, and nearly complete recovery after compression under strains exceeding 50%, thus overcoming the traditional strength-recoverability trade-off in micro-/nanolattices reported recently. We also present the design, fabrication and mechanics of 3D pyrolytic carbon nanolattices. The pyrolytic carbon nanolattices with octet- and iso-truss topologies have the diameters of the individual struts varying from 261 nm to 679 nm. The smallest characteristic size of the struts approached the limits of resolution of the available three-dimensional lithograph technologies. In situ SEM and ex situ compressive testing revealed that these pyrolytic carbon nanolattices have a compressive strength of ~1.90 GPa at a density below 1.0 g/cm3. As a result, the pyrolytic carbon nanolattices achieved an exceptional specific strength of 1.90 GPa g-1 cm3, which is 1-3 orders of magnitude higher than those of nearly all micro/nanolattices reported so far. The compression experiments also showed that these nanolattices have the average fracture strains of 14.0% and 16.7%, respectively, which are larger than those of various brittle nanolattices reported previously. More interestingly, these nanolattices become insensitive to fabrication-induced defects. Furthermore, we characterized the microstructures and mechanical properties of pyrolytic carbon single micropillars. These micropillars consist of 1-1.5 nm curved graphene layers, and have an average tensile strength of 1.60 GPa, a compressive strength approaching the theoretical limit of ~13.7 GPa, a substantial elastic limit of 20-30% and a low density of ~1.4 g/cm3. More remarkably, the pyrolytic carbon micropillars with diameters below 2.3 m sustained compressive strains that exceed 50% without catastrophic fracture, deforming like rubber. The unique mechanical properties of architectured materials mentioned above are attributed to the controlling of characteristic size of materials, and the optimization of structural topology and the selection of constitute materials.

BIOGRAPHY:

Xiaoyan Li is a tenured associate professor in the Department of Engineering Mechanics, Tsinghua University. He received his Ph.D. in Engineering Mechanics from Tsinghua University in 2007. After that, he received his Ph.D. in Mechanical Engineering from Brown University in 2012. His current research interests focus on deformation and fracture mechanisms/behaviours of nanostructured materials (including nanocrystalline and nanotwinned materials, low-dimensional materials), energy storage materials and mechanical metamaterials, and fabrication and design of architectured materials and high entropy alloys based on the mechanical principles. So far, he has published 52 papers (35 after joining Tsinghua) in refereed journals, including Nature, Nature Mater., Nature Nanotech., Nature Comm., Nano Lett., PNAS, Adv. Mater., PRL, Nano Energy, Science Advances, ACS Nano etc., as well as important journals in the field of mechanics (including JMPS, JAM, IJSS); and 3 book chapters. His research has been highlighted by news media such as Nature News, Science Online, NSF, R&D Mag, ScienceDaily, PhysOrg, Nanotimes, Nanowerk and Sciencenet.cn and so on. He served as an editor of Science China-Technological Science (2018-2022), the National and International Committee Members for 14th International Conference on Nanostructured Materials in 2018, and Journal Club Editor of iMechanica in 2018. He has organized six symposia for international conferences, and has served as the proposal reviewer for NSFC and the reviewer for more than 40 peer reviewed journals. He received the Best Paper Award as a Young Scientist at the International Fracture Conference 2013, Chinese National Science Foundation Award for Excellent Youth Scientists in 2015, Extreme Mechanics Letters Young Investigator Award in 2018 and Elsevier Eshelby Mechanics Award for Young Faculty in 2018