KTH SOLID MECHANICS KEYNOTE SEMINAR; Thursday, March 9th, 16.15; https://kth-se.zoom.us/j/62253263818

Norman Fleck

"Mechanics aspects of solid state lithium ion batteries"

Li ion batteries discharge by the transport of Li ions from an anode (such as graphite or Li metal) to a cathode comprising ceramic particles that swell upon lithiation. The next generation of batteries comprise cathode particles in the form of single crystals made from layered nickel rich materials. Recently, optical microscopy has been performed that reveal the diffusion of Li within these single crystals ("Operando visualisation of kinetically-induced lithium heterogeneities in single-particle layered Ni-rich cathodes" by Chao X, et al., Joule 6, 1-12, 2022.) This allows for a direct comparison with a fully coupled chemo-mechanical model of Li diffusion, including the role of stress. Predictions reveal that the level of induced stress in the single crystals is sufficient to induce cracking when the particles are large and the rate of discharge (lithiation) is very fast (full battery discharge in 10 minutes). In the final part of the talk, a constrained compression test is reported to simulate the mechanical state of a lithium dendrite within a solid state battery. Lithium microspheres are compressed between parallel quartz platens into a pancake shape of thickness on the order of 15 µm. Full adhesion with no slip exists between the lithium and platens, and the attendant mechanical constraint implies that the average pressure on the pancake-shaped specimens increases with increasing aspect ratio of radius to height. In addition to mechanical constraint, a thickness-dependent size effect is observed whereby the flow strength of the lithium increases from 0.72 MPa in the bulk to 4.5 MPa at a thickness of 15 µm. The lithium deforms in a power-law creeping manner at room temperature, and to simplify interpretation of the results the relative velocity of the loading platens is adjusted to ensure that the true compressive strain rate is held fixed. Additional measurements of lithium flow strength are obtained by subjecting the pancake-shaped specimens to simple shear. The size effect under shear loading is minor compared to that observed for constrained compression, and this is explained by appealing to strain gradient plasticity theory.

Norman Fleck has been Professor in the Mechanics of Materials at Cambridge University since 1997. He has worked on a wide range of experimental and theoretical problems in solid mechanics, starting from a PhD in metal fatigue at Cambridge, post-doctoral studies on the mechanics of metal rolling of thin foil (with K L Johnson at Cambridge) and on creep fracture (with J W Hutchinson at Harvard), and then subsequent employment at Cambridge (a lecturer in 1985 to Professor in 1997). Much of his fundamental research originated through collaboration with international industry, and the results are fed back into design and lifing methods, finite element codes and experimental results: this has allowed for the lightweighting of vehicles and the use of a wide range of materials in more extreme applications, ranging from the compressive failure of composites to multi-phase lattice design. He was the founder-Director of the Cambridge Centre for Micromechanics in 1990 and served as Head of Division for Mechanics, Materials and Design at Cambridge (1996-2008). He is President of IUTAM (2020-2024) and is a Fellow of the Royal Society, London, a Fellow of the Royal Academy of Engineering and a Foreign Member of the US NAE."