LMS Seminar

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The failure of adhesive joints: mechanisms ranging from ductile fracture to corrosion by diffusion-controlled growth

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ABSTRACT

Adhesive joints are increasing used in engineering components, particularly in the bonding of dissimilar materials. This talk focuses on two types of failure mechanisms of a sandwich joint: ductile failure under load versus delamination by corrosion, such as hydrolysis of the interface between adhesive and substrate.

Part 1: The tensile strength of an adhesive joint is predicted for a centre-cracked elastic layer, sandwiched between elastic substrates, and subjected to remote tensile stress. A tensile cohesive plastic zone, of Dugdale type, is placed at each crack tip, and the cohesive zone is characterised by a finite strength and a finite toughness. An analytical theory of the fracture strength is developed (and validated by finite element simulations). The macroscopic strength of the adhesive joint is determined as a function of the relative magnitude of crack length, layer thickness, plastic zone size, specimen width and elastic modulus mismatch between layer and substrates. Fracture maps are constructed to reveal competing regimes of behaviour. The study highlights a structural length scale in the form of layer height times modulus mismatch: this scale is on the order of 1 metre when the adhesive layer height equals one millimetre and the elastic modulus of the substrate is one thousand times that of the adhesive layer. The in-plane structural dimensions (including crack length) must exceed this structural dimension in order for a remote K-field to exist within the substrate. Experimental validation of the cohesive zone approach is achieved by measuring the sensitivity of fracture strength to crack length and layer height for a centre-cracked strip made from cellulose acetate layer, sandwiched between aluminium alloy substrates.

Part 2: A fundamental study is reported on the diffusion of a corrosive species from the side face of a sandwich layer. The corrodent diffuses along 2 competing paths: a ‘surface path’ within an interfacial edge crack and simultaneously along a ‘bulk path’ through the sandwich layer. The analysis is motivated by the practical problem of delamination of adhesive joints employed in ship construction, but has much wider applicability. Debonding initiates at the tip of the pre-existing delamination when a critical quantity of corrodent per unit area has reacted at the interface immediately ahead of the tip. The reaction rate at the delamination tip and the overall time to debond the interface are determined. Failure maps are constructed to show regimes of behaviour, with axes that make use of the sandwich layer geometry and the relative diffusivity of corrodent within the delamination crack and within the sandwich layer.

BIOGRAPHY

Norman Fleck is a Professor of Mechanics of Materials (1997), and Director of the Cambridge Centre for Micromechanics (1990) at Cambridge University Engineering Department. His research centres on Micromechanics: the development of physically based models of deformation and fracture of engineering materials by experiment, theory and numerical analysis. The research has very wide scope, and combines scientific insights and practical application. A guiding philosophy has been to condense practical engineering design problems into fundamental problems in mechanics, then generate constitutive models and implement them within finite element code. Examples are the compressive failure of engineering composites by plastic microbuckling, the coupled electro-mechanical switching of ferroelectric devices, fatigue life prediction, the mechanics of metal rolling of thin foil, size effects in plasticity effects from hardness testing to cleavage at crack tips, and more recently coupled electro-mechanical phenomena in solid state lithium ion batteries. Currently, Norman Fleck is President of the International Union of Theoretical and Applied Mechanics (IUTAM). He is a member of several learned Societies (FRS FREng NAE, Fellow of the European Mechanics Society).