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THE FAILURE OF ADHESIVE LAYERS: FROM FAST FRACTURE TO STRESS CORROSION

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Abstract

Adhesive joints are increasing used in engineering components, particularly in the bonding of dissimilar materials. This talk focuses on deformation and failure mechanisms of a sandwich joint: brittle fracture in elastic layers, ductile failure by cohesive zone modelling, diffusion-controlled attack of an interface and toughening of an adhesive layer by the presence of micro-architectured reinforcement. A fracture mechanics is developed for adhesive joints by paying due respect to embedded singularities.

1. Introduction

Adhesive layers differ from a homogeneous solid by adding a compliant, weak layer to the material system. The additional layer gives the possibility of additional failure modes within the layer or along the interface. Alsao it provdes for additional paths of diffusion of a corrodent, both with the layer and along the interface. Commonly, the layer moderates an outer singularity in stress to an inner singularity at a delamination tip, or at the free corner of the interface, for example. Adhesives are increasing used in engineeringcomponents in order to reduce mass, but life prediction and certification of the joint remains a challenge.

2. Results

The talk considers 3 examples where the integrity of an adhesive joint poses a challenge.

Example 1: The tensile strength of an elastic-brittle 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.

Example 2: A fundamental study is reported on the diffusion of a corrosive species within a sandwich layer, as sketched in Figure 1. The corrodent diffuses within an interfacial edge crack and simultaneously through the sandwich layer. 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. Predictions are made both for the initiation of debonding and for the rate of propagation of a delamination.

When the critical amount of corrodent for debonding is large enough for the delamination velocity to be much slower than the rate constant of the reaction, a much simpler Laplace problem holds in a coordinate system that moves with the delamination tip. Then, the spatial integral of the reaction rate profile along the intact adhesive/substrate interface can be used to estimate the growth rate of the delamination. For a thick sandwich layer, the growth rate is governed by a singular field of flux that is reminiscent of a K-field in fracture mechanics or a dislocation field in elasticity theory. The nature of the singularity depends upon the relative magnitude of bulk to surface diffusion. Both singular fields are absent for a thin sandwich layer, and diffusion is essentially one-dimensional along a thin strip.

Example 3: The degree of toughening of an adhesive joint is explored by suitable modification to the microarchitecture of the substrates, and by the additional of a reinforcement architecture to the adhesive. To again additional insight, size effects are explored such that the length scale of the microstructure is comparable to that of the layer thickness.

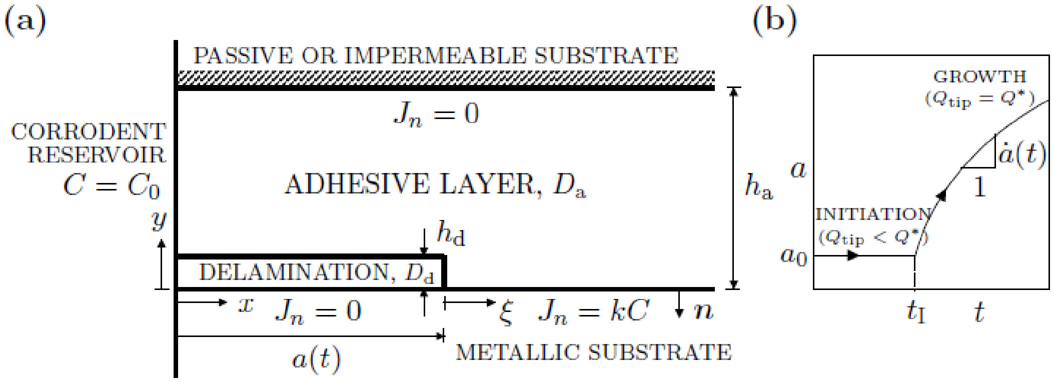

Figure 1: Delamination of an adhesive sandwich layer by diffusion of a corrosive species: (a) sketch of the problem and (b) qualitative solution in terms of delamination length versus time.

3. Conclusions

A fracture mechanics of the failure of adhesive joints is developed based on the coupling an outer stress field, where the adhesive layer can be neglected, to an inner field within the adhesive layer. In this manner failure problems due to the initiation and subsequent growth of delamionatilon can be assessed and used in a predictive design methodology.

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