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ANNOUCEMENT OF A ROUND ROBIN ON THE ANALYSIS OF THE PEEL TEST

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Abstract. There is some controversy over the analysis of the peel test when there is significant plastic deformation. To resolve this controversy a round robin on its analysis is announced contributions to which are invited. Details are given of test cases to be analysed.

1. Introduction. The peel test is an important and simple method of characterizing the cohesive energy of flexible films, but there remains some controversy over the interpretation of the test. If the films remain elastic, the cohesive energy obtained from an energy balance under steady state peeling depends only on the peel force and the peel angle providing the strain in the film is reasonably small. There is no dispute over this result. However, if the film is plastically deformed during peeling this simple approach gives the total energy dissipated during peeling which is the cohesive energy plus plastic work of bending and unbending of the film. There is no general agreement in the apportionment of the energy dissipation rate. There have been two main approaches to the apportionment of the energy release rate.

The simplest treatment of the peel test assumes that the deformation can be analysed by beam theory. Kim and Aravas (1998) used a power law hardening material to model the plastic bending and unbending and stated the importance of the rotation of the beam, ϕ, at the tip of the peel on the energy apportionment. Kinloch et al. (1994) used a linear hardening law to model peeling. They used a semi-empirical relationship for the rotation of the beam, ϕ, based on the deformation of a beam on elastic foundation. This work is the basis of a draft ESIS protocol for the peel test (Moore and Williams, 2002). Moidu et al. (1995, 1998) have given a similar analysis. In their later paper (Moidu et al., 1998) they analyse the detached part of the film assuming a linear hardening material and use a linear approximation to the moment-curvature expression for the attached portion of the film to calculate the rotation ϕ. They assume that the adhesive is elastic and take into account both the normal and the transverse stiffness. They get a check on the accuracy of their method by comparing the cohesive energy obtained from global considerations with the cohesive energy obtained locally at the tip of the peel.

The second method uses a cohesive zone and finite element analysis for either the whole film (Yang et al. 2000) or for the attached film and a length of a few film thicknesses of the detached film and slender beam theory (Wei and Hutchinson, 1998). Both Yang and Hutchinson (1998) and Yang et al. (2000) use a Tvergaard/Hutchinson (1993) cohesive zone model (CZM). Wei and Hutchinson (1998) give the theoretical peel force for a film directly bonded to a thick substrate, whereas Yang et al. (2000) analyse a T peel test of two strips of aluminium 1 and 2 mm thick bonded together by an adhesive 0.25 mm thick. Wei and Hutchinson (1998) do not model the details of the plastic work of unbending. Yang et al. (2000) use a power law for the stress-strain relationship for the aluminium and do not model the elastic deformation explicitly.

At present there is no way to decide objectively what are the ranges for which the various peel test analyses are reasonably accurate and the various results give different prediction of the variation of peel force with film thickness for the behaviour of very thin films where the energy dissipated is in the limit for zero thickness equal to the cohesive energy. Modelling of the cohesive zone is probably important for an intermediate film thickness. The composite analysis technique of Wei and Hutchinson (1998) where in the detached film away from the tip of the peel slender beam theory is used and a finite element analysis elsewhere seems sensible.

As yet there are no standard FEM packages that allow a cohesive zone to be embedded within the analysis. Although analysis using bending theory is simple and a programme can easily be run on a PC, there are ranges where it is likely to be inaccurate for example when the maximum cohesive stress is large. It would be useful to establish the limits of the applicability of bending theory to the peel test.

In view of the undoubted advantages of using bending theory if it is adequate, it is suggested that two parallel analyses be undertaken one using the Wei and Hutchinson technique or other FE method and the other using bending theory. However, to give bending theory its best chance of success the cohesive zone should be modelled. Plastic bending should be modelled in the attached film as well as in the detached film. Such a requirement necessitates numerical solution in the attached part of the film.

Because of the importance of the test, a Round Robin to assess the accuracy of the different methods and to enable recommendations to be made for the analysis of peel tests is desirable. All who are interested in the peel test are invited to join the authors in a Round Robin and they are asked to signify their interest by e-mailing the first author. The results of the Round Robin will be submitted to the International Journal of Fracture.

2. Specification of the peel test to be analysed. Because the transverse deformation in the film, especially under high plastic strains, is the most difficult to analyse approximately, it is suggested that the T-Peel of a two films of equal thickness directly bonded together without an adhesive should be analysed. Thus, in this Round Robin, bonding without an adhesive is specified. If a finite thickness is given to the cohesive zone for reasons such as numerical stability, its thickness should be stated in the report. To avoid problems with mode-mixity, the T-peel test with equal film thickness is chosen as the model test.

Since for numerical expediency in FEM, the cohesive zone is considered to run along the entire interface, this assumption will be adopted for analyses by any method.

The parameters considered important are:

(a) The thickness, h, of the film being peeled compared to a material based length scale, R_0, which is a function of the cohesive energy, Γ_0, Young's modulus, E, and the yield strength, σ_y, given by

$$R_0 = \frac{1}{3\pi\left(1-\nu^2\right)} \frac{E\Gamma_0}{\sigma_y^2}, \tag{1}$$

where ν is the Poisson's ratio

(b) The ratio of the maximum cohesive stress, $\hat{\sigma}$, to the yield strength, σ_y.

(c) The strain-hardening rate.

(d) The yield strain.

3. Parameters to be used in the peel test analyses.

The cohesive zone model (CZM): The description of the stress-displacement in the CZM, which is assumed to exist along the entire interface, is shown in Fig. 1. The cohesive energy is given by

$$\Gamma_0 = \int_0^{\delta_c} \sigma dv = \frac{1}{2}\hat{\sigma}\delta_c[1-\lambda], \tag{2}$$

where δ_c is the opening of the cohesive zone at final separation. The value of the parameter λ, which determines the "elastic opening of the cohesive zone, shall be taken as 0.1.

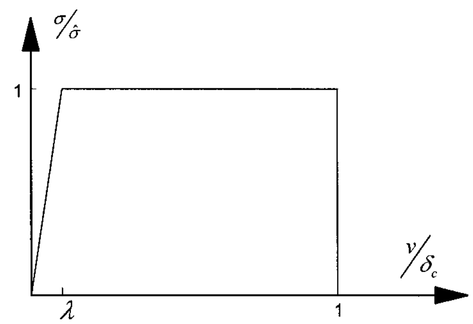

Figure 1. Cohesive stress-displacement relationship.

The maximum cohesive stress: Three values of the ratio of the maximum cohesive stress to the yield stress are to be considered

$$\frac{\hat{\sigma}}{\sigma_y} = 1, \quad 2, \quad 4$$

Stress-strain relationship of the film:

A power law hardening is chosen since it is the most widely used. The preferred stress-strain relationship is

$$\frac{\sigma}{\sigma_Y} = \frac{\varepsilon}{\varepsilon_Y} \quad \varepsilon \le \varepsilon_Y$$
$$\frac{\sigma}{\sigma_Y} = \left(\frac{\varepsilon}{\varepsilon_Y}\right)^n \quad \varepsilon > \varepsilon_Y \tag{3}$$

Three yield strains:

$$\varepsilon_y = 0.001, \quad 0.003, \quad 0.005$$

and two strain hardening exponents

$$n = 0.05, \quad 0.3$$

will be considered. For those using an approximate beam analysis an alternative case for the low strain hardening exponent is perfect plasticity (n=0).

Film thickness: Four film thicknesses will be considered:

$$\frac{h}{R_0} = 0.25, \quad 0.5, \quad 1.0, \quad 2.0.$$

The Poisson's ratio: $\nu = 0.3$.

4. Reporting. The peel force normalised by the cohesive energy is to be reported for all combinations making 72 different results. The details of the method of solution are to be reported. The deadline for the receipt of results by the co-ordinator is six months from the date of publication of this announcement.

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