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A RATE-DEPENDENT COHESIVE-ZONE MODEL SIMULATING STICK-SLIP CRACK PROPAGATION

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Rate dependent crack initiation and propagation has been the subject of extensive experimental, theoretical, analytical and numerical studies. This is because in many problems of great engineering interest the dependence of fracture processes on the loading rate cannot be ignored and often plays a key role, particularly when it leads to unstable crack growth or stick-slip crack propagation, the latter being a sequence of transitions from slow and stable crack growth to very fast and unstable crack propagation and vice versa.

Theoretically, the problem can be studied in the framework of Griffith theory of fracture, by observing that in the rate-dependent case the fracture energy G_c, intended as the total energy dissipated per unit of new formed crack area, is a function of crack speed $\dot{a}$, i.e. $G_c = \gamma(\dot{a})$, whereby crack speed instabilities may occur if γ is decreasing in part of its domain, see for example [1, 2]. Within this theoretical framework, models to study stick-slip crack propagation are of a rather phenomenological nature, whereby γ is determined experimentally, which is particularly challenging in its decreasing branches [2].

Cohesive-zone models (CZMs) represent a widely used alternative method to analyse crack growth. If they are developed within a damage-mechanics formulation a damage variable D ranging between 0 and 1 can be introduced with the usual meaning. The natural extension of the above described phenomenological approach to model rate dependent crack growth is to assume a rate-dependent evolution law for D in such a way that the entire power dissipated Π is a non-linear function of $\dot{D}$. With this approach, crack speed jumps may occur if Π is non-convex in $\dot{D}$ [3].

An alternative approach consists of introducing other internal variables α_i, $i = 1,2,\ldots,n$, within the CZM to capture different dissipation mechanisms, so that the entire dissipated power is a function not only of $\dot{D}$ but also of $\dot{\alpha}_i$ [4]. The advantage of this approach is that the internal variables α_i and their evolution laws can provide a much richer description of the actual dissipation mechanisms which occur at a micro-mechanical scale. This can lead to a model which is based more on first principles and less on phenomenological assumptions.

In this contribution attention will be focussed on rate-dependent CMZs developed within the framework of thermodynamics with internal variables using this latter of the above described approaches. In particular, a rate-dependent model will be presented in which (i) a rate-independent evolution law is assumed for the damage variable D and (ii) additional internal variables are associated with visco-plastic dissipation (differently from previous work [4], where the additional internal variables are associated with visco-elastic dissipation). In this case the overall specific dissipation is found to be a decreasing function of the applied rate of displacement jump on the interface. In a structural problem, this implies that the total dissipation is a decreasing function of the crack speed. Therefore, one would expect that crack velocity jumps and stick-slip crack propagation can occur. This is confirmed by preliminary numerical results: for example Figure 1 shows the load-displacement curve obtained for a DCB specimen made of two aluminium arms bonded with a visco-plastic adhesive, by using the proposed visco-plastic CZM within a nonlinear finite-element model with an implicit dynamic solution scheme.

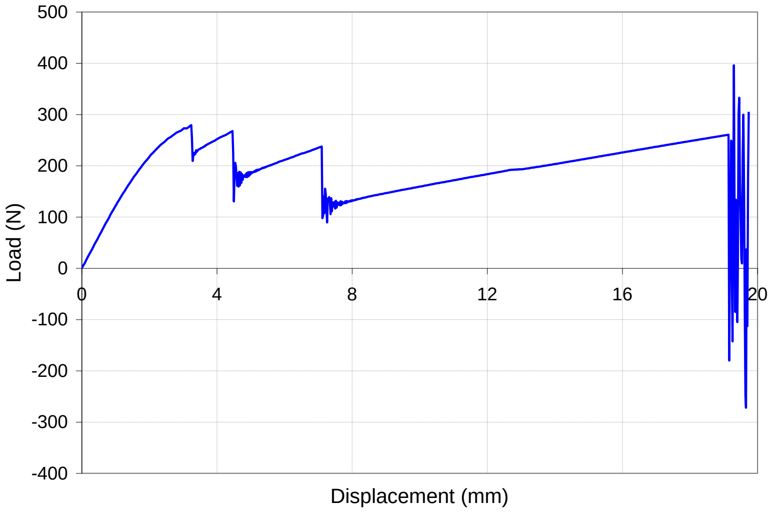

Figure 1: load-displacement curve showing stick-slip crack propagation before final failure.

More results will be discussed and analysed in detail to show the great potential of the proposed approach to predict rate-dependence and crack velocity instabilities based more on the underlying physics and relying less on phenomenological hypotheses.

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