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A visco-elastic cohesive zone model for rate and temperature dependent interlaminar fracture of composites

Ganapathi Ammasai Sengodan, Giuliano Allegri and Stephen Hallett

A cohesive zone modelling (CZM) framework that accounts the effect of loading rate and temperature on the delamination behaviour of laminated composites is presented. The loading and unloading part of the traction-separation curve is represented using the generalized Maxwell model and sub-micro-crack formation combined with Zhurkov kinetic theory of failure. For a given loading rate, the proposed model is able to match the delamination prediction from bilinear models, with static parameters. The new model capability can however additionally extend to different loading rates and temperature conditions, without additional or calibrated parameters. The energy dissipation due to the viscoelasticity and thermo-plastic particle toughening of the interface are also accounted in the current modelling framework. The developed models have been implemented in Abaqus/Explicit as a VUMAT material user subroutine.

Mixed-mode viscoelastic CZM

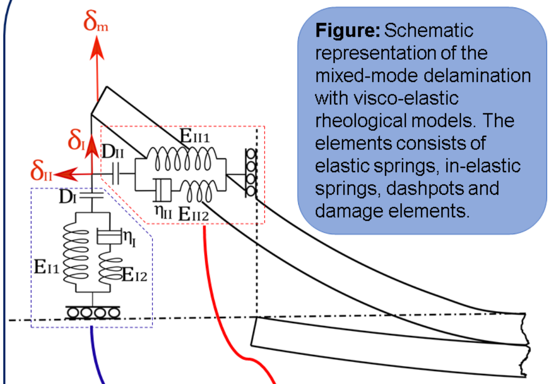


Figure: Schematic representation of the mixed-mode delamination with visco-elastic rheological models. The elements consists of elastic springs, in-elastic springs, dashpots and damage elements.

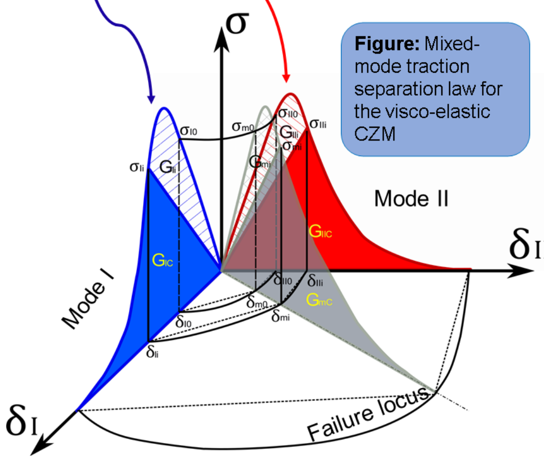


Figure: Mixed-mode traction separation law for the visco-elastic CZM

Constitutive equations

Traction-separation

$$\sigma(T,t) = \left(1 - D(T,t)\right)\int_0^t E_0 \dot{\delta}(s)ds + \sum_{i=1}^{N}\int_0^t E_i \exp\left(-\frac{t-s}{\tau_i}\right)\dot{\delta}(s)ds$$

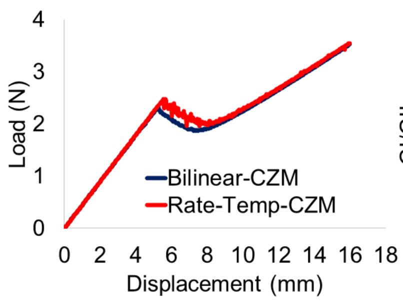
Rate of damage

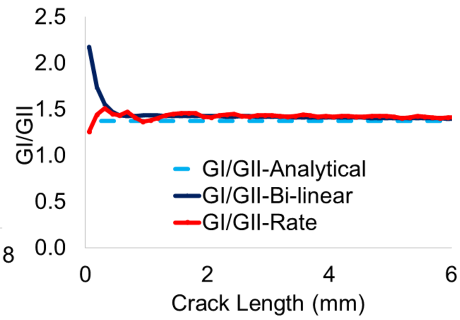
$$\frac{dD(T,t)}{dt} = \left(1 - D(T,t)\right)^p \frac{a_T}{t_0}\exp((-U + \gamma\sigma(T,t))/(RT))$$

Mixed-mode damage law

$$D_m = 1 - \left(1 - \frac{G_{mi}}{G_{mC}}\right)\left(\frac{\delta_{m0}}{\delta_m}\right)$$

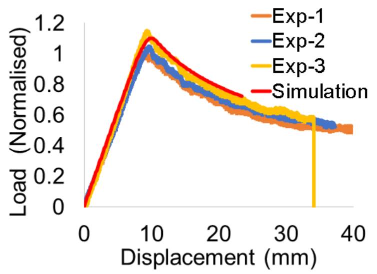
Fixed ratio mixed-mode, *GI/GII=1.33*

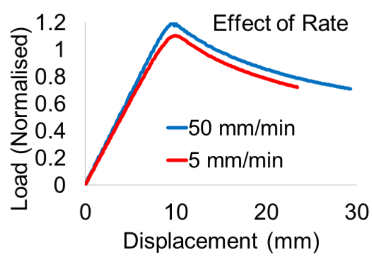


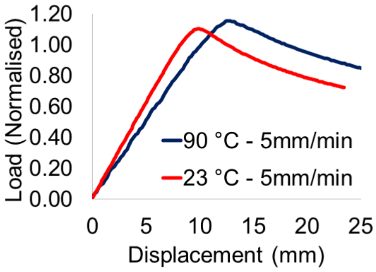


Figures: Comparison of the predictive capability of the rate and temperature dependent viscoelastic model against the traditional bi-linear CZM model at a loading rate of 1mm/S.

Mode-I; double cantilever beam







Salient features of proposed model:

- Energy dissipation due to the viscoelasticity and thermo-plastic particle toughening is accounted
- Fibre bridging effects included by modifying the unloading part of the traction curve
- Effect of moisture on the delamination could be included by using proper shift functions

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