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MEASUREMENT OF MIXED-MODE COHESIVE LAWS OF A UD COMPOSITE UNDERGOING DELAMINATION WITH LARGE-SCALE BRIDGING

Erives R., Sørensen B. F., Goutianos S.

DTU Wind and Energy Systems
Technical University of Denmark, Risø Campus, Roskilde Denmark
Email: riea@dtu.dk, web page: https://wind.dtu.dk/

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ABSTRACT

Cohesive zone modelling is often regarded as one of the most advanced tools to simulate fracture of composite materials. Conceptually, cohesive zone modelling enables the simulation of both crack *initiation* and *propagation* in an efficient manner e.g., without the need for initial crack, and without the need for re-meshing. These and other advantages have led to the development of many advanced CZM capable of modelling complex loading (e.g., mixed-mode and cyclic [1]). However, most of these CZMs rely on idealised cohesive laws formulated as simple functions, where their traction separation relationship is defined a priori using simple functions (e.g., bi-linear softening [2], trapezoidal [3] and exponential [4]). This means that the functional form (and shape) of the cohesive laws is not determined experimentally but assumed instead. Since the shape of cohesive laws provides a "footprint" of the damage mechanisms within a real fracture process zone, an accurate measurement of the shape of cohesive laws has great scientific value to study the fundamentals of fracture. The type of cohesive laws which derives its functional form (shape) from a potential function are known as potential-based cohesive laws [5] [6]. If cohesive laws are to be understood as constitutive equations for surfaces (interfaces), then, the parameters describing these laws need to be determined experimentally for each different interface or material. As such, there is a great practical and scientific need for efficient procedures to experimentally determine cohesive laws of different material interfaces.

To experimentally determine the cohesive laws of an interface, one can start by assuming that cohesive laws can be derived from a potential function [5] which depends on the normal and tangential openings:

$$\Phi = \Phi(\delta_n, \delta_t), \quad (1)$$

and that

$$\Phi(0) = 0,$$

Such a potential function can be determined by fitting the (experimental) fracture resistance (expressed in terms of the J-integral) as a function of the normal and tangential end-openings [7].

$$J_R = \Phi(\delta_n^*, \delta_t^*) \quad (2)$$

It follows that partial differentiation of the potential function with respect to the normal and tangential opening gives the normal and shear cohesive tractions, respectively.

$$\sigma_n = \frac{\partial\Phi(\delta_n,\delta_t)}{\partial\delta_n}, \quad (3)$$
$$\sigma_t = \frac{\partial\Phi(\delta_n,\delta_t)}{\partial\delta_t},$$

An appropriate selection of the functional form of the potential function is fundamental to establish a relationship between the fracture resistance and the failure mechanisms modelled within the fracture process zone [8].

The potential function in Eq. 2, is fitted using experimental R-curves obtained from fracture mechanics experiments. The double cantilever beam with (un-even) bending moments is a steady-state test configuration, for which a closed for solution exist, which is independent of the crack length. Furthermore, such a test configuration ensures stable crack growth, which is required to extract useful data for the determination of cohesive laws. A theoretical framework to extract cohesive laws for composite materials with large-scale fracture process zones is presented in [9] and [8]. The methos is somewhat general in the sense that it does not make assumptions on the material behaviour such as the coupling of cohesive laws [8]. The main assumption of the proposed framework is that cohesive laws can be derived from a potential function, and that the phase angle between the normal and tangential opening displacements remains constant. The fitted potential function using the parameters described in [8] is shown in Figure 1.

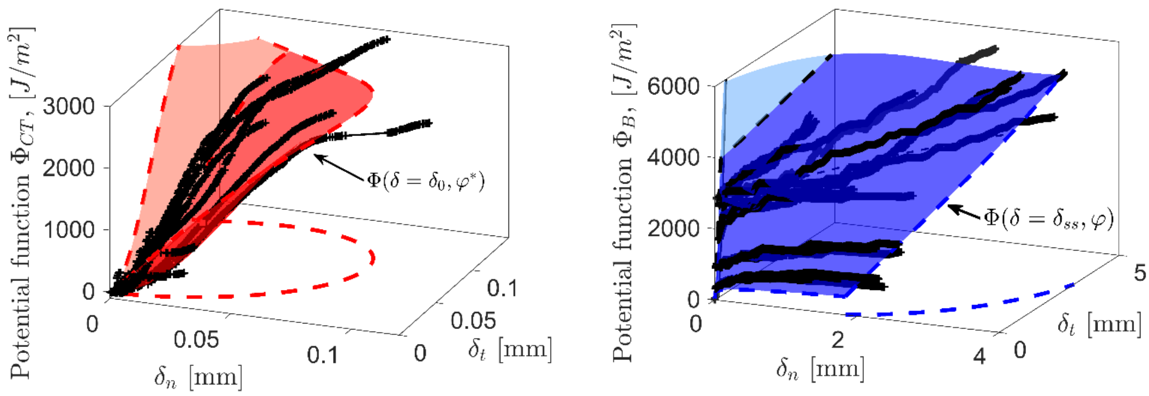

Figure 1: Experimental R-curves shown with the black markers, and the fitted potential function shown in red for the crack-tip region, and in blue for the bridging region [8].

By first determining a potential function that fits the shape of experimentally measured R-curves closely, we then ensure that the combined work of the cohesive tractions closely matches the fracture resistance of the materials. In a way, the potential function is determined empirically, and the cohesive laws are derived from the potential function.

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