11th International Conference on Composites Testing and Model Identification
J. Costa, J. Renart and N. Blanco (Editors)
Girona, 2023

OBTAINING THE J-INTEGRAL AND MODE MIXITY OF CLIMBING DRUM PEEL TEST BY FINITE ELEMENT MODELLING

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Keywords: Polymer composites, Climbing drum peel test, Interface properties, Finite elements

ABSTRACT

Fibre composites are used for their high specific stiffness and strength and possibility for tailoring the properties in the different directions depending on the loads in a given application. Wind turbine blades are almost entirely made of fibre composites and sandwich structures to keep the weight low at a reasonable cost. As a result, a wind turbine blade contains many interfaces both between the individual layers in the composite and sandwich structures, and as adhesive bond lines between the different parts. Therefore, it is of great importance to have reliable methods to experimentally measure the interface strength in composites. A commonly used approach to measure the mode I (opening) fracture toughness (G_{IC}) of a composite is the Double Cantilever Beam (DCB) test. Although the crack is assumed to progress as a straight crack, the loading configuration in the standard DCB test (e.g. ASTM D5528) results in a parabolic-like shape of the crack. In addition, it is necessary to either measure the crack length during the test or carry out a compliance calibration. As an alternative to the DCB test for measuring G_{IC}, Daghia and Cluzel [1] proposed the Climbing Drum Peel (CDP), which is also a standardised test (ASTM D1781). The test set-up is shown in Figure 1.

Figure 1: Climbing drum peel test setup

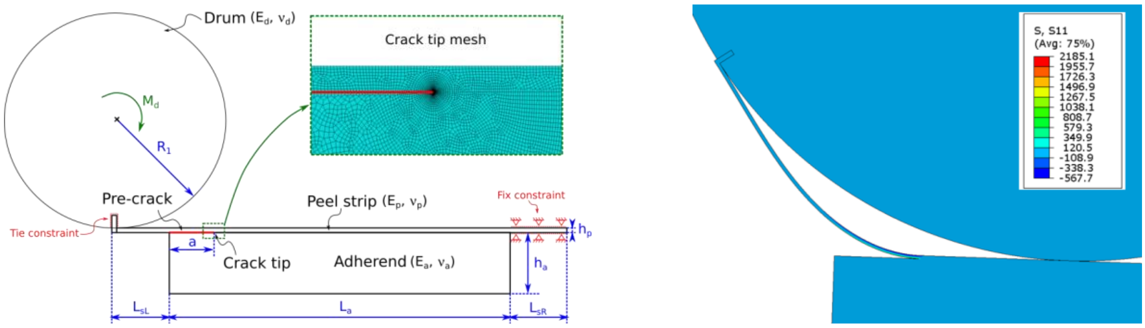
The CDP test is relatively simple and quick to perform, and the loading configuration leads to a straighter crack front than for the DCB test [1]. Daghia and Cluzel [1] proposed a simple energy consideration approach to calculate G_{IC}, which does not require any knowledge about the crack length and other local effects. They define the fracture energy as

$$G_{Ic} = \frac{\Delta E_{debond}}{\Delta A} = \frac{F_d - F_w}{w} \frac{r_2 - r_1}{r_1} \tag{1}$$

where F_w is the winding force, F_d the winding and delamination force, w the width of the specimen, and r_1 and r_2 are radii on the drum and flanges (see [1] for details).

However, although the CDP test is suggested as an alternative to the mode I DCB test, other studies (e.g. [2]) considering a regular peel test find the test to be mixed mode with values depending on the peel angle among other parameters. The approach suggested by Daghia and Cluzel [1] is attractive due to the simplicity of the test and the subsequent data handling. However, it is unlikely that the CDP test is actually a mode I test, and therefore the purpose of the current work is to study the mode mixity in more detail by Finite Element (FE) modelling. The overall aim is to be able to use the CDP test as a supplement to uneven bending moment DCB [3] tests, where the mode mixity can be varied, which requires that we understand the behaviour of the mode mixity in the CDP test.

A static implicit FE model as illustrated in Figure 2(a) was established in Abaqus. A steel roller (drum) was fixed to one end of the peel strip where a torque, M_d = 840 N·mm, was applied to pull up the strip (Figure 2(b)). The thickness of the peel strip was h_p = 0.4mm, the thickness of the adherend was h_a = 30mm, the length of the adherend was L_a= 250mm, and the length of the peel strip sticking out at the ends were $L_{sL} = L_{sR}$ = 25mm. The length of the pre-crack was a = 10mm. The peel strip and adherend were both modelled as a unidirectional glass fibre composite with $E_p = E_a$ = 40 GPa and $\nu_p = \nu_a$ = 0.3. The inner radius of the drum was R_1 = 51.1mm modelled with material properties of steel (E_d = 210 GPa, ν_d = 0.3). The J-integral at the crack tip was evaluated using a contour integral approach, and the stress intensity factors K_1 and K_2, to calculate the mode mixity, were extracted using the interaction integral approach. The used specimen geometry, material properties, and applied drum torque were based on experimental results.



(a) Model definition and crack tip mesh (b) Peel strip at full torque in Abaqus

Figure 2: Finite element model

When assuming linear elasticity, the J-integral should be equivalent to the energy release rate as applicable for Equation 1. At the torque M_d, (Figure 2(b)), the J-integral from the FE model was found to be 580 J/m^2 whereas the analytical solution by Equation 1 gave G = 549 J/m^2. The corresponding mode mixity in the FE model varied gradually with increasing torque from an initial value of $\varphi = \tan^{-1}(K_2/K_1) = -37.9^{\circ}$ to a final value of $\varphi = -21.9^{\circ}$ at a torque of M_d. In other words, the mode mixity in the test appears to depend on the interfacial strength. However, both the J-integral and the mode mixity were found to be significantly influenced by the choice of boundary conditions of the model, which is likely to also be one of the reasons for the difference between the fracture energy obtained by the analytical and FE model, respectively. Thus, further work is required to determine the most realistic boundary conditions and to decide whether it is necessary to model the steel bands on the drum and/or consider the problem in 3D.

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