COMPUTATIONAL ANALYSIS OF 2D-DCB BONDED COMPOSITE JOINTS USING TRAPEZOIDAL TRACTION SEPARATION LAW

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1. INTRODUCTION

Finite Element Analysis (FEA) simulations have proven to be a valuable tool for evaluating the mechanical behaviour of bonded joints. In particular, cohesive models have enabled the simulation of adhesive degradation, making it possible to simulate failure mechanisms such as ductile, adhesive, and mixed adhesive-adherent failure [1]. Although FEA analyses can provide advantages and disadvantages, intrinsic and epistemic uncertainties that can affect experimental analysis are often not taken into account [2]. Studies involving the failure mechanisms of laminates and their failure mechanisms, such as failure with Cohesive Zone Model (CZM) in bonded composite joints, have shown interesting results [3-6]. Trapezoidal traction separation law (TSL) has been found to be a useful tool in such studies and can be applied to simulate brittle and ductile behaviour, depending on the failure type (*e.g.*, hybrid failure adhesive-laminate).

This work presents a contribution that applies trapezoidal traction separation law in two-dimensional models of Double Cantilever Beam specimens made of different carbon/epoxy laminates and adhesives. The numerical results are compared with experimental results of force x displacement, obtained using finite element models created using Abaqus® software [7]. The models employed a quadrilateral four-node plane strain element (CPE4R) to represent the composite adherents and a quadrilateral two-dimensional cohesive element (COH2D4) for the adhesive layer. Python™ scripts were used to generate all numerical models, which were then linked with Abaqus® software.

2. MATERIALS AND METHOD

To conduct this study, several steps were taken to obtain numerical simulations of DCB bonded composite joints. The traction separation laws were used to generate the simulations.

2.1. Numerical analysis

The numerical model used in this study is based on [8] and utilizes a Double Cantilever Beam (DCB) specimen made of carbon/epoxy with a pre-crack length (a_0) of 58 mm, an adherent length (L) of 120 mm, an adherent width (B) of 21.5 mm, an adherent thickness (h) of 1.82 mm, and an adhesive thickness (t_A) of 0.2 mm. The geometric properties of the DCB specimen and boundary conditions are shown in Figure 1.

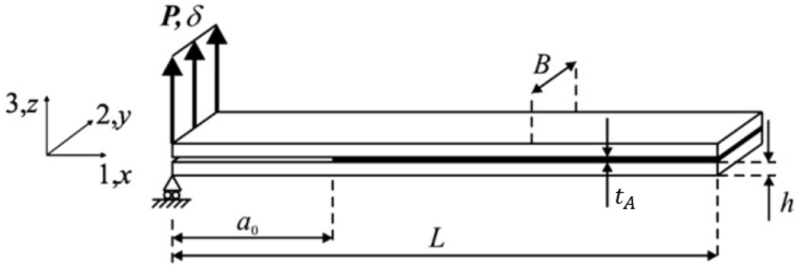

Figure 1 – DCB modelling containing its geometric dimensions: h – adherent thickness, a_0 –pre-crack length, L – Adherent length, t_A – Adhesive thickness, and B – adherent width. (Adapted from [8]).

The DCB model used in this study employs a two-dimensional approach, which was implemented using Abaqus® software. To account for the large displacement/rotation fields that occur under increasing loadings, geometric non-linearity was considered. The DCB joint is modelled using two types of elements: a quadrilateral four-node plane strain element (CPE4R) to represent the composite adherent and a quadrilateral two-dimensional cohesive element (COH2D4) to represent the adhesive layer. A viscosity parameter of 10^{-5} was applied to the COH2D4 element to improve its convergence. The use of this meshing size methodology ensured accurate numerical results. To generate all numerical models, macro-Python™ scripts were employed and linked with Abaqus® software.

2.2. Damage model

To model the damage degradation of the adhesive layer, this study utilized a traction separation law based on the Cohesive Zone Model [7] that takes into account the mechanical properties of the adhesive. Equation (1) was used to apply the damage variable (D), and the relationship between traction and displacement was defined as follows:

$$t = (I - D)K\varepsilon, \tag{1}$$

where **t** and **ε** are the tensile and strain vectors, ***K*** is the stiffness matrix, and *I* is the identity matrix.

Uncoupled behaviour ($K_{ns} = K_{sn} = 0$) was taken into consideration in this study. Following the methodology described by Campilho *et al.* [8], normal stiffness was defined as K_{nn} = E and shear stiffness as K_{ss} = G for small adhesive thickness. The trapezoidal traction separation law was defined as tabular softening using Abaqus® [7] and based on [6].

Independent mode was employed in all simulations due to the loading, which was only in a single direction (pure mode I). The damage initiation was the quadratic damage stress (QUADS). This damage model becomes active when it reaches or exceeds a value of one, and is defined as follows:

$$f = \left\{\frac{\langle t_n\rangle}{t_n^0}\right\}^2 + \left\{\frac{t_s}{t_s^0}\right\}^2, \tag{2}$$

where t_n is the component normal to the cracked surface and t_s is the shear component of the cracked surface, t_n^0 and t_s^0 are the peak values of the nominal stresses.

3. RESULTS AND DISCUSSION

The numerical and experimental results are presented in Figure 2. In all cases, when r = 0.0, the TSL takes on a linear shape. Each set of numerical results with varying r values from 0.0 to 0.40 represents a different behaviour of the trapezoidal TSL, with notable differences between them. It was observed that as the r values increase, the peak values of force (P) also increase, but not significantly.

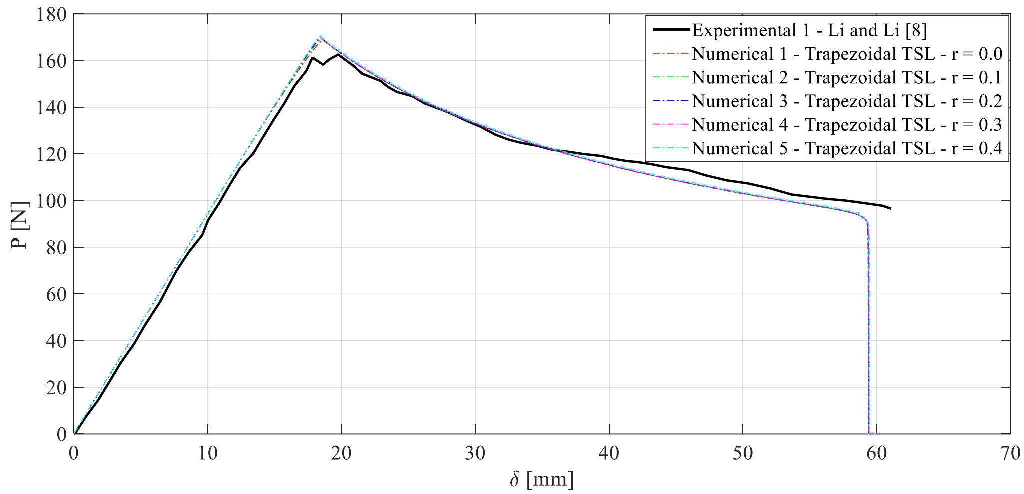

Figure 2 – Experimental and numerical results of DCB based on traction separation laws.

Although some discrepancies between numerical and experimental results were observed, the numerical models employed in this study offer several advantages. Specifically, the meshing size approach used in the simulations resulted in good agreement with experimental data. However, it is worth noting that there may have been modelling errors that could have impacted the numerical results [9]. To gain a deeper understanding of the relationship between various mechanical and geometric factors and fracture strength, the incorporation of statistical methods may be beneficial. Furthermore, employing other approaches could also help to refine both numerical and experimental investigations of mechanical failure in bonded composite joints subjected to pure mode I loading.

4. CONCLUSIONS

This study presents an interesting approach for evaluating the trapezoidal traction separation law [6] in Double Cantilever Beam bonded composite joints using two-dimensional Finite Element models based on experimental results [8]. The numerical approach used in the simulations showed good agreement with the experimental results, indicating the effectiveness of this methodology. However, it is important to consider possible modelling errors that could have influenced the numerical results. Future studies could incorporate statistical analysis to better understand the influence of mechanical and geometric variables on the force-displacement relationship in DCB bonded composite joints.

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