Experimental and numerical investigation of mode-I adhesive debonding in DCB tests with variable plate width

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Double cantilever beam (DCB) test is the most commonly used test for determining the fracture resistance of structural adhesive joints in mode-I debonding. Test specimens are made of two equal plates that are first glued together and then exposed to opening load, which causes crack propagation along the bonded surface. During the experiment, load-line displacement, applied force and crack length are measured continuously. Using these data, the fracture toughness of the adhesive can be computed according to the procedure given in the relevant ISO standard [1]. The calculations are based on simple beam theory and linear elastic fracture mechanics (LEFM) equations.

In this work, we will investigate the influence of the width of a DCB specimen on the fracture resistance. We use aluminium plates of thickness $h = 6.0$ mm, length $L = 250.0$ mm and four different values of width $b = \{30.0, 60.0, 120.0, 240.0\}$ mm. Three different adhesives, whose behaviour ranges for brittle to ductile, are applied with a constant thickness $t_a = 0.5$ mm for all specimens. After curing period recommended by the adhesive manufacturer, DCB specimens with piano hinges are tested using a tensile-testing machine. Experiments are performed under monotonically increasing displacement with load-line displacement speed of 2.0 mm/min. Using the optical measurement system BOM ARAMIS, complete displacement field is recorded during the experiment, which can be used to obtain the actual load-line displacement of the plates (different from that recorded on the tensile-testing machine grips) and the position of the crack tip (see Figure 1). Measurements from the tensile-testing machine and optical measurement system are synchronised in order to obtain the correct set of (δ, F, a) measurements, where δ is the load-line displacement, F is the applied load and a is the crack length.

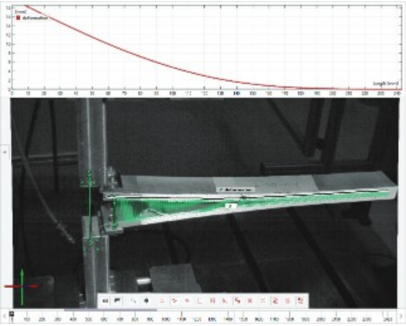

Figure 1. Optical measurement system BOM Aramis.

For the smallest width ($b = 30.0$ mm), the DCB specimen can be accurately modelled using beam theory. Fracture toughness of the adhesive can be described using the critical energy release rate in mode I (G_{Ic}), or a richer modelling can be used, e.g. cohesive-zone models (CZM). In this work, we use data-reduction schemes from a relevant standard [1] and compare the values obtained with an alternative approach called Enhanced Simple Beam Theory (ESBT) [2] that is based on the concept of equivalent crack length and therefore does not require the measurement of the crack length. Additionally, we model the adhesive using a bi-linear CZM at the interface, which is suitable for ductile adhesives because of the softening in the load-displacement curve before reaching the peak value of the load. Solutions of the problem are obtained using the closed-form solutions [3] for Timoshenko beam theory and a bi-linear CZM at interface. Therefore, there is no need to use finite-element models since the accuracy is comparable [2] and the solution can be obtained faster. For each type of adhesive, the following parameters are identified: G_{Ic}, σ_{max} (maximum traction at the interface) and k (initial stiffness of the adhesive).

For wider specimens, plate models are used instead of beam models. This type of modelling can be used to determine the shape of the crack front, which is curved instead of straight as assumed in beam models. Here we simulate the DCB test numerically using a two-layer finite-element model. The elements describing aluminium layers derive from the Mindlin plate theory for the moderately thick plate structures [4] and, therefore, can model the experiment with great accuracy. The elements used involve bending, shear and membrane strains in the assembly of the element stiffness matrix. Starting from the pure displacement-based approach and the general expressions for the shear strains, selective constraints for the shear are assumed and a layered plate element is formulated on the mixed concept. Transverse displacement and rotation fields are linked using the problem-dependent linked interpolation expressions. In the bending part of the formulation, the starting transverse displacement interpolation has a cubic order and the rotation interpolations are quadratic. In the membrane part, the displacement interpolations are linear at the same time. The element passes the general constant-bending patch test and has 24 degrees of freedom after the internal bubble parameters are statically condensed in the element stiffness matrix. The layers can have different material characteristics, but these are assumed linear for each layer.

References

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