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THE EFFECT OF COMPUTATIONAL PARAMETERS ON THE PERFORMANCE OF A COMBINED CZM-VCCT METHOD

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Summary. A combined method of cohesive zone modelling (CZM) and virtual crack closure technique (VCCT) of the finite element basis can be used to simulate crack growth in structures with no initial flaw. In this study, we investigate the effects of the form of the CZM traction-separation law, CZM damage criterion, VCCT tolerance and the length of the bonded interface on performance of the combined method. Based on the results, the VCCT tolerance as well as the CZM damage criterion have a negligible effect on the simulated failure process for the studied joint geometry. In turn, the effect of the traction-separation law is significant on the simulated fracture process.

1 INTRODUCTION

Fracture analysis of adhesively bonded joints is important due to the required durability and also damage tolerance of load-carrying structures. The widely used methods—cohesive zone modelling (CZM) and virtual crack closure technique (VCCT)—have specific advantages in the analysis of bonded joints and interfaces[1,2]. Though VCCT have been found a powerful method for simulations of delamination and crack growth, it lacks features to account for proper crack nucleation and crack onset process.

We have previously studied the application of CZM to simulate the butt joint test (see ISO 6922 standard) and the related behavior of an adhesive[3]. Proper simulation of the fracture process requires capturing the crack initiation, which can be accomplished using the CZM method. However, the selection of the CZM fracture parameters is dependent on the finite element mesh and selected length-scale of the validation. As a solution for simulation of intact stuctures, without any existing flaw, we have recently analyzed a combined method of VCCT and CZM[4]. The combined method can be used to simulate crack growth in structures with no initial flaw.

For a bi-linear traction-separation law, the combined method can be implemented using a specific function relating initiation stress (σ_0) and fracture toughness (G_{IC}) of the CZM zone. Consequently, the performance of the combined method depends on the sensitivity of the stress distribution on the behaviour of the CZM zone in the modelled structure. Fundamentally, the coupling of the two methods must enable simulated crack growth, which satisfies the definition of the cohesive zone length[5] and the requirement of small plastic zone radius (see ISO 25217 standard) presumed in the process of fracture toughness determination. Here, we investigate the effects of the form of the CZM traction-separation law, CZM damage criterion, VCCT tolerance and length of the modelled bond on performance of the combined method.

2 PROBLEM FORMULATION

Two different structures were modelled using a commercial finite element code Abaqus 6.14-2 standard (Simulia, Dassault Systèmes): a butt joint (BJ) specimen and a double cantilever beam (DCB) specimen. the 2-D models were meshed using linear elements (CPE4R/CPE4I/CAX4R) and cohesive elements (COH2D4). The CZM mesh was applied to the crack tip and the VCCT interface was applied along the interface following the last node of the CZM zone—more details can be found in our previous studies[3,4]. During simulation, enforced displacement (Z-direction) was applied to a point in the load block and a point in the upper adherend, for the DCB and BJ model, respectively. The material properties are given in Table 1 and the models are illustrated in Figure 1. To study the effect of the CZM traction-separation law on the behavior of the combined method in the BJ specimen during simulation of a tensile test, a bi-linear law and a trapezoidal law was implemented for separate simulation runs. Similarly, the effect of the CZM damage criterion was analysed for strain and stress (e/s) based criterions and for maximum and quadratic value limits (max/quad). The effect of the VCCT tolerance was studied for values of 1...20%. Finally the effect of a shortened DCB specimen glue line on the stress re-distribution during the nodal release process of the combined method was studied for a DCB specimen with a 15 mm intact glue line behind the crack tip and for three different parameter sets of the combined method.

Property	*BJ model*	*DCB model*
Adherend Young's modulus	70 GPa	71 GPa
Adherend Poisson' ratio	0.33	0.33
Adhesive Young's modulus	2.45 GPa	2.45 GPa
Adhesive Poisson' ratio	0.38	0.38
VCCT critical strain energy release rates	$G_{VCCT} = G_{CZM} = G_{IC}$	1820 J/m^2
CZM cohesive strength values	variable	variable

Table 1: Material properties applied to the finite element models in this study.

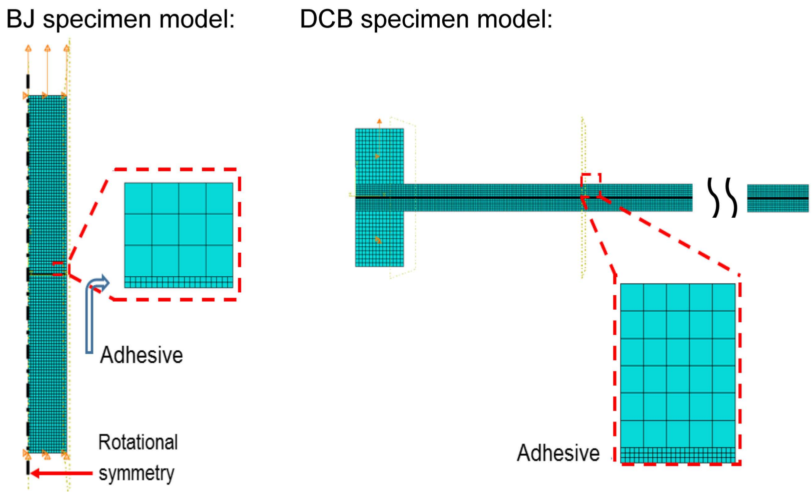

Figure 1: 2-D finite element models used in this study.

3 RESULTS

The results of the simulations are shown in Figure 2. In Figure 2(a), it can be seen that the effect of the traction-separation law is significant. The applied trapezoidal law clearly postponed the damage initiation. Surprisingly, the application of the trapezoidal law seemed not to result in ductile behavior of the fracture process for the BJ model. As shown in Figure 2(b), the effect of the VCCT tolerance over the studied range of values was negligible in the case of the BJ model. Similarly, the effect of the chosen damage criterion for the CZM zone of the combined method was minor on the fracture process (Figure 2(c)). The effect of the CZM parameter set on the re-distribution of the stress field was studied for the DCB model. A short glue line after the crack tip is expected to increase the effect of the CZM damage state on the stress re-distribution. However, the influence of the length of the bonded interface was not found significant (Figure 2(d))—presumably because the bond interface in the DCB specimen is loaded only amidst the crack tip ($\approx$10 mm).

4 CONCLUSIONS

In this study, we investigated the effects of the form of the CZM traction-separation law, CZM damage criterion, VCCT tolerance and the length of the bonded interface on the performance of the combined VCCT-CZM method. Two different adhesively bonded specimens were simulated. Based on the results, the VCCT tolerance as well as the CZM damage criterion have a negligible effect on the simulated failure process of the butt joint specimen. In turn, the effect of the traction-separation law is significant; trapezoidal law postponed the damage onset during the simulation of tensile testing. The influence of the length of the bonded interface was not significant in the case of the DCB specimen.

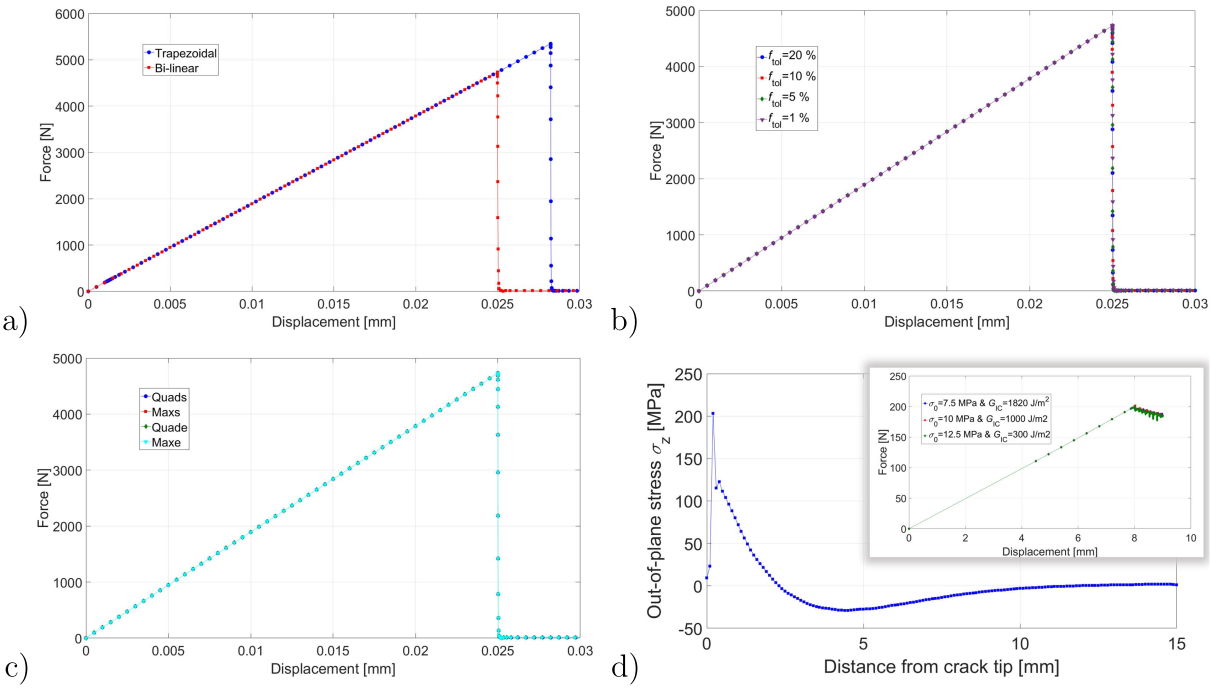

Figure 2: Simulation results: a) the effect of the traction-separation law for the BJ model; b) the effect of VCCT tolerance for the BJ model; c) the effect of damage criterion for the BJ model; d) the effect of the length of bonded interface for the DCB model.

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