Direct generation of cohesive zone laws of adhesives

DS Correia, ID Costa, EAS Marques (INEGI, Portugal), RJC Carbas, LFM da Silva

Advanced Joining Processes Unit

Introduction

Adhesives have been increasingly employed in industrial applications, leading to the need for mechanical characterisation techniques that can provide the data needed to build advanced numerical models to help design bonded connections. Currently, this involves a complex network of specimens and data reduction methods that are complex, time-consuming and expensive. A novel specimen concept is being studied to prevent these problems, combining four tests into one. In this work a specimen for direct extraction of mode I and II fracture toughness is being numerically studied.

Numerical details

A numerical study was conducted on a brittle adhesive, starting with mode II, using the end-loaded split (ELS) test, followed by mode I, recuring to the modified double cantilever beam (mDCB) test. This was done by numerically computing behaviour changes as a function of the specimens' geometry (Figure 1), and analysing the respective load-displacement (P- δ) curves and R-curves - computed using CBBM [1], for mode I.

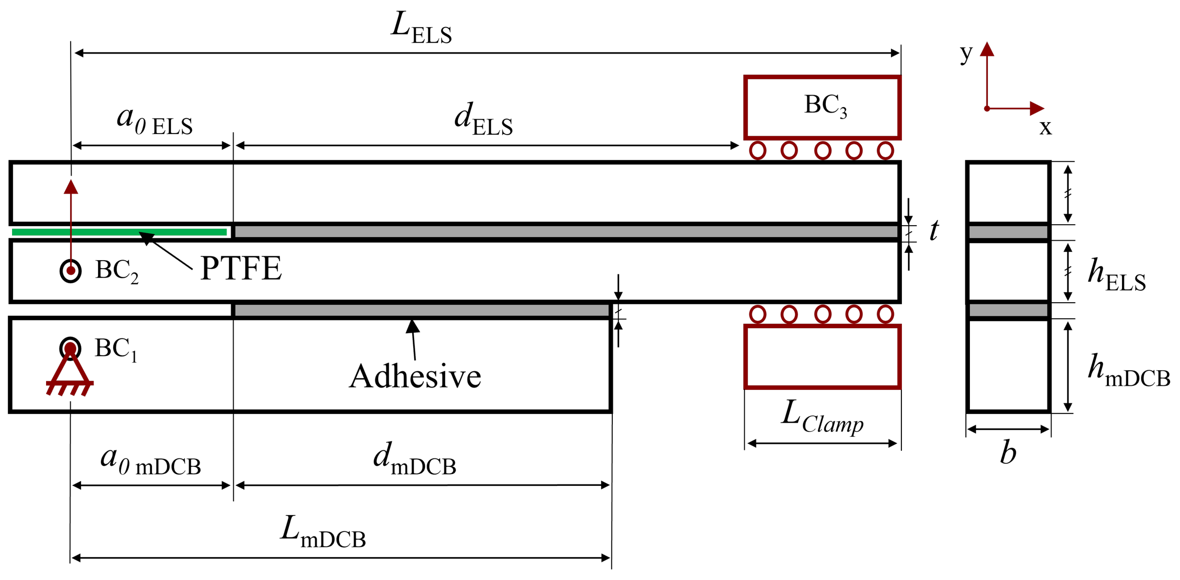

Figure 1 – Relevant dimensions of the ELS specimen and of the mDCB specimen, combined into one single scheme. Dimensions in millimetres.

The numerical simulations were run in Abaqus following the boundary conditions presented in Table 1.

Table 1 – Boundary conditions associated with each test, mDCB for mode I and ELS for mode II. (0) means blocked and (-) means free.

Condition	Mode I - mDCB	Mode II - ELS
BC_1	(0; 0 ;-)	Deactivated
BC_2	(0; u_y ;-)	(0; u_y ;-)
BC_3	(- ; -; 0)	(-; 0 ; 0)
PTFE	Frictionless contact	Frictionless contact

Numerical results

Concerning the ELS specimen, the main conclusions are related with experimental repercussions, namely stable crack propagation and substrate plasticization.

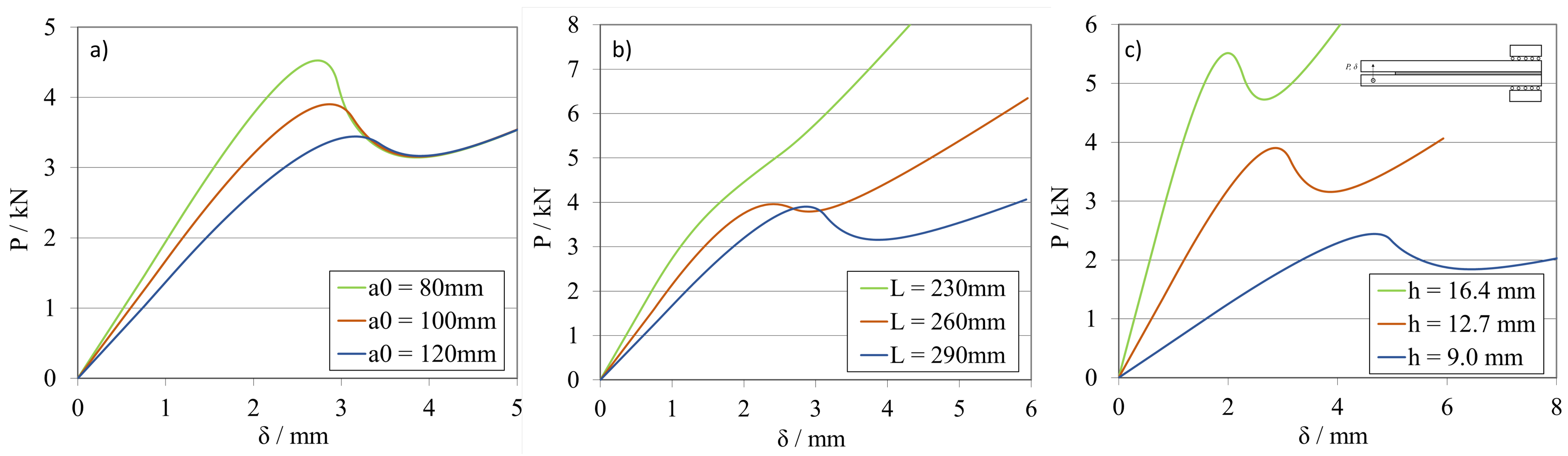

Figure 2 – P-δ curves of the isolated ELS test as a function of geometrical changes. a) Initial crack length (a_0); b) Total length (L); c) Specimen height (h).

As such, by increasing a_0 a more stable crack propagation is attained. To allow the proper development of the fracture process zone a sufficiently high L is necessary. Additionally, small values of h imply much larger deflection which may result in plastic deformation of the substrates. Following these conclusions having $a_{0\ ELS} > a_{0\ mDCB}$ was tested:

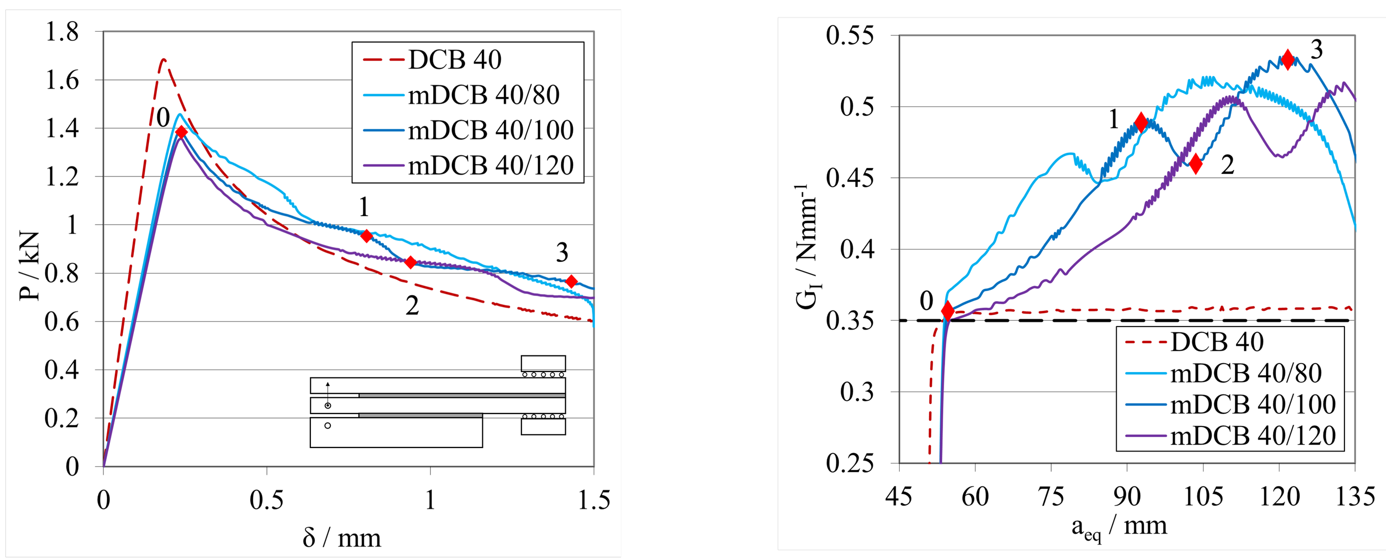

Figure 3 – P-δ curves related to $a_{0\ ELS} > a_{0\ mDCB}$, compared against the correspondent standard DCB. Auxiliary red markers represent the stages of crack evolution for the dark blue curve. Test code: "test type" (DCB or mDCB) followed by the "DCB a_0" or "mDCB a_0/ELS a_0".

This configuration proved worse in mode I characterization, as proved by the R-curves' discrepancy against the standard DCB test. As well as the stress distribution evolution shown in Figure 4 during crack propagation.

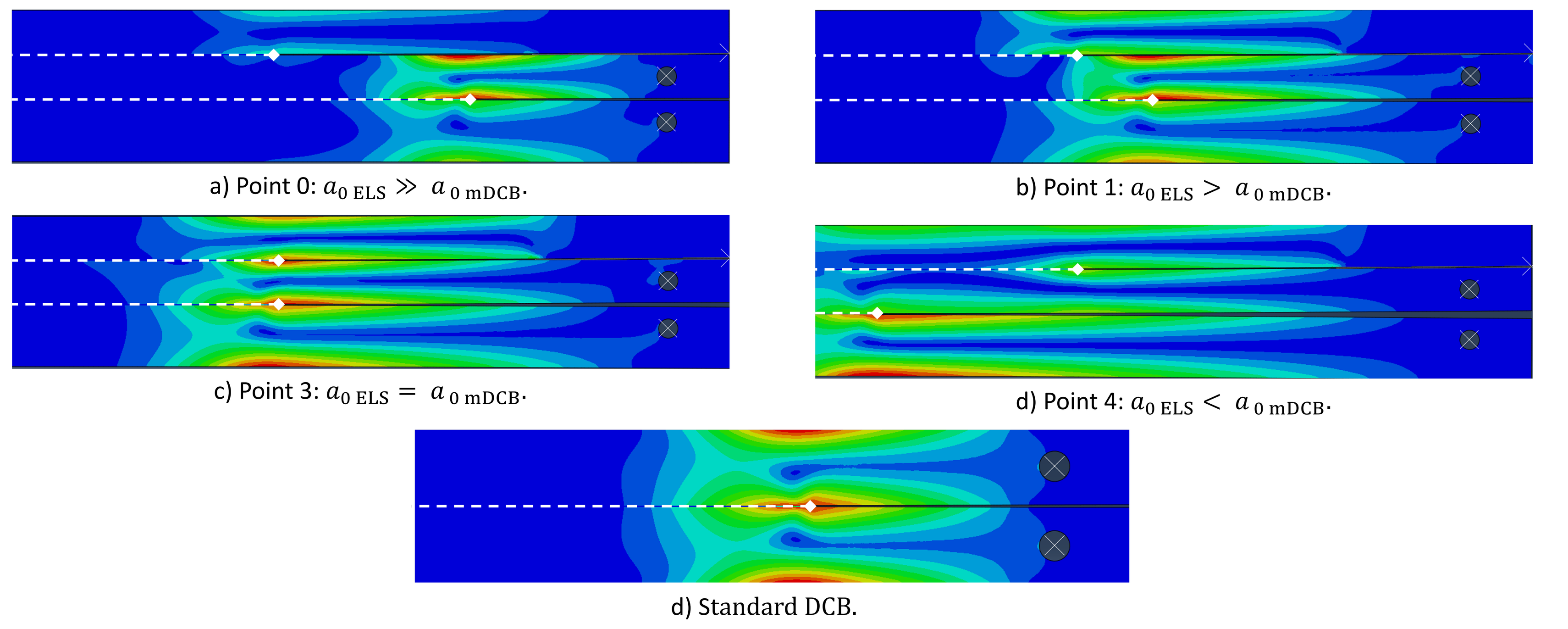

Figure 4 – Stress distributions associated with the variation of $a_{0\ ELS}$ and $a_{0\ mDCB}$ configurations, plus the standard DCB stress distribution for reference. The dashed white line easily identifies each adhesive layers, as well as the evolution of the crack tips.

As seen in the evolution from Point 0 to 4, the ELS crack tip stress concentration interferes with the mDCB crack as is propagates. However, if $a_{0\ ELS} < a_{0\ mDCB}$ this problem could be avoided:

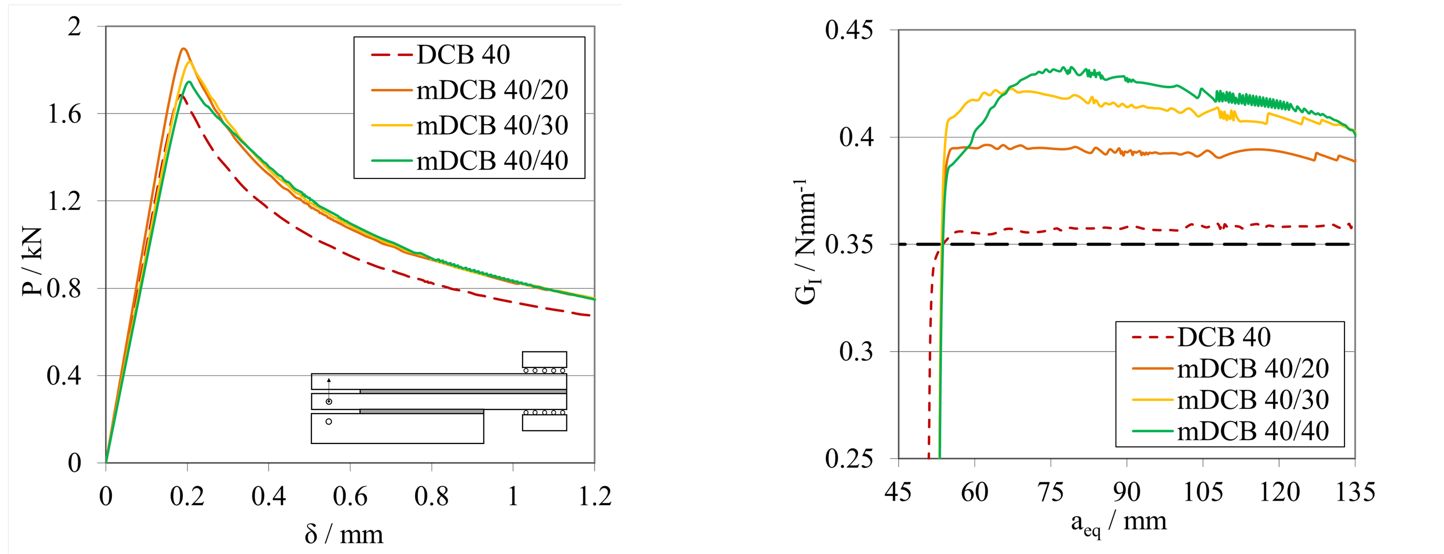

Figure 5 – P-δ curves related to $a_{0\ ELS} \leq a_{0\ mDCB}$ with a fixed $a_{0\ mDCB}$, compared against the correspondent standard DCB.

Proven that a difference of 20 mm was enough to remove the ELS crack tip influence, it was possible to simply offset G_{IC} recuring to the mDCB. Following this, a higher value of $a_{0\ ELS}$ was tested as they benefit the ELS test stability, the intermediate value of Figure 2a was used:

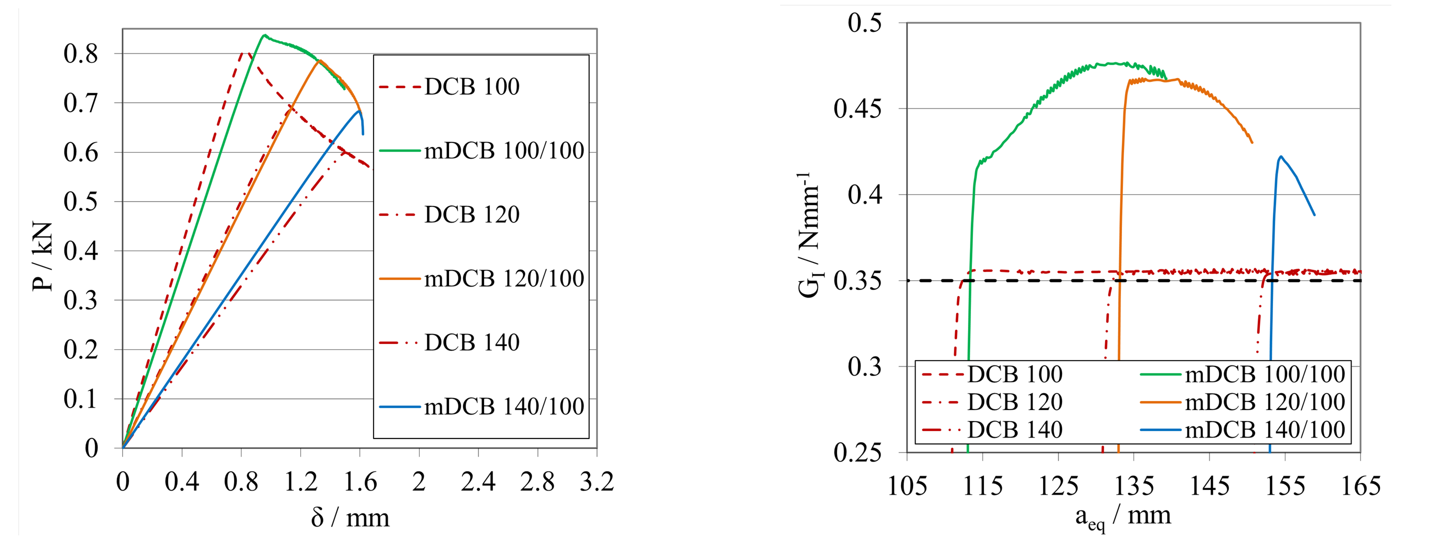

Figure 6 – P-δ curves related to $a_{0\ ELS} \leq a_{0\ mDCB}$ with a fixed $a_{0\ ELS}$, compared against the correspondent standard DCB.

A similar behaviour was found but with a smaller plateau due to the lower mDCB adhesive length, as expected.

Conclusions

In this work, a study was carried out to better understand the parameters which govern the operation of a unified specimen for characterising adhesives under fracture. For the ELS test, the initial crack length, $a_{0\ ELS}$, high values are recommended to improve the stability of the test. For the modified DCB test, a relation of crack lengths where $a_{0\ ELS}$ is smaller than $a_{0\ mDCB}$ is recommended. By using the same CBBM formulation, originally made for standard DCB's, as the data reduction scheme of the modified DCB test, it was possible to obtain a R-curve with a stable plateau, simply overestimated which may result in a simple correction factor.

In the end, this unified mode I (mDCB) plus mode II (ELS) specimen proved effective in characterising two adhesive properties in one single test.

References

[1] de Moura et al. Crack equivalent concept applied to the fracture characterization of bonded joints under pure mode I loading. Composites Science and Technology, 68(10-11):2224–2230, 2008.

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