Development of a unified specimen for adhesive characterization: Numerical and experimental study on the mode I (mDCB) fracture component

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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 [1] is being studied to prevent these issues, combining four tests into one. In this work mode I fracture toughness component of the unified specimen is being numerically and experimentally studied.

Numerical and experimental details

A numerical study on the mode I component of the proposed specimen was conducted, recuring to the modified double cantilever beam (mDCB) test [2], seen in Figure 1a). This was done by analysing its stress distribution during propagation, as well as the load-displacement (P-δ) curves and R-curves - computed using a custom compliance beam-based method (CBBM) [2]. The experimental testes (Figure 1b), were then compared against the numerical curves, previously obtained.

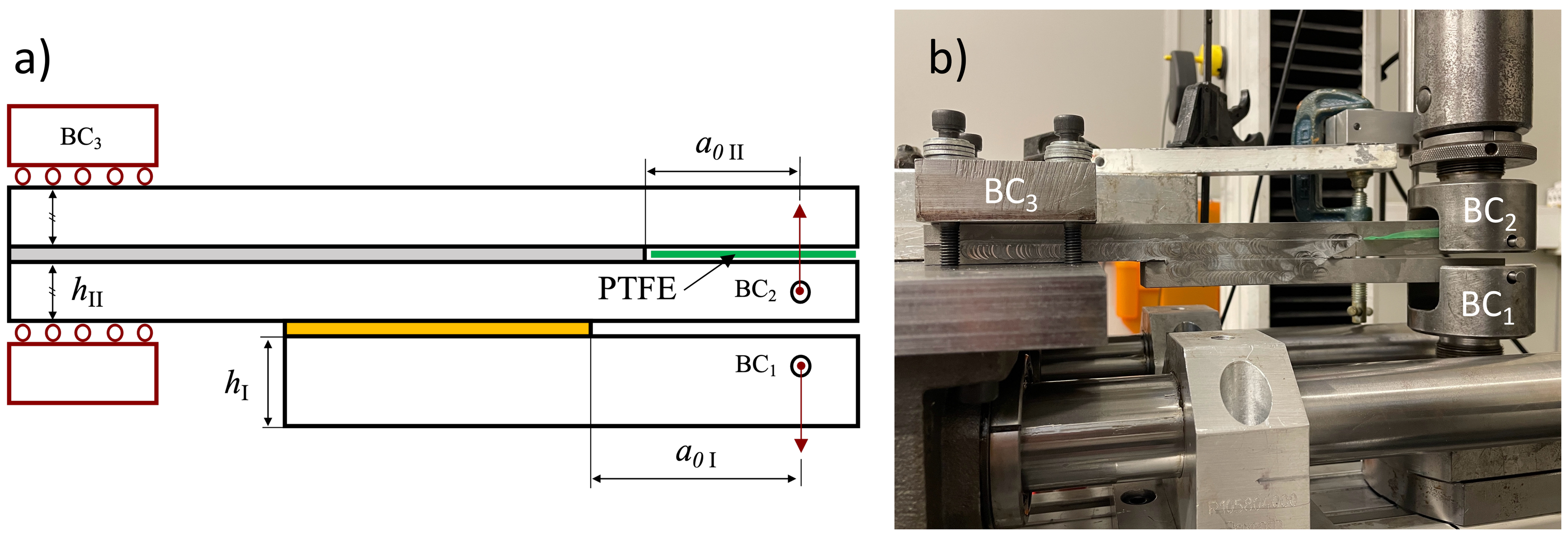

Figure 1 – Numerical and experimental apparatus. a) Relevant dimensions and numerical boundary conditions, b) experimental setup.

Two adhesives were used, a brittle and a tough one, their standard mode I facture properties were presented later in the comparison against the mDCB test results, but they were also used for the numerical models.

The numerical simulations were run in Abaqus following the boundary conditions presented in Table 1, defined as depicted in Figure 1a).

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

BC_1	**BC_2**	**BC_3**	**PTFE**
(0; 0 ;-)	(0; u_y ;-)	(- ; -; 0)	Frictionless contact

The experimental samples were manufactured recuring to steel substrates following the stacking sequence presented in Figure 2.

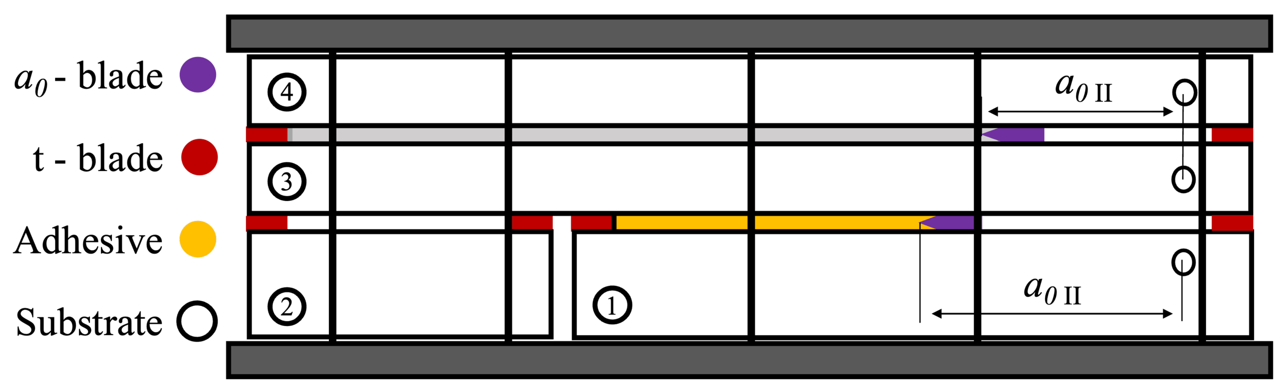

Figure 2 – Schematic representation of the stacking sequence used in experimental sample manufacturing.

The samples were then tested using a specially designed apparatus, as seen in Figure 1b), and analysed with the custom CBBM equation [2].

Numerical and experimental results

The evolution of stress distribution of the mDCB test during crack propagation was analysed, see Figure 3. Looking from Point 0 to 4, the ELS crack tip stress concentration interferes with the mDCB crack as is propagates. However, if $a_{0\,\mathrm{II}} < a_{0\,\mathrm{I}}$ this problem could be avoided.

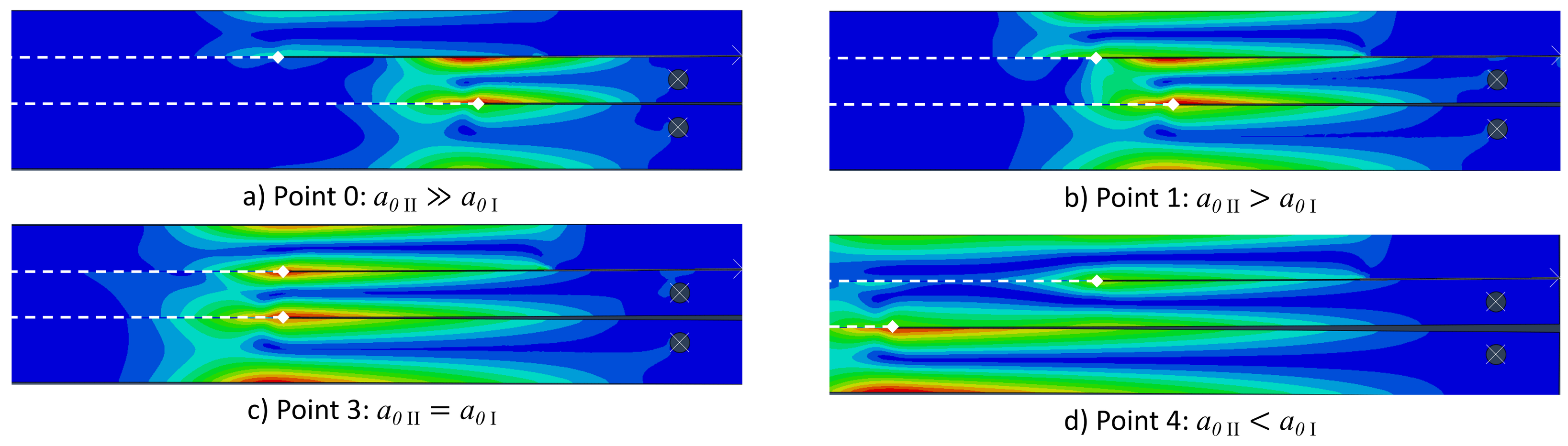

Figure 3 – Stress distributions associated with the propagation of $a_{0\,\mathrm{I}}$ and its passage through $a_{0\,\mathrm{II}}$. The dashed white line easily identifies each adhesive layers, ELS on top and mDCB on the bottom, as well as the evolution of the crack tips.

Following the the numerical study its results wer compared against experimental tests. The P-δ curves are presented in Figure 4a for the brittle adhesive, and Figure 4b for the tough one.

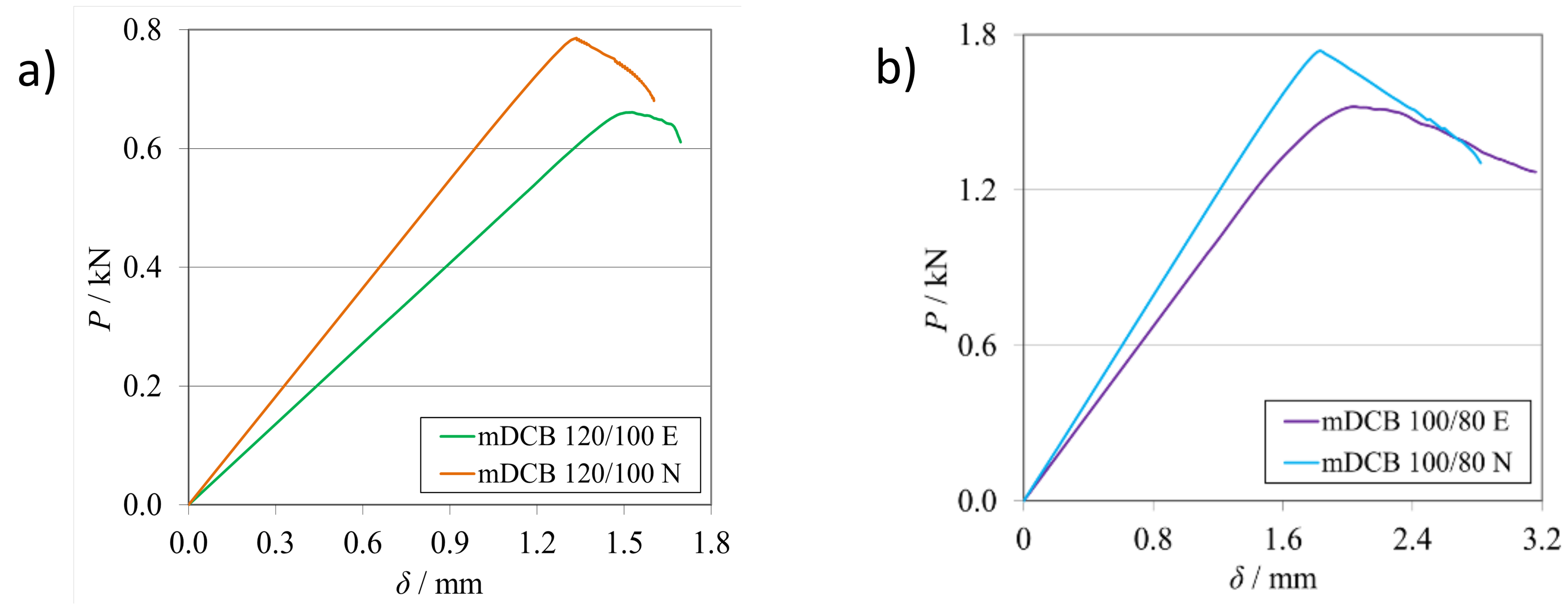

Figure 4 – P-δ curves related to the brittle (a) and tough (b) adhesives, numerical (N) versus experimental (E) results.

The respective R-curves are shown in Figure 5a and Figure 5b for the brittle and tough adhesives, respectively. The black dashed line represents the experimental G_{IC} obtained through the standard DCB test.

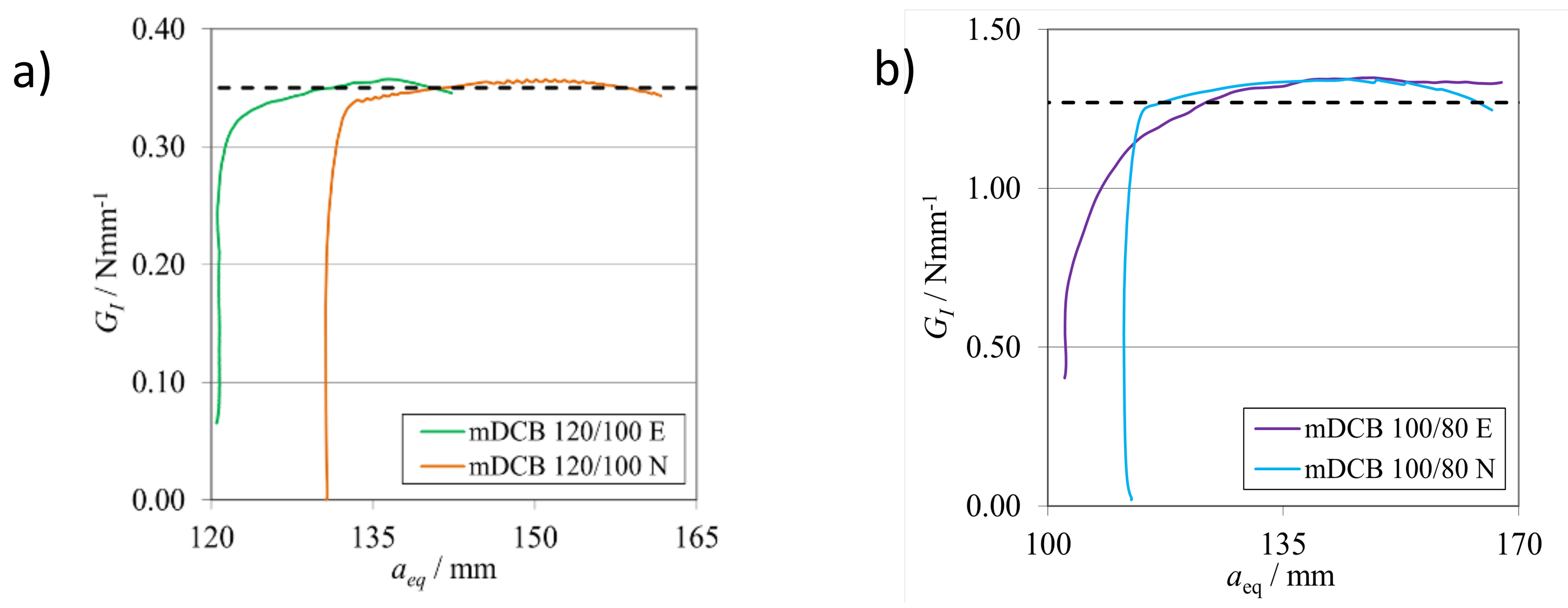

Figure 5 –R-curves related to the brittle (a) and tough (b) adhesives, numerical (N) versus experimental (E) results.

The experimental G_{IC} values obtained through the mDCB were compared against the standard DCB, whose results are presented in Table 2.

Table 2 – Relative G_{IC} errors between the standard DCB and the modified DCB methods, for both adhesives.

	$G_{\mathrm{IC\,DCB}}$ / Nmm^{-1}	$G_{\mathrm{IC\,mDCB}}$ / Nmm^{-1}	**Δ**
Brittle adhesive	**0.35** ± 0.08	**0.34** ± 0.02	**-3%**
Tough adhesive	**1.27** ± 0.05	**1.31** ± 0.07	**+3%**

Overall it can be said that the numerical simulations predicted well the experimental behaviour of the specimen. And the fracture toughness obtained through the mDCB is similar to the one of the DCB test.

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 mode I fracture. Numerical and experimental results presented good correlation between each other, and overall showed comparable characterisation performance in relation to the standard methods presenting errors smaller than 5%. As such, it was possible to develop a robust specimen and custom data reduction method to characterise adhesives under mode I loading.

References

[1] Faria et al. 2022. Novel mechanical characterization method applied to non-structural adhesives: Adherend material sensitivity. Univ. Porto—J. Mech. Solids, 1, 25–30.
[2] Correia et al. 2023. Dev. of a unified specimen for adhesive charact.—Part 1: Numerical study on the mode I (mDCB) and II (ELS) fracture comp. Materials, 16, 2951.

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