Direct generation of cohesive zone law data of adhesives: design and validation of a unified specimen

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1. Introduction

The mechanical properties of adhesives are essential for advanced numerical models in bonded connection design. Traditionally, determining these properties requires four separate specimens, tests, and data reduction schemes—making the process **complex**, **time-consuming** and **costly**. A **new specimen concept** [1-3] addresses these issues by combining **four specimens into one** (see Figure 1), that is tested step-by-step under certain boundary conditions (**BCs**). This work presents the numerical design recurring to Abaqus® of the the **strength** and **fracture components** of this unified specimen.

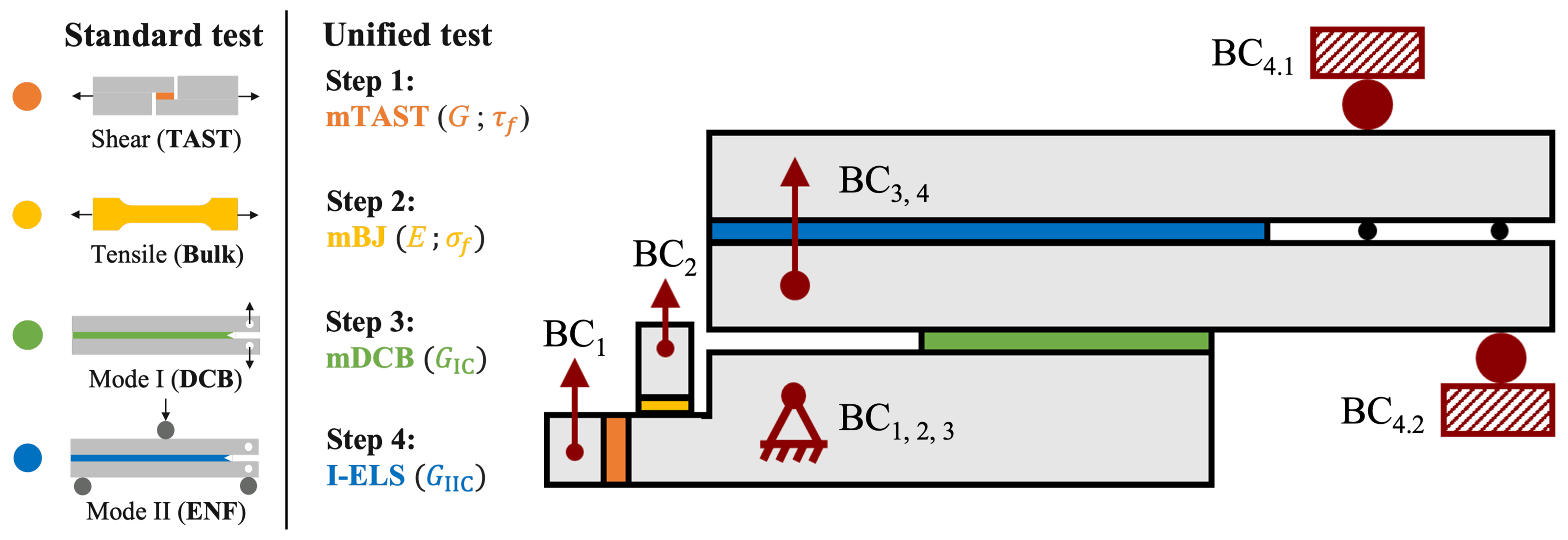

Figure 1. **Unified specimen for adhesive characterization**: modified Thick Adherend Shear Test (**mTAST**) and modified Butt Joint (**mBJ**), for shear and tensile loading; modified Double Cantilever Beam (**mDCB**) and Inverse Loaded End Split (**I-ELS**) for mode I and II fracture. Updated from Faria *et al.* [1].

2. Strength tests

Due to the joint-based nature of this specimen, the main issue reported in literature is the **stress concentrations on the multi-material corners** of the specimen–caused by stiffness discontinuities [4, 5]. Cognard et al. [4, 5] proposed several **solutions**; the most effective are **beaks** (**B**) and **notches** (**N**) .

These configurations were compared to a **reference** (**Ref**) sample. Linear elastic simulations used steel substrates (E = 210 GPa & ν = 0.33) and a stiff adhesive (E = 4890 MPa & ν = 0.4). Both **loading conditions** were applied with displacement control.

Their effectiveness was assessed by comparing adhesive stress distributions for all geometries (see Figures 2 and 3).

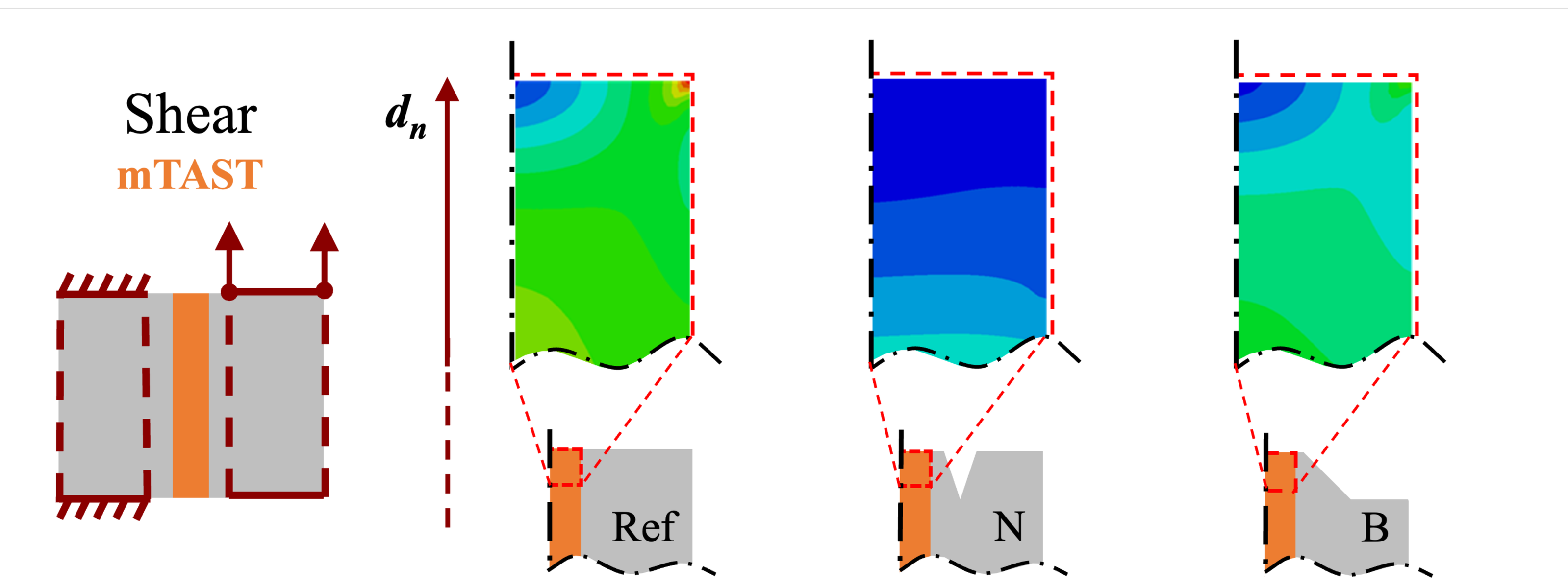

Figure 2. **Normalized adhesive stress distribution**, in relation to **Ref**, of the **mTAST** specimens (shear loading) for different measures to reduce stress concentration effects: **Ref**, **B** and **N**.

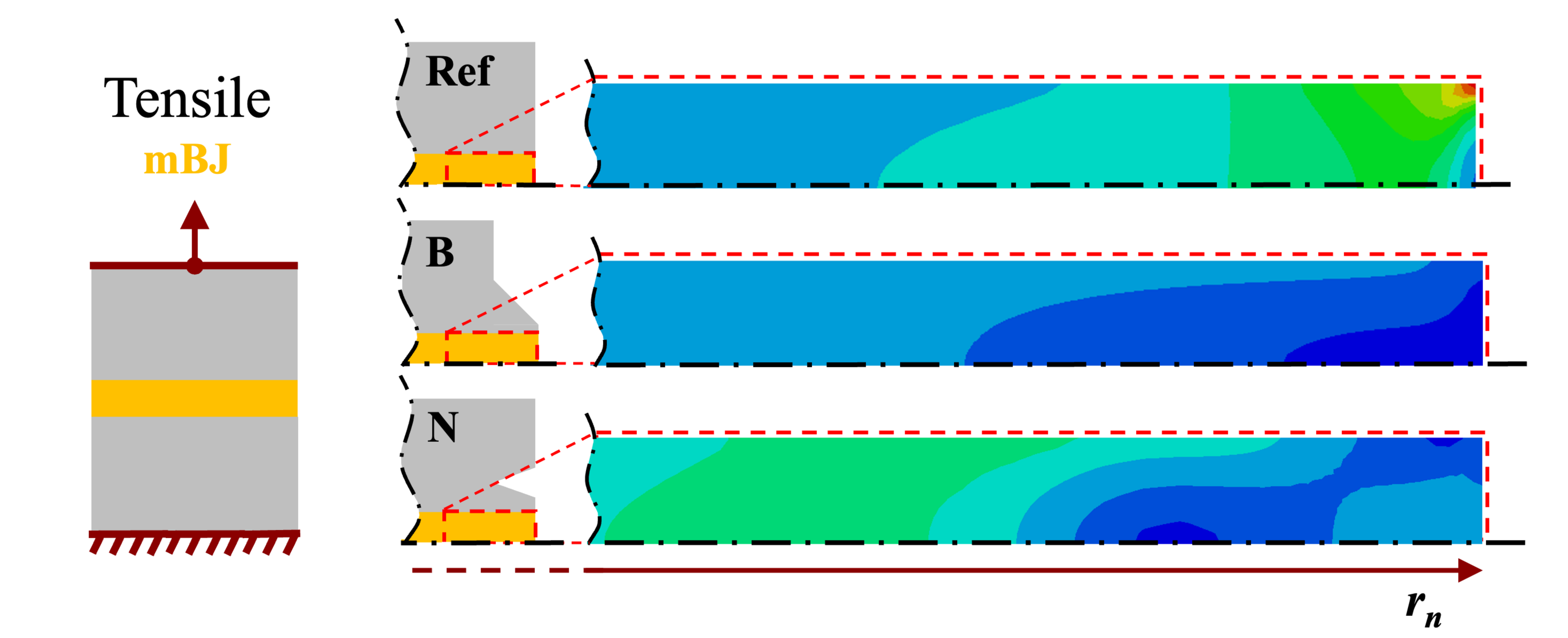

Figure 3. **Normalised adhesive stress distribution**, in relation to **Ref**, of the **mBJ** specimens (tensile loading) for different measures to reduce stress concentration effects: **Ref**, **B** and **N**.

Results show that **reference** samples have **stress concentrations** at the vicinity of the substrate-adhesive multi-material corner. Both beaks (**B**) and notches (**N**) improve the stress distribution compared to the reference, but only one is fully effective for each loading mode. In shear (**mTAST**), **notches** (**N**) give uniform stress through the thickness. For tensile (**mBJ**), **beaks** (**B**) provide the best, most uniform stress distribution.

4. Fracture tests

For the **mDCB** test, there is the need to access **conflicts between boundary conditions** [3], since the **mode II rollers** (**$BC_{4.1}$** and **$BC_{4.2}$**) may cause interfere if they are active during **Step 3,** and not simply in **Step 4** (see Figure 1).

In regard to the **I-ELS test**, looking at previous research on mode II [2], one of the main concern for **stable crack propagation** is the proper development of the **fracture process zone (FPZ)**. One of the most relevant factors in this regard is the specimen's dimensions, being the **total specimen length**, in this case, the most important one to consider.

Steel substrates were used once more, and two adhesives were simulated recuring to **Cohesive Zone Modelling (CZM)**: one **brittle** (◆ - G_{IC} = 0.35 Nmm^{-1} & G_{IIC} = 2.40 Nmm^{-1}) and another **tough** (◆ - G_{IC} = 1.27 Nmm^{-1} & G_{IIC} = 7.22 Nmm^{-1}). The BCs for **mode I and II** considered displacement control (**$BC_{3,4}$**), pins (**BC_3**) and rollers (**BC_4**).

The ***P*-*δ* curves** and **R-curves** of the simulated conditions can be seen in Figures 4 and 5.

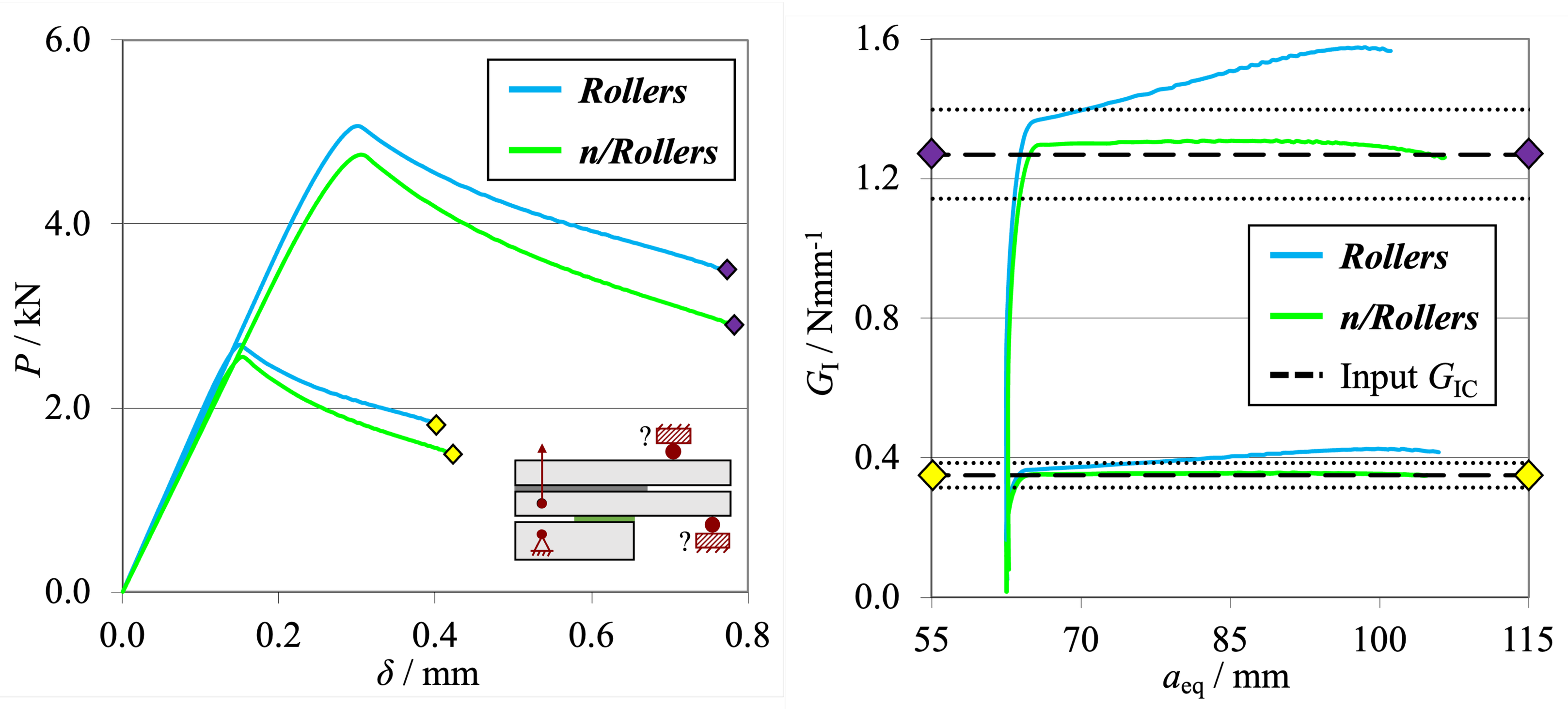

Figure 4. ***P*-*δ*** and **R-curves of the mDCB test**, for mode I fracture. **Active rollers** in blue (—) and **inactive rollers** in green (—). Two adhesives where considered: one **brittle** (◆) and one **tough** (◆).

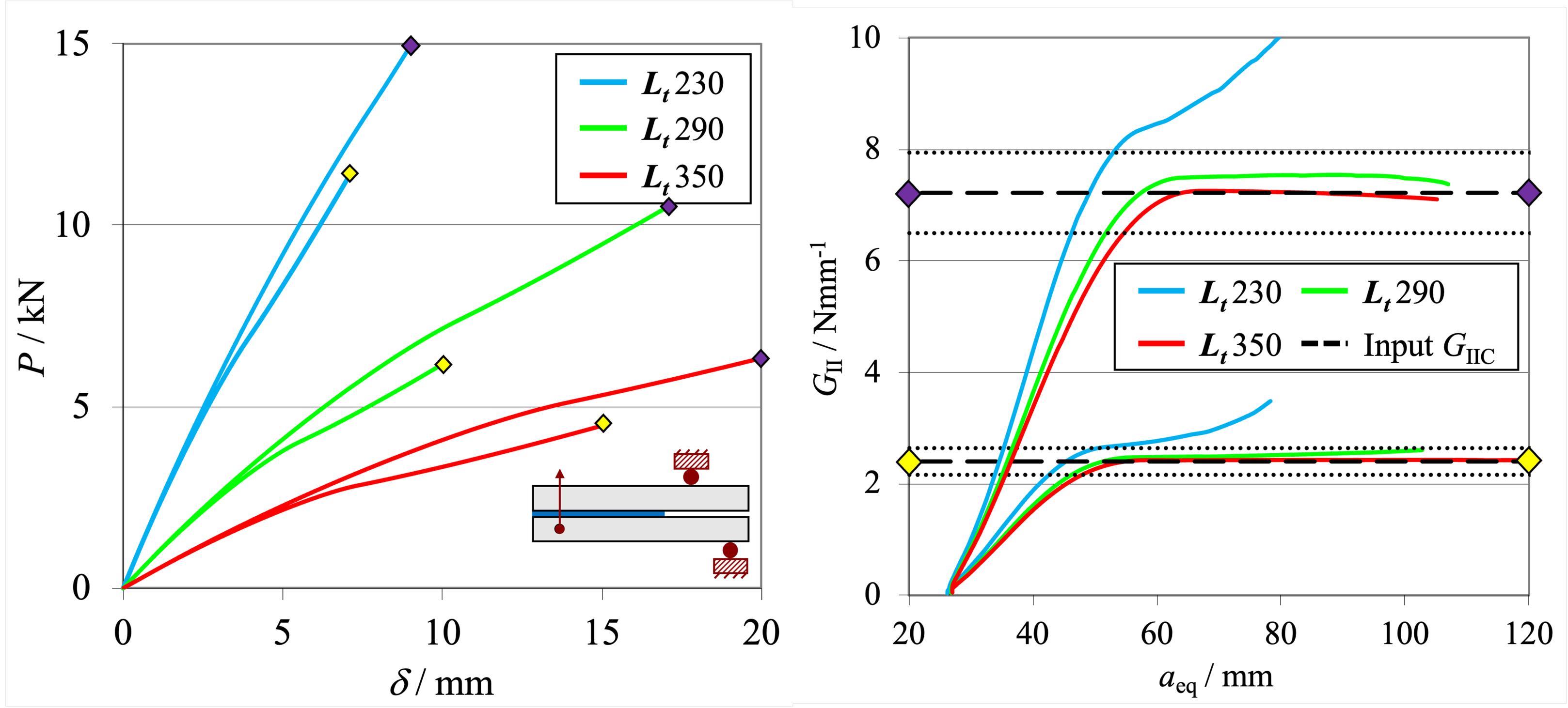

Figure 5. ***P*-*δ*** and **R-curves** of the **I-ELS** test, for mode II fracture. **Total length** increases from blue (—), to green (—) and red (—) .Two adhesives where considered: one **brittle** (◆) and one **tough** (◆).

The **mode I** results (Figure 4) show that the **mode II rollers should be inactive**, since in both adhesives the R-curve was severely influenced by it. This overestimation of the $G_{I/II}$ as the crack gets closer to the **BCs** is already documented for the ELS tests [2].

As for the **mode II** curves (Figure 5), **total specimen length** clearly influences the FPZ's evolution, resulting in **more stable crack propagation as it increases** (red curve, —).

For small values, the FPZ is restricted by the **BC**, resulting in the overestimation of G_{II}.

6. Conclusion

Overall, the **unified concept works** as a whole. The **measures** proposed to **reduce stress concentrations** in the strength components proved **effective** in both **shear** and **tensile** loading. As for the fracture components, it was proven that the **mode II rollers should be inactive** during the **mode I** test; and that the length of the **mode II** test should be sufficient for a proper development of the FPZ, resulting in stable crack propagation.

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). Development of a unified specimen for adhesive characterisation - Part 1: Numerical study on the mode I (mDCB) and II (ELS) fracture components, Materials, 16, 2951.

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[4] Cognard *et al.* (2005). Development of an improved adhesive test method for composite assembly design. Compos. Sci. Technol., 65, 359–368.

[5] Cognard *et al.* (2008). Analysis of the nonlinear behaviour of adhesives in bonded assemblies — Comparison of TAST and ARCAN tests. Int. J. Adhes. Adhes., 28-8, 393-404.

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