Development of a unified specimen for direct generation of cohesive zone law data of adhesives – Strength components

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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, slow, and costly. A **new specimen concept** [1] addresses these issues by combining four tests into one (see Figure 1). This work numerically and experimentally investigates the **strength components** of this unified specimen.

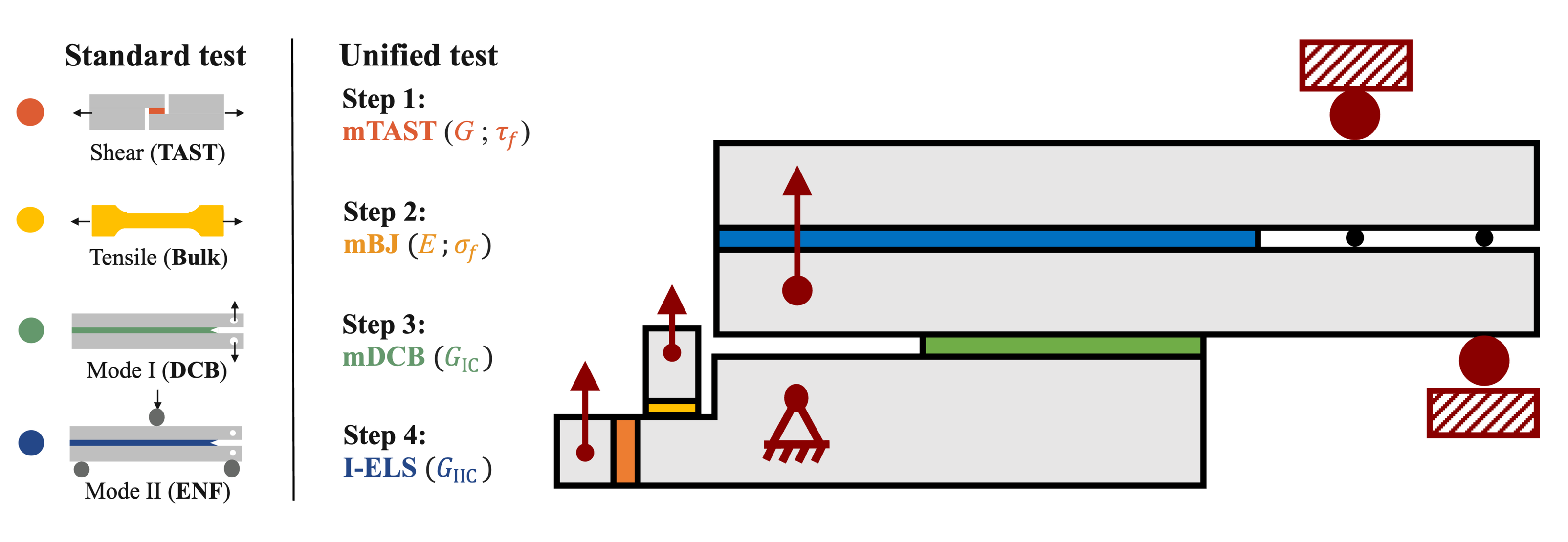


Figure 1. **Unified specimen for adhesive characterization**: modified Thick Adherend Shear Test (**mTAST**) and modified Butt Joint (**mBJ**), for shear and tensile loading; modified **DCB** and Inverse **ELS** for mode I and II fracture. Adapted and updated from Faria *et al.* [1].

2. Numerical study

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 [2, 3]. Cognard et al. [2, 3] proposed several **solutions**; the most effective are **beaks** (**B**) and **notches** (**N**) .

These configurations were simulated in Abaqus® and compared to a **reference** (**Ref**) sample. Linear elastic simulations used steel (E = 210 GPa & ν = 0.33) as the substrate and a stiff adhesive (E = 4890 MPa & ν = 0.4). Both **shear** and **tensile loading** were applied under displacement control.

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

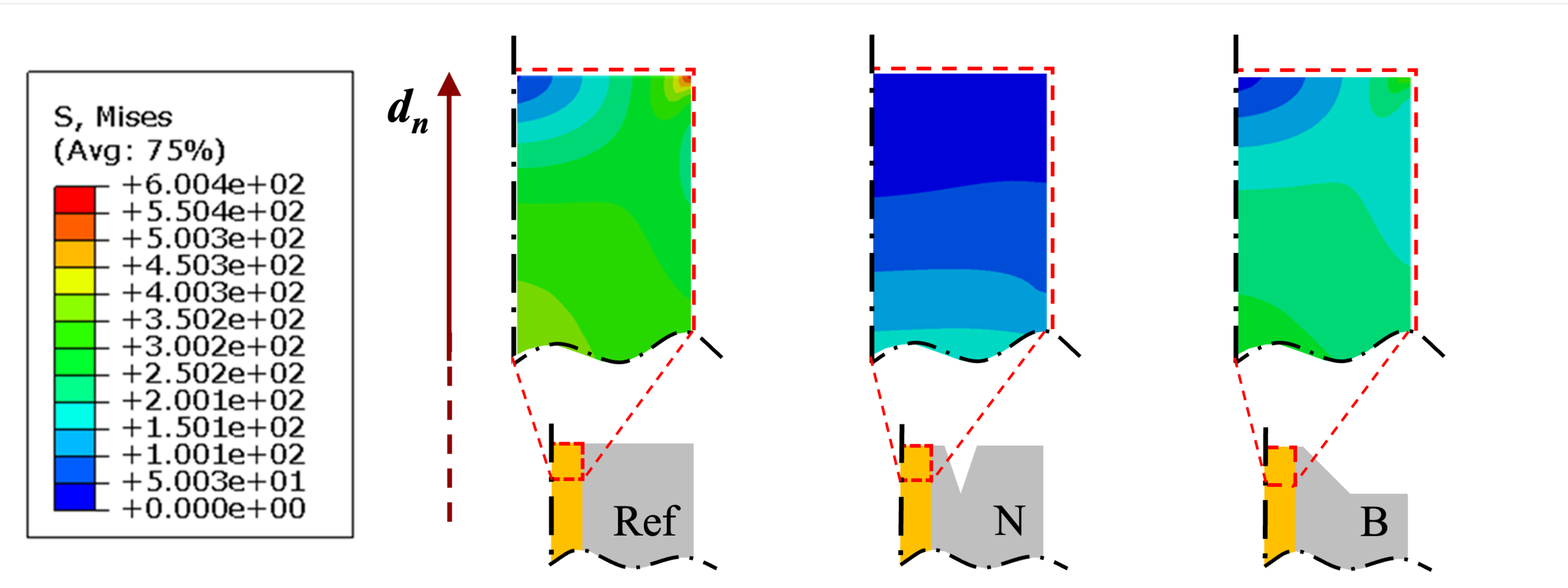


Figure 2. **Stress distribution**, in the adhesive, of **mTAST** specimens for different measures to reduce stress concentration effects.

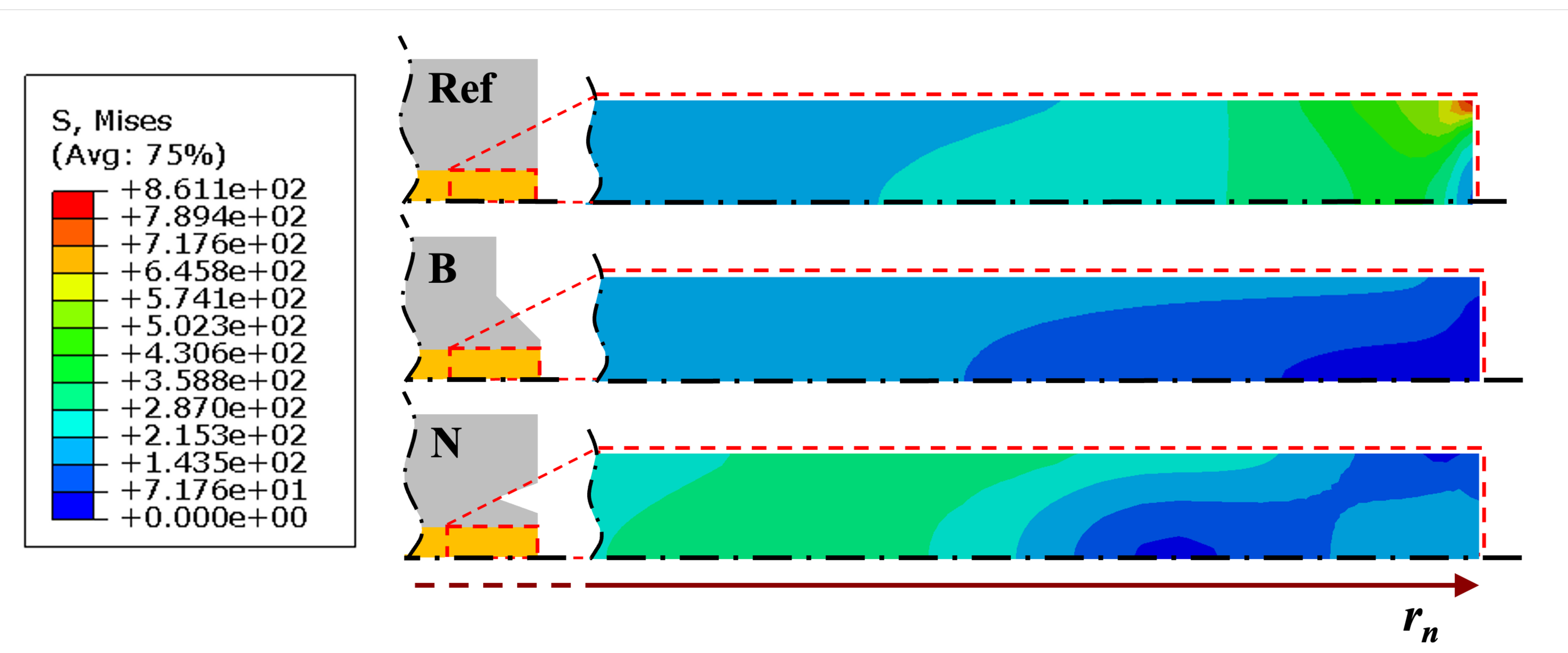


Figure 3. **Stress distribution**, in the adhesive, of **mBJ** specimens for different measures to reduce stress concentration effects.

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. Experimental study – Shear loading

The **mTASTs** were performed recuring to a **custom apparatus** that clamps each end of the joint (see Figure 4) in order to load it in pure shear.

A **universal uniaxial testing machine** was used; the load was recorded by a load cell, and displacement through **Digital Image Correlation** (**DIC**) by means of a speckle pattern, as seen in Figure 4b.

For reference, **TASTs** were performed as well following the same procedures but with its own apparatus.

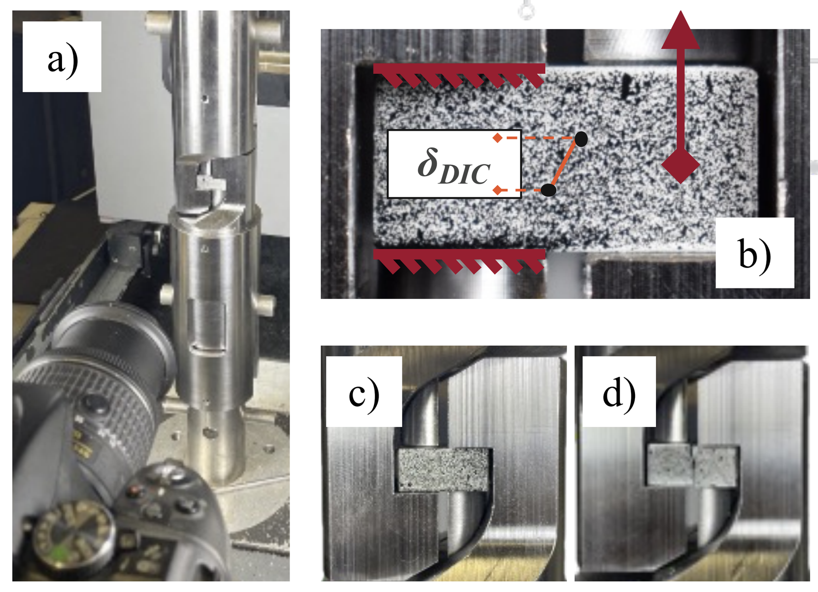
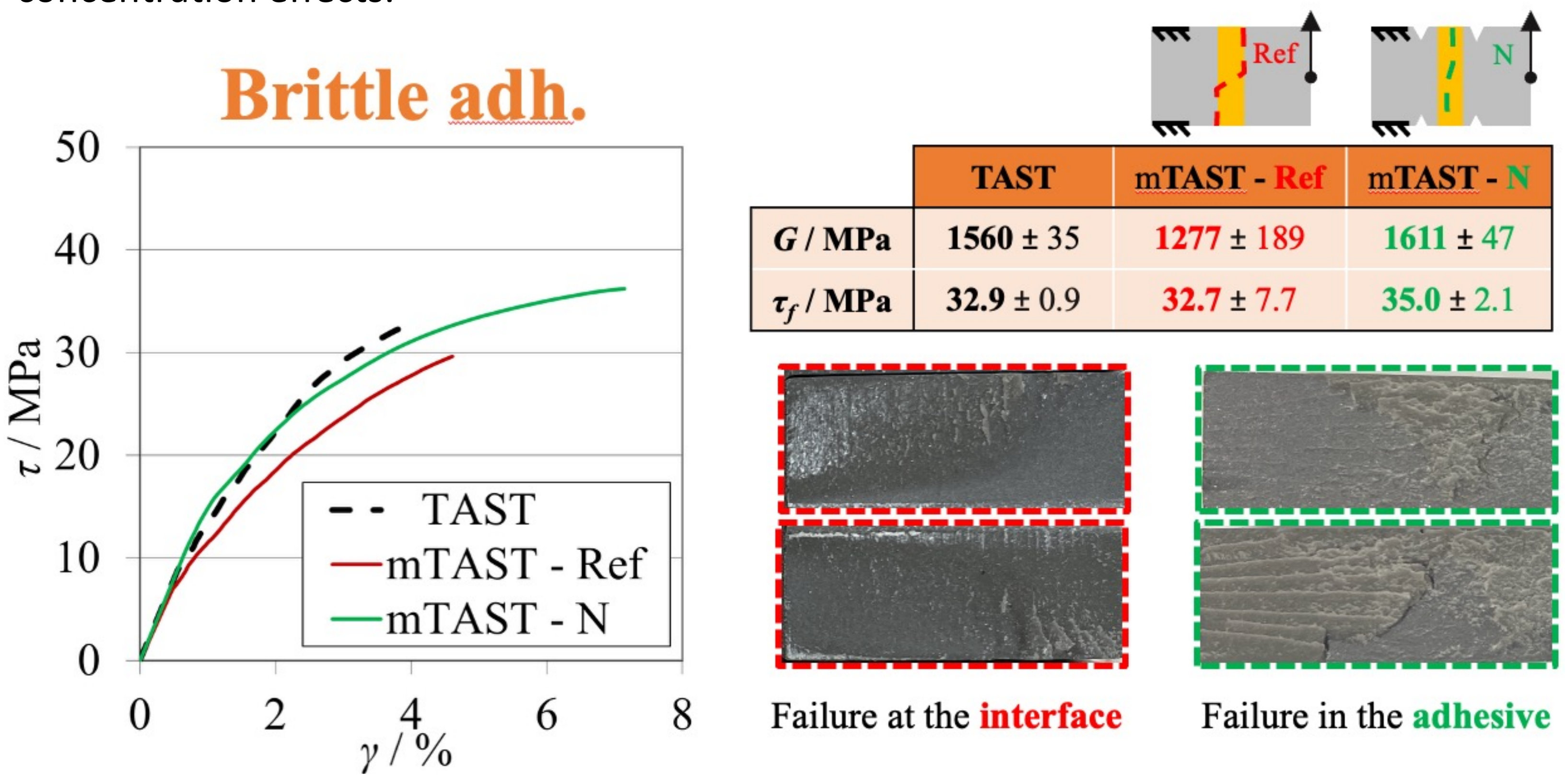


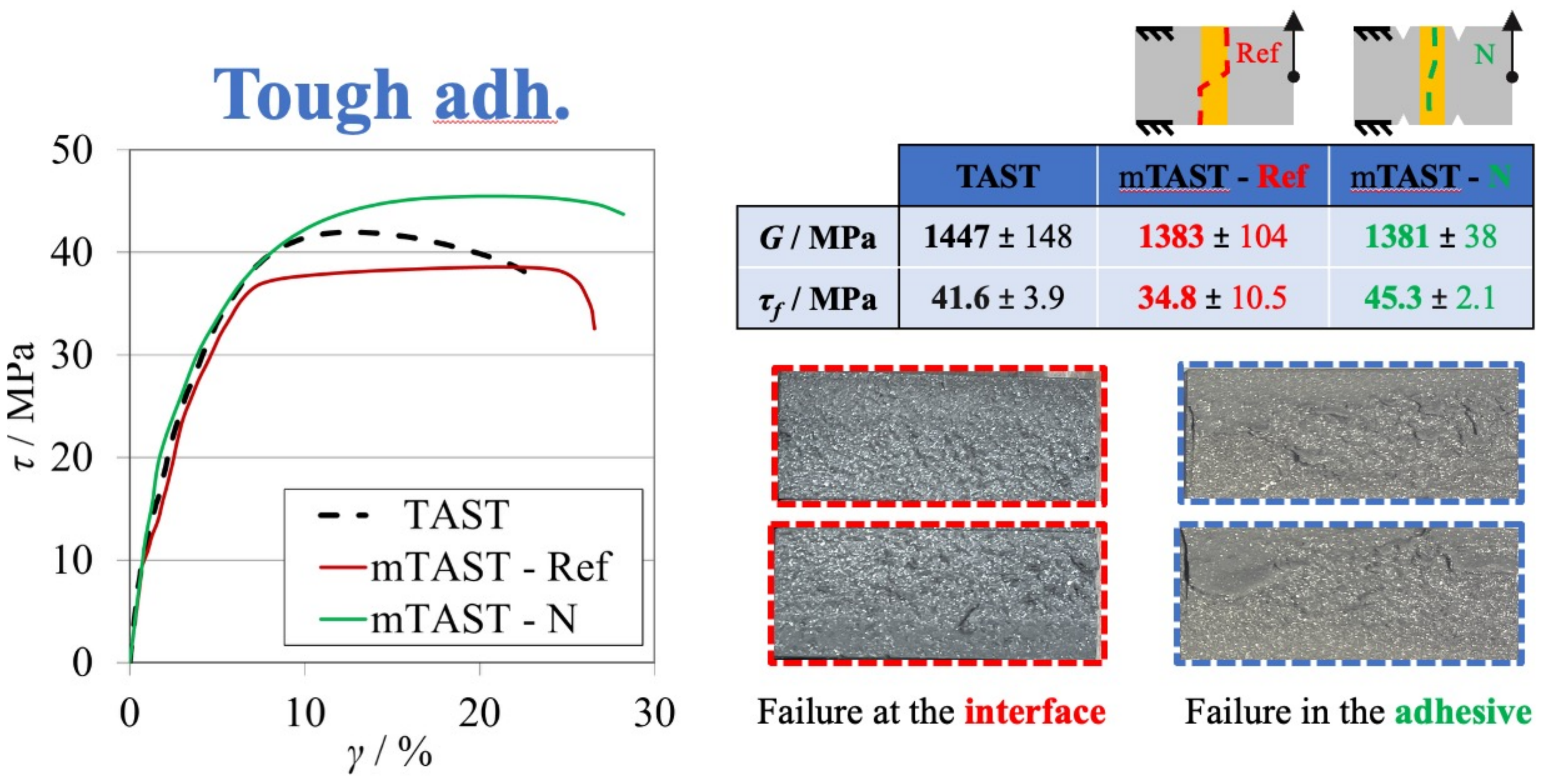
Figure 5. **Experimental mTAST setup** (a). DIC procedure (b). Before testing (c). After testing (d).

For both adhesives, the **mTAST with notches** (**N**) **outperforms the TAST and reference** (**Ref**), matching numerical predictions. Stiffness remains similar, but **maximum joint strength increases**—by about **3 MPa** for the **brittle adhesive** and **5 MPa** for the **tough adhesive**. Fracture surfaces confirm this: **reference** (**Ref**) samples **fail at the interface**, while **notched** (**N**) samples **fail within the adhesive**, showing reduced stress concentration effects.



	TAST	mTAST - Ref	mTAST - N
G / MPa	1560 ± 35	1277 ± 189	1611 ± 47
τ_f / MPa	32.9 ± 0.9	32.7 ± 7.7	35.0 ± 2.1

Figure 5. **Summary of the experimental results** obtained for the brittle adhesive – **TAST**, **mTAST** (**Ref**) and **mTAST** (**N**). Representative experimental curves, mean property values and fracture surfaces.



	TAST	mTAST - Ref	mTAST - N
G / MPa	1447 ± 148	1383 ± 104	1381 ± 38
τ_f / MPa	41.6 ± 3.9	34.8 ± 10.5	45.3 ± 2.1

Figure 6. **Summary of the experimental results** obtained for the tough adhesive – **TAST**, **mTAST** (**Ref**) and **mTAST** (**N**). Representative experimental curves, mean property values and fracture surfaces.

6. Conclusion

Overall, the **concept works as a whole**. In this work it was possible to see that the **measures** proposed to **reduce stress concentrations** proved **effective**. Experimentally the **notched shear strength test** (**mTAST - N**) showed **better characterization** capabilities in relation to the standard TAST test. The **novel tensile test** (**mBJ**) geometry showed **promising results numerically** but still awaits experimental testing.

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] Cognard *et al.* (2005). Development of an improved adhesive test method for composite assembly design. Compos. Sci. Technol., 65, 359–368.
[3] 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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