Quasi-static and intermediate test speed validation of SHPB specimens for the determination of mode I, mode II fracture toughness of structural adhesives

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Introduction

Adhesive joints in real world applications are often subjected to a combination of **mode I** and **mode II** loadings, the ratio of which is highly dependent on service conditions. Methodologies for the determination of the fracture envelope under **static conditions** already exist, so the next research challenge lies in understanding how an adhesive joint behaves under mode I, mode II and mixed-mode **impact conditions** [1].

In this work a methodology is proposed to determine **fracture energy in mode I and mode II** using specimens that can be tested from **quasi-static conditions up to velocities only achieved resorting to SHPB machines** (SHPB specimens).

Methodology

1. SHPB specimens

SHPB specimens for mode I and mode II, represented in Figure 1, were tested at **0.2 mm/min**, quasi static (**QS**) and **0.1 m/s**, intermediate speed (**IS**) and, using digital image correlation (Figure 2), **traction-separation laws** (TSLs) for each condition were **directly determined**.

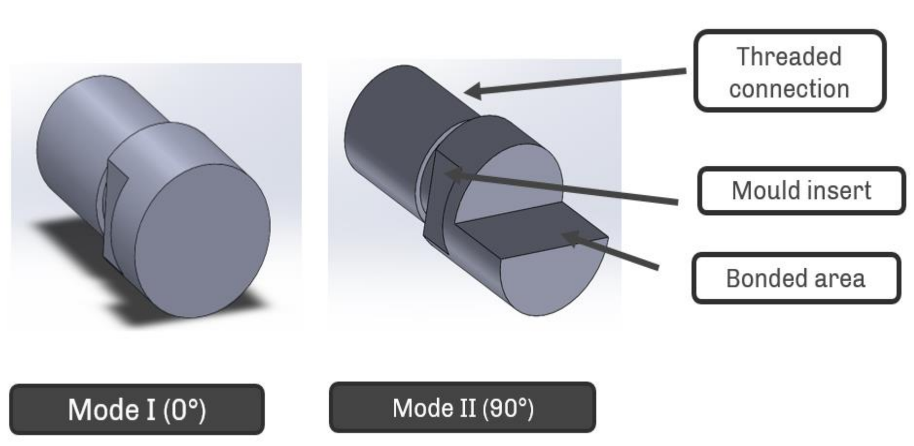

Figure 1 – Representation of the substrates of the novel SHPB specimens for mode I and II configurations

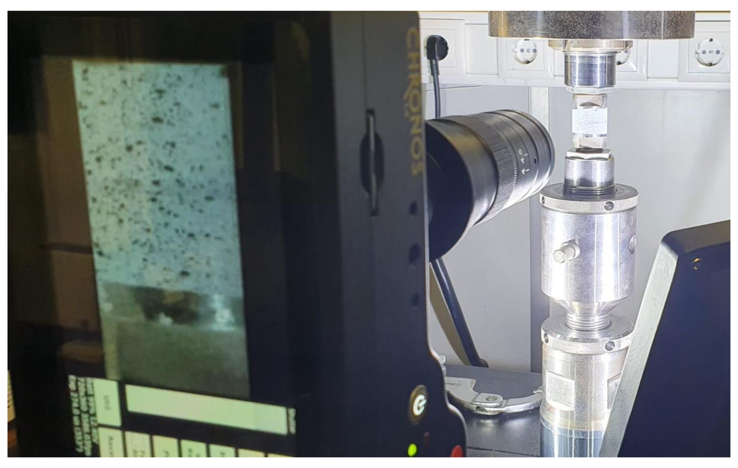

Figure 2 – Test setup ant IS condition using SHPB mode I specimen.

$d = 1 - \frac{}{E}$

Due to the geometrical constrains derived from the operating principle of a SHBP, developing a data reduction scheme that allows for direct calculation of fracture energy is highly challenging. A more effective methodology is to obtain the **TSLs** (Figure 3) of a given joint and **determine the fracture energy through the area below the TSL curve**.

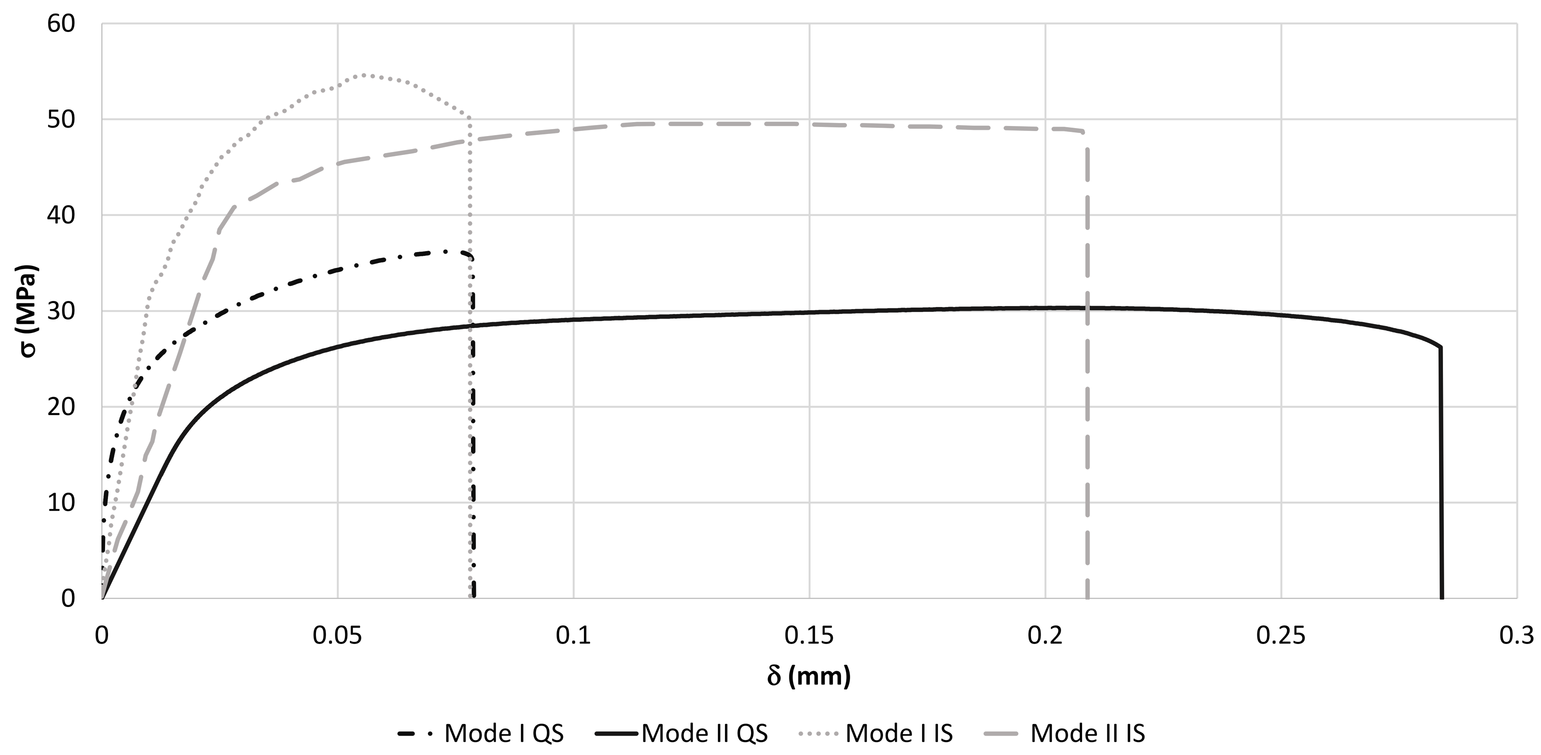

Figure 3– Custom TSLs for Epoxy A at QS and IS conditions.

2. Single lap joints (SLJ)

Numerical simulations and **experimental tests** of SLJ were done at both **QS** and **IS** conditions to assess the reliability of the aforementioned TSLs. Tensile and shear **elastic modulus** were obtained directly from the **slope of the elastic domain** in the TSLs whereas tensile and shear **strength** were defined as the **points of transition from the elastic to plastic domains**. The **damage variable** was obtained resorting to the following damage formula (Equation 1) applied to the custom TSLs. Information regarding mesh and loading conditions are presented in Figure 4.

$$d = 1 - \frac{\sigma}{E\delta} \quad (1)$$

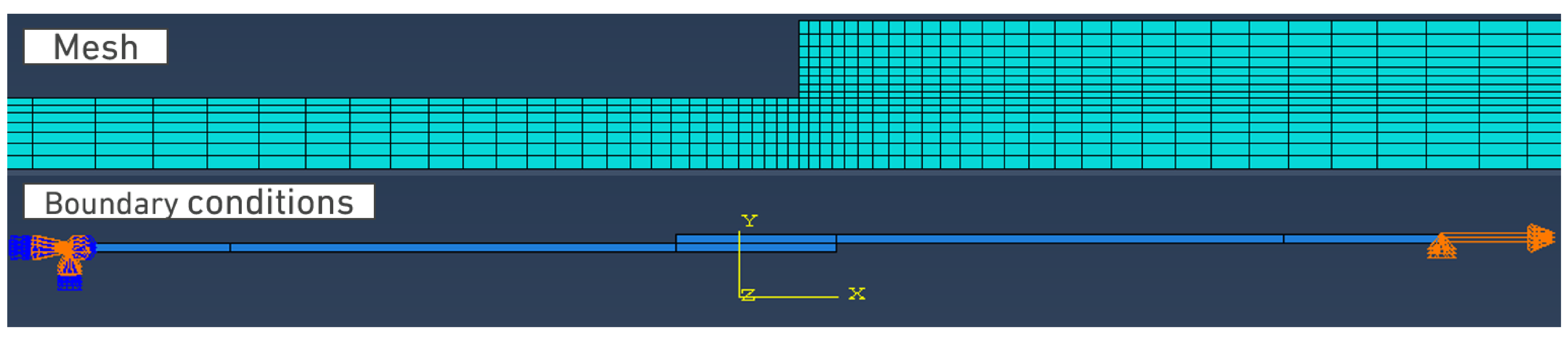

Figure 4– Numerical details of SLJ (mesh and boundary conditions).

Results

1. Fracture energy comparison - SHPB specimens vs DCB/Apparatus

In Figure 5 is possible to observe a summary of the **fracture energy** values obtained with this new procedure, in addition to previously published results determined by the research team, namely those reported in Borges et al. [2].

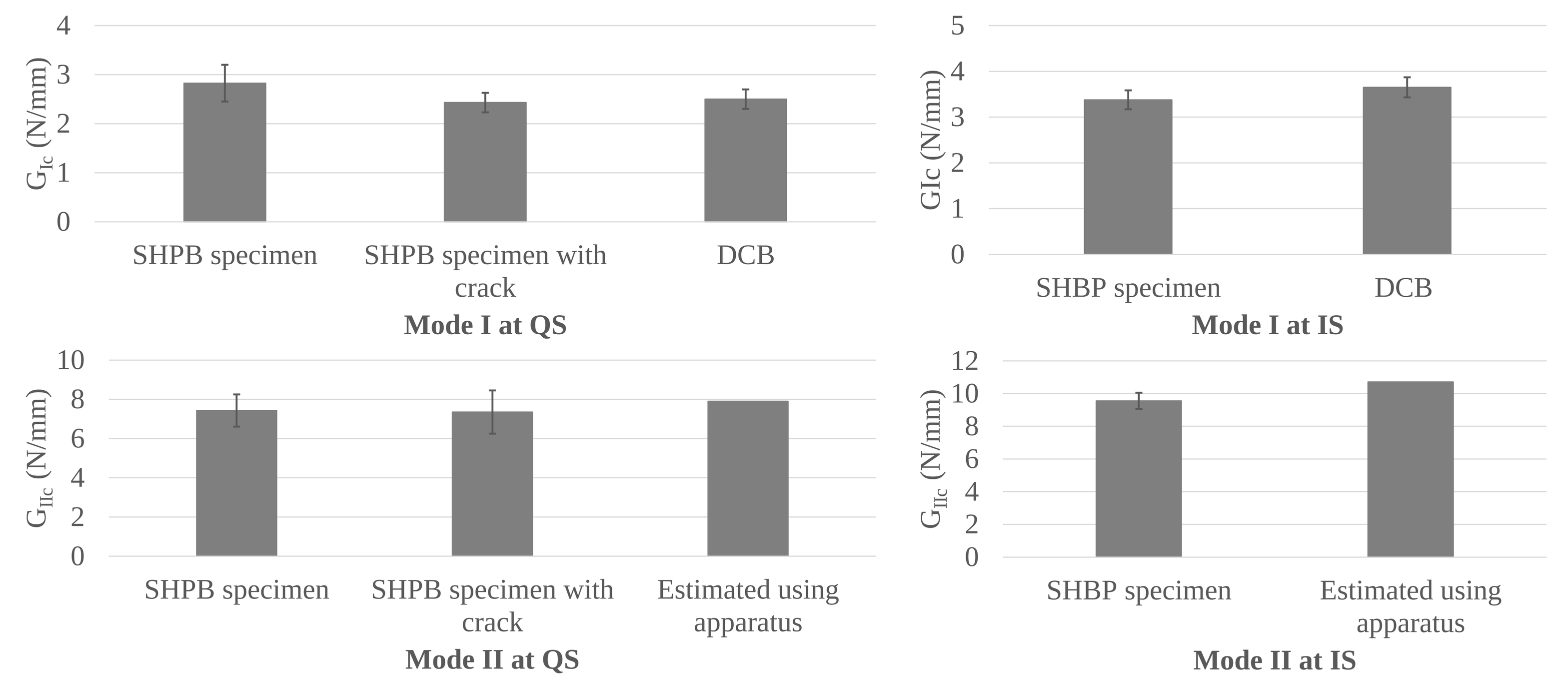

Figure 5 – Fracture energy comparison - SHPB specimens vs DCB/ENF/Apparatus of Epoxy A adhesive at QS and IS conditions.

2. Single lap joints (SLJ)

Representative experimental and numerical **load-displacement curves** obtained from SLJ tests for each loading condition are presented in Figure 5.

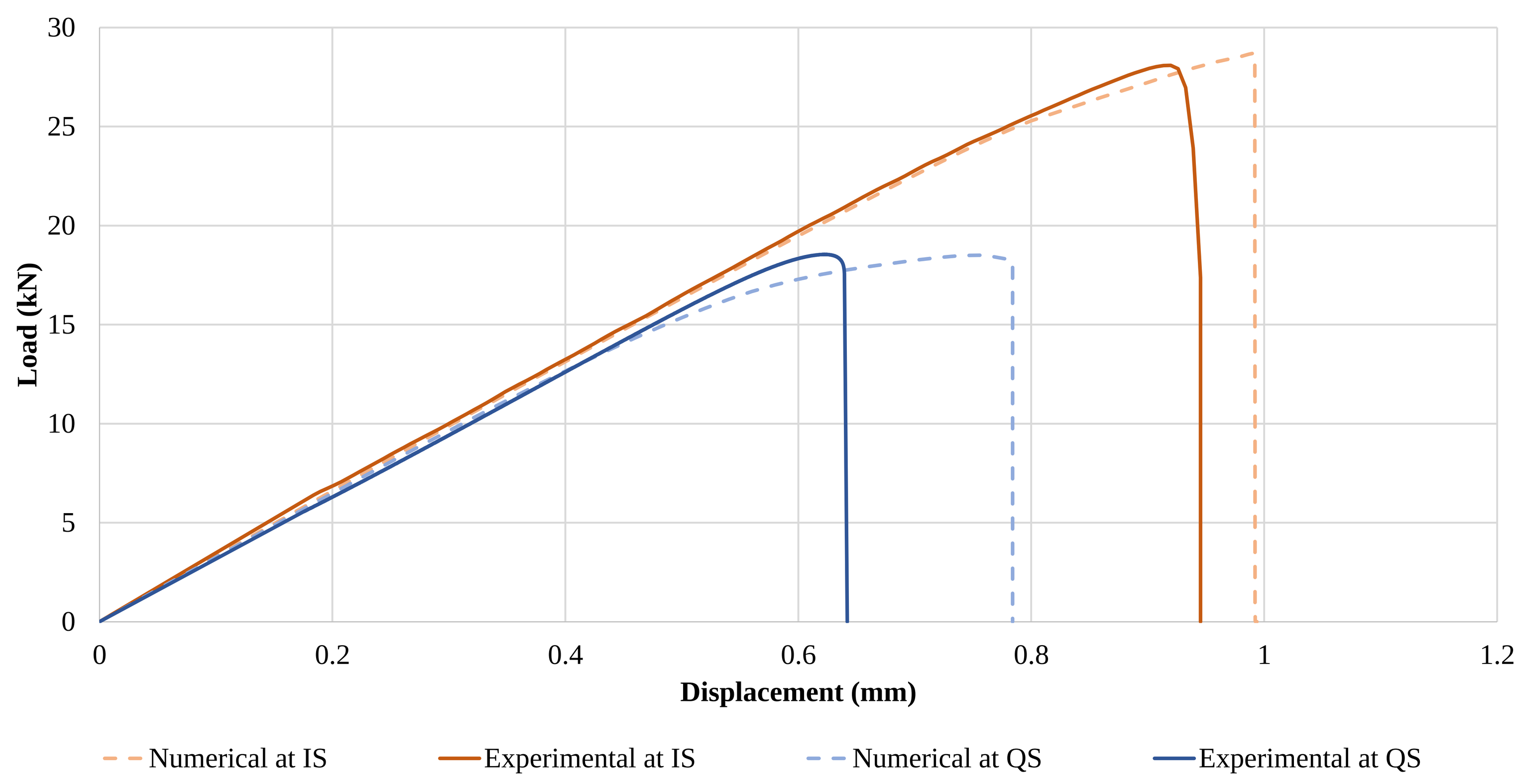

Figure 6 – Load-displacement curves of SLJs using Epoxy A adhesive at QS and IS conditions.

Conclusions

From this study, it was possible to conclude that the **presented procedure allowed** to determine values of **fracture energy similar** to those obtained with proven fracture energy determination tests, such as **DCB** and mixed mode using a validated **apparatus**.

From this study, it was also possible determine **custom TSLs** that were able to **accurately predict the performance** of a different specimen geometry (**SLJ**), operating mainly in the plastic domain, something that classical law shapes such triangular and trapezoidal have difficulty to accomplish.

References

[1] J. Machado et al., "Adhesives and adhesive joints under impact loadings: An overview," *The Journal of Adhesion*, vol. 94, no. 6, pp. 421-452, 2018

[2] C. Borges et al., "A strain rate dependent cohesive zone element for mode I modeling of the fracture behavior of adhesives," *Proceedings of the Institution of Mechanical Engineers Part L-Journal of Materials-Design and Applications*, 2020.

Acknowledgements

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