Design of SHPB specimens for the determination of mode I, mode II and mixed mode fracture toughness of structural adhesives

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Introduction

Adhesives are increasingly being used in the automotive industry as an alternative to classical mechanical joining methods, as they improve strength to weight ratio and reduce the cost of the projected structure. In the automotive industry, it is crucial to ensure passengers' safety if a collision occurs, for that, the behaviour of the entire structure should be analysed under impact conditions, and this includes the adhesives.

The present work to aims **design and to define a strategy to validate novel Split Hopkinson Pressure Bar (SHPB) specimens** in order to understand how the mechanical properties of structural adhesives vary as a function of strain rate, through the definition of fracture toughness envelopes.

Design approach

The working principle of a SHPB, represented in Figure 1, consists in launching a striker at high velocity that impacts into a setup bar-specimen-bar generating a stress wave that will load the specimen. In order to achieve the objective proposed in this work, there is a couple of design directions that one must follow to accomplish the design of specimens able to be used in the determination of the energy release rate using a SHPB machine for different loading directions: due to the operating principle of SHPB machines, the geometry should be as close as possible to a cylinder in order to allow proper stress wave transmission to the specimen and the specimens should be designed with different bondline angles so that different mixed mode conditions can be evaluated.

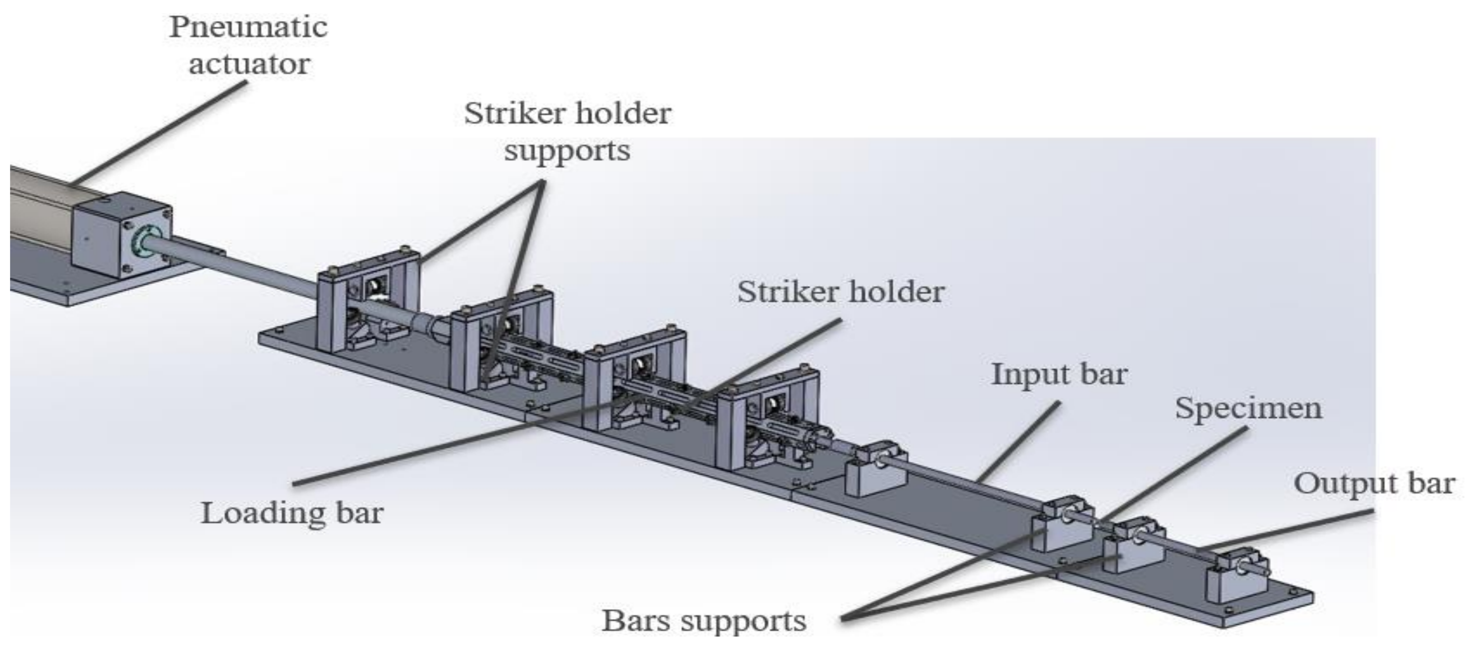

Figure 1 – Scheme of a representation of an SHPB machine.

The final design of the specimens consists in two similar substrates, presented in Figure 2, bonded together. As shown in the image for the pure mode II substrate, the geometry consists in a threaded connection, in order to assemble the specimen to the bar, the bonded area that is designed at an angle with the loading direction to induce different mode mixities and an insert that allows the alignment in the mould to guarantee maximum geometrical accuracy.

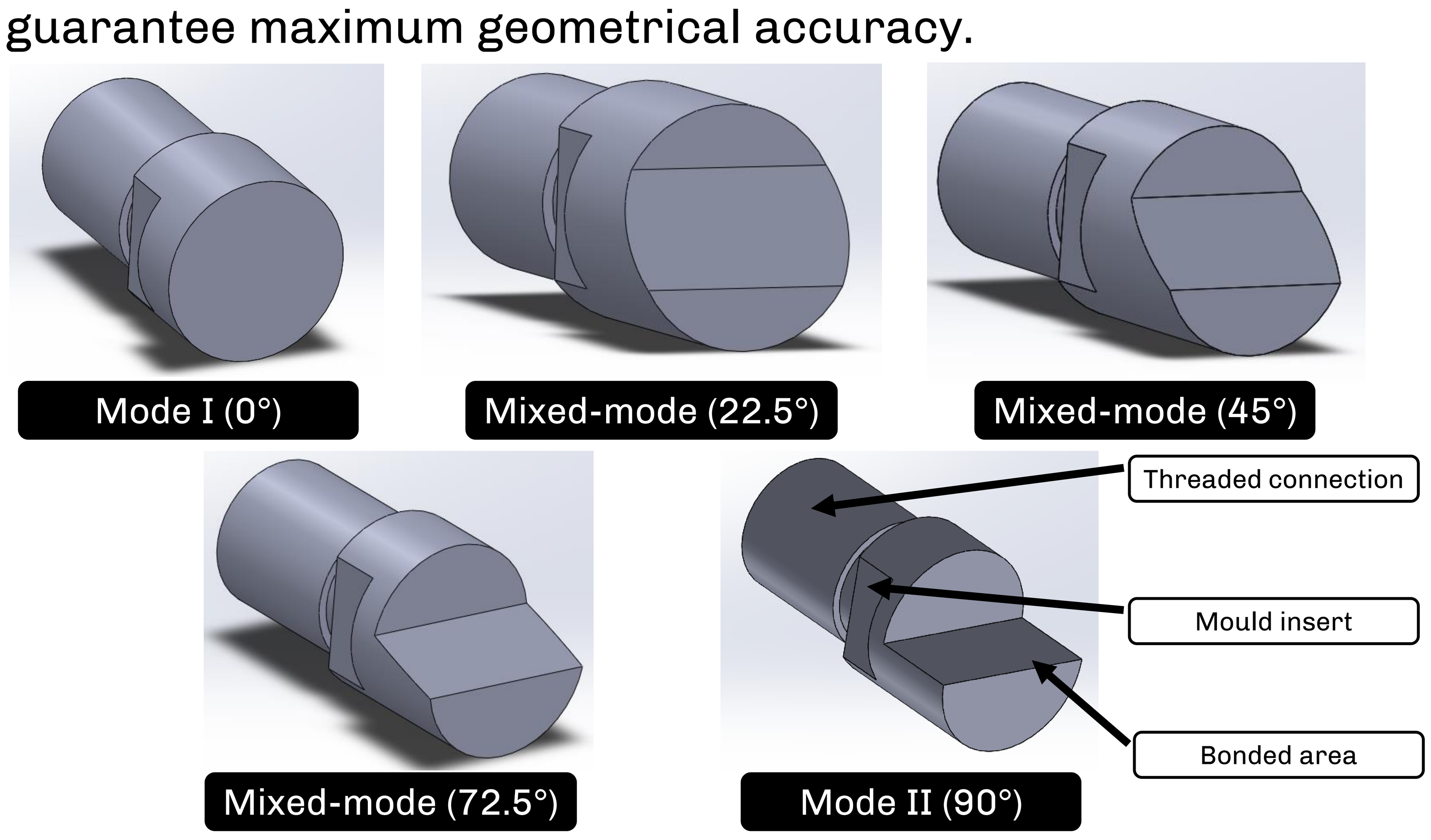

Figure 2 – Representation of the substrates of the novel SHPB specimens for different mode configurations.

SHPB specimen validation

To evaluate the newly designed SHPB specimens, the authors started by focusing on the pure mode I and mode II specimens. The objective is to validate the new specimens by testing both the new specimens and the uniformly accepted tests proposed in the literature, like DCB and ENF, at quasi-static and intermediate strain rates and by resorting to simulation tools, namely finite element models with cohesive elements.

Due to the influence of the CZM law shape in the numerical predictions the authors opted by the use of the direct method based in the J-integral formulation since cohesive law for each mode can be estimated with a single test.

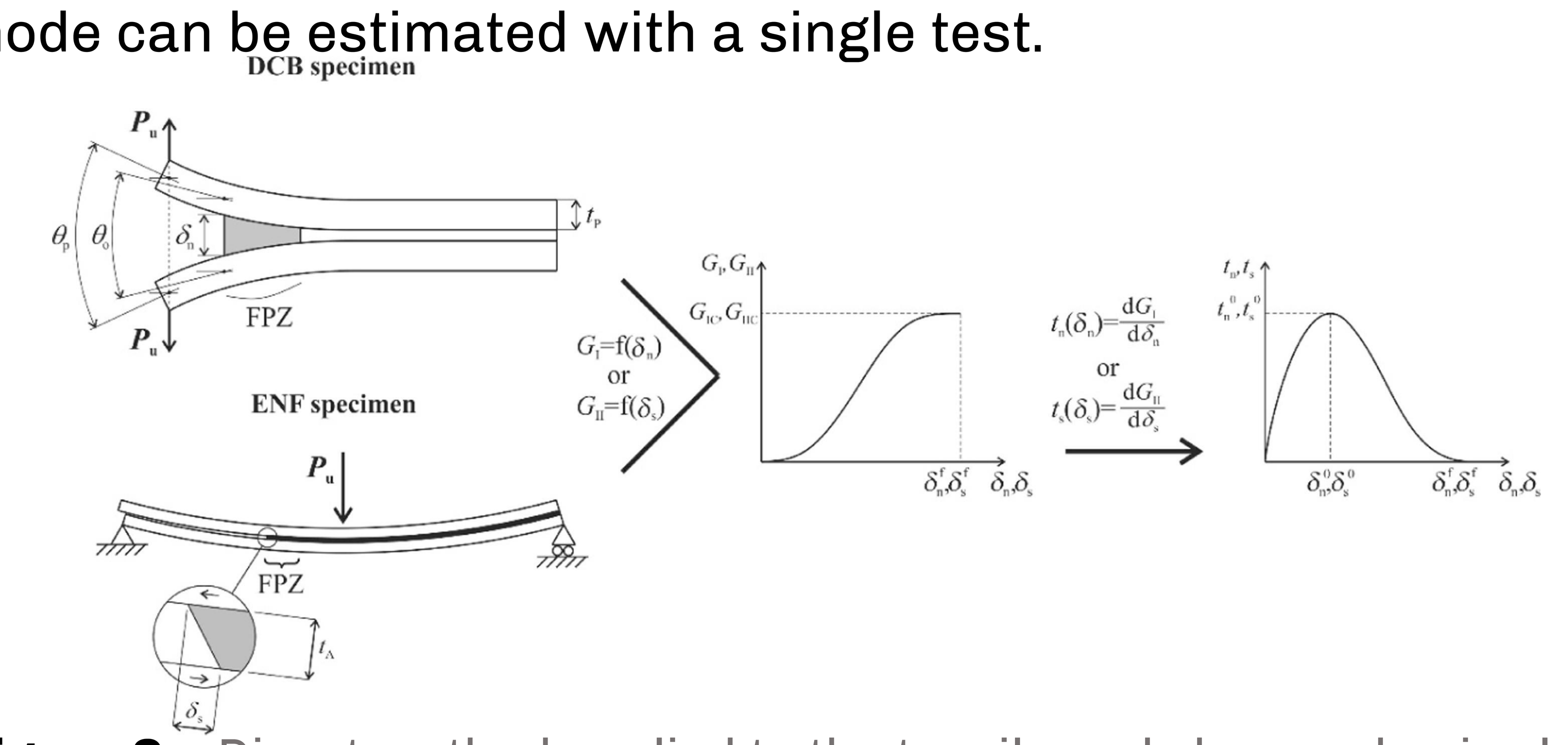

Figure 3 – Direct method applied to the tensile and shear cohesive law estimation [1].

For proper comparison, specimens must be tested at same strain rate. Nunes et al. [2] studied the evolution of the strain rate for both DCB and ENF as can be seen in Figure 2. Moreover they found that the evolution shown in the graphics approximately changes with the test speed in a proportional manner.

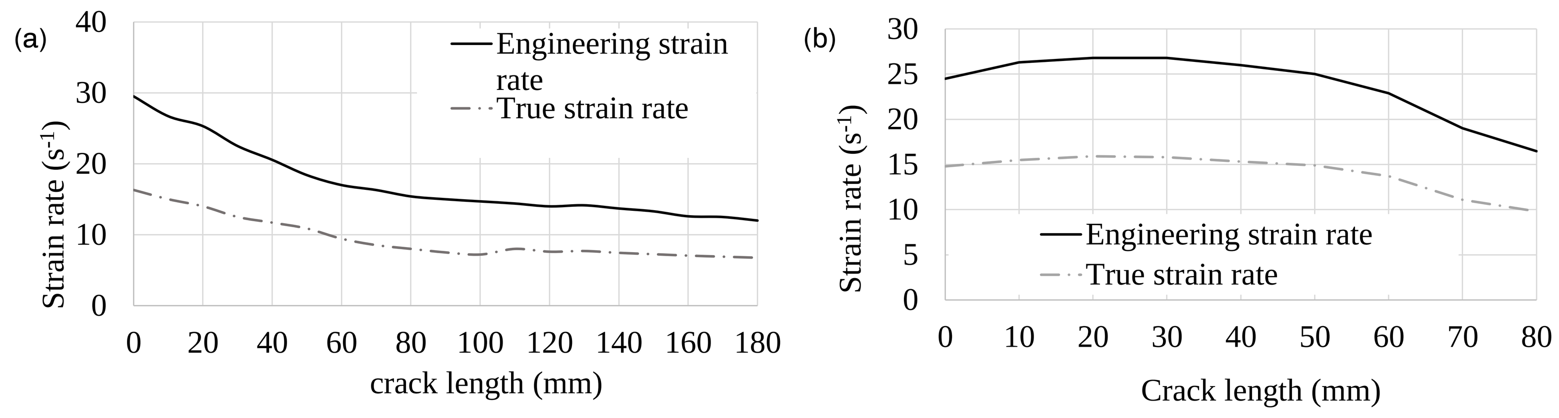

Figure 4 – Strain rate along the crack length for DCB (a) and ENF (b) at 15 mm/s.

With the information in the graphics above and the equation of strain rate: $\dot{\varepsilon} = \frac{v}{L_0}$, where v is the velocity and L_0 the reference distance, the table below shows the test speed for each test that must be ensured to allow for testing at equivalent strain rates.

Strain rate	Test Speed			
	DCB	SHPB mode I	ENF	SHPB mode II
3.33E-02 s^{-1}	1 mm/min	0.4 mm/min	1.2 mm/min	0.4 mm/min
200 s^{-1}	100 mm/s	40 mm/s	120 mm/s	40 mm/s

References

[1] Carvalho, UT et al., "Validation of pure tensile and shear cohesive laws obtained by the direct method with single-lap joints," *International Journal of Adhesion and Adhesives*, vol. 77, pp. 41-50, 2017.

[2] Nunes, P.D et al., "Numerical assessment of strain rate in an adhesive layer throughout double cantilever beam and end notch flexure tests," *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*, p.0954408920916007, 2020.

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