The design of bonded joints for impact applications - a practical methodology

E.A.S Marques (INEGI, Portugal), P.D.P. Nunes, C.S.P. Borges, A. Akhavan-Safar, R.J.C. Carbas, L.F.M da Silva

Advanced Joining Processes Unit

Introduction

The usage of adhesively bonded structures in the automotive industry has greatly increased recently, driven by need to implement lightweight, multimaterial structures which allow for the reduction of total vehicle weight and thus the reduction of emissions and energy consumption.

However, there are still many difficulties associated to the design of these structures, especially under impact conditions, which necessitates thorough research on specific impact testing and material characterization procedures.

High speed testing equipment

Material characterization under high strain rates of adhesives is poorly suited to commercial testing equipment. Thus, a special set of testing devices (Figures 1 and 2) has been custom developed by the Advanced Joining Processes Unit (AJPU), focusing on the specific needs of bonded joint testing.

Figure 1 – Custom designed drop-weight tester machine and associated instruments.

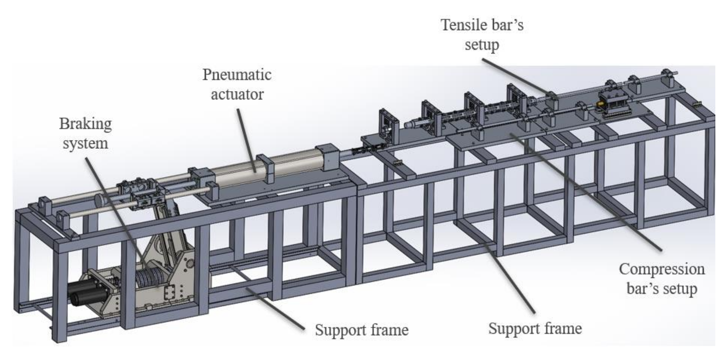

Figure 2 – Custom designed split-Hopkinson pressure bar apparatus with dual direction actuator

Material characterization

The determination of the strain rate dependent properties of adhesives are essential for modelling purposes. Envelopes should be determined, which indicate the strain rate dependency of properties such as the stiffness, strength and the fracture toughness (Figure 3).

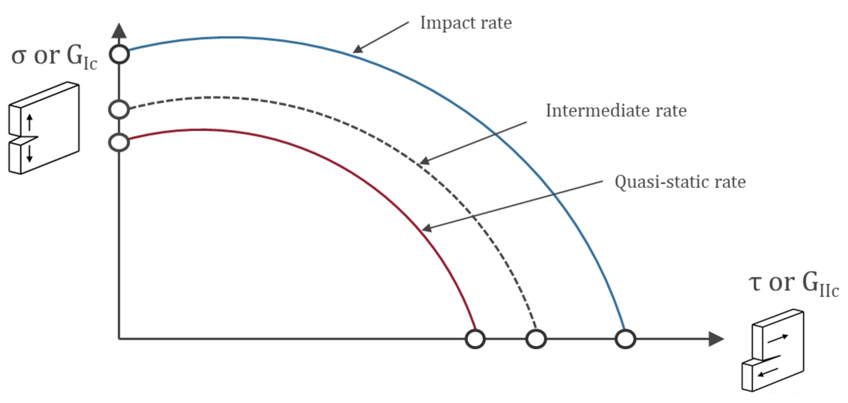

Figure 3 – Example of a strain rate dependent envelope for different mechanical properties of an adhesive.

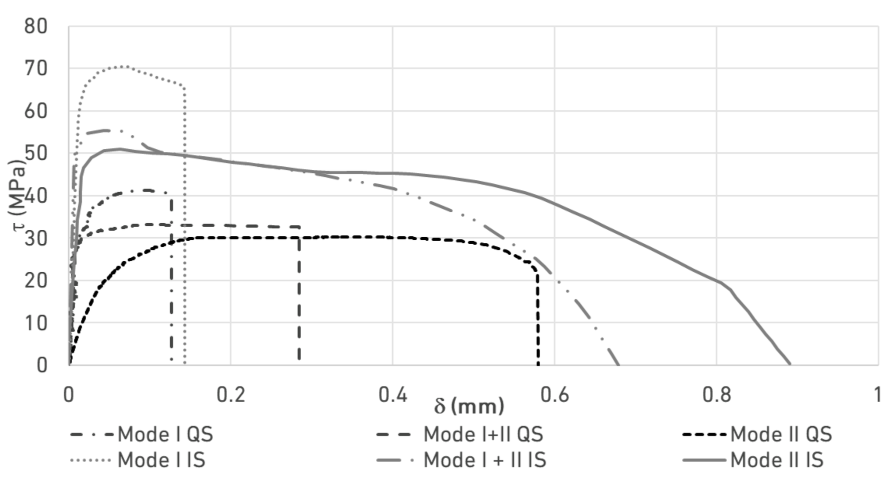

Figure 4 – Directly determined strain rate dependent constitutive laws for a crash resistant adhesive.

This characterization procedure can also be simplified with the use of directly determined constitutive laws (Figure 4).

Such approach require only a single test for each loading mode condition and strain rate level, greatly minimizing the number of tests that must be carried out.

Material property envelopes can be determined directly from these laws (Figure 5), or the law can be directly inserted in a suitable numerical model.

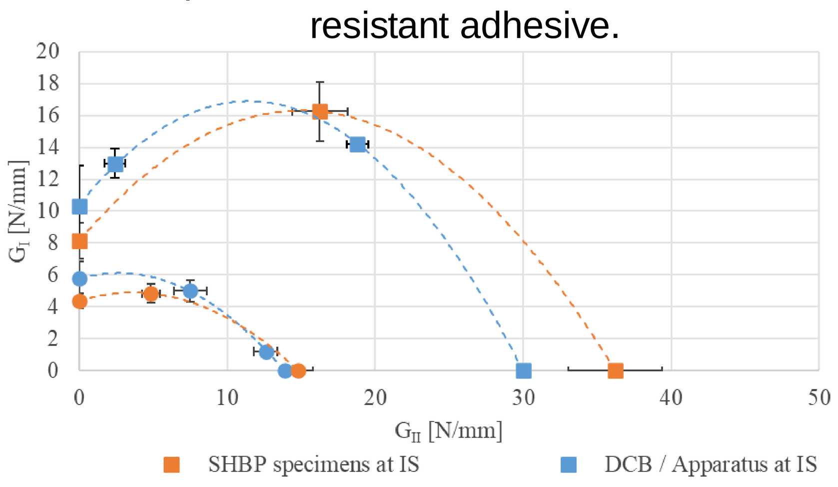

Figure 5 – Strain rate dependent fracture toughness envelope for a crash resistant adhesive extracted with a direct approach.

One key aspect of impact characterization procedures is the control of the strain rate. Strain rate can vary greatly during the test (Figure 6), which can change the measured values. Specimen and procedure design must be adjusted accordingly.

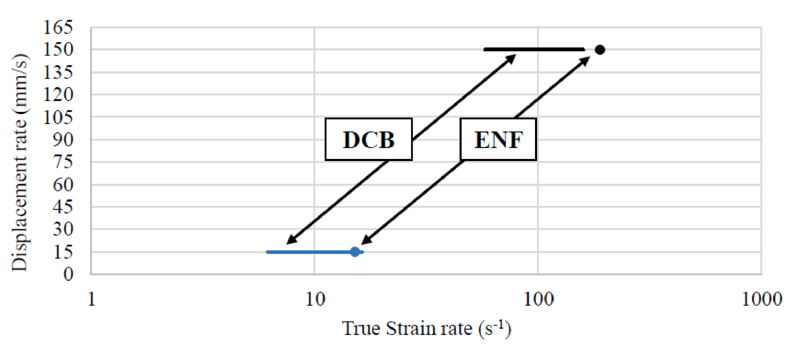

Figure 6 – Variation of true strain rate during double cantilever beam and end notched failure test procedures

Joint testing

Testing at the joint level is of great importance to validate the bonding process and the design procedure.

Several impact joint testing procedures have been devised, relying mainly on specialized tooling for drop-weight testing machines (Figures 7 and 8).

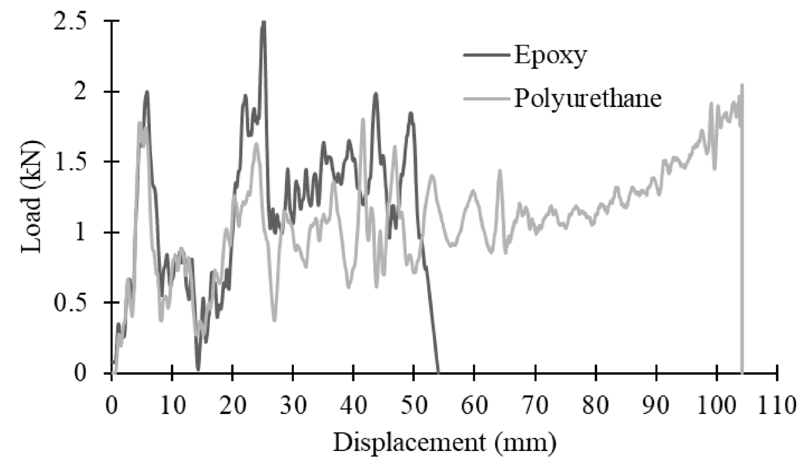

Figure 7 – Comparison of performance of two different adhesives during a full-scale joint impact testing procedure

Figure 8 – Testing procedure for impact testing of full-scale bonded joints.

Numerical modelling

Numerical modelling approaches for simulating the strain rate behavior of adhesive joint must rely on finite element models which can update the material properties as a function of the local strain rate (Figure 9).

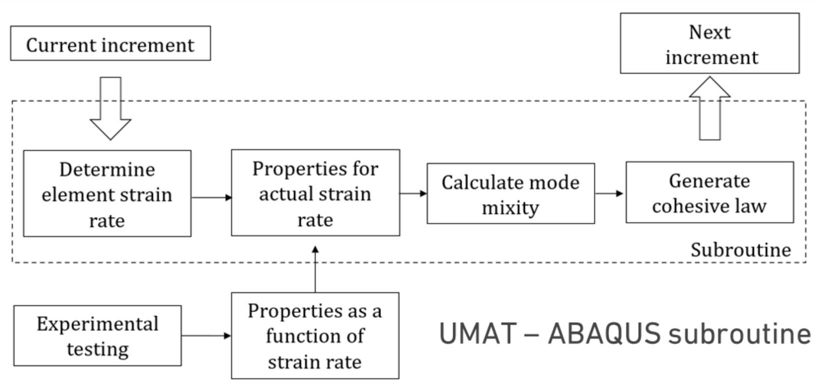

Figure 9 – Algorithm for a strain rate dependent cohesive law for an adhesive.

These models include cohesive zone modelling approaches, where cohesive elements are introduced in the adhesive layer, allowing to simulate damage and failure with good accuracy (Figure 10).

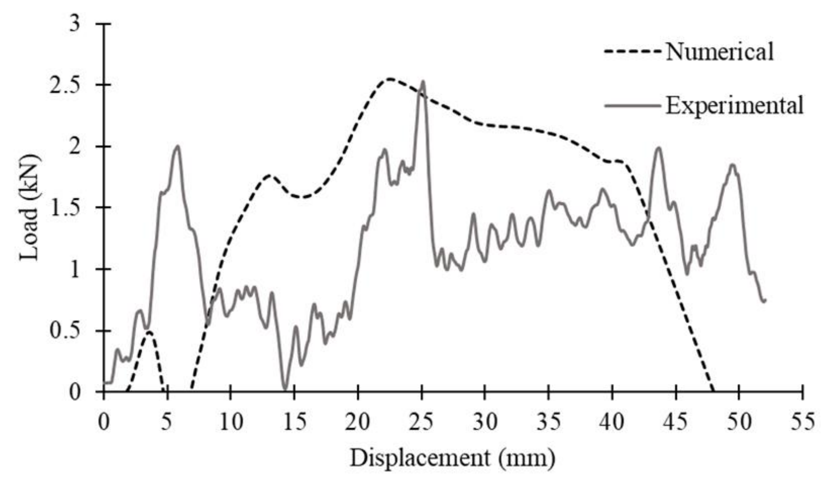

Figure 10 – Comparison of numerical and experimental data for a numerical model of a bonded joint with cohesive elements.

In order to account for inertial effects, dynamic explicit modelling is used, allowing for accurate failure load determination.

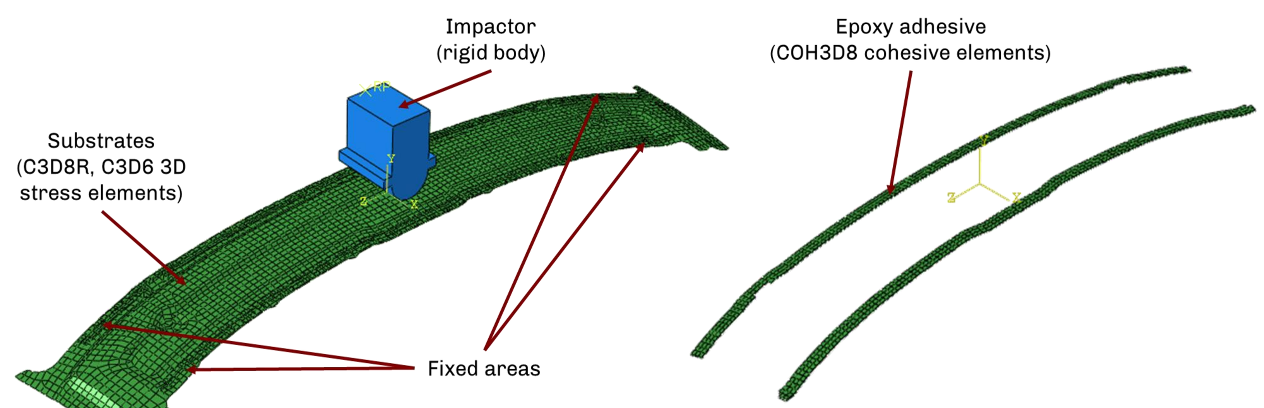

Figure 11 – Integration of cohesive elements in the adhesive layer of an automotive component

Conclusions

The study of the impact behavior of adhesive joints is fundamental for the design of lightweight, crash resistant structures;

Several material characterization processes have been successfully used for the determination of strain rate dependent mechanical data, supporting the design optimized impact resistant bonded structures;

Approaches based on cohesive zone modelling can be successfully used to model this behavior, although work on strain rate dependent modelling and characterization requires careful assessment of the local strain rates acting on the adhesive layer.

Acknowledgements

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