Functionally graded adhesive joints under impact loads

M.Q. dos Reis (INEGI, Portugal), R.J.C. Carbas, E.A.S. Marques, LFM da Silva

ADVANCED JOINING PROCESSES UNIT

Introduction

The industrial application of adhesively bonded joints has increased significantly in the last few years, driven by benefits such as the increased design flexibility, high vibration damping, the capability of joining dissimilar materials and the possibility of being used in combination with other joining techniques. However, the presence of stress concentrations at the overlap ends, especially in single lap joints, is one of the major drawbacks associated with this technique, reducing joint strength. To solve this issue, several techniques have been proposed, such as the use of adhesive spew, adhesive and adherend shaping, mixed adhesive joints and functionally graded adhesive joints. Functionally graded adhesive joints use an adhesive layer where the properties gradually vary along the overlap length, which results in the reduction of stress concentration peaks at the ends of the overlap, leading to a more uniform stress distribution. Multiple techniques for the creation of a functionally graded bond line have been presented in the literature, such as the inclusion of particles and nanoparticles and the use of functionally graded curing. However, the experimental works available in the literature only report results for quasi-static loading conditions, with the impact behaviour of these joints being an unstudied topic. The main objective of the present work is to fill this gap and study the mechanical behaviour of functionally graded adhesive joints loaded under impact conditions, using both experimental testing and numerical modelling. The results obtained show that, unlike what is found for quasi-static loads, graded joints do not offer significant strength improvement under impact loads. In contrast, energy absorption is significantly increased. This behaviour is explained by the completely different stress distribution on the adhesive layer for quasi-static and impact conditions, leading to the lower effectiveness of functionally graded adhesives under impact loads.

Experimental methodology

Materials:

- Adhesive: Loctite Hysol® 3422 (Henkel, Dublin, Ireland);
- Adherends: High strength steel (HSS) with tensile strength of 1050 MPa.

Single lap joints

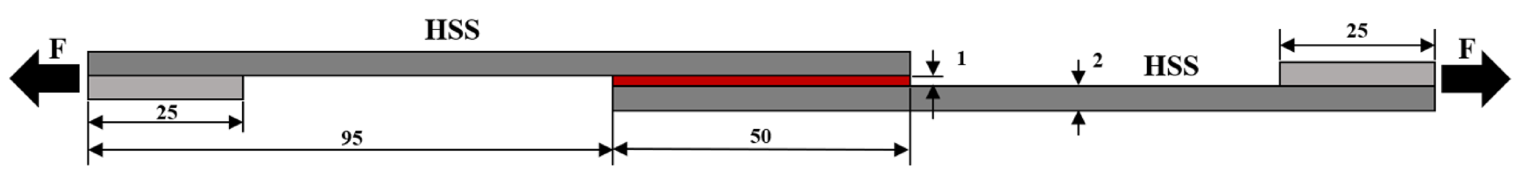

Figure 1 – Homogeneous adhesive SLJ

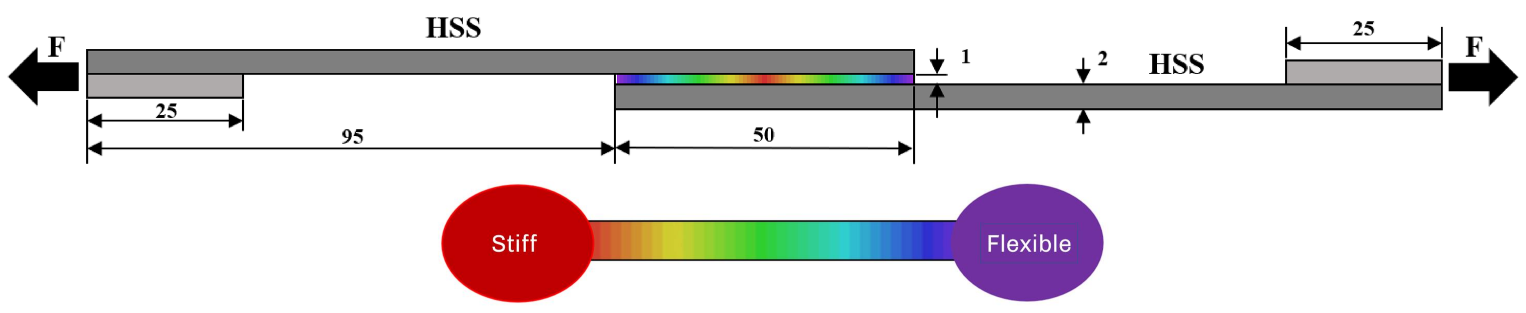

Figure 2 – Graded adhesive SLJ

Methods:

- Quasi-static tests: A universal testing machine Instron model 3367 with a load cell of 30 kN and the tests were performed a constant crosshead rate of 1.0 mm/min.
- Impact tests: A drop-weight machine specifically designed by the authors with a maximum tests speed and load of 5 m/s and load cell of 50 kN. The impact tests were performed at a velocity of 3 m/s.

Numerical details

The numerical simulations were carried out with the Abaqus® finite element analysis (FEA) software.

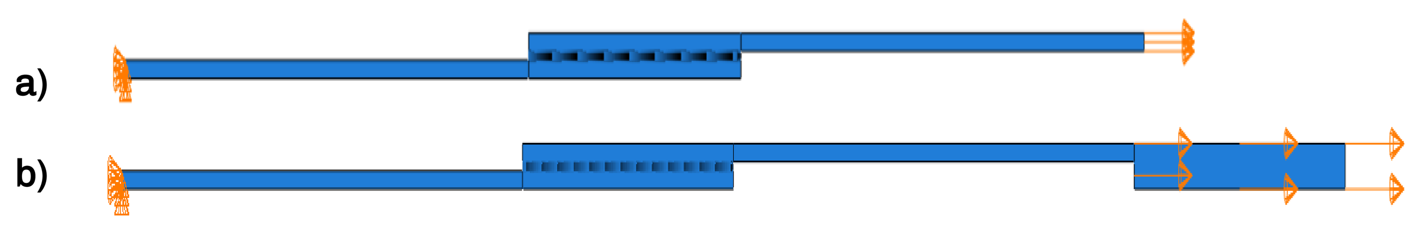

Figure 3 – Model boundary conditions a) static b) dynamic.

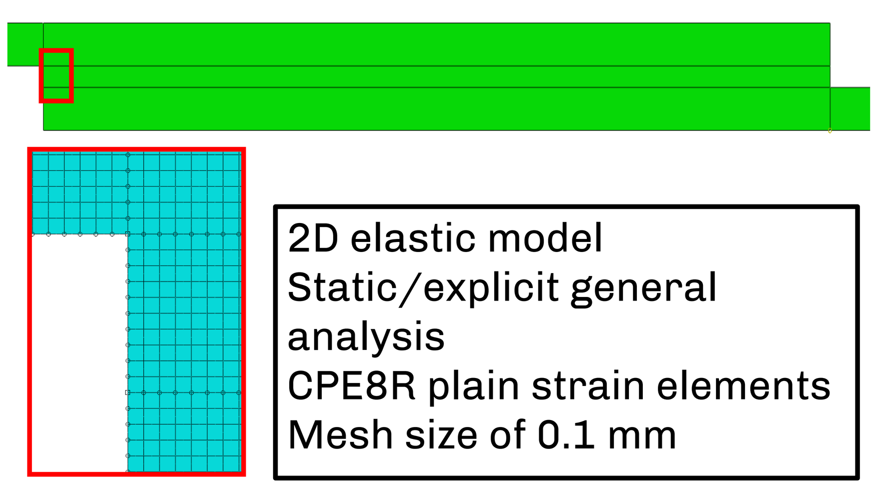

Figure 4 – Model details for elastic analysis

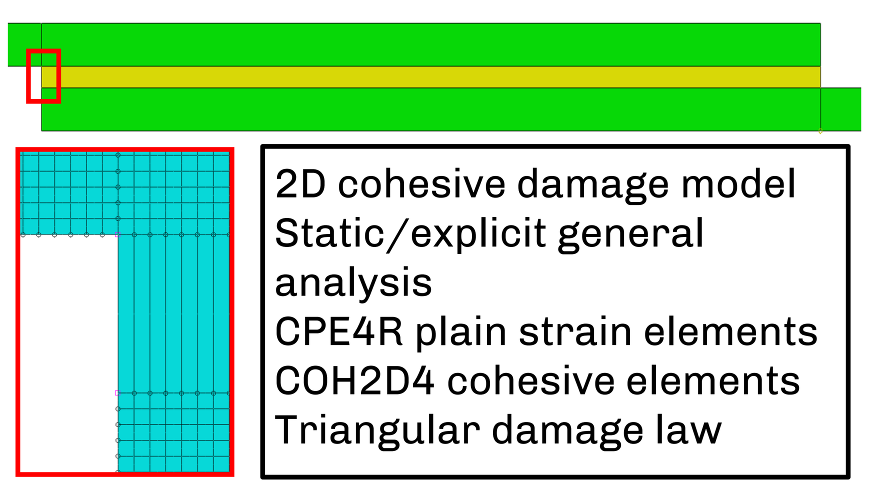

Figure 5 – Model details for CZM analysis

Results

The numerical and experimental load-displacement curves for the isothermally and graded cured SLJs tested under quasi-static and impact conditions.

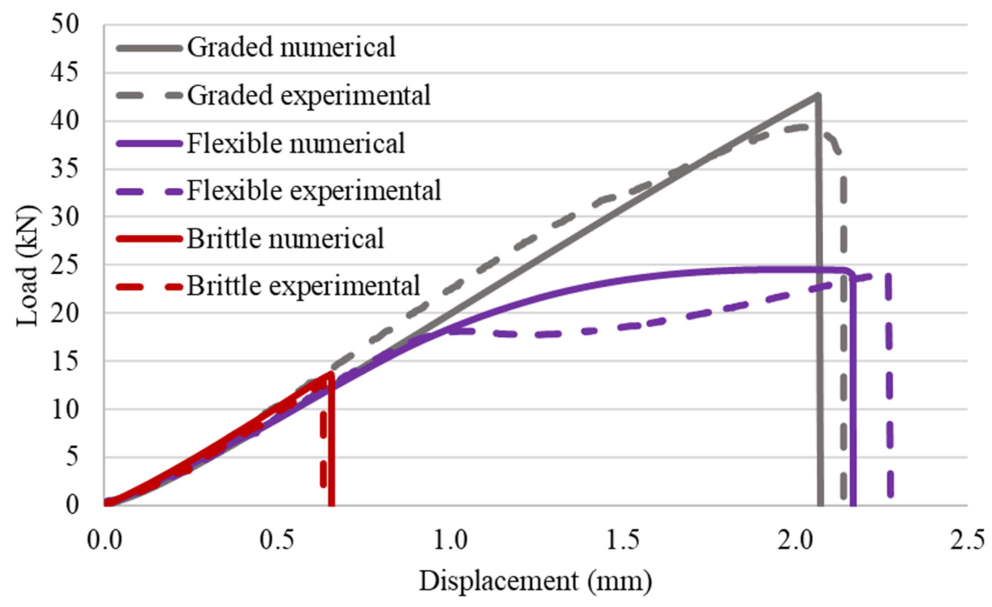

Figure 6 – Numerical and experimental P-δ curves in quasi-static conditions [3]

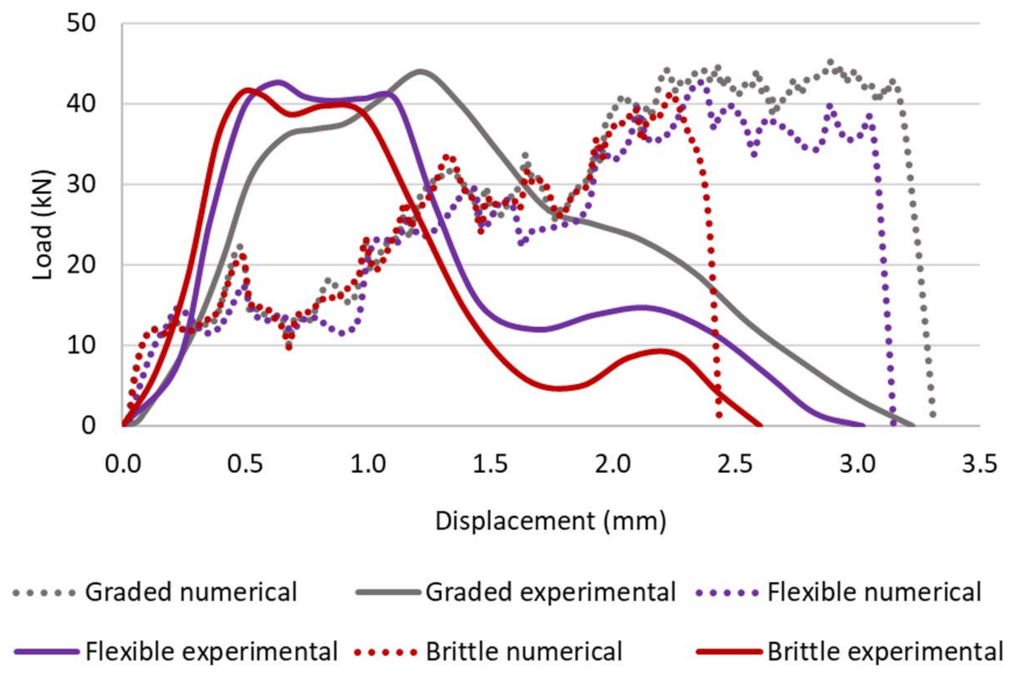

Figure 7 – Comparison between numerical and experimental P-δ curves impact conditions

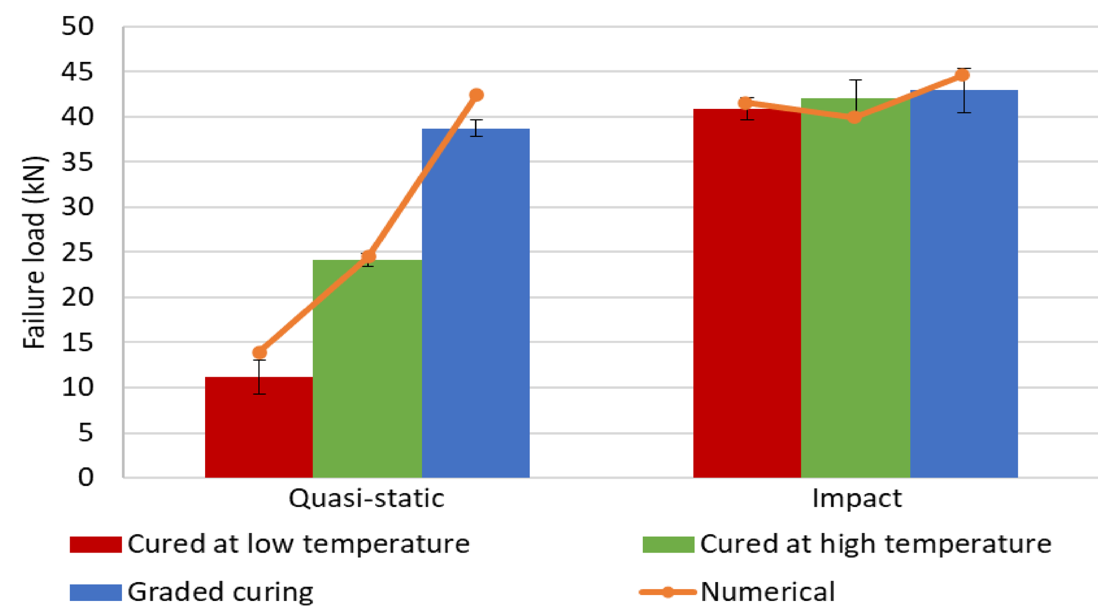

Figure 8 – Numerical and experimental failure loads in quasi-static and impact conditions

Conclusions

1. The functionally graded joints provided an average improvement in failure load of 5% in comparison with isothermally cured joints at low temperature (brittle behaviour) and 2% with joints cured at high temperature (ductile behaviour) against 246% and 61% obtained under quasi-static conditions;
2. The FGAJs showed an increase of the displacement and energy absorption up to 51% under impact conditions, with an unchanged failure load, which is very significant result for the design of bonded components to be subjected to impact loads;
3. Cohesive zone modelling was able to predict the failure load of the homogeneous and graded joints properly. Moreover, the output of adhesive degradation provided by the software shows that under impact conditions the failure is not transferred to the centre of the bondline, as observed in quasi static conditions, which lead to the low effectiveness of the graded adhesive under impact. However, the proposed model is quite limited with regards to strain rate dependency of material properties, which limits the accuracy in the prediction of the displacement and energy absorption.

References

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[2] R.J.C. Carbas, L.F.M. da Silva and G.W. Critchlow, Int J Adhes Adhes, 48, 110 (2014).
[3] M.Q. dos Reis et al., Proc. Mech. E, 234, 436 (2020).

Acknowledgements

The authors would like to thank FCT for financially supporting this work through grants 2020.09991.BD and Nº 028473 POCI-01-0145-FEDER-028473, and Henkel Iberia for supplying the adhesive Loctite Hysol® 3422