Analytical modelling of single-lap joints, L-joints, and T-joints with bio-based materials for the automotive industry

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ADVANCED JOINING PROCESSES UNIT

Introduction

Adhesive bonding has gained significant importance in the **automotive industry** due to its numerous advantages, including the potential to effectively reduce the overall weight of structures [1]. However, with **growing environmental concerns**, efforts are being made to introduce **eco-friendly materials** into the industry. To facilitate their integration, it is crucial to develop tools that can **assist in the design phase**. This work focuses on the study of an **analytical model** that proved to be suitable to study bio-based adhesive joints. More specifically, **SLJ, L-joints and T-joints**.

Analytical method

Bigwood and Crocombe's model [2] focuses on studying only the overlap region of the joint. The joint is subjected to axial forces, shear forces, and bending moments in the overlap edges (Fig.1).

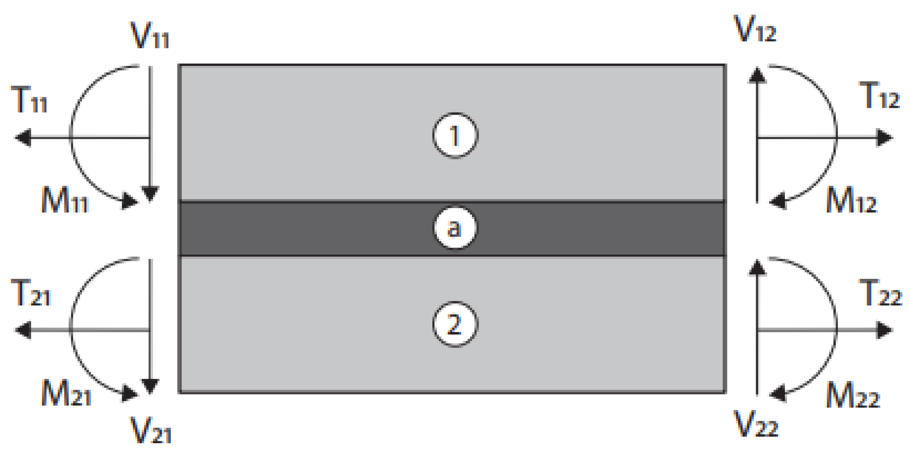

Figure 1 – The general adherend-adhesive-adherend sandwich with general loading.

The analytical model presented considers a full **elastic analysis** where both adherends and adhesive are considered isotropic and may have constant thickness. The peel and shear stress distributions are given by:

$$\begin{aligned}\sigma_y =& A_1 \cos(K_5 x)\cosh(K_5 x) + A_2 \cos(K_5 x)\sinh(K_5 x) \\ &+ A_3 \sin(K_5 x)\cosh(K_5 x) + A_4 \sin(K_5 x)\sinh(K_5 x)\end{aligned} \quad (1)$$

$$\tau_{xy} = B_1 \cosh(K_6 x) + B_2 \sinh(K_6 x) + B_3 \quad (2)$$

To determine the reactions for the SLJ, bending moment factors were used. This was not possible for the other joint geometries, for which linear statics was applied.
This investigation focused on joints with **pine wood substrates** and a **bio-adhesive** that cures at **zero-thickness**.
The results of the analytical model were **compared against finite element analysis (FEA)**, where the adhesive was simulated using cohesive elements and considering a triangular traction-separation law.

Results and Discussion

The distributions of peel and shear strength along the overlap length for SLJ, L-joints and T-joints are shown in Fig. 2.
It can be seen that:

- **Peel stress:** the accuracy of the peel stress distribution was **not optimal**, which was attributed to the **extremely low adhesive thickness**.
- **Shear stress:** The stress distributions given by the numerical model and FEA are **very similar**.

However, when the stress of the analytical analysis does not perfectly match the numerical model, it is always higher, resulting in a more **conservative approach**, and enabling the use of the analytical model for a **safe design of all of the joints under analysis.**
Including Crocombe's nonlinear analysis [3] could broaden the range of applications and improve the accuracy and reliability of the results.

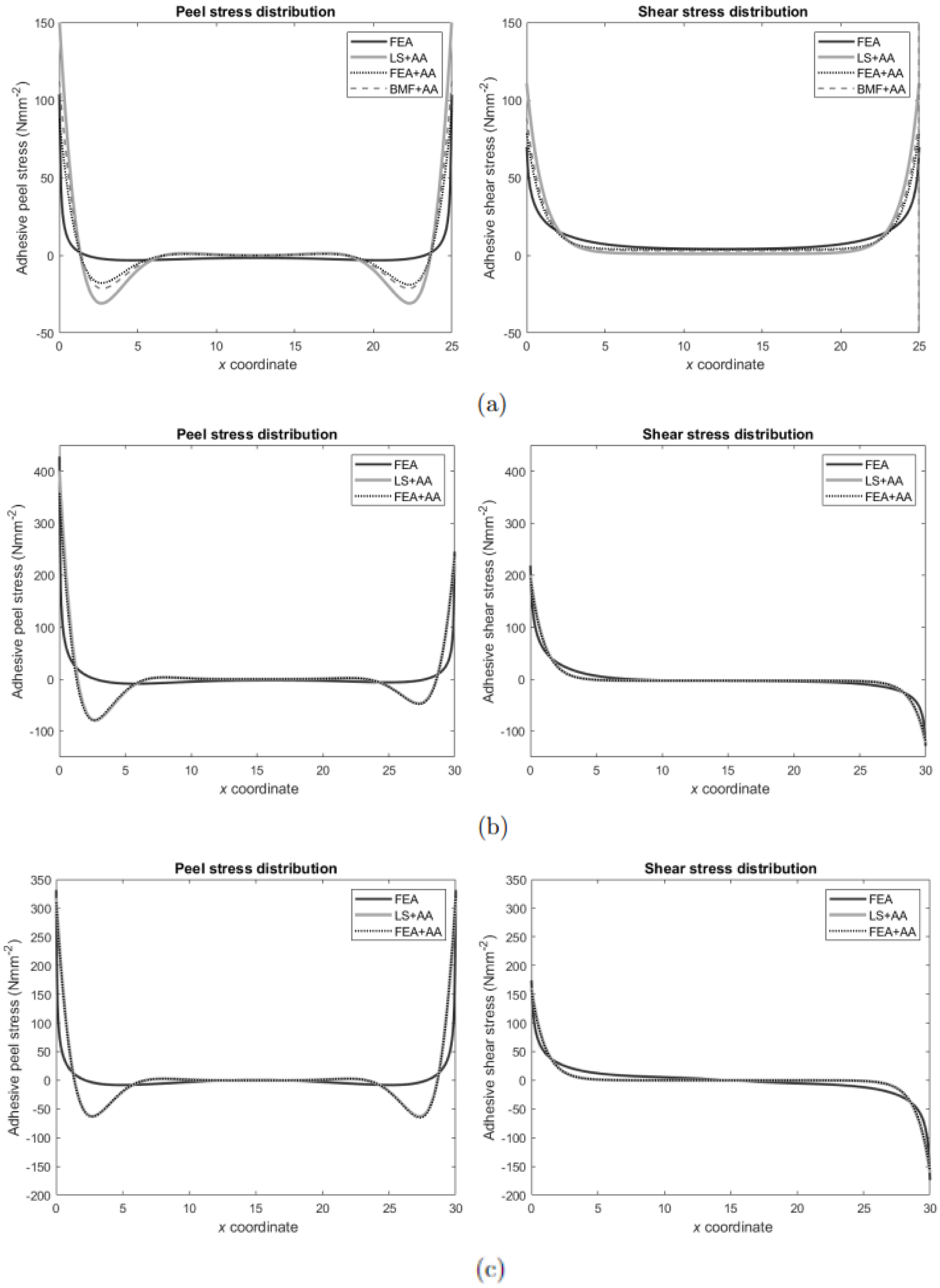

Figure 2 – Stress distributions for adhesive joints with bio-materials: (a) SLJ, (b) L-joint, (c) T-joint.

Conclusions

The stress distributions obtained from the analytical model deviated from the initially expected values. Nevertheless, a comparison between the critical stress obtained revealed a high degree of similarity in the calculations. Considering the advantages of simplicity and efficiency, the analytical model can be effectively employed in practical applications, providing valuable insights for the pre-design stage. However, for more precise results and a comprehensive understanding of joint behavior, additional validation through experimental testing or more advanced numerical methods may be necessary.

References

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[3] DA Bigwood and AD Crocombe. Non-linear adhesive bonded joint design analyses. International journal of adhesion and adhesives, 10(1):31–41, 1990.

Acknowledgements

This research was funded by the PTDC/EME-EME/6442/2020 "A smart and eco-friendly adhesively bonded structure for the next generation mobility platforms" funded by national funds through the F.C.T., I.P.