Adhesive flow analysis in manufacturing hybrid bolted-bonded joints

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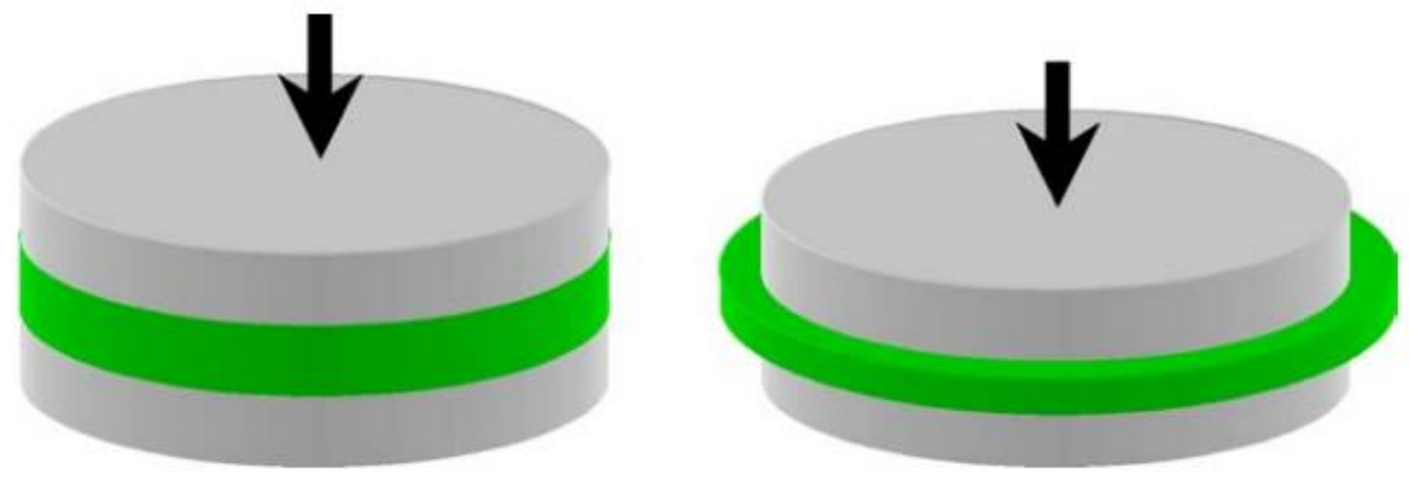
Introduction

In recent years, there has been increased interest in combining adhesive bonding with mechanical joining techniques in manufacturing industrial structures. This approach takes advantage of the strengths of each method, resulting in significant enhancements in joint strength, efficiency and flexibility, particularly when combining bolts with adhesive bonding in steel adherends. A key challenge of this process is controlling adhesive flow and thickness, a crucial parameter for bonded joints. Our research focuses on analyzing adhesive flow and thickness distribution during the manufacturing of hybrid bolted-bonded single lap joints.

Numerical Procedure

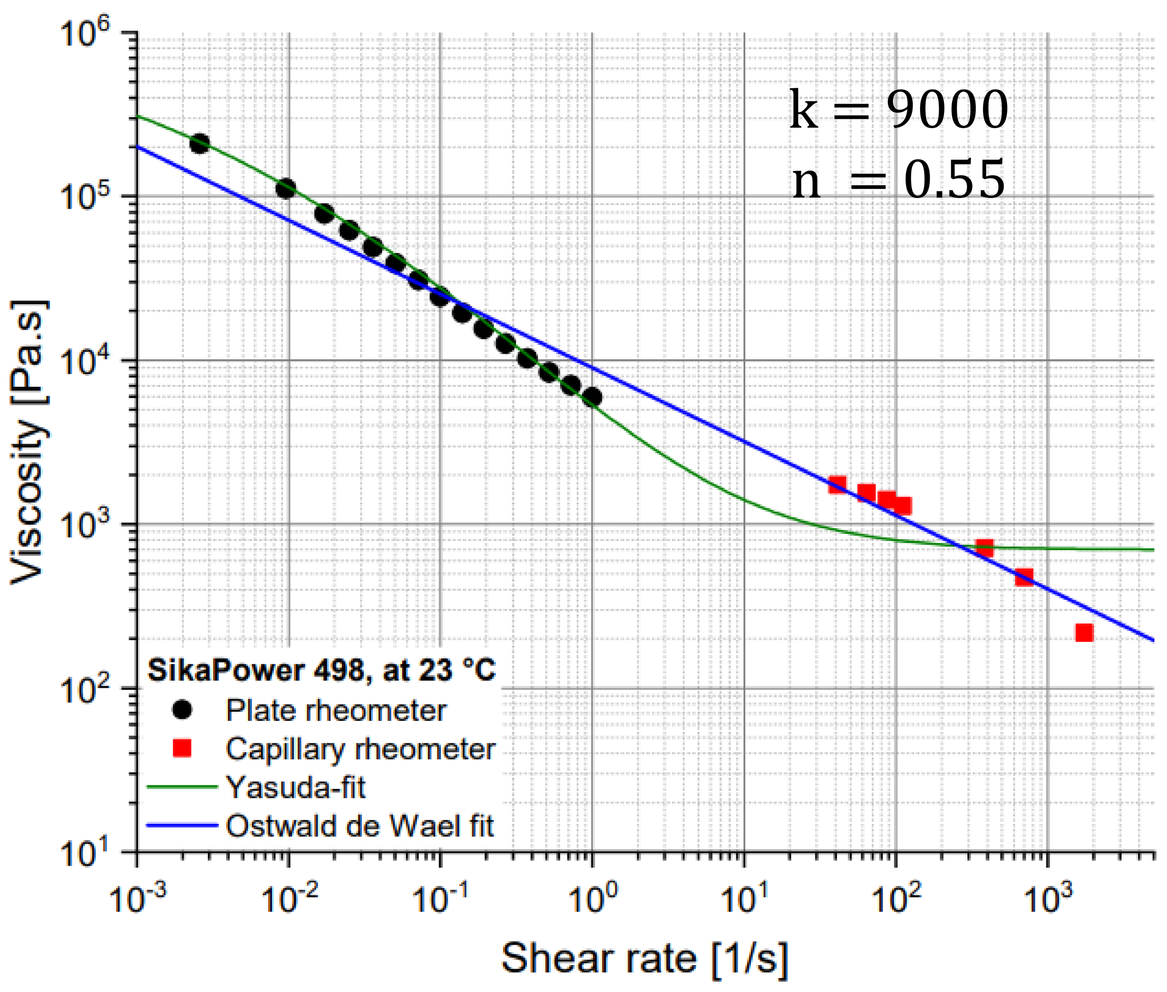
One particularity of hybrid bolted-bonded joints is that the adhesive is applied in its liquid state and its pressing behavior is termed squeeze flow. For this reason, a Computational Fluid Dynamics (CFD) approach was considered and the commercial software Ansys Fluent was chosen.



(a) (b)

Figure 1 – Squeeze flow illustration before a) and after b) the squeezing process.

First, squeeze flow simulations with structural epoxy adhesive, Sika Power 498, were done to compare with the literature and to serve as model validation.



Power law rheological model:

$$\eta(\dot{\gamma}) = k \cdot \dot{\gamma}^{n-1}$$

Figure 2 – Rheological characterization of Sika Power 498 epoxy adhesive [1].

Numerical Results

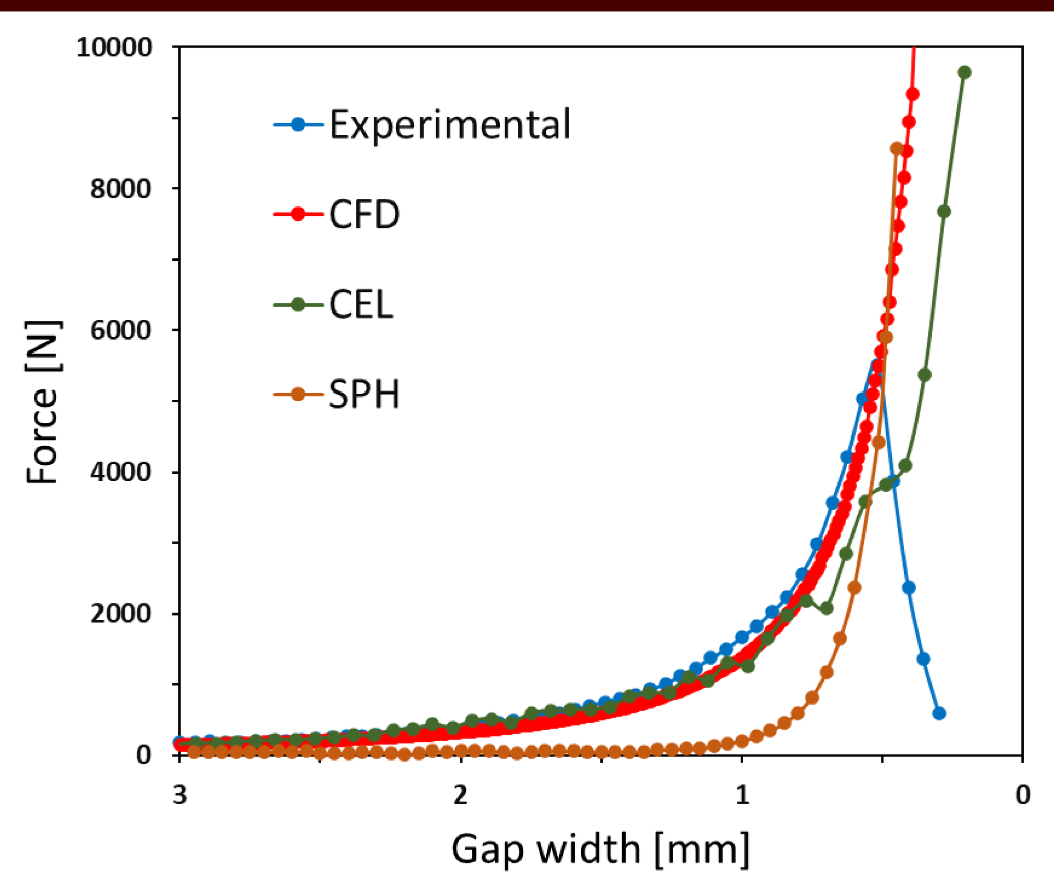


Figure 3 – Squeeze flow results and comparison with existing literature for Sika Power 498.

Carreau rheological model:

$$\eta(\dot{\gamma}) = \eta_\infty + (\eta_0 - \eta_\infty)\left[1 + (\lambda \cdot \dot{\gamma})^2\right]^{\frac{n-1}{2}}$$

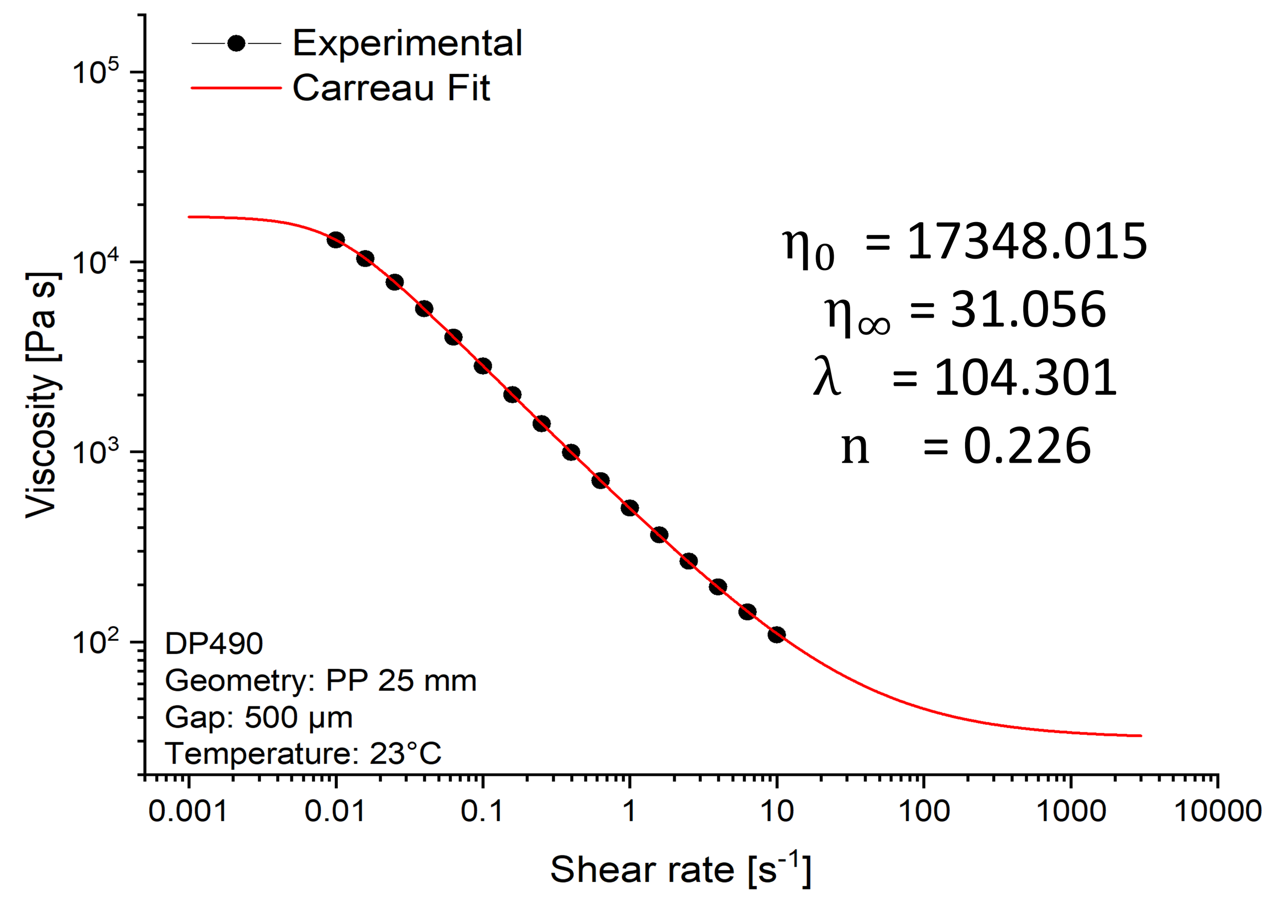


Figure 4 – Rheological characterization of DP460 epoxy adhesive.

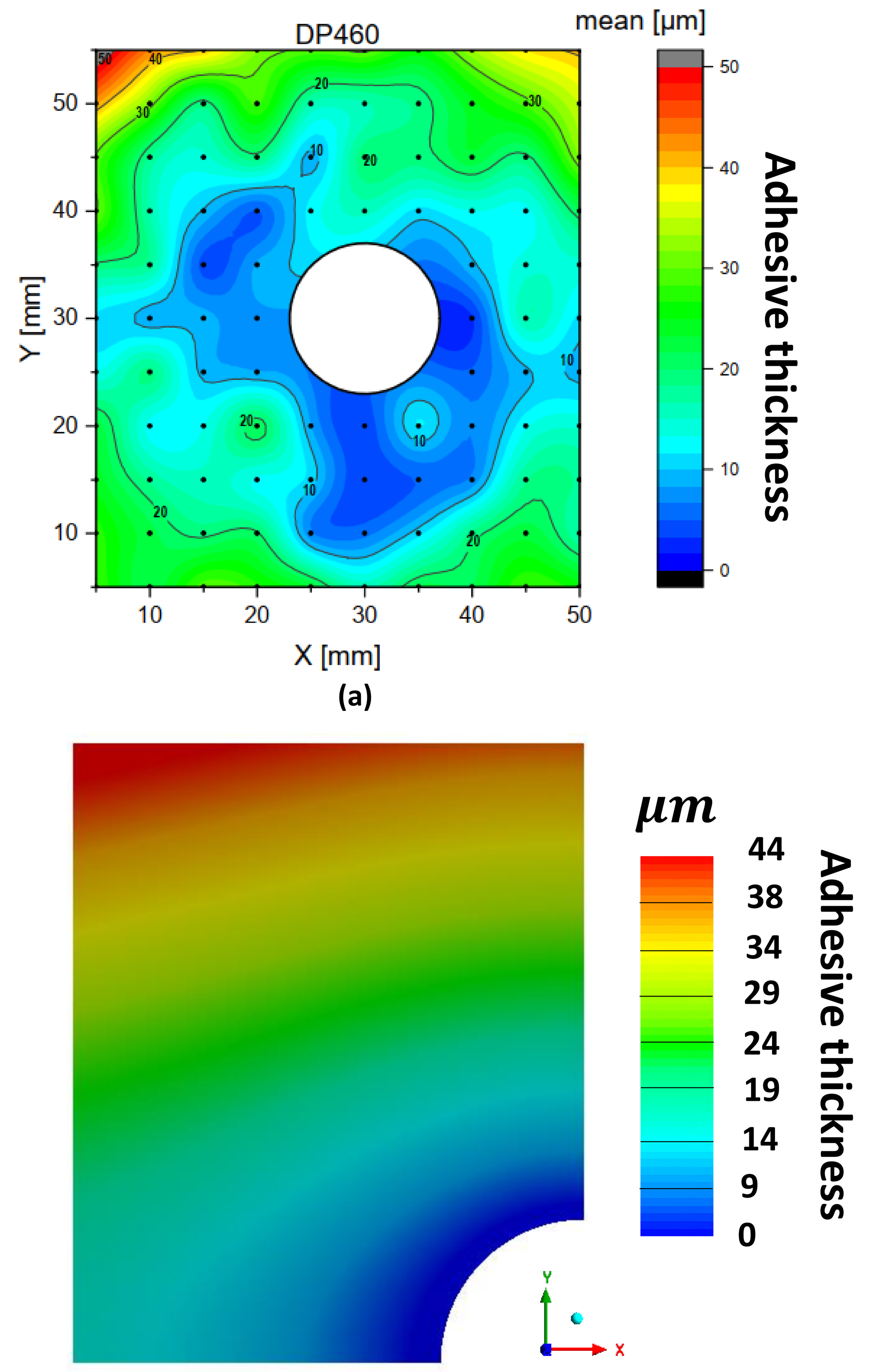


Figure 5 – Adhesive layer thickness distribution comparison a) experimental [2] and b) numerical results.

Conclusions

The use CFD sees the behavior of the adhesive in its liquid state in the best light compared to other numerical methods previously used in the literature, although it only portrays its viscous, and not its viscoelastic, behavior. Despite CFD limitations and simplifications, results show that it is the rheological behavior of the adhesive, its viscosity and the geometry, which lead to pressure gradients high enough to cause deformation of the steel substrate, that influence the thickness of the adhesive layer. Contrary to what one might think, it is not the local movement of the bolt that is primarily responsible for the metallic deformation seen. The future work looks promising as comparisons will be made with new materials.

Reference

[1] M. Huf, T. Vallée, H. Fricke, "Numerical modelling and experimental validation of squeezing flows in the automobile production," Manufacturing Technology and Advanced Materials, 2024.

[2] K. Yokozeki, T. Vallée, F. Mohr, T. Evers, "Adhesive layer thickness distribution in hybrid joints", Manufacturinh Technology and Advanced Materials, 2024.