# Rheology effects on adhesive flow and substrate forces in manufacturing adhesive joints

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1. Introduction

The squeeze flow of uncured adhesives during assembly is critical for joint reliability and uniform stress transfer. However, a lot of the existing literature on numerical models often relies on idealized conditions, not effectively capturing crucial effects like complex shear-thinning behavior rheology, localized surface forces at the adhesive-substrate interface, and dissipation energies.

To address this gap, a fully 3D transient computational fluid dynamics (CFD) framework was developed, modeling the adhesive as a Bird-Carreau-Yasuda (BCY) fluid. A comprehensive parametric study has been conducted to evaluate the isolated effects of zero-shear viscosity, BCY relaxation, surface tension and static contact angles on reaction forces and viscous dissipation.
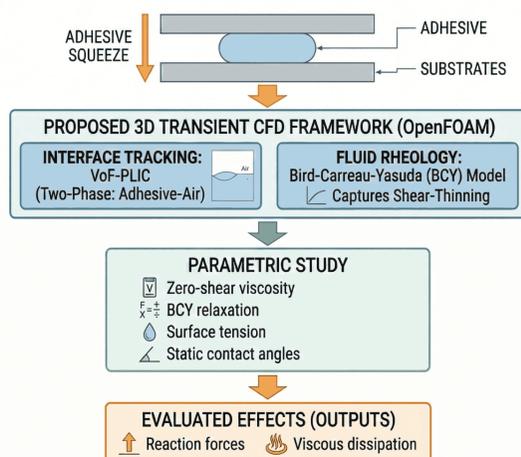

2. Methodology
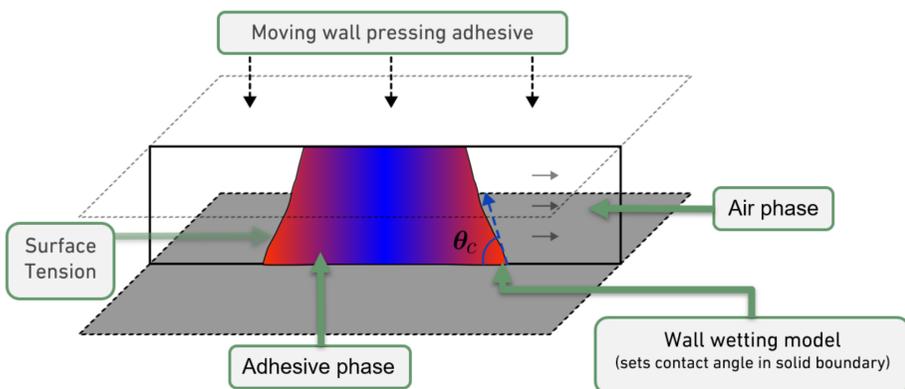
The squeeze system is modelled as a two-phase Volume of Fluid (VoF) solver based on the Finite Volume framework of OpenFOAM, whereas the interface properties, including the fluxes, are tracked through a Piecewise Linear Interface Construction (PLIC) algorithm. Transient simulations are run on a dynamic mesh in parallel and post–processed to extract relevant data.
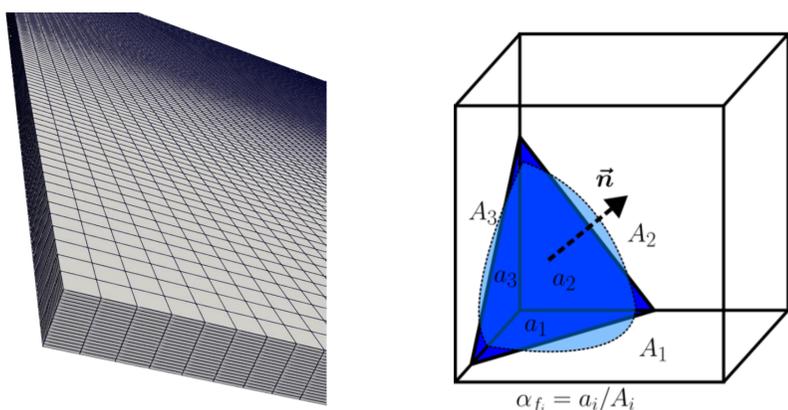
3. Results
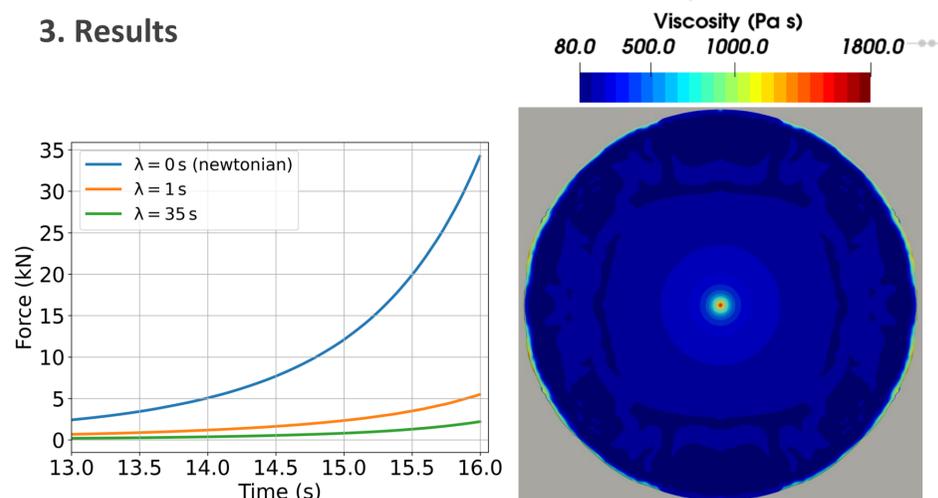
The total vertical reaction force scales positively with zero-shear viscosity, directly reflecting the bulk resistance to deformation. Similarly, stronger shear-thinning behavior, achieved via higher relaxation parameters or lower power-law coefficients, results in a marked reduction in the reaction force. This occurs due to the decreased effective viscosity at the high shear rates generated during the squeeze motion.
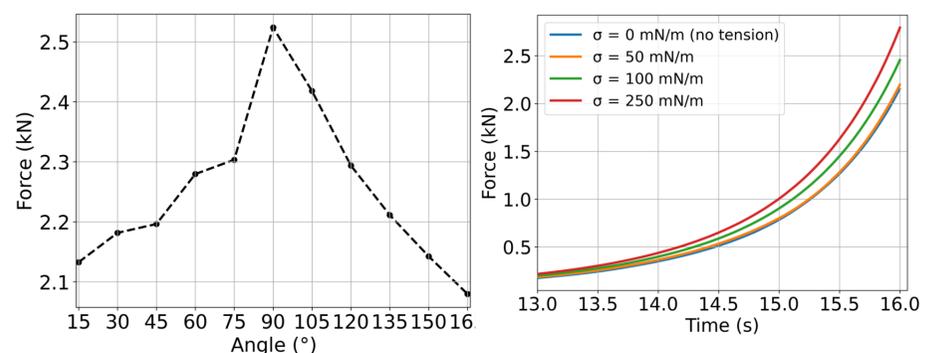
Surface forces dictate boundary interactions and significantly shape the energy dissipation characteristics of the flow. Surface tension resists the increase in interfacial area associated with lateral spreading. While it scales positively with the reaction force, its contribution to the total normal load is relatively slight compared to bulk viscosity.

Furthermore, both the total reaction force and the viscous dissipation rate exhibit a non-monotonic dependence on wettability, peaking at a static contact angle of 90°. At this neutral wetting state, the fluid front remains perpendicular to the plates, minimizing interfacial curvature and Laplace pressure. Consequently, the hydraulic pressure gradient is entirely directed toward driving bulk radial flow, thereby maximizing flow resistance to compression and maintaining higher bulk shear rates, responsible for the increased dissipation.

6. Conclusions

Reaction load is dominated by bulk fluid properties, scaling with viscosity and decreasing with shear-thinning, while dissipation remains very sensitive to surface interactions. The neutral wetting dynamic at 90° creates a peak in mechanical resistance and energy dissipation due to minimized interfacial curvature. Identifying these parametric dependencies streamlines numerical modeling and allows for improved predictions in adhesive dispensing and joint manufacturing.