Bonding of membranes by viscous polymers: Infiltration kinetics and its impact on mechanical integrity of the bonded polymer/membrane structure

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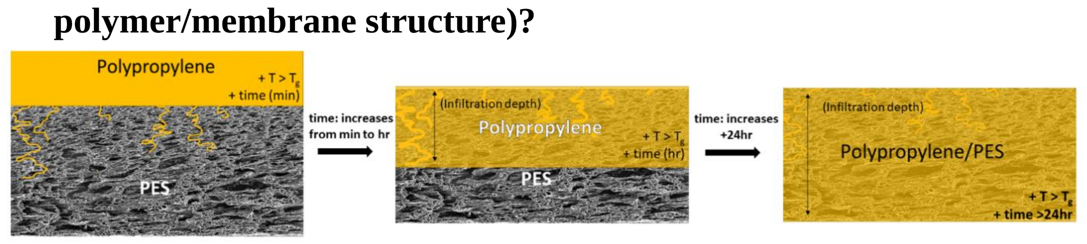
Motivation

Ultrafiltration (UF) or microfiltration (MF) membranes are bonded with a thermoplastic polymer for insertion to housing/casings.

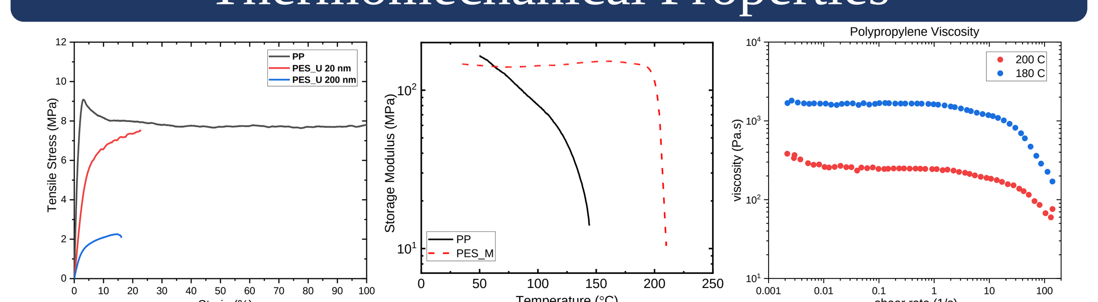
However, under normal operating conditions, these bonded filters fail or blister causing leakage.

Research Objective

- **Understand the infiltration kinetics of a viscous polymer in porous membranes.**
  Specifically, what is the influence of membrane asymmetry, hydrophilicity as well as bonding time, and temperature?
- **What is the mechanical integrity for these bonded regions (i.e. polymer/membrane structure)?**



Thermomechanical Properties

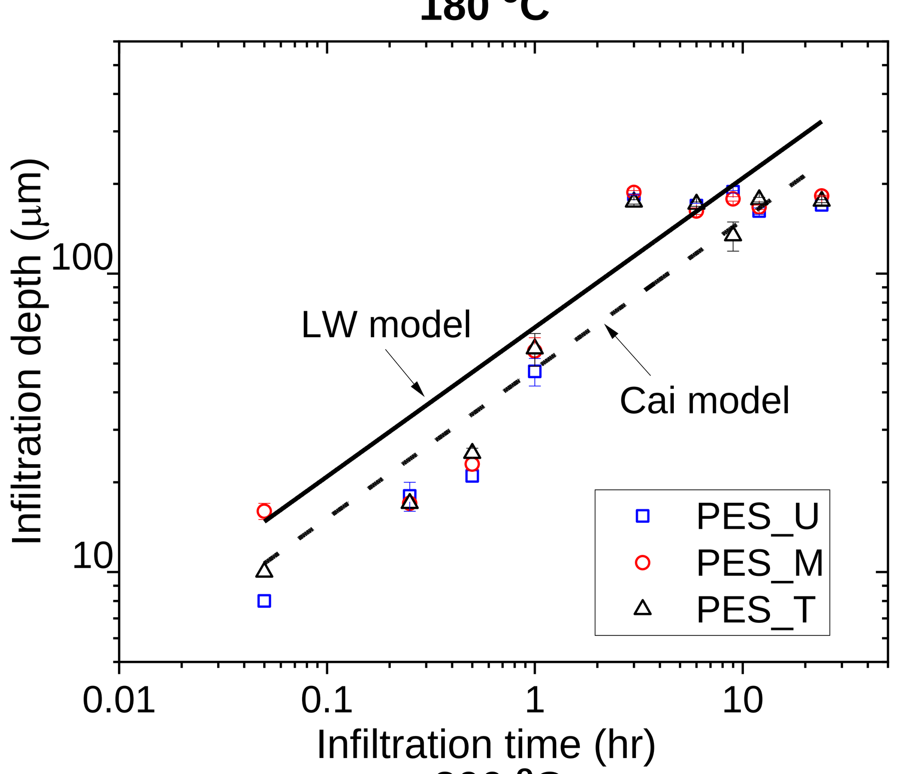


Infiltration Kinetics for symmetric 200nm PES Membranes

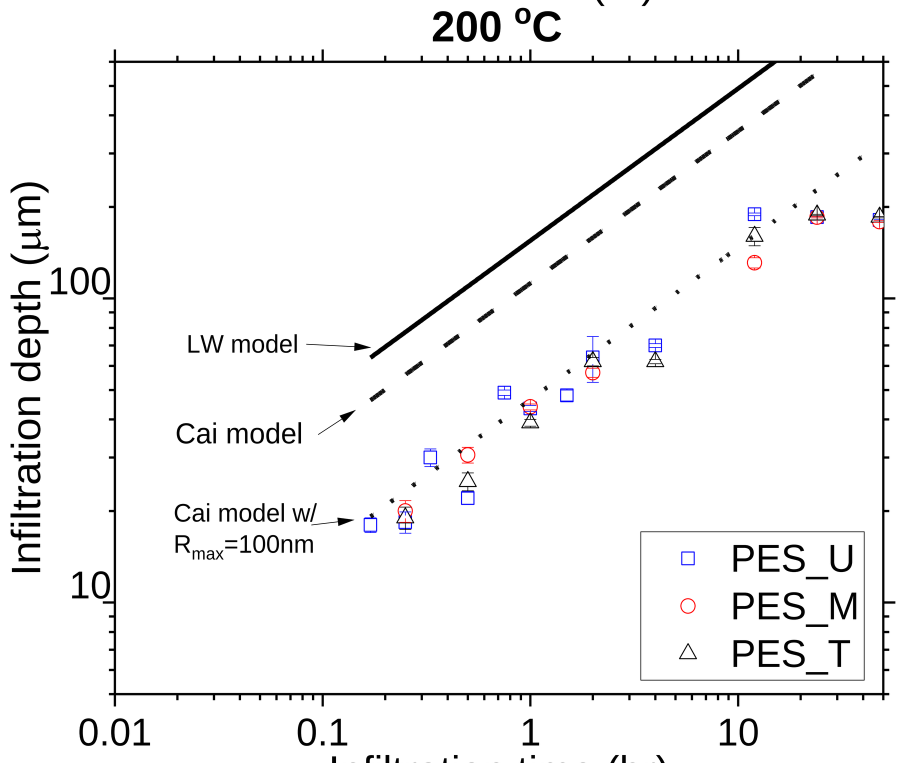
The solid and dash lines represent predictions of LW model and Cai model respectively. The Cai model, accounts for membrane structure, pore geometry, α, and tortuosity, τ; better estimating for infiltration depth. **Lucas Washburn model** $L(t) = \frac{R\gamma cos\theta_E}{2\eta_0} t^{1/2}$

Cai model $L(t) = \frac{\varphi\, \alpha^{\frac{3}{2}}(S_w - S_i)\tau(D_f{}^4 - D_f)^{1/8} R_{max}\gamma cos\theta_E}{2\eta_0} t^{1/2}$

180 °C

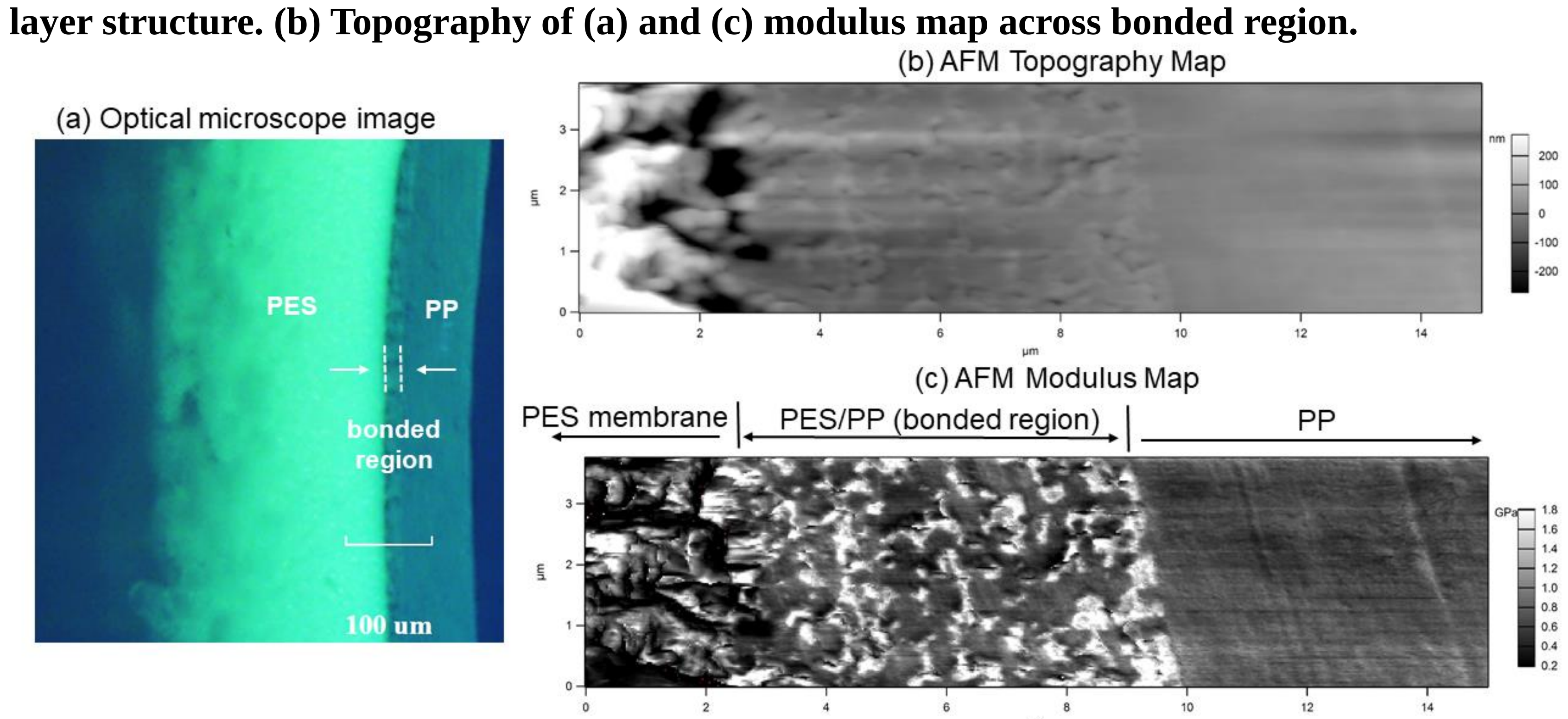


200 °C

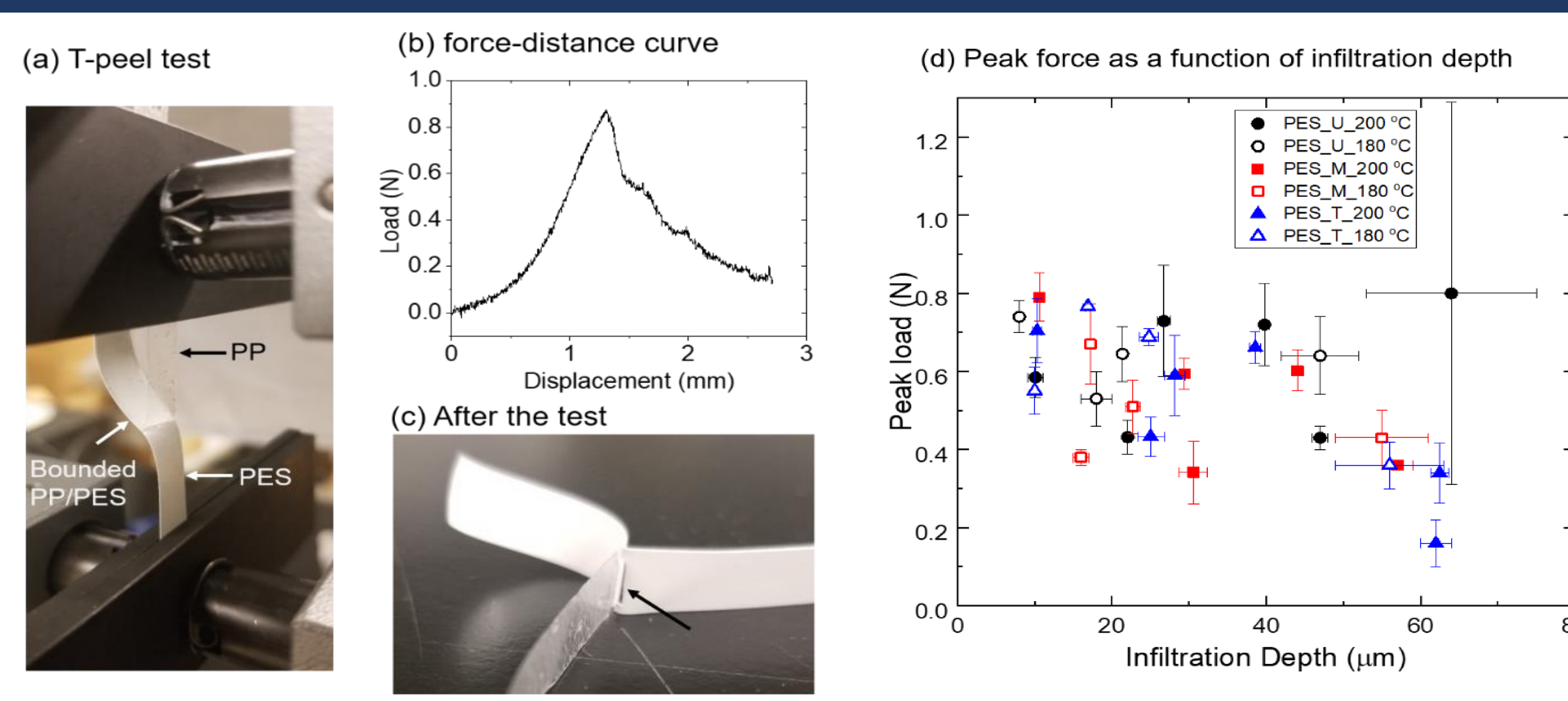


Infiltration Verification for 200 nm via AFM

(a) Optical image of the cross-section of a PES_U and PP bonded at 180 °C for 3 min, showing a tri-layer structure. (b) Topography of (a) and (c) modulus map across bonded region.

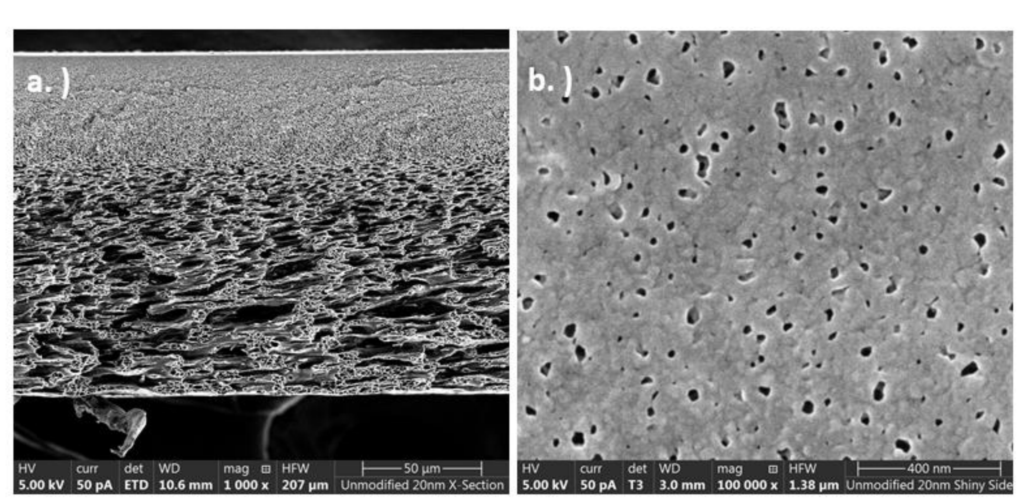


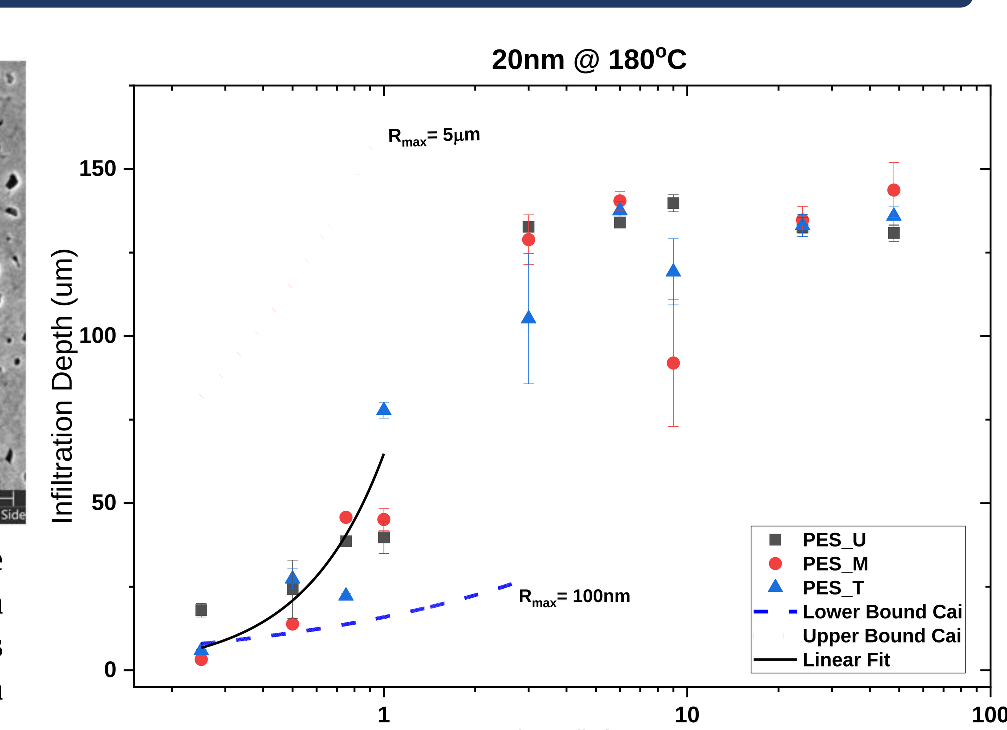
200 nm T-Peel Test and Peak Force Achieved



a) T-peel test set-up. b) the force distance curve representing the peak force achieved. c) image of membrane failure at the bonded interface. (d) Infiltration depth vs peak load achieved in (b)

Infiltration Kinetics for asymmetric 20nm PES Membranes





The PES asymmetric structure (above a.)) possesses a range of pore radii. Upper and lower bound Cai model prediction curves account for such and are presented to the right. PP is in contact with the surface imaged above, presenting a surface porosity of 3-6%.

Acknowledgements

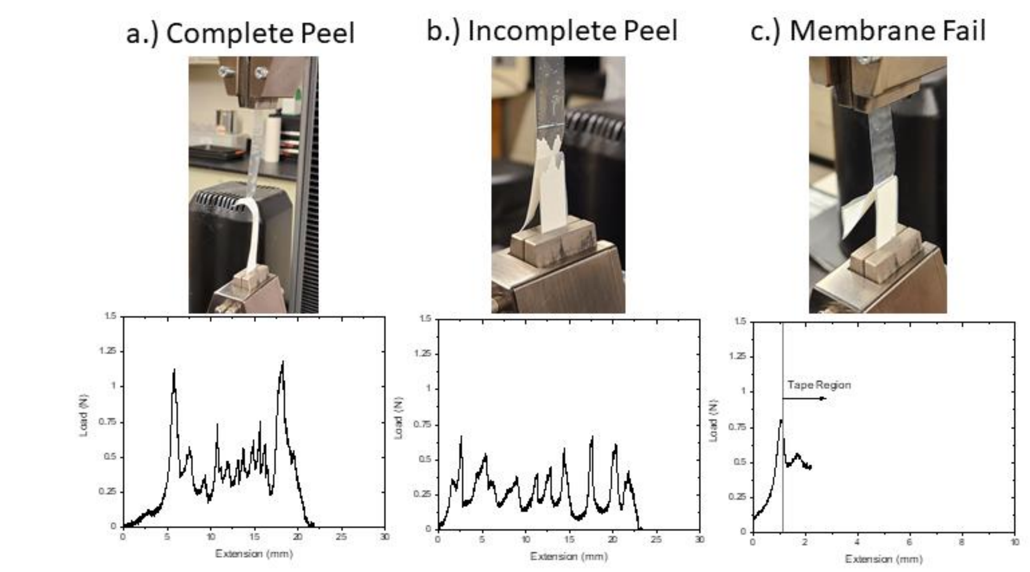
Jaylene Martinez is funded via NSF-GRFP ADGE 1650115

Mechanical Testing is done in house at Mechanical Engineering Department, CU Boulder

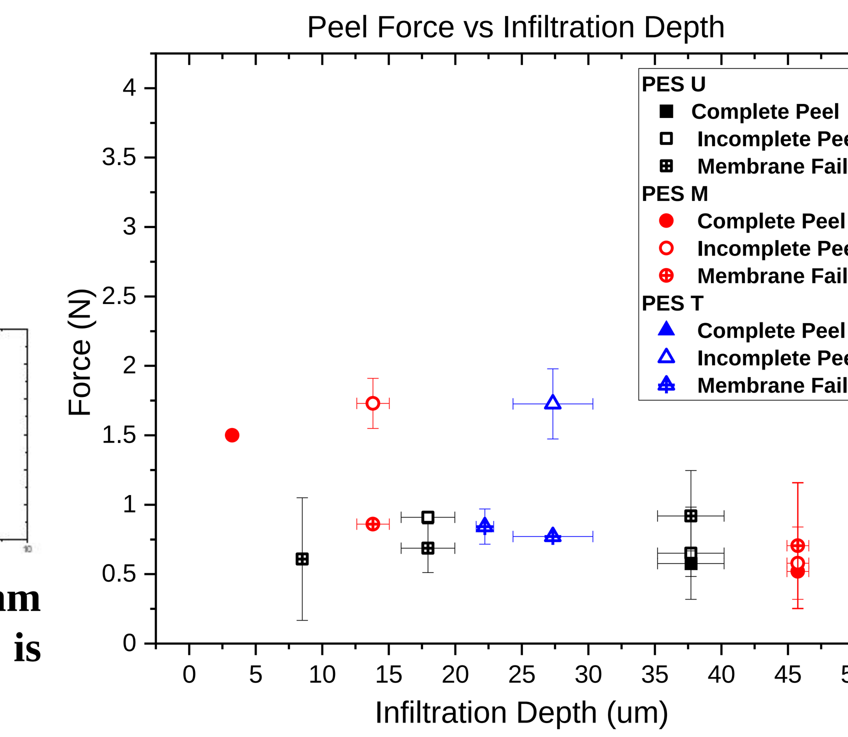
Membrane Fabrication is done via NIPS Process at MilliporeSigma

Atomic Force Microscopy (AFM) imaging is done at the National Institute for Standards and Technologies (NIST) Materials Characterization Division

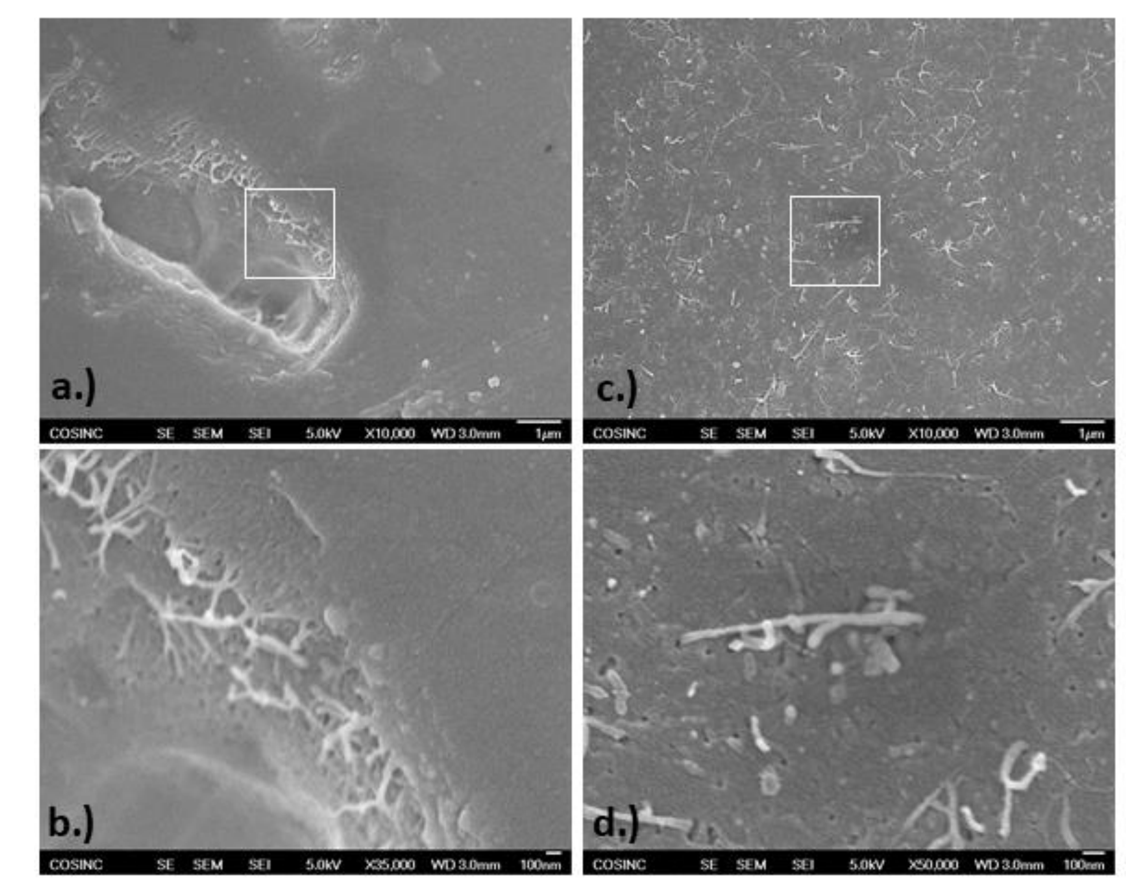
T-Peel test Failure Behavior for 20 nm and Peel Force Achieved

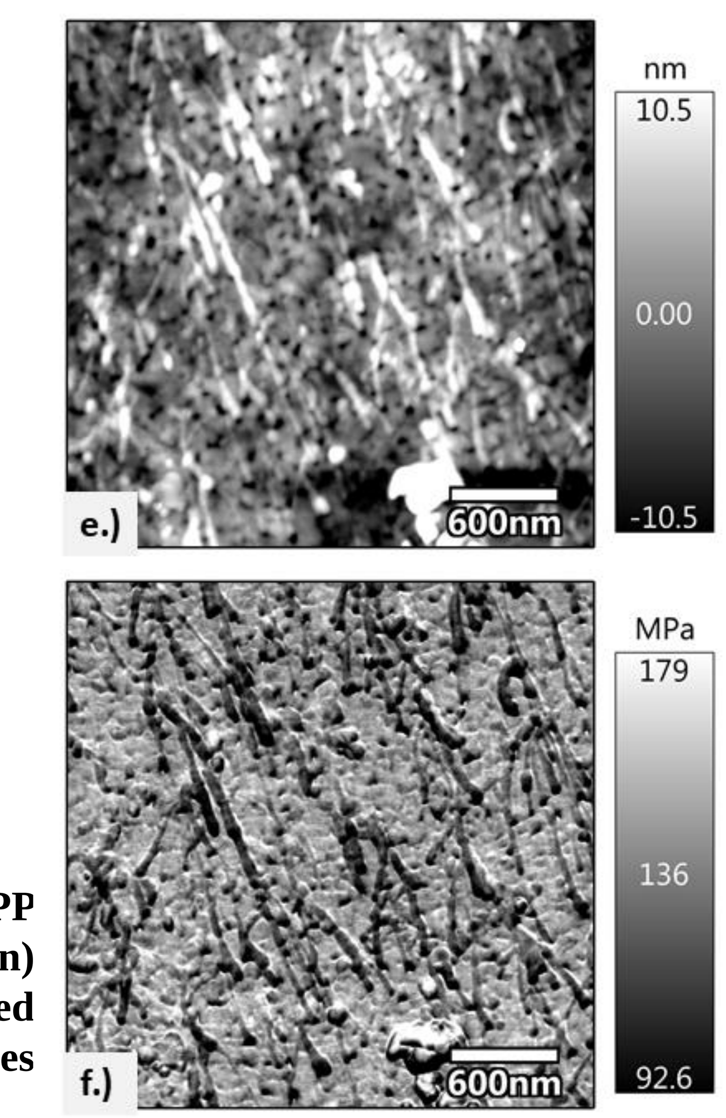


The bonding strength of PP/PES for 20 nm presented 3 types of failure. The bond strength is loosely related to infiltration depth.



Post Peeling Membrane Surface Scans for 20 nm





(a/b) PES_U surface (bonded at 45min) presents a dense layer of PP with no visible open pores. (c) PES_M surface (bonded at 45min) presents fiber-like at the pore interface (d). This image is verified using AFM (f) which clearly presents two different modulus values indicating two different materials: soft PP and rigid PES_M.

Conclusion

Capillary infiltration kinetics were found for modified, MF, polyethersulfone (PES) membranes with nominal pore sizes of 200 nm and 20 nm.

@ A nominal pore size of 200 nm

Infiltration kinetics were better described by the Cai model that takes into consideration membrane structure characteristics.

Chemical modification did not alter bonding ability with polypropylene.

AFM scan showed a tri-layer structure presence within the bonded region PP/PES with corresponding modulus values.

The bonding strength of PP/PES, i.e, peak load (d), was loosely related to infiltration depth and is instead dominated by the strength of the membrane.

@ A nominal pore size of 20 nm

Infiltration kinetics showed fast infiltration when compared to the 200 nm experiments

Chemical modification did not alter bonding ability with polypropylene even with smaller pores and low surface porosity

T-Peel tests results in three types of failure: Complete peel, incomplete peel due to membrane fracture, and membrane failure.

Post-peel analysis (AFM scans) confirmed infiltration exists even with those which experienced complete peeling.

Resulting publication: Martinez, J. et al. "Capillary Bonding of Membranes by Viscous Polymers: Infiltration Kinetics and Its Impact on Mechanical Integrity of the Bonded Polymer/Membrane Structure". *Journal of Membrane Science, Jan 2022*