From molecular architecture to macroscopic failure in pressure-sensitive adhesives through multi-scale characterization

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Introduction

Pressure-sensitive adhesives (PSAs) are replacing fasteners in safety-critical EV battery and electronics assembly, yet their long-term failure cannot be predicted from chemistry. This work links the molecular architecture of acrylic PSAs, resolved by a rapid FTIR fingerprint (<30 min), to viscoelastic, fracture and creep performance across scales.

Experimental details & results

- Adhesive B: mobility-controlled; branching 0.59, low filler, tri-layer;
- Adhesive C: network-controlled; branching 0.30, 24.7% filler, single-layer;
- FTIR-ATR deconvolution → three molecular indices;
- DMA, micro-CT, peel and creep testing;
- Cohesive-zone FE models built for each geometry.

Molecular fingerprint (FTIR)

- 3 indices from one spectrum: branching 1.95× for Adhesive B, network constraint 4.3× and silicon 24.7% for Adhesive C;
- Rapid, non-destructive classification <30 min (vs weeks of testing);
- Could predict stiffness, adhesion and durability across scales.

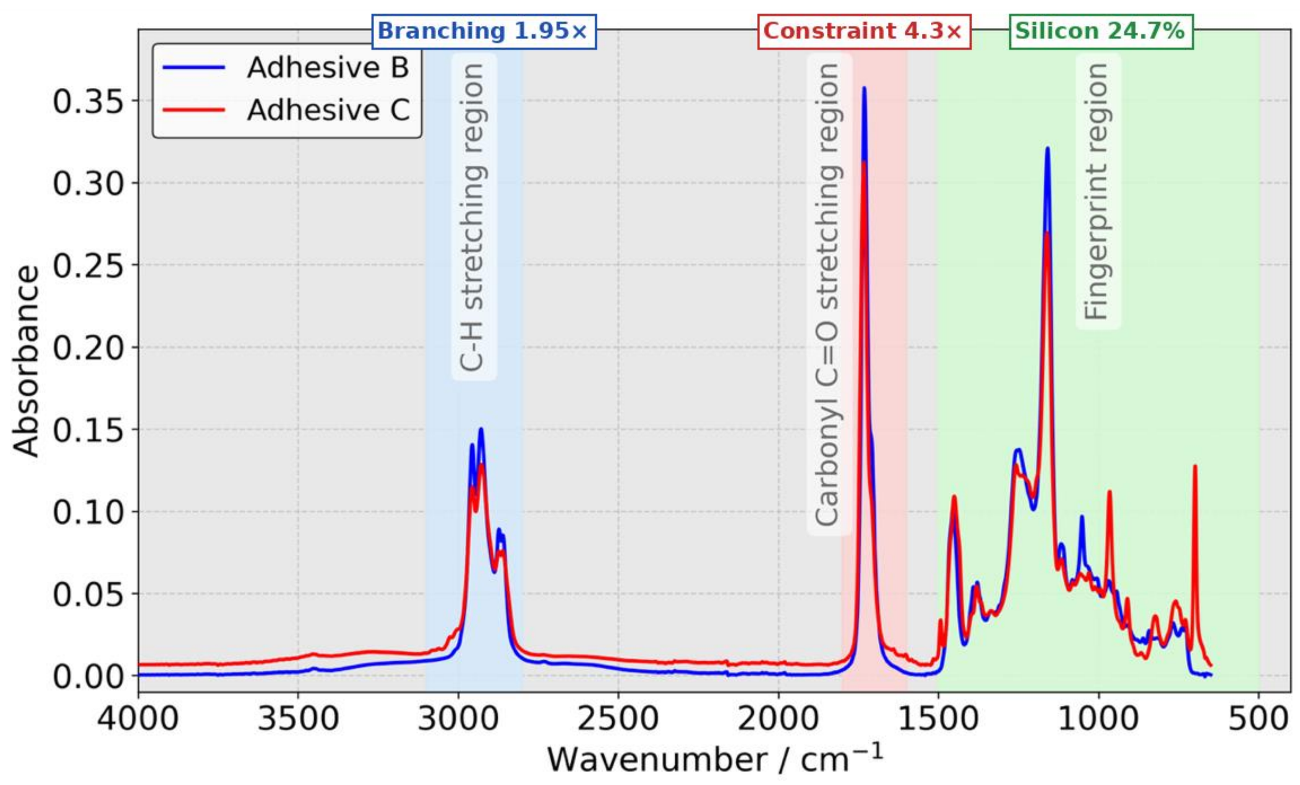

Figure 1 – FTIR spectra of Adhesives B and C with the three molecular fingerprints highlighted.

Performance trade-offs (B vs C)

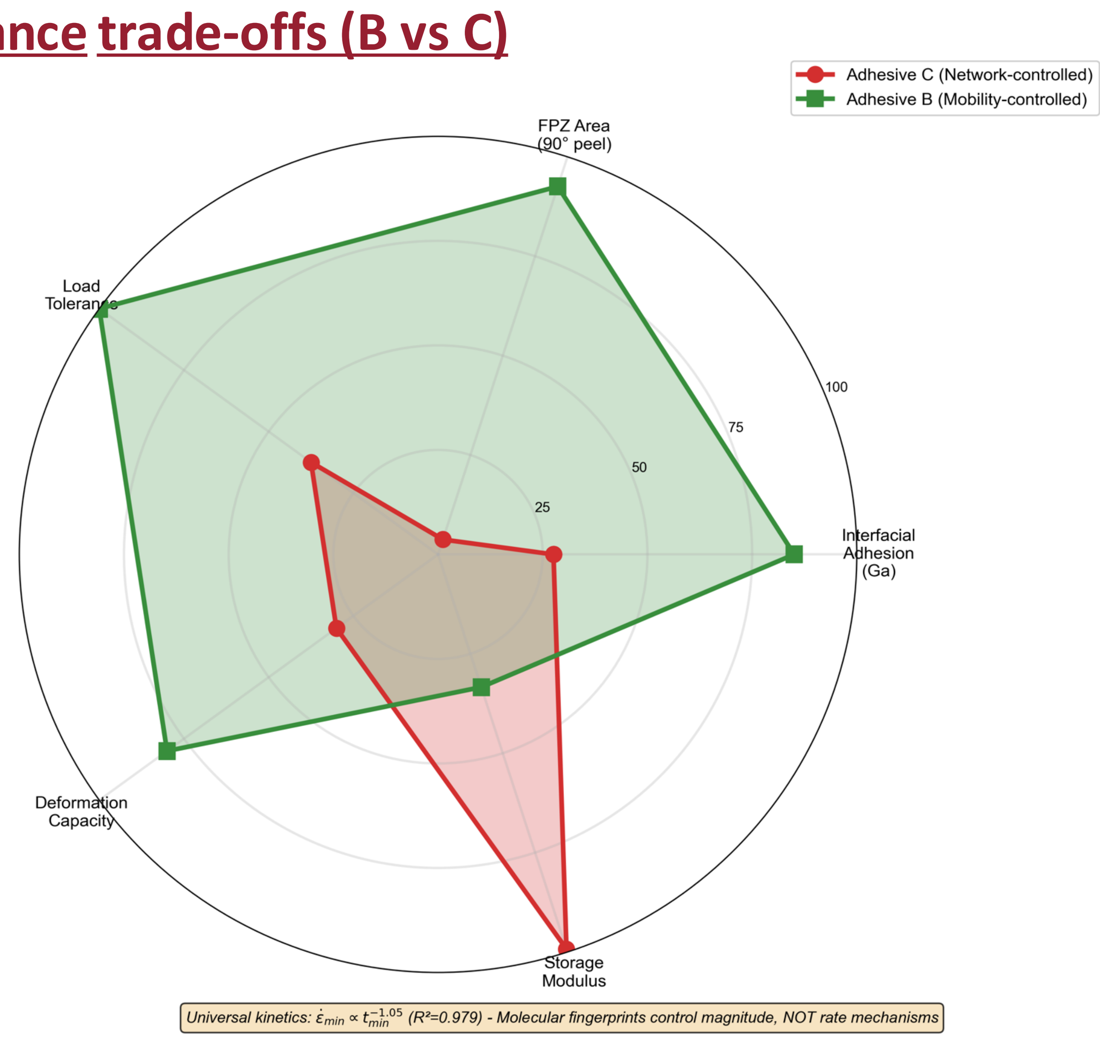

Figure 2 – Multi-scale performance: mobility-controlled B (deformation, adhesion, load tolerance) vs network-controlled C (stiffness).

Fracture & modelling

Peel testing (30–180°) resolves interfacial adhesion, fracture-process zones and mode mixity; cohesive-zone FE reproduces failure within 8% and transfers across loading geometries: interfacial failure behaves as a material property.

Foam architecture (micro-CT) & fingerprint framework

Cellular structure

Adhesive B: closed-cell tri-layer, ≈34% porosity. **Adhesive C:** filler-reinforced, lower porosity, with a depletion zone (Fig. 3).

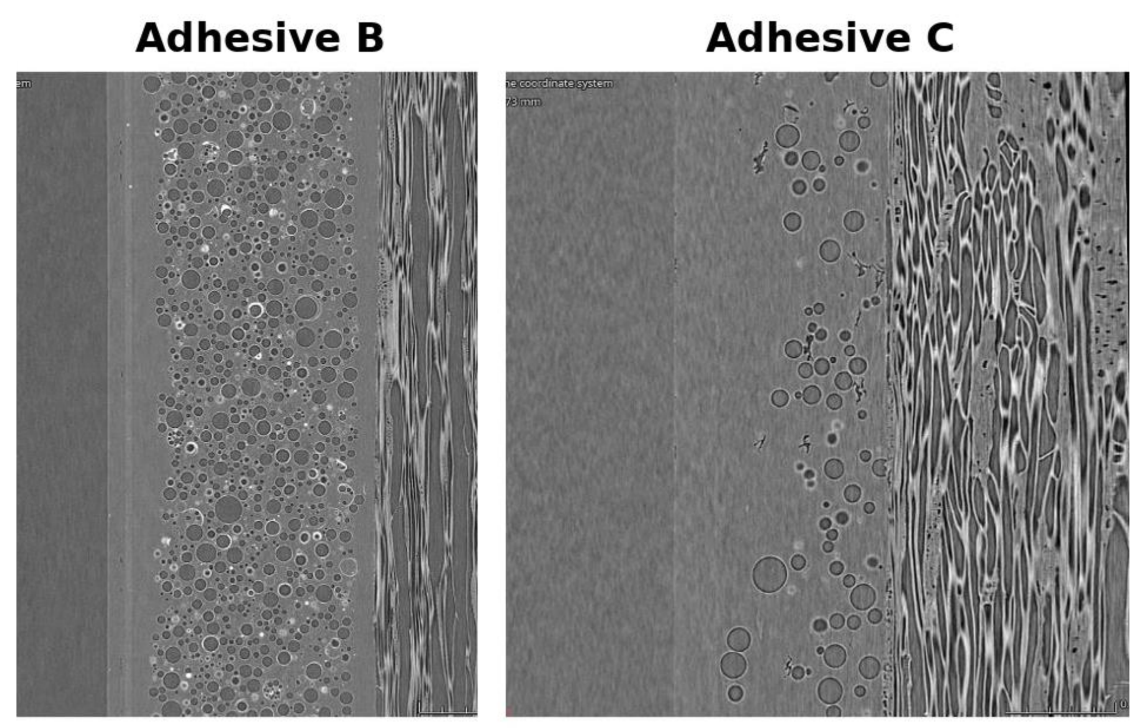

Figure 3 – Micro-CT cross-sections of Adhesives B and C foam architecture.

Molecular fingerprint framework

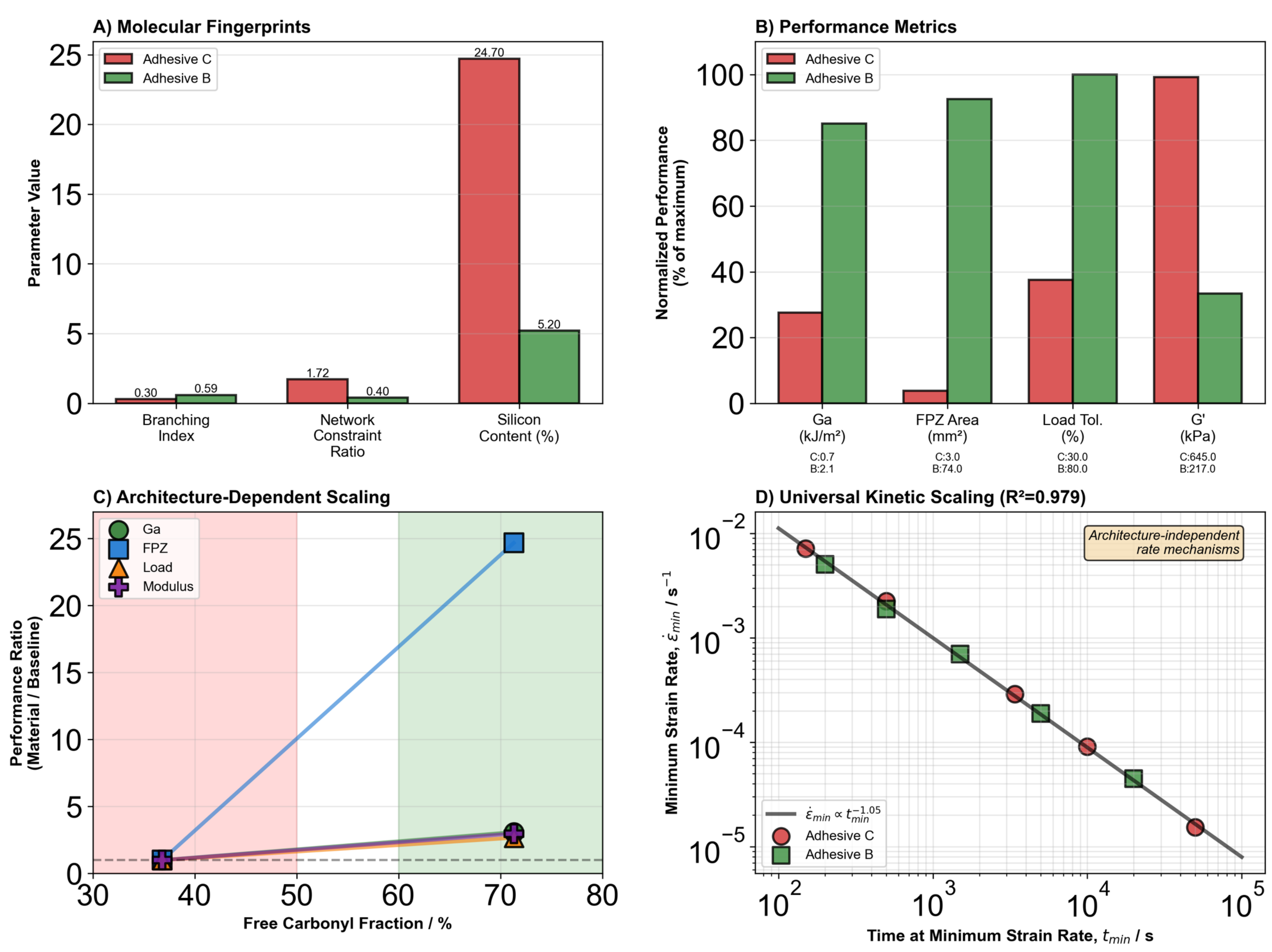

Figure 4 – Fingerprints (A) set performance across scales (B, C); creep collapses onto one universal law (D, R^2=0.98) — fingerprints govern magnitude, not rate.

Key findings & Conclusions

✓ Three FTIR fingerprints (branching, network constraint, silicon) classify architecture in <30 min — replacing weeks of testing.

✓ Architecture sets performance across scales: 3.0× modulus (B), 3.1× adhesion energy (B), 24.7× fracture-process-zone (B); CZM transfers within 8%.

✓ Creep is universal within the tested boundaries ($\dot{\varepsilon} \propto t^{-1.05}$, R^2=0.98): fingerprints govern magnitude, not rate → temperature-accelerated lifetime prediction.