Creep behaviour and fracture analysis of acrylic PSAs: assessing durability and performance

BD Simões (INEGI, Portugal) | EAS Marques | RJC Carbas | S Maul | P Stihler | P Weißgraeber | Lucas FM da Silva

Introduction

This study examines the long-term performance of acrylic PSA joints under creep loading using a multi-scale approach. Testing of 50 single-lap joints revealed three failure modes linked to interfacial quality. Image analysis and SEM quantified features like adhesive failure and void content. Statistical and survival models identified adhesive failure, especially near edges, as the key predictor of rupture. Viscoelastic stress redistribution, captured via Prony series, explained early failure at defect sites. Findings offer a framework for predicting and improving PSA joint durability under sustained loads.

Experimental Testing

PSA's Tg and rheological properties

The adhesive's Tg was –40.2 °C, determined via DMA. Rheological measurements showed elastic dominance (G′ > G″) across tested frequencies, placing the material inside Chang's viscoelastic window for high-shear PSAs. No terminal flow behaviour was observed, indicating time-dependent deformation under sustained load (Fig.1).

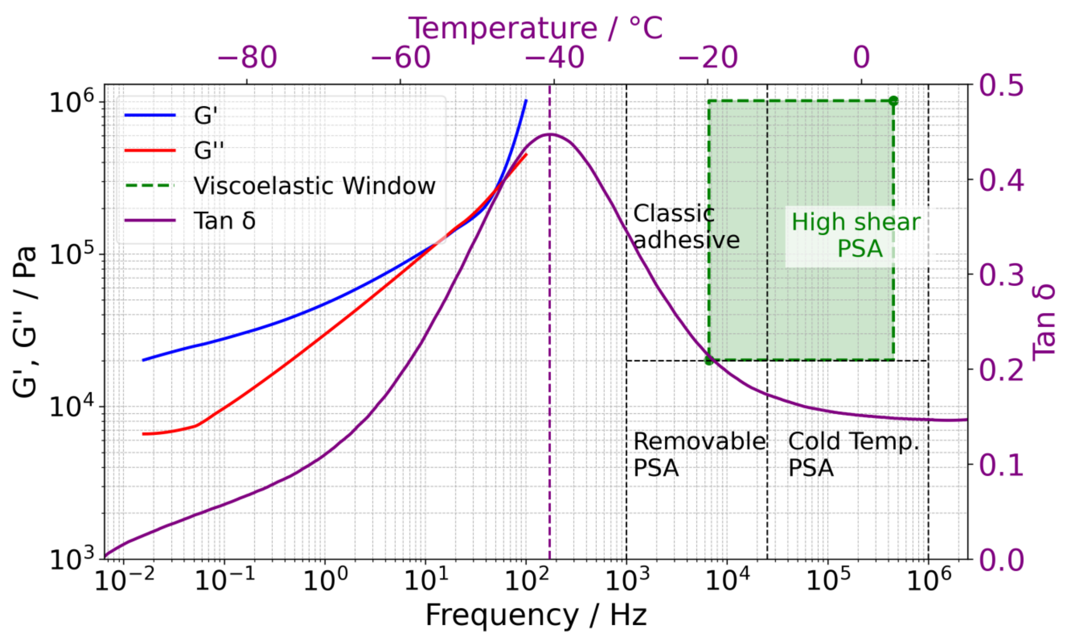

Figure 1 – Rheological profile placing the PSA within the high-shear viscoelastic window, with Tg ≈ –40 °C and G′ > G″.

Creep and relaxation tests

SLJ specimens were tested under constant load at 60% of their quasi-static strength using a custom lever-arm setup. Creep results showed high variability in rupture time, enabling classification into three failure modes, Fig.2 (left). Relaxation tests revealed fast initial stress decay, modelled with Prony series to describe viscoelastic stress redistribution, Fig.2 (right).

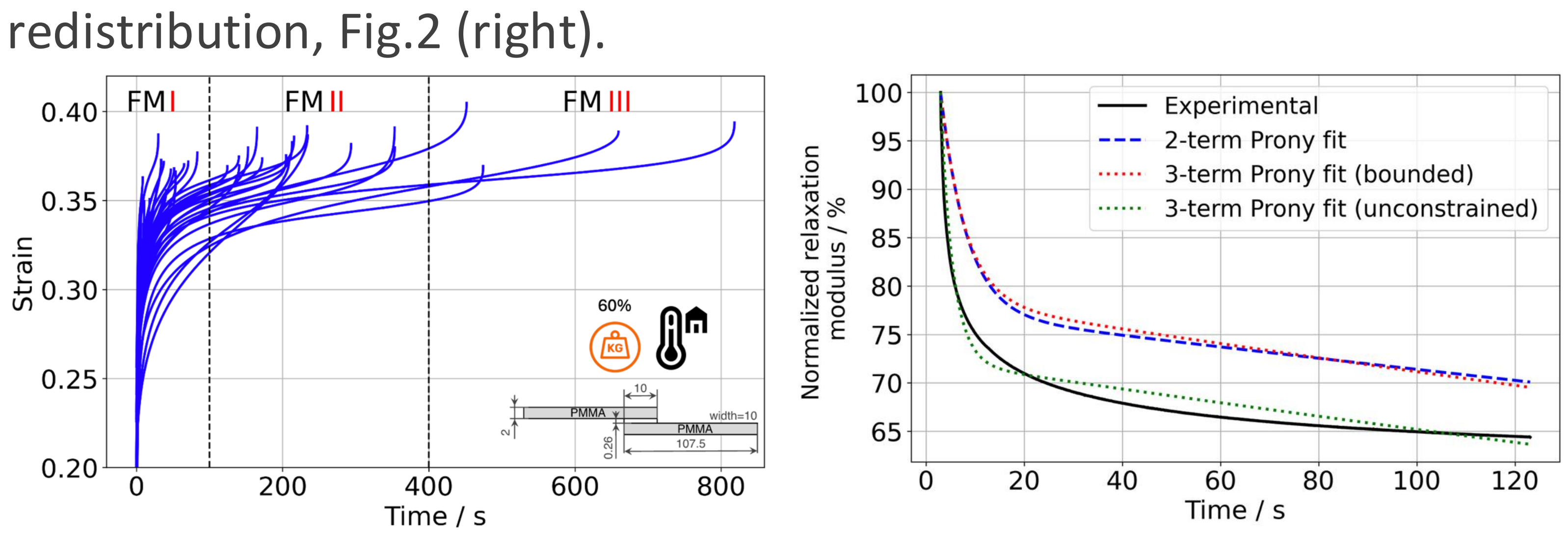

Figure 2 – Creep curves (left) showing failure mode ranges; stress relaxation fit (right) modelled with Prony series.

As shown in Fig. 3, early damage differs across failure modes. FM I exhibits immediate edge debonding, while FM II shows early voiding. FM III begins with distributed, cohesive strain, consistent with its delayed rupture behaviour.

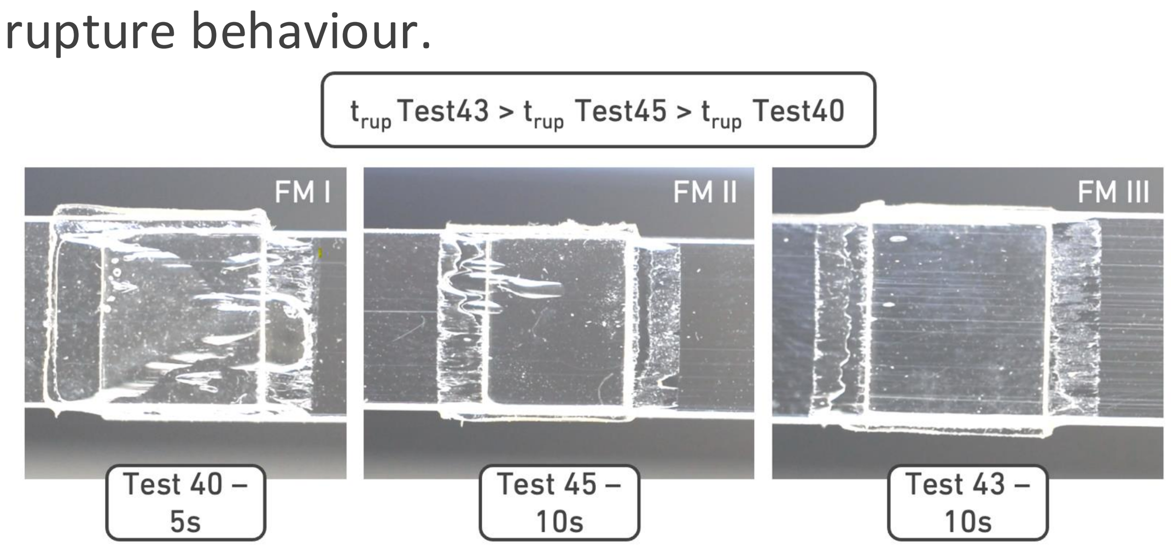

Figure 3 – Early damage evolution in FM I–III during creep loading. FM I initiates with edge debonding; FM III shows distributed, cohesive deformation from the start.

Microstructural and statistical analysis

SEM analysis

SEM analysis of joint edges revealed interfacial discontinuities in both unpolished and polished samples. Unpolished specimens showed roughness and poor local contact, while polishing improved conformity but did not eliminate defects. Some imperfections extended deeper into the overlap. These micro-defects, particularly near corners, are potential stress concentrators and may trigger early rupture depending on their severity and location (Fig. 4).

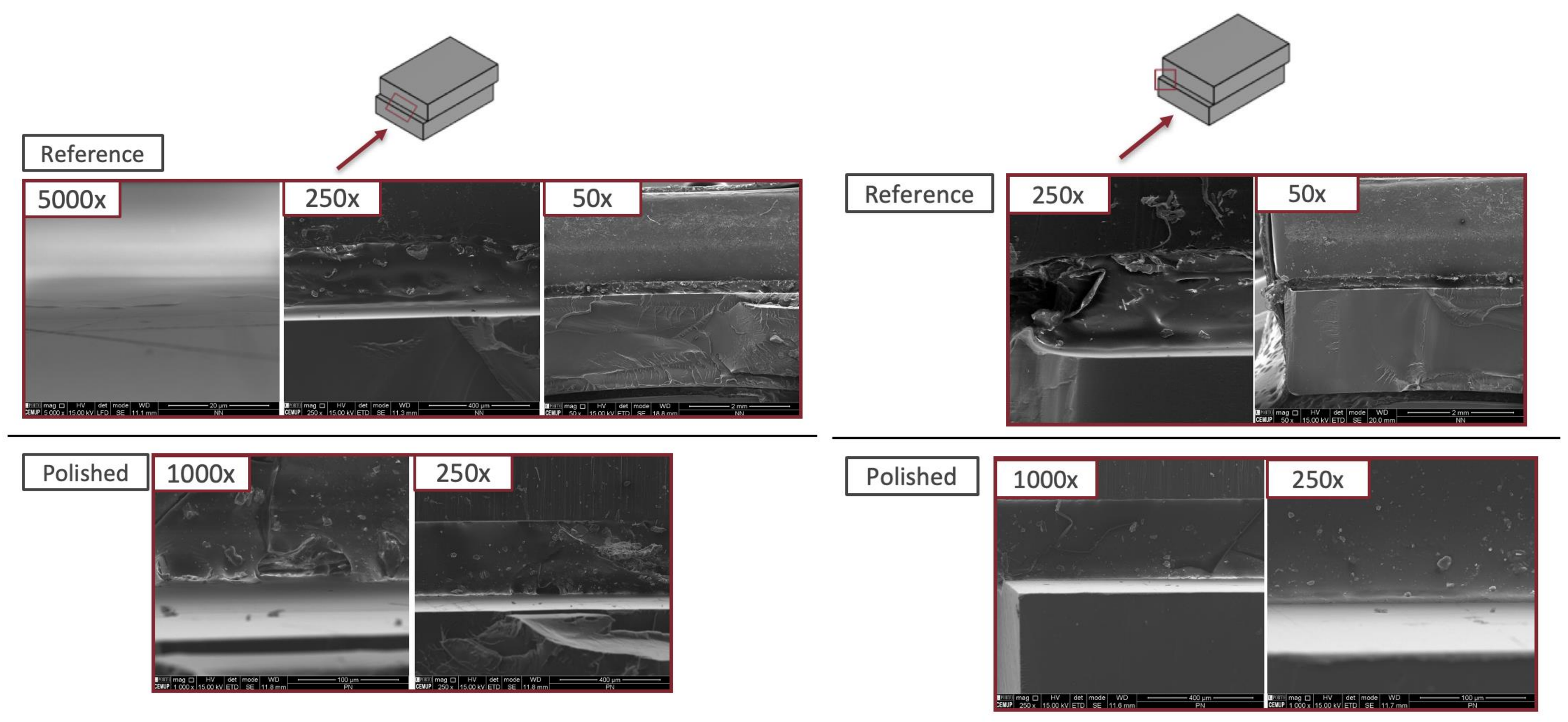

Figure 4 – SEM at the overlap edge: middle (left) and corner (right) views. Unpolished joints show voids; polishing improves contact but not uniformly.

Model predictions and survival probability

Statistical models quantified how interfacial features affect rupture behaviour. As shown in the Fig. 5, OLS regression provided a strong fit between predicted and actual rupture times, with clear clustering by failure mode (FM I–III). Among the variables, %adhesive failure emerged as the only significant predictor. The Cox model confirmed a 5% increase in failure risk per 1% adhesive failure, while voids and overlap area had no significant effect. Survival curves further revealed distinct durability trends, with FM III joints exhibiting the longest lifetimes.

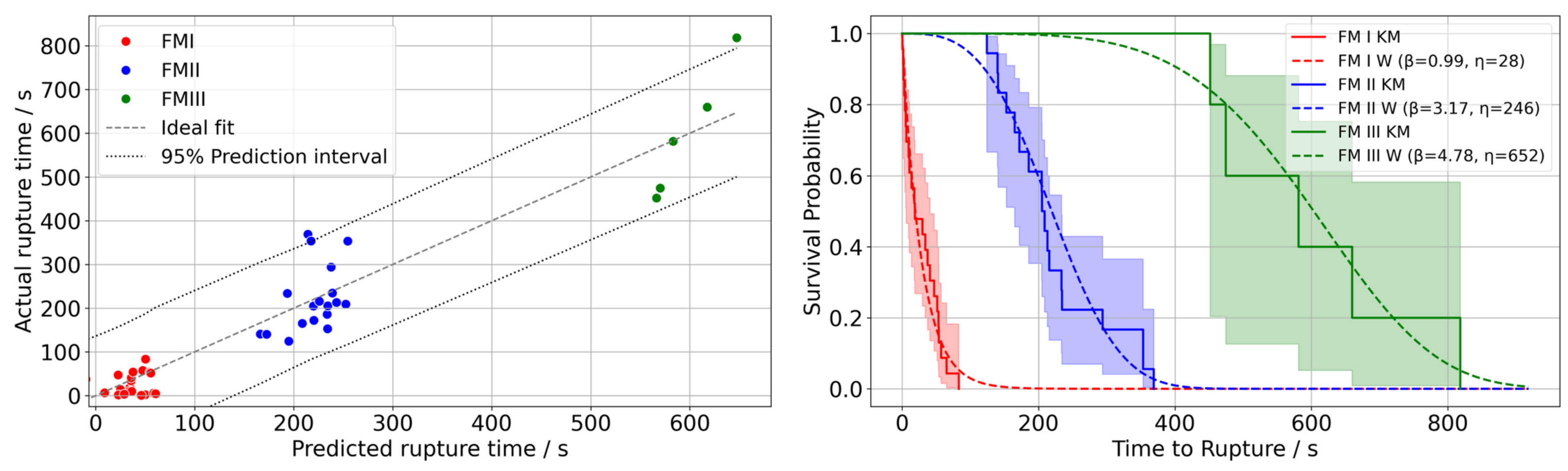

Figure 5 – OLS model fit (left) and survival curves (right) show rupture time and durability trends across failure modes FM I–III.

Conclusions

This study found that PSA joint failure under sustained loading is mainly driven by interfacial quality, especially adhesive failure near edges. Statistical models and SEM imaging confirmed its strong link to rupture time. While some defects are tolerated, early failure often starts at imperfections.

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