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Norwegian Public Roads Administration



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Ageing Susceptibility of Bio-Binders

Implications for long-term performance

Ali Mirhosseini, 14.10.2026



2024

What is in the binder?

Bio-oil content and
chemical composition

FTIR • GC-MS • C-14 • NMR



2024

What did we learn?

Chemical analysis shows promise for identifying and quantifying bio-additives.

Ageing affects the chemical signal.

Reliable quantification requires calibration.

Next question: How do these binders perform?





2025

How does the binder perform?

Fatigue resistance of bio-binders

DSR · LAS · Damage resistance

2025

What did we learn?

LAS offers a promising way to assess fatigue and damage resistance.

Bio-binders require systematic performance evaluation.

Long-term behaviour needs further investigation.

Next question: How does ageing affect performance?



Experimental programme

Fixed aged-binder fraction: 30%

PAV-aged AC 70/100 used as a RAP surrogate

Remaining 70%: virgin AC 70/100 + rejuvenator

Anova

5% • 10% • 15%



TOP

5% • 10% • 15%



Sylvaroad

5% • 10% • 15%



Reference

0% rejuvenator



Rejuvenator dosage: % of total binder mass

10 formulations

(9 rejuvenated blends + 1 reference)

Compare each formulation at two ageing stages

After short-term ageing (RTFOT)



PAV

After additional PAV ageing



Same test suite for both ageing stages (all 20 binder conditions)



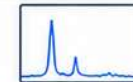
Penetration & softening point
Basic properties



LAS
Fatigue resistance



MSCR
Rutting resistance

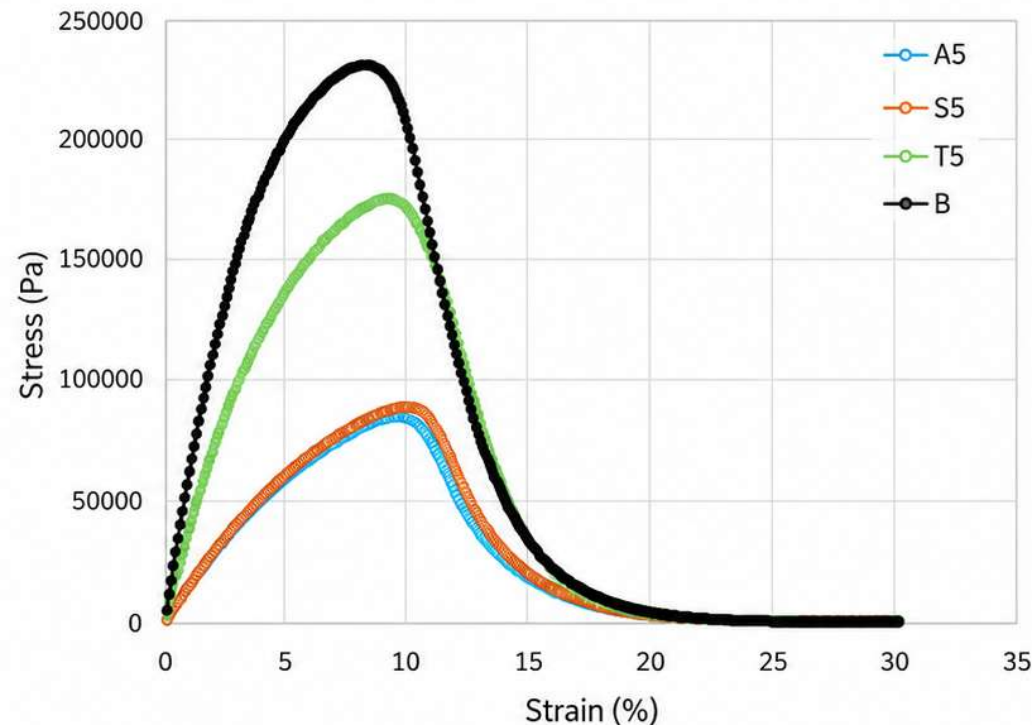


FTIR
Chemical changes

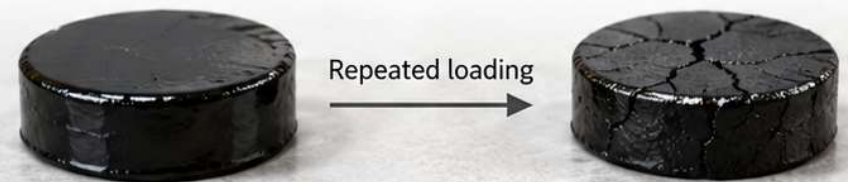
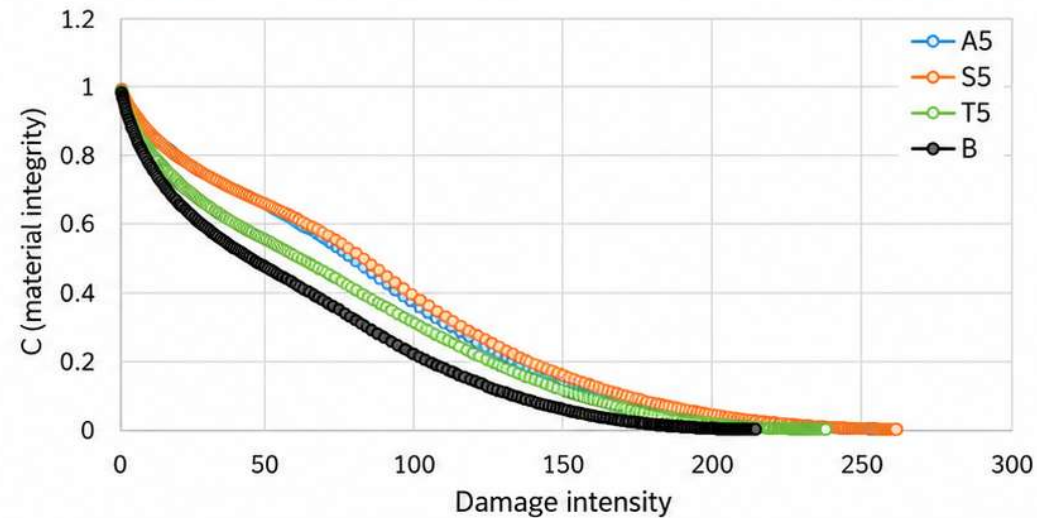
3 rejuvenators × 3 dosages + reference • 2 ageing stages

Fatigue damage response before PAV

Stress-strain response · 5% dosage



Damage characteristic curves · 5% dosage



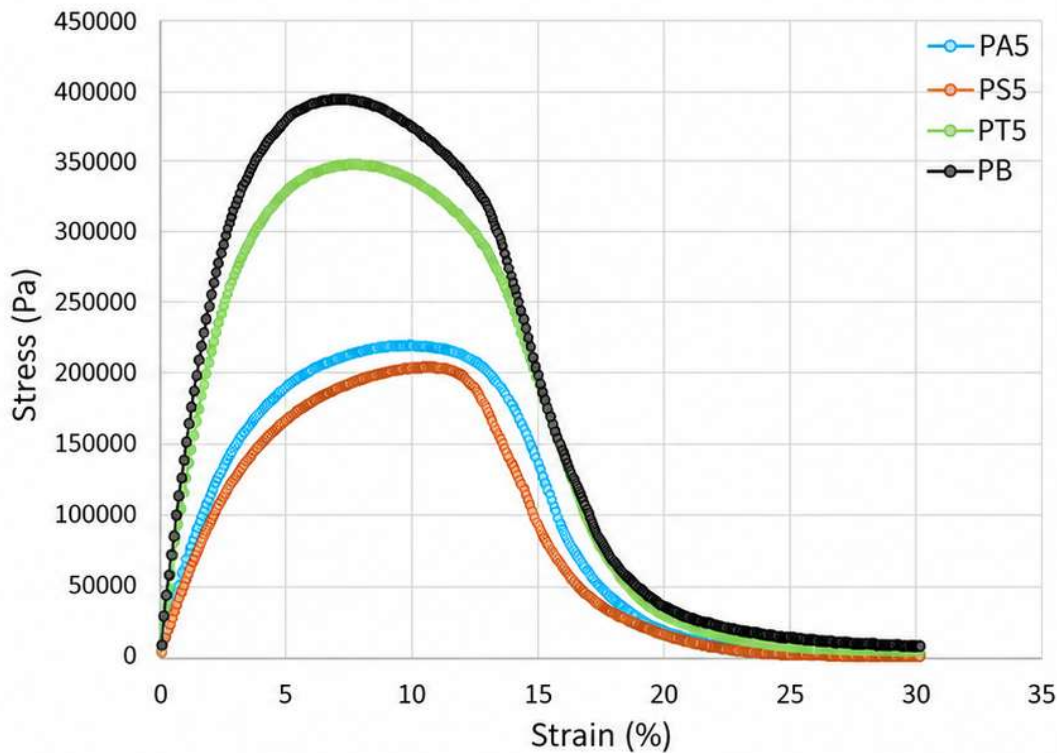
Conceptual illustration of fatigue damage

Lower peak stress can coexist with greater damage tolerance

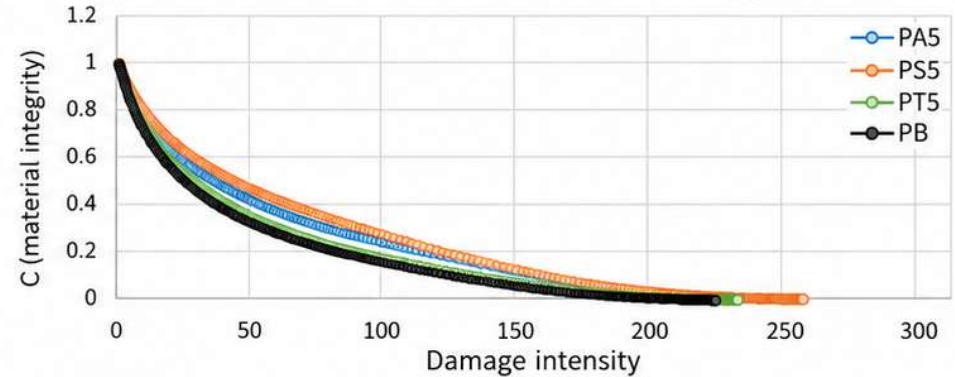
A: Anova S: Sylvaroad T: TOP B: reference

Fatigue damage response after PAV

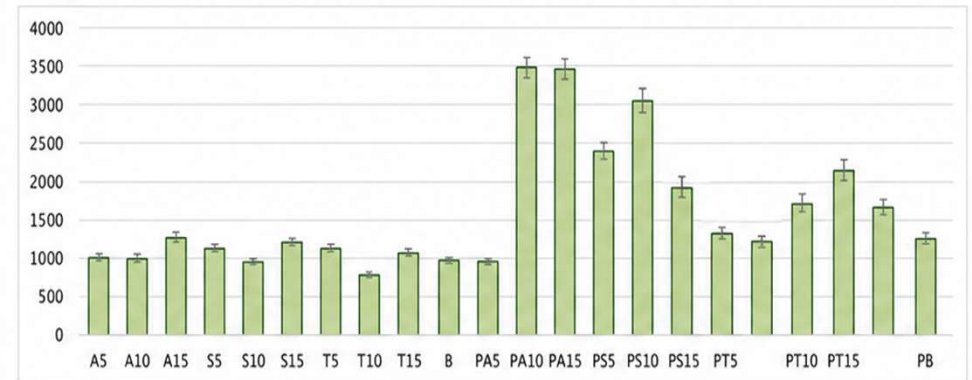
Stress-strain response | 5% dosage



Damage characteristic curves | 5% dosage



Fatigue life at 5% strain



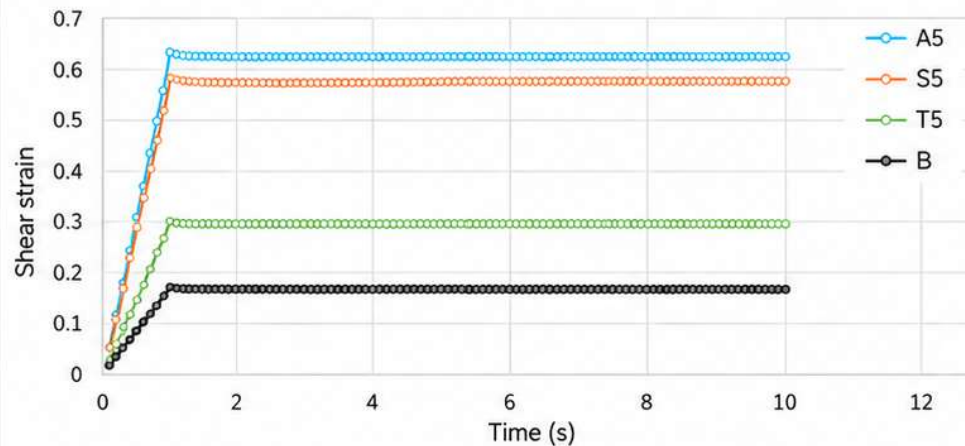
Higher peak stress does not necessarily mean better damage tolerance

A: Anova S: Sylvaroad T: TOP B: reference P: after PAV ageing

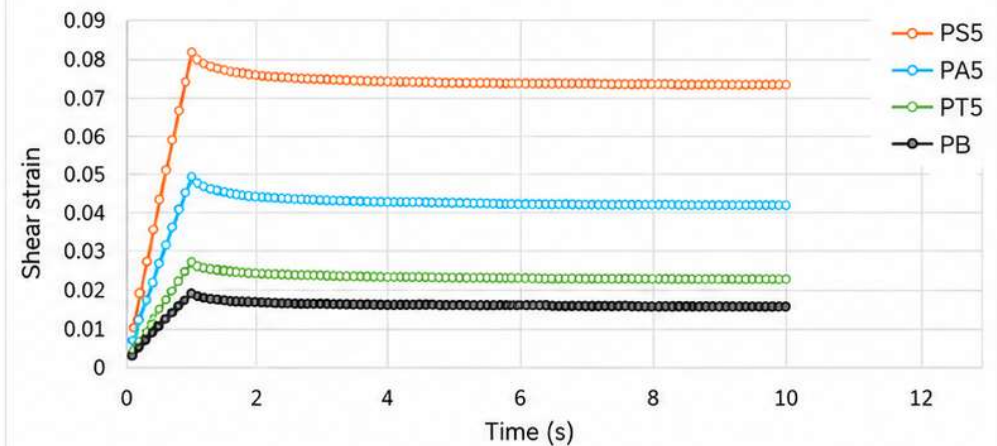
Rutting resistance after ageing

MSCR at 58°C

Before PAV · 5% dosage



After PAV · 5% dosage



TOP at 5–10%

- Low post-PAV Jnr among rejuvenated blends

Anova and Sylvaroad at 15%

- High Jnr persisted after PAV ageing

Lower Jnr indicates greater rutting resistance.

After PAV	Jnr,3.2 (kPa ⁻¹)	Recovery (%)
PB	0.15	20.9
PT5	0.22	17.0
PT10	0.44	3.7
PA5	0.42	12.7
PS5	0.77	5.9
PA15	5.56	0.0
PS15	10.97	0.0

Fatigue benefits must be balanced against rutting resistance

FTIR: chemical ageing

Carbonyl level reflects both rejuvenator chemistry and ageing

Measured spectra after PAV

5% rejuvenator dosage + reference binder

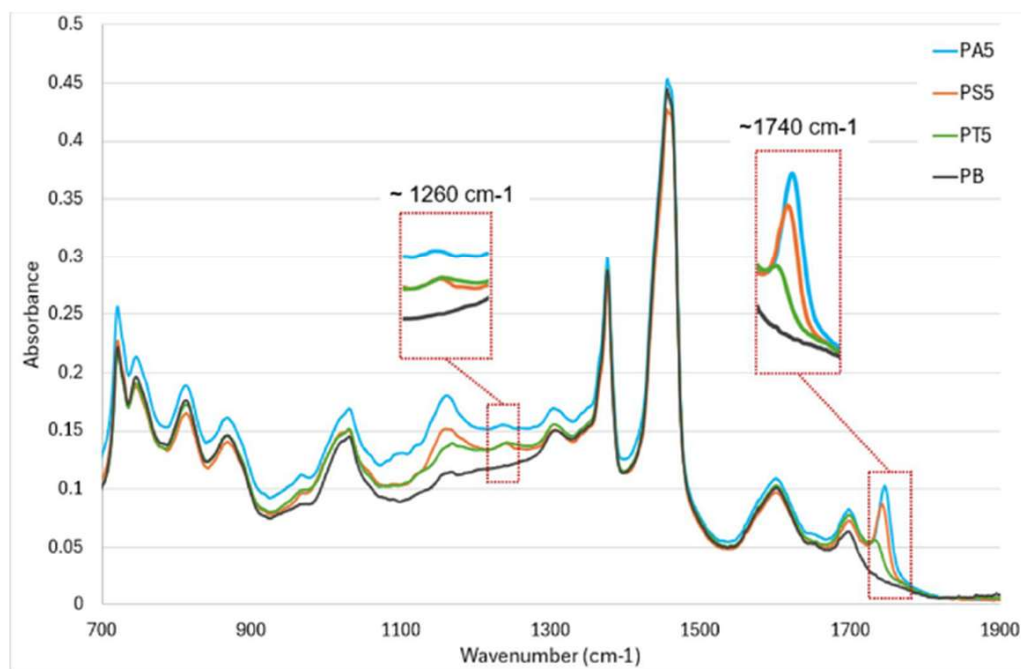


Table 5 values. Methods specify 1700 cm⁻¹ for CI; the spectral inset highlights the ester region near 1740 cm⁻¹.

Carbonyl index at 15% dosage

Published means $\pm$ SD (n = 3)

Binder	Before PAV	After PAV	Δ CI
Anova	0.230 $\pm$ 0.010	0.240 $\pm$ 0.010	+0.010
Sylvaroad	0.215 $\pm$ 0.009	0.210 $\pm$ 0.009	-0.005
TOP	0.110 $\pm$ 0.006	0.120 $\pm$ 0.006	+0.010

Δ CI = after PAV – before PAV

Peak-based index; no integrated areas reported

Small CI changes relative to reported SD

Sulfoxide index increases in every blend

Lower absolute carbonyl index alone does not establish better ageing resistance.



Conclusions and next steps

Implications for biobinder evaluation

Assess both initial properties and performance after ageing.
Compare binders at matched initial performance to isolate ageing effects.

LAS + MSCR + FTIR: a promising test package

LAS: fatigue resistance and damage tolerance

MSCR: rutting resistance and recovery

FTIR: chemical changes during ageing

Together, these tests can support future biobinder evaluation and performance-based specifications.



Conceptual illustration

Next steps for ageing assessment

Changes in FTIR band areas

Changes in normalized carbonyl and sulfoxide areas are candidate indicators of ageing sensitivity.

Validate against additive chemistry and mechanical performance.

Proposed extension: this study reports peak-based indices.

Beyond one PAV cycle

One cycle may not capture long-term ageing.
Add ageing stages and assess performance retention.

Validate with field RAP, low-temperature tests and mixtures.

Biobinder selection should balance fatigue and rutting after ageing

Phase 1 published. Phase 2 ahead.

Materials and Structures

2026 · Volume 59 · Article 313

Chemo-mechanical assessment of ageing and performance trade-offs in bio-based rejuvenators for RAP-rich binders

Ali Foroutan Mirhosseini · Arman Hamidi · Thor Asbjørn Lunaas

doi: 10.1617/s11527-026-03195-1



PHASE 1 · COMPLETED

LAS + MSCR + FTIR

Ageing revealed performance trade-offs



PHASE 2 · PLANNED

Match initial performance

Track changes through further ageing

Similar starting properties. Different ageing responses?

PHASE 2

Different sources. Different chemistry.

Bio-based oils require product-specific evaluation



Wood-derived



Vegetable oils



Cashew-shell oils



Used cooking oils



Animal-fat-derived

Illustrative feedstock and product examples



What varies?

- Feedstock and processing
- Composition and molecular structure
- Volatile fractions

Bio-based oils are not chemically interchangeable

AGEING IN SERVICE

Heat, oxygen and sunlight

PAV captures thermal oxidation, but excludes light exposure



Thermal-oxidative ageing

Heat and oxygen promote oxidation
Hardening can reduce stress relaxation

PAV: accelerated oxidation under heat and pressure

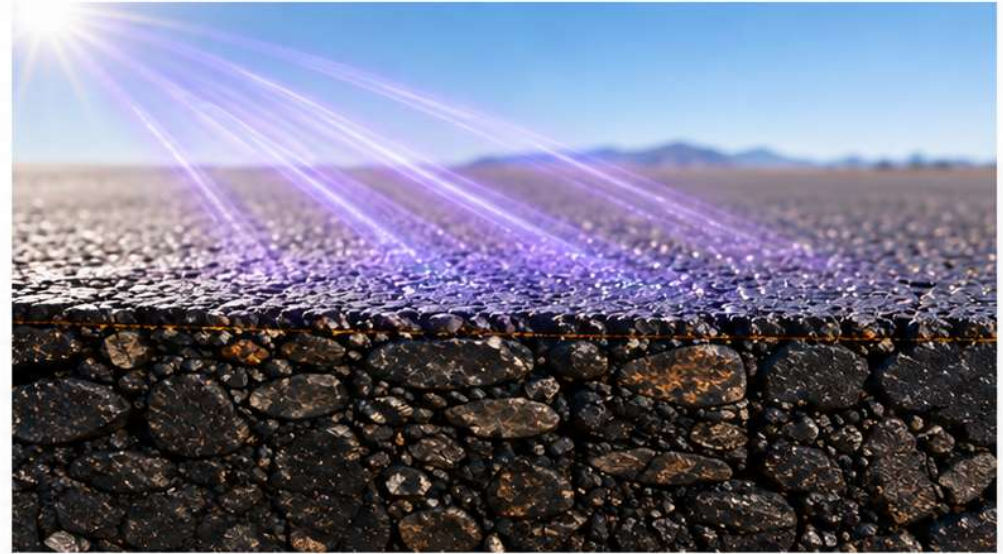


Photo-oxidative ageing

Sunlight can drive additional surface reactions
Response depends on spectrum, dose and binder chemistry

Light exposure is absent from conventional PAV

Longer PAV conditioning does not reproduce sunlight exposure

Conceptual illustrations of field exposure

AGEING IN SERVICE

Moisture and reactive gases

Field exposure includes processes beyond conventional PAV



Moisture-related damage

Water can weaken binder–aggregate adhesion
Effects depend on binder chemistry and the mixture

Moisture damage can interact with chemical ageing



Reactive atmospheric species

Ozone and nitrogen oxides can alter oxidation pathways
Responses may differ between biobinder products

Conventional PAV does not reproduce these exposures

PAV is one part of durability assessment, not the whole field environment

Conceptual illustrations of field exposure

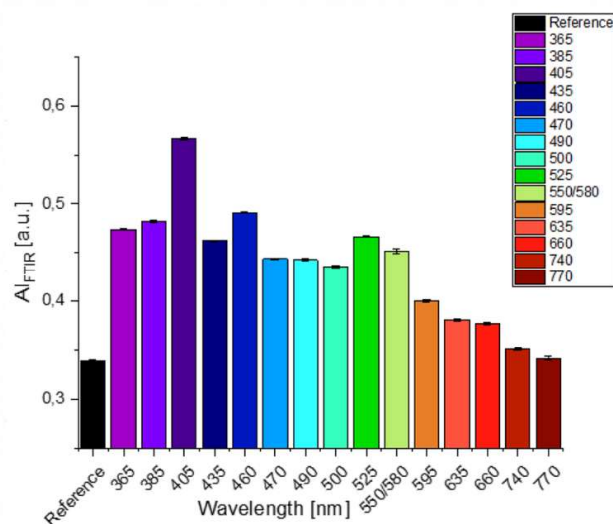
EVIDENCE FROM THE LITERATURE

Light changes the ageing response

Two studies on unmodified 70/100 bitumen: implications for biobinder research

Visible light also contributes to oxidation

LED exposure adjusted to solar spectral irradiance



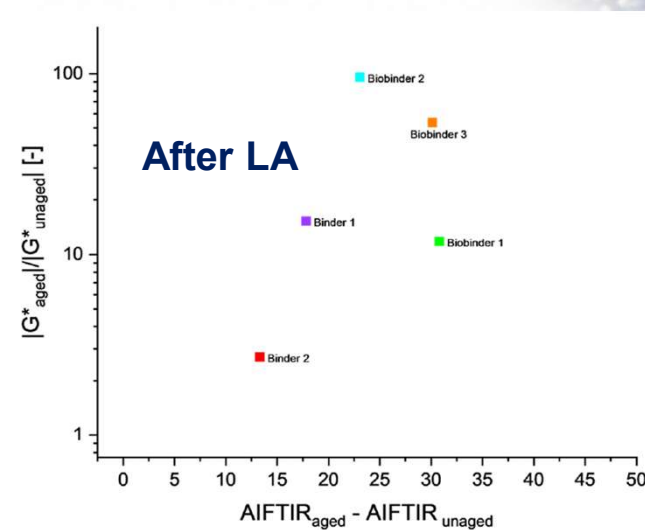
405 nm gave the highest surface FTIR ageing index

under the solar-adjusted exposure used in this study.

Mirwald et al. (2022), Fig. 15, right panel

Light + heat differs from PAV ageing

72 h at 80°C with light; comparison with 1x, 3x and 4x PAV



Similar FTIR indices accompanied different stiffness.

Light + heat produced higher |G*| than 4x PAV.

Mirwald et al. (2025), Fig. 8; DSR at 46°C, 1.592 Hz

Implication for bio-oils: test whether chemistry changes the response to each exposure.

These papers motivate that question; they do not directly compare bio-oils.

Sources: doi:10.1016/j.conbuildmat.2021.125816 · doi:10.1080/14680629.2025.2456919 · Figures cropped from originals (CC BY).

FTIR indices follow each study's own protocol; absolute values should not be compared across papers.

Phase 2: test programme

Match crossover temperature, then track performance through ageing

1 Screen dosages



Three bio-oils

Bio-oil	RAP	Neat PMB
5%	30%	65%
10%	30%	60%
15%	30%	55%

Nine trial blends
(all percentages by total binder mass)



Reference:
PMB 65/105
No RAP or bio-oil

2 Match and prepare



Crossover temperature matching

Select one matched dosage per bio-oil
Prepare three selected blends + reference

Common conditioning for crossover comparison

3 Progressive ageing and testing

RTFO



LAS • MSCR • FTIR

PAV ×1



LAS • MSCR • FTIR

PAV ×2



LAS • MSCR • FTIR

PAV ×3



LAS • MSCR • FTIR

Parallel aliquots at each ageing endpoint

Compare absolute performance and change with ageing



UV exposure: feasibility and access under investigation
Core programme: thermal-oxidative ageing

Key messages and outlook

Performance after ageing matters

Initial softening alone cannot establish long-term suitability.

Bio-oils need individual evaluation

Chemistry and ageing exposure both matter.

Phase 2: performance retention

Match crossover temperature and track progressive PAV ageing.

UV exposure: feasibility under investigation.



Our goal: a stronger basis for evaluating biobinder durability



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