

High-Quality Horizontal Recycling of Polymer-Modified Asphalt

From Sustainable Highways to Heavy-Duty Airport Runways

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sinking in the North Atlantic
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from New York, and the
sinking was the worst
disaster in the history of
the world.

The Titanic was a
British ship, and it was
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CUNARAN MURDER

Gravy Found Red in Tinted

REMARKABLE PHOTOGRAPH OF SURVIVORS IN HALF-EMPTY LIFEBOAT OF TITANIC



CALL OF WARNING WAS NOT TAKEN ON THE TITANIC

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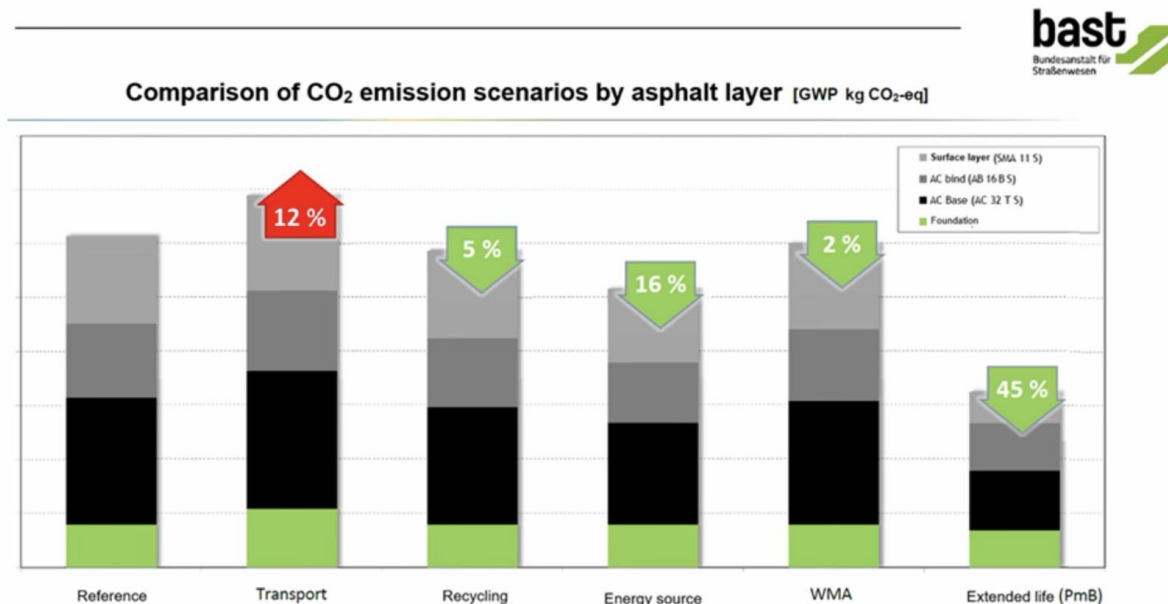
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Which Lifeboat Has the Most Capacity?

BAST tested several ways to cut CO₂ in asphalt. The biggest capacity by far is a longer service life — which polymer-modified bitumen delivers, up to –45%.



Source: BAST (Bundesanstalt für Straßenwesen) — CO₂ emission scenarios by asphalt layer [GWP kg CO₂-eq]. Each bar is one measure vs. the reference; –45% reflects BAST's assumed life-extension factor.

The lifeboats, by capacity (GWP)

Longer service life (PMB)	–45%
Plant energy source	–16%
Recycling	–5%
Warm mix (WMA)	–2%
Transport	+12%

Ordinary recycling saves ~5%. Horizontal PMB recycling keeps the polymer active — so the recycled mix also earns the –45% life-extension lever. That is the rare lifeboat that pulls both.

🕒 The Sector Agrees on the Direction



POSITION STATEMENT ON

Recycling of Asphalt Containing Polymer-modified Bitumen

Eurobitume — Position Statement

The European bitumen sector's recent position statement confirms it plainly: recycling asphalt that contains polymer-modified bitumen is

possible · inevitable · sustainable

So the question is no longer whether we do this — it is how well we do it.

🕒 Presentation Overview

01

Introduction

PMB RAP: challenge & opportunity

02

Lab Study — SMA 40% RAP

Bio-based rejuvenation of PMB granulate

03

Field Case — Schiphol 60% RAP

150,000 t airport runway rehabilitation

04

Conclusions & Outlook

Key takeaways for practice

01

Introduction

The circularity challenge in polymer-modified asphalt

🎯 The Circularity Challenge in Road Infrastructure

Why now?

- First-generation heavy PMA pavements (1990s–2000s) are reaching end of service life.
- Netherlands: >400,000 t PMA placed at Schiphol before 2003.

A missed opportunity

- PMA granulate mostly downcycled into standard base layers.
- Polymer value discarded — treated like ordinary RAP.

The ambition: horizontal recycling

- Reuse PMB RAP in the same layer, at the same quality.
- Maintain polymer functionality — don't downgrade.

Drivers & the central question

- EU circular-economy targets; less virgin bitumen; lower ECI per m².
- Can field-aged PMB RAP be rejuvenated to original quality?

This talk answers: YES — here is the evidence.

🕒 Why PMB RAP Is Different — Residual Polymer Value

Polymer modifications

- SBS (styrene-butadiene-styrene)
- EVA (ethylene-vinyl-acetate)
- Often combined for performance
- Identified by FTIR of recovered binder

Aging behaviour

- Effectiveness decreases over time
- Weather → viscosity → workability shifts
- But polymer is NOT gone — FTIR peaks remain
- Field-aged binder harder than lab predicts

Key research finding

- Active SBS confirmed in road-aged PMB
- RECYPMA (EU, 2013): granulate is a resource
- Proper homogenisation unlocks the benefit
- Fresh RAP (<1 yr) needs pre-blending first

○ FTIR Confirms Residual Polymer

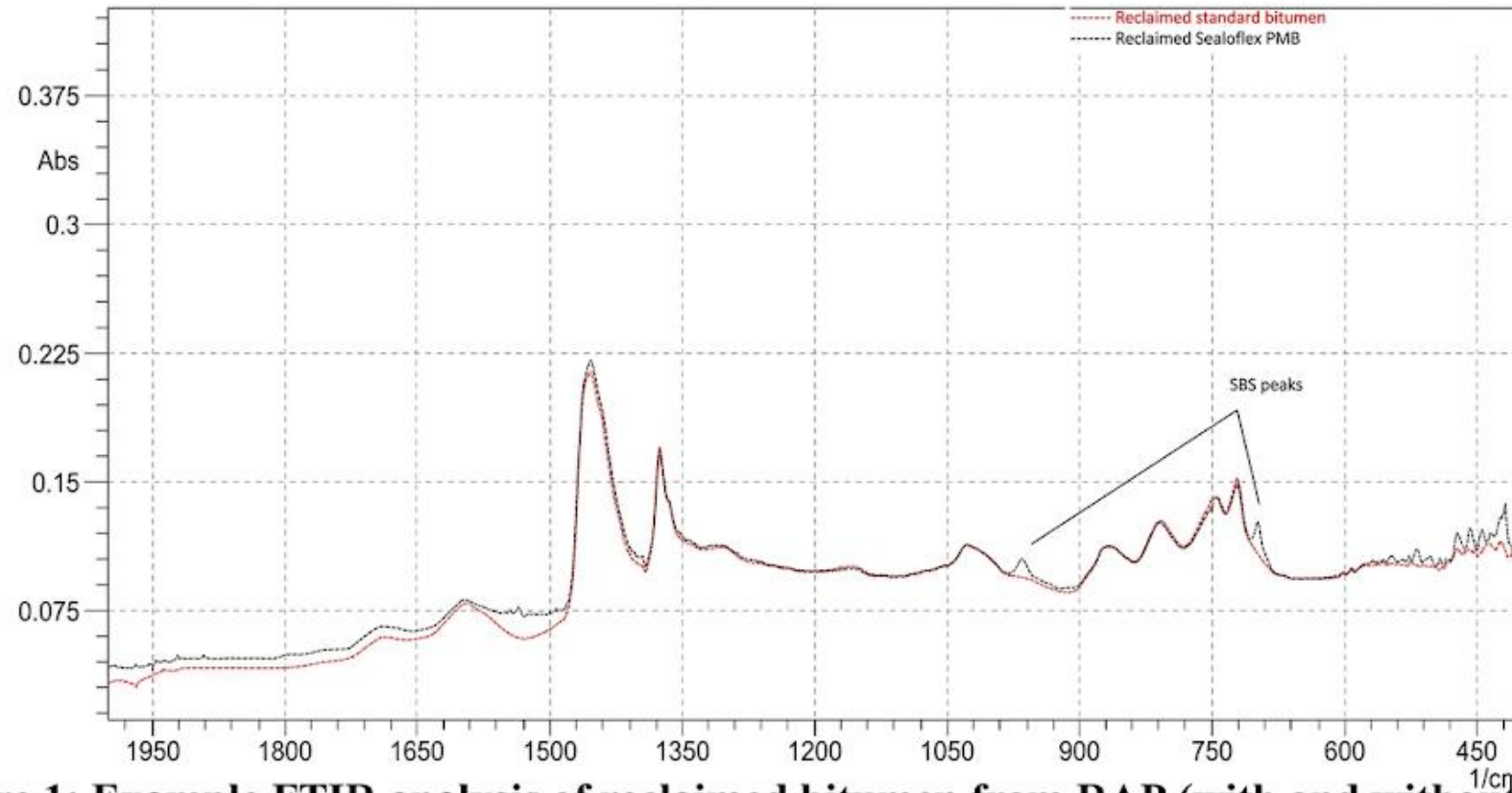


Figure 1: Example FTIR analysis of reclaimed bitumen from RAP (with and without PMB).

Figure 1: FTIR analysis of reclaimed bitumen from RAP (with and without PMB). SBS peaks remain visible after 15–20 years in service.

🎯 A 25-Year Track Record of PMB RAP Reuse

40% PMA porous granulate in AC base 22 — better deformation resistance than standard RAP

Dutch RWS study

1997

2-year study confirms active polymer in granulate; homogenisation is the key

RECYPMA (EU)

2013

Bio-based rejuvenation restores original quality at 40% RAP (Ooms / BituNed)

SMA 8G+ lab study

2024

2005

Motorway A12

AC base 22 with 40% PMA granulate + PMB virgin binder — no production or paving issues

2021

Schiphol 18R/36L

150,000 t with 60% PMB RAP — first runway-scale horizontal recycling in NL

One number to remember: fatigue resistance ϵ_6 rises from 132 $\mu\text{m}/\text{m}$ (standard RAP) to 213 $\mu\text{m}/\text{m}$ (PMB RAP) — a 61% improvement, simply by using polymer-modified granulate.

🕒 Two Complementary Case Studies

Case Study 1 — Lab

- Upgrading SMA PMB RAP (SMA-NL 8G+ surface course)
- Location: Province Gelderland, NL
- RAP content: 40%
- New binder: Sealoflex SFB 4-100 (BR)
- Rejuvenator: bio-based CNSL oil
- Goal: restore original PMB quality
- Key tests: DSR master curves, BBR, ΔT_c

Case Study 2 — Field

- Schiphol runway 18R/36L (base & binder course)
- Location: Amsterdam Schiphol Airport
- RAP content: 60% (PMB granulate)
- New binder: Sealoflex SFB 5-90 LT
- Scale: ~150,000 t in 13 weeks; ~600,000 m²
- Goal: meet tight airport specifications
- Key tests: stiffness, fatigue, deformation

02

Lab Study — Upgrading SMA with 40% PMB RAP

Bio-based PMB rejuvenation · Ooms Producten laboratory · Province Gelderland

🕒 Context: SMA-NL 8G+ in Gelderland — End of Service Life

Background

- Gelderland has applied SMA-NL 8G+ since 2003
- Optimised for service life + noise; ~8% air voids
- Made with PMB (Sealoflex SFB 3-100)

The problem today

- Layers now reaching end of service life
- RAP reused in standard asphalt — polymer wasted
- SMA gradation makes SMA-to-SMA reuse uncommon

The opportunity

- Selective milling separates SMA RAP cleanly
- PMB still contains active SBS (FTIR confirmed)
- Field experience: up to 65% RAP in SMA feasible

Research objective

- Verify field-aged PMB can be upgraded to original quality
- Using a soft PMB + bio-based rejuvenating oil (CNSL)
- Target ≥40% RAP in new SMA 8G+
- Commissioned by BituNed + Province Gelderland

🕒 Lab Study — Sample Definitions & Test Programme

Sample	Definition
PMB (Fresh)	Factory Sealoflex SFB 3-100 — currently used by Gelderland
PMB (road-aged)	Field-aged PMB recovered from old SMA 8G+ RAP (DCM extraction)
PMB (lab-aged)	Artificially aged — 4× PAV (80 hr, 100 °C)
PMB (BR)	Sealoflex SFB 4-100 (BR): soft PMB + bio-based cashew-nutshell oil
PMB (road-new)	40% road-aged + 60% BR — simulates the 40% RAP scenario
PMB (lab-new)	40% lab-aged + 60% BR

Test battery: Penetration · Softening point R&B · Fraaß breaking point · Viscosity 135/185 °C · FTIR · BBR (S=300, m=0.300) · DSR sweep -10...+70 °C · ΔT_c . Aging: 2× PAV = usage phase, 4× PAV = end-of-life.

⦿ Aged Binder Characterisation — Field vs. Lab Aging

Property	PMB (lab-aged) 4× PAV	PMB (road-aged) Field SMA	PMB (Fresh) Reference
Penetration (× 0.1 mm)	20	8	94
Softening point R&B (°C)	81.0	85.0	68.0

⚠ **Field-aged binder (pen = 8) is much harder than lab-aged (pen = 20).** 4× PAV underestimates real end-of-life aging in gap-graded mixes (SMA / PA).

- FTIR confirms SBS peaks still present in road-aged binder.
- Band near 1010 cm⁻¹ is wider in the field sample — the signature of real oxidative aging in service.
- Consequence: calibrate blend ratios and PMB(BR) softness to the real field penetration, not the lab-aged simulation.
- For SMA / PA surface courses, consider >4× PAV or alternative aging protocols.

FTIR: Lab-Aged vs. Road-Aged PMB

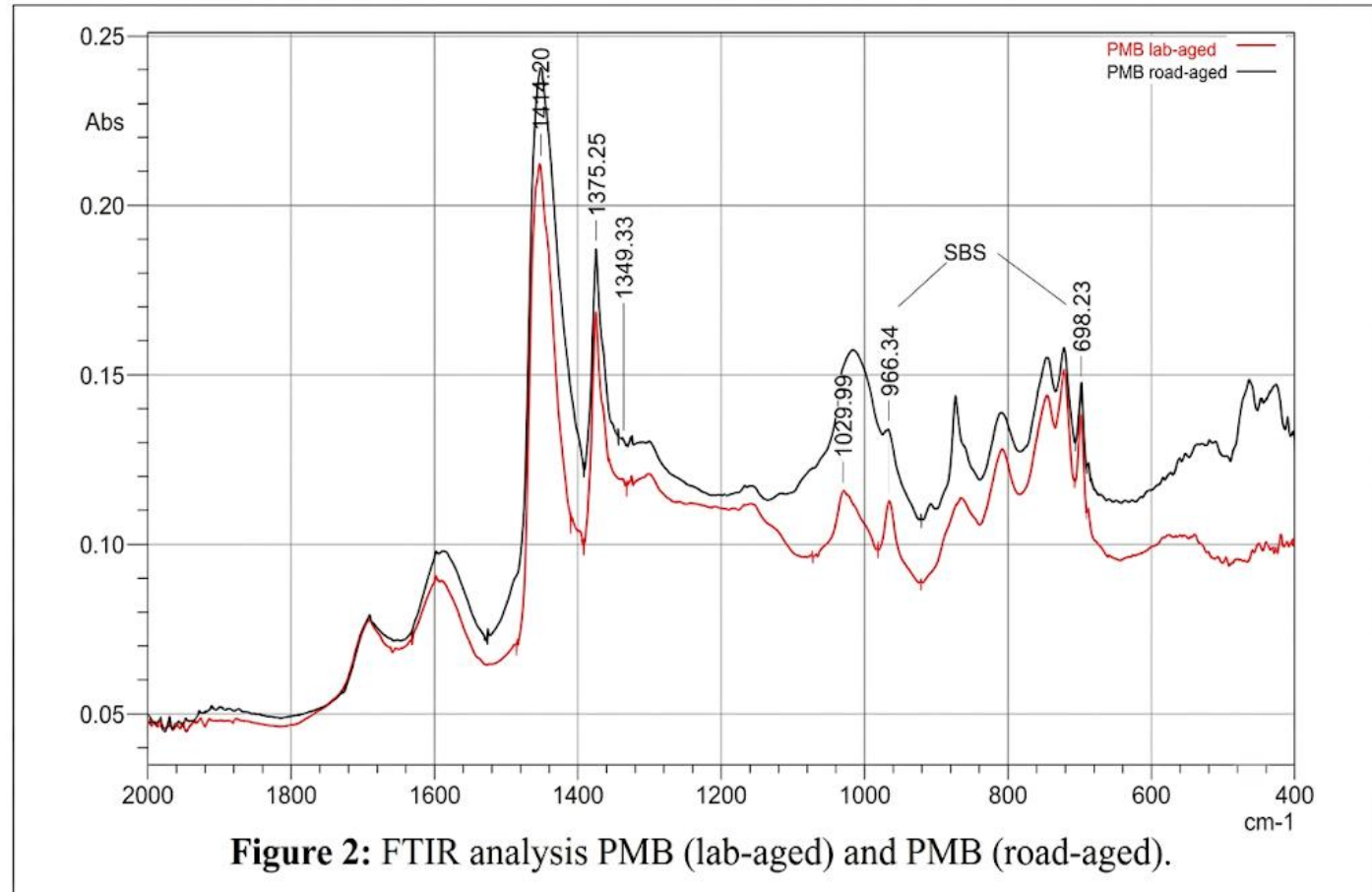


Figure 2: FTIR of PMB (lab-aged) vs. PMB (road-aged). SBS markers ($\sim 700, 966 \text{ cm}^{-1}$) present in both; broader band near 1010 cm^{-1} marks real in-service oxidation.

🕒 Rejuvenation Results — Does Blending Restore PMB Quality?

Property (EN 14023)	PMB (lab-new)	PMB (road-new)	PMB (Fresh) ✓ Target
Penetration (× 0.1 mm)	52	41	94
Softening point R&B (°C)	69.0	64.2	68.0
Fraaß breaking point (°C)	-24	-18	-19

✓ Winter performance — restored

Fraaß of road-new (-18 °C) matches fresh (-19 °C). Low-temperature G* at high frequency tracks fresh PMB — less risk of early raveling.

✓ Rutting resistance — improved

At high temperature / low frequency, road-new is stiffer than fresh PMB — better summer rut resistance. A bonus from the recycled polymer.

The dual benefit: winter performance maintained + summer rutting improved vs. fresh PMB. The new binder wraps around old particles and fully blends over years in service; production & paving at 175 °C is unaffected (lower BR viscosity).

Master Curve — Winter Performance Preserved

Table 4: Bitumen properties blended bitumen

Bitumen properties (EN 14023)	PMB (lab-new)	PMB (road-new)	PMB (fresh)
Penetration (x 0,1 mm)	52	41	94
Softeningpoint R&B (°C)	69.0	64.2	68.0
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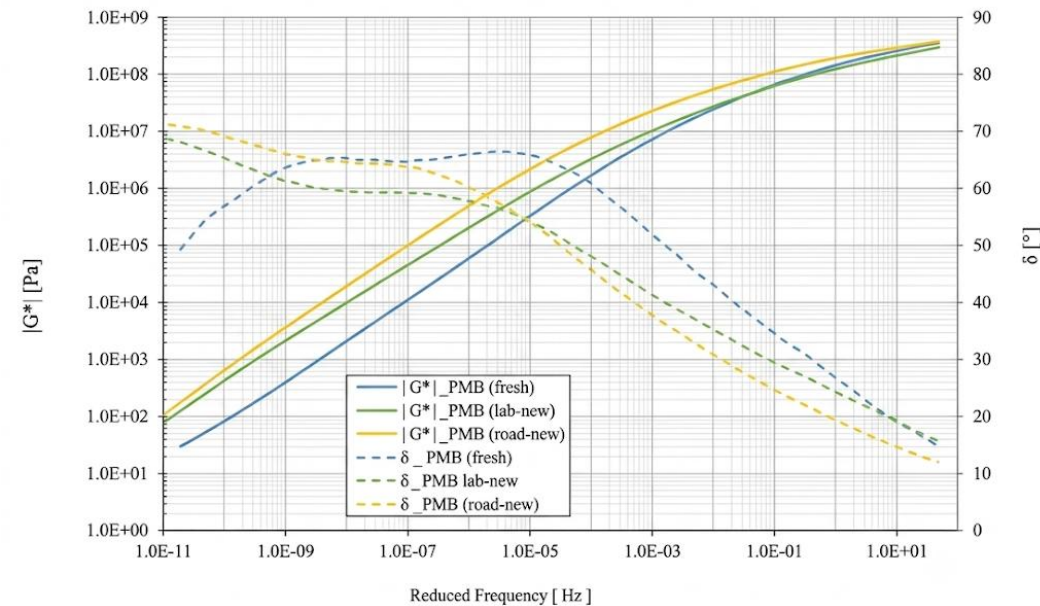


Figure 3: Master curve at -10 °C for PMB (lab-new), PMB (road-new) and PMB (fresh).

Figure 3: Master curve at -10 °C for PMB (lab-new), PMB (road-new) and PMB (fresh). Recycled blend and fresh binder overlap on the winter side; recycled sits slightly stiffer at high temperature.

🕒 Long-Term Durability & Recommended PMB(BR) Specification

After 2× PAV (≈ 12-year usage phase)

Property	lab-new	road-new	fresh
Penetration (0.1 mm)	20	20	31
Softening R&B (°C)	92.0	81.0	73.8
Fraaß (°C)	-12	-10	-15
BBR S=300 (°C)	-19.6	-15.2	-19.5
BBR m=0.300 (°C)	-10.8	-12.1	-19.1
ΔTc (°C)	-8.8	-3.1	-0.4

Recommended PMB(BR) specification (EN 14023)

Property	PMB (BR) spec
Penetration [dmm]	130–170
Remaining pen. RTFOT [%]	≥ 60
Softening pt R&B [°C]	≥ 80
Diff. R&B RTFOT [°C]	≤ 2
Fraaß [°C]	≤ -18
Elastic recovery 25°C [%]	≥ 90
Viscosity 135 °C [mPa·s]	500–1500
Viscosity 185 °C [mPa·s]	100–300

G stiffness at high frequency stays nearly constant through service life → no early raveling expected. The headline spec: a genuinely soft binder (pen ≥ 130) to rejuvenate 40%+ aged RAP.*

○ Durability — Stiffness Holds Over Service Life

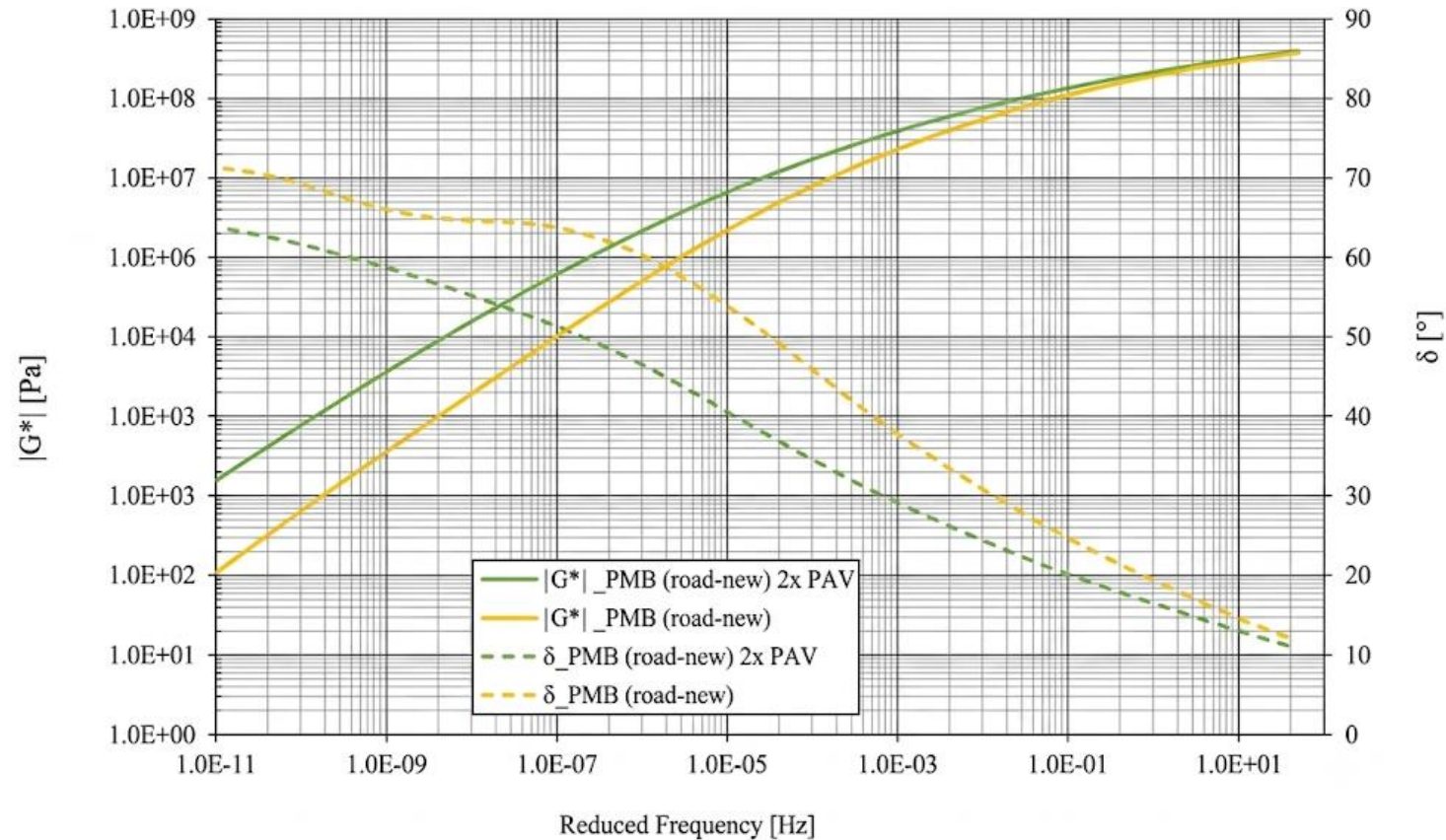


Figure 5: Master curve at -10 °C for PMB (road-new) before and after 2x PAV.

Figure 5: Master curve at -10 °C for PMB (road-new) before and after 2x PAV. Curves stay close at the high-frequency end — stiffness barely shifts over the simulated service life.

03

Field Case — Schiphol Runway 18R/36L

60% PMB RAP · 150,000 tonnes · 13 weeks · Amsterdam Airport

🕒 Schiphol Runway 18R/36L (Polderbaan) — Background

3,800 m

Runway length

60 m

Runway width

600,000

m² replaced

80k / 65k

Landings / takeoffs per year

Original construction (2002–2003)

- Three open-graded PMA layers + one dense-graded
- Sealoflex SFB 5-50 (HT) — Superpave PG 76-22
- Designed for rutting & reflective-cracking resistance; CTB foundation



2021 rehabilitation

- Antiskid removed, PMA milled and replaced
- Decision: reuse 60% of old PMA RAP — first runway at this % in NL
- New binder SFB 5-90 LT + low-temp additive
- Challenge: variable crude → single-refinery base bitumen for the whole project

🕒 RAP Logistics — Selective Milling & Binder Selection

Material recovery

- ~1,400,000 m² selectively milled
- ~130,000 t PMA granulate recovered
- Partly crushed on site, taken to the plant

Why homogeneity is critical

- Granulate must be one source / modification
- Only then can the polymer benefit be counted in design
- Mixed granulate = value cannot be guaranteed

New binder: Sealoflex SFB 5-90 LT

- Heavily modified, elastic recovery $\geq 90\%$
- Better workability at lower temperatures
- + chemical low-temperature additive (wetting)
- + rejuvenating agent (Anova) in the mix

Special surface layer

- FlightFlex porous friction course — no RAP
- Antiskid rules preclude RAP in the surface
- Placed by Heijmans; operational May 2021

Selected PMB — Sealoflex SFB 5-90 LT Specification

PMB property	Specification	Unit
Penetration (EN 1426)	80–120	mm × 0.1
Softening point R&B (EN 1427)	≥ 85	°C
Elastic recovery (EN 13398)	≥ 90	%
Force ductility at 5 °C (EN 13589)	≥ 5.0	J
MSCR Jnr,3.2kPa at 60 °C (EN 16659)	≤ 0.1	1/kPa

🕒 PMB Quality Control — Managing Binder Variability at Scale

Why strict QC was essential

- Crude-source changes → PMB variability
- 60% RAP amplifies sensitivity to virgin binder
- Small base-bitumen deviations → big PMB shifts

QC strategy

- Single-refinery base bitumen for the whole project
- Batch-by-batch testing over ~25 batches
- Limits tighter than EN 14023

Monitored per batch

- Penetration (target 80–120)
- Softening point R&B (≥ 85 °C)
- Force-ductility energy at 5 °C (cracking)
- MSCR Jnr & R% at 60 °C (rutting, elasticity)

Result

- ~3,000 t PMB produced and approved
- All 25 batches within tight limits
- Consistent quality across the 13-week window

🕒 Batch-by-Batch QC — Penetration & Softening Point

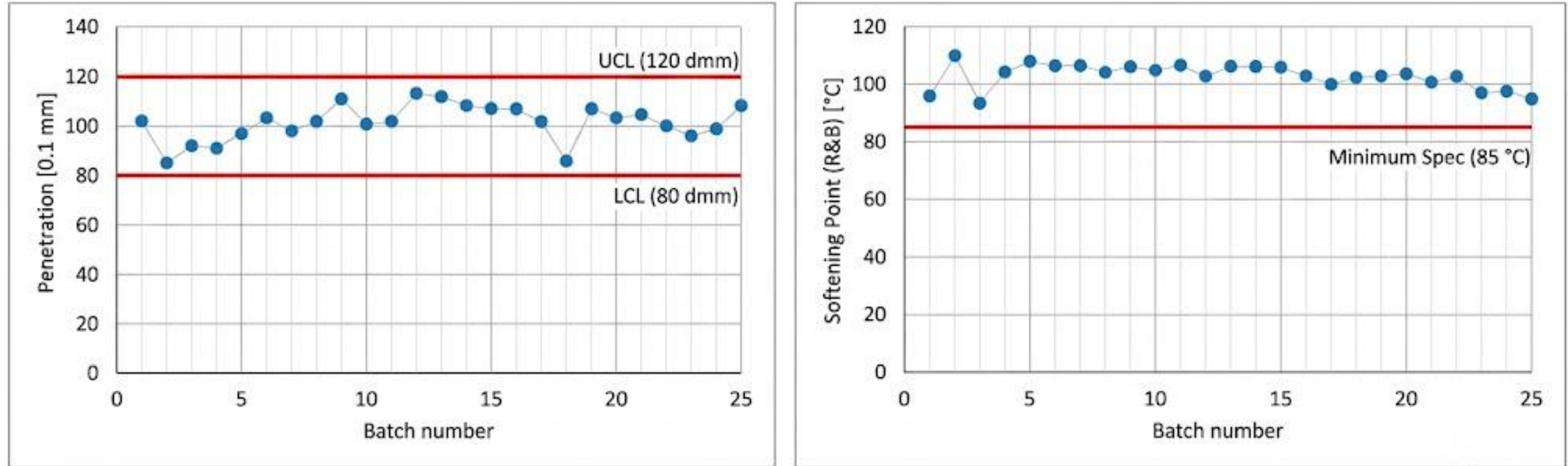


Figure 2 and 3: Process control charts for obtained penetration and Ring & Ball softening point of the produced PMB across 25 consecutive batches. Target specification ranges are indicated by the red lines.

Figures 2–3: Process control charts for penetration and Ring & Ball softening point across 25 consecutive PMB batches. Red lines are the specification limits.

Batch QC — Cracking & Rutting Parameters

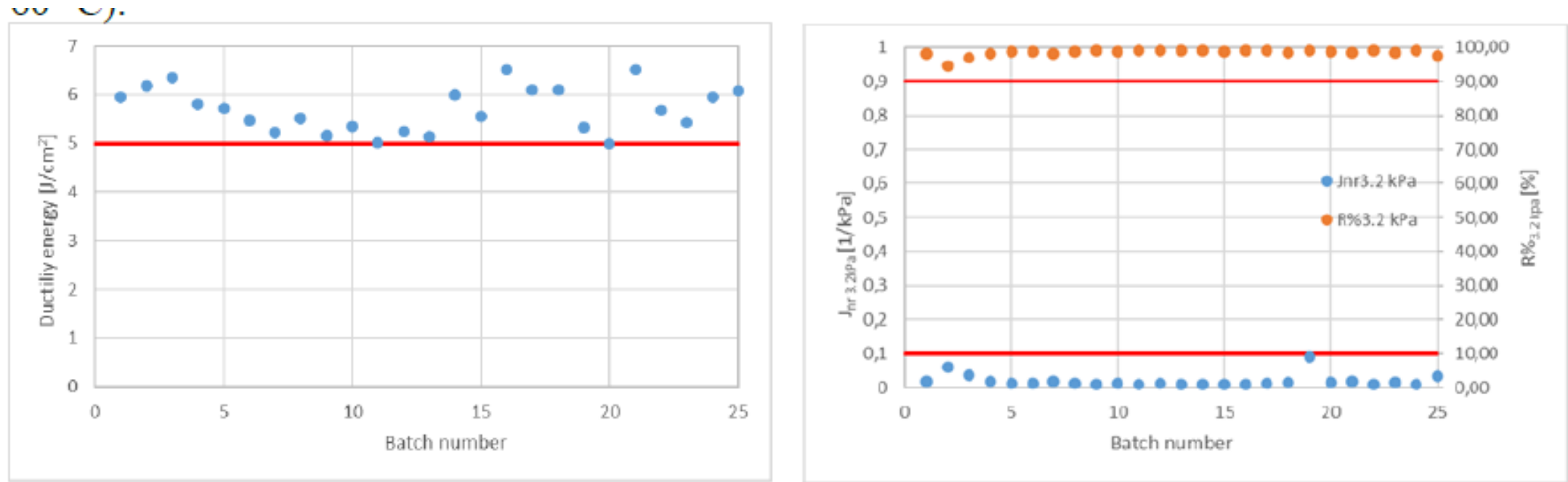


Figure 4 and 5: Obtained force ductility energy ($E_{0.2-0.4m}$) at 5 °C and MSCR $J_{nr, 3.5 \text{ kPa}}$ and $R\%_{3.5 \text{ kPa}}$ at 60 °C.

Figures 4–5: Force-ductility energy at 5 °C (cracking) and MSCR $J_{nr, 3.5 \text{ kPa}}$ & $R\%_{3.5 \text{ kPa}}$ at 60 °C (rutting, elastic recovery) across the production batches.

🕒 Mix Performance — Meeting Airport Specs with 60% PMB RAP

Asphalt property	60% RAP Dense PMA	60% RAP Open PMA	0% RAP Fresh PMA	Standard RAP
Stiffness S_{mix} (MPa)	4,014	4,401	2,767	~3,500
Deformation f_c ($\mu\text{m}/\text{m}/\text{s}$)	0.05	0.05	0.15	0.22
Fatigue ϵ_6 ($\mu\text{m}/\text{m}$)	291	268	362	132

Stiffness — safety buffer

4,000–4,400 MPa — 45% above fresh PMA (2,767).
More robust runway-slab calculations.

Rutting — 3× better

$f_c = 0.05$ vs 0.15 fresh and 0.22 standard RAP.
Residual polymer suppresses deformation.

Fatigue — sufficient

$\epsilon_6 = 268\text{--}291$ — below fresh (362) but well above
standard RAP (132). Ample on a CTB base.

Every airport specification met — with a recycled mix at 60% RAP.

🕒 Field Outcome — Delivery, Scale & Environmental Impact

150,000 t

New asphalt paved

13 weeks

Delivery window (2021)

~3,000 t

PMB — all batches compliant

60%

PMB RAP — no issues

Operational outcome

- Runway back in operation May 2021; no structural problems
- No workability issues in production or paving
- FlightFlex friction course met antiskid without a conventional layer
- Stiffness, fatigue, deformation — all verified vs. airport specs

Circular-economy value

- ~130,000 t high-quality PMA horizontally recycled
- Significant virgin-binder saving; lower ECI per m²
- No downgrading to base — full polymer value retained
- Proof of concept at airport scale — replicable, on 25+ years of NL experience

04

Conclusions & Outlook

Key takeaways for practitioners and researchers

Key Takeaways

01

PMB RAP retains active polymer

FTIR confirms SBS peaks after 15–20 years. The polymer value is real and measurable — treat PMB RAP as a resource, not waste.

02

Bio-based rejuvenation restores quality

CNSL-based PMB(BR) at 40% RAP returns the binder to original functional quality: winter performance equal, summer rutting improved.

03

60% RAP viable at airport scale

Schiphol 18R/36L: 150,000 t in 13 weeks, all specs met. Horizontal recycling works for the most demanding infrastructure.

04

QC is the critical enabler

Homogeneous RAP + single-refinery base bitumen + batch testing = consistent performance. QC investment pays back in confidence.

“

PMB RAP is not a waste product — it is a high-value asset for circular road infrastructure.

Dr. Mohamad Mohajeri · R&D Manager, Ooms Producten (Pankas Holding) · TU Delft PhD in Road Engineering

Thank you

Questions welcome

Dr. Mohamad Mohajeri · Ooms Producten (Pankas Holding)

Key references

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