University of Antwerp
SuPAR | Sustainable Pavements and Asphalt Research

Flemish experience with BSM

Prof. Wim Van den bergh

Dra. Ecem Nur Barisoglu

FOAM

• Tetra project HBC.2020.2094 FOAM

Content

- SuPAR
- Flanders' vision towards sustainable use of RAP
- SuPAR's approach
- FOAM Project
- Structural Design for Flanders
- Environmental assessment - LCA

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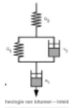
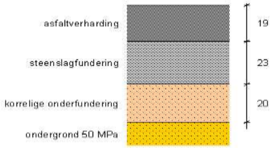
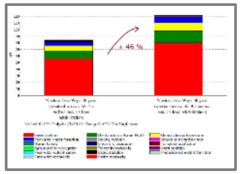
SuPAR | Sustainable Pavements and Asphalt Research

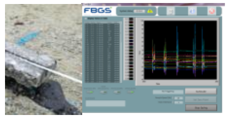
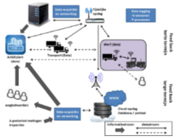
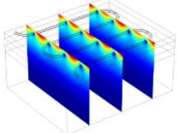
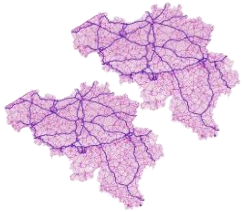
Sustainable Climate Resilient and Smart road structures
Asphalt Technology
Basic, Strategic-basic and applied research

Sustainable Asphalt Pavement & Materials
- Ageing and healing mechanisms
- Recycling and regeneration technologies
- Surface characteristics
- Structural design and environmental impact
- Innovative materials

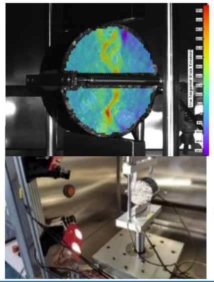
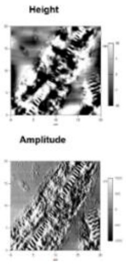





Smart road technologies and management:
- Road IT and FBG
- Asphalt Solar Collector
- Data analysis & management
- Optimization strategies

Experimental Material Research
Asphalt Laboratory
Advanced Rheological Binder Laboratory
Microstructure Laboratory
VOC test lab

Test tracks

Asphalt Innovation Symposium
Research meets Industry
Asphalt Innovation Symposium
December 11th, 2025

12th meeting:
EATA 2027
June 8–10, 2027
hosted by University of Antwerp, Faculty of Applied Engineering

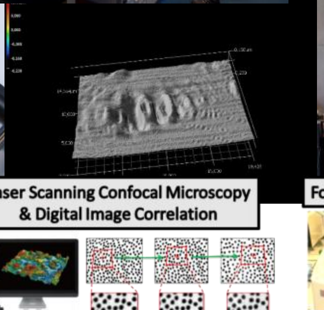
cost
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

COST ACTION CA 24141
CRIPI
Climatic Resilience Initiative for Pavement Infrastructure

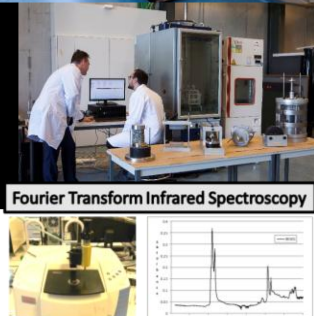




Rheology



Laser Scanning Confocal Microscopy & Digital Image Correlation



Fourier Transform Infrared Spectroscopy

Flanders’ vision towards sustainable use of RAP

- **Flemish road authority supports industry towards sustainable use of materials (including recycling) via standards, GPP, financial benefits**
- **Pavement sector CO-road map: production, material and energy use**

- Promising: the use of (processed) RAP
  - highest potential via reuse as asphalt (bound) and as aggregate (unbound)
  - huge resource yearly and in future
    - 4.8 Mt new asphalt
    - 2.3 Mt site-won asphalt,
      - 1.3Mt RAP in asphalt
      - 1.0Mt used as aggregate
  - → Yearly more than 2Mton accumulated in roads since…60 years…

- **Ambition SuPAR - Flanders: increased optimized use of RAP – no higher environmental impact**

SuPAR's approach

- RAP can be used in asphalt – preferred
- RAP can be used in base as alternative for new aggregates
- Condition:
  - no higher environmental impact
  - "better to use RAP in base than in asphalt if impact is less"
    - transport from/to sites/ hinder – social aspects
    - less use of new resources: RAP instead of new aggregates/binder
    - less use of energy /CO_2: RAP-composite instead of cement treated base
    - high quality of base material: semi-bound better than unbound/cracking material

Test Track Assenede AWV

Project FOAM (2021-2023)

- Bitumen-Stabilised Material
- Collaboration with industry
- Prestudy mix design
- Structural Design
- Demonstration by 2 test tracks (KMA)
- Monitoring of construction process
- Post study
  - sampling cores
  - lab versus in situ
  - energy: LCA/LCCA

FOAM

University of Antwerp

- Tetra project HBC.2020.2094 FOAM

Outcome FOAM

- Material for base layer (larger sites)
    - Alternative for unbound and cement-treated base layer material
- Guidelines for Flemish Industry
- Justification for application
- Flemish Standard SB250 (2025)
- Monitoring of applications
- 2025-2026: Kielsbroek
- Future steps: airfields, Green Public Procurement
- Monitoring

15-4 Funderingen – bitumengebonden fundering

Vlaanderen
is wegen en verkeer

bitumengebonden fundering toegevoegd

4.11 Bitumengebonden fundering

4.11.1 Beschrijving

Een bitumengebonden fundering is een semi-flexibele fundering waarbij granulair materiaal van een asfaltverharding wordt samengebonden met bitumen, cement en water.

4.11.2 Materialen

De materialen zijn:

- bitumengebonden funderingsmengsels volgens SB250-24-5.3.6.

FOAM

Duurzame funderingen door in situ recycling met schuimbitumentechnologie

PART III:

Mix design of BSM

EMIB Energy & Materials in Infrastructure & Buildings University of Antwerp

Odisee

Final reports

- Part II - Market potential for BSM in Flanders
- Part III - Mix design of BSM
- Part IV - Structural design of pavements with BSM base
- Part V - Sustainability assessment of pavements with BSM
- Part VI - Syntheserapport proefvakken

Proposed standard structures →

Instructions mix design →

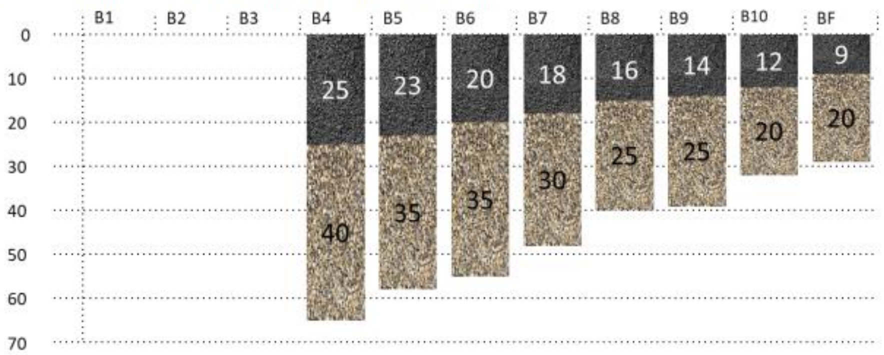
Partners →

https://www.uantwerpen.be/en/research-groups/supar/research/research-projects/foam/

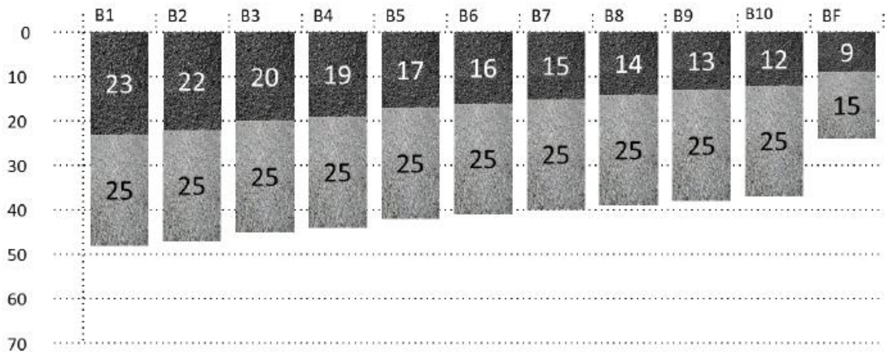
Structural Design

- Typical Flemish Asphalt Roads:
  - Asphalt: surface layer and 1/2/3 base layers
  - Base: unbound or bound (cement-treated/lean asphalt/lean asphalt)
  - Subbase
- Structural design via asphalt fatigue failure, bound base failure and permanent deformation in subbase
- Typical material properties and failure criteria in standards
- **Definition of Standard Structures based on #ESAL$_{100kN}$**

Asphalt + unbound base (B7=1..2 MESAL)



Asphalt + cement-base (B8=0.5 ..1 MESAL)



Structural Design

Table 1: Summary of distress models/ transfer functions of common paving materials (recognized in Belgium & worldwide)

Layer	Material	Design parameter	Response location	Failure mode (Terminal condition)	Transfer function N= the maximum allowed number of loading repetitions
AC layers	Bitumen mix	Horizontal tensile strain Ɛh "m/m"	Bottom	fatigue cracking @ %20 lane area cracked	$N = \left(\frac{0{,}0016}{\varepsilon_h}\right)^{4{,}76}$
	Bitumen mix with high stiffness AVS	Horizontal tensile strain Ɛh "m/m"	Bottom	fatigue cracking @ %20 lane area cracked	$N = \left(\frac{0{,}0081}{\varepsilon_h}\right)^{7{,}39}$
Base layer	Cement stabilised material	Horizontal tensile strain Ɛh "m/m"	Bottom	fatigue cracking @ %20 lane area cracked	$\log N = 12 - 8000 * \varepsilon_h$
	Lean concrete (gravel)	Horizontal tensile stress σh "MPa"	Bottom	fatigue cracking @ %20 lane area cracked	$\log N = 14 * \left(1 - \frac{\sigma h}{1.20}\right)$
	Lean concrete (gravel-bitumen)	Horizontal Tensile strain Ɛh "m/m"	Bottom	fatigue cracking @ %20 lane area cracked	$N_f = \left(\frac{0.00111}{\varepsilon h}\right)^5$
	Foam-BSM / Emulsion-BSM Stabilized material	Deviator Stress Ratio DSR	Roughly at top ¼ depth in BSM	shear permanent deformation @ 10mm rut-depth with Reliability 90%	Stellenbosch BSM Design Function [1]: $\log N = A - 57.286(DSR)^3 + 0.0009159(P_{MMD}.RetC)$
Subgrade	Sand/clay ...	Compressive vertical strain εv "m/m"	Top	permanent deformation @ 12.5mm rut-depth	$\frac{1}{N} = \left(\frac{\varepsilon_v}{0{,}011}\right)^{1/0{,}23}$

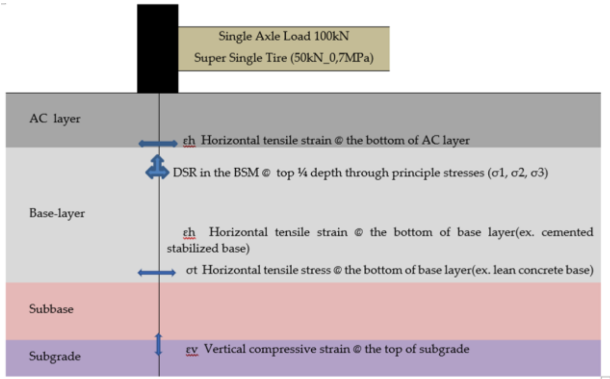


Figure 3 : Critical analysis positions in the pavement structure

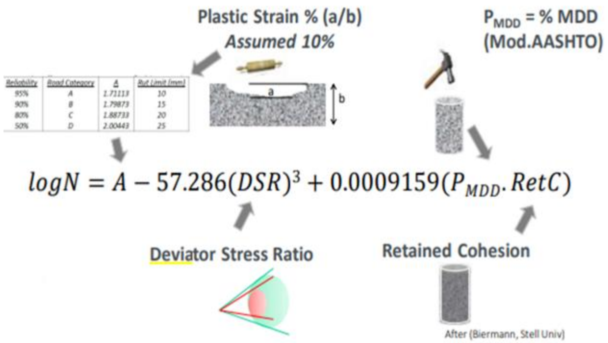
$$Deviator\ Stress\ Ratio\ DSR = \frac{\sigma_d}{\sigma_{d,f}} = \frac{\sigma_1 - \sigma_3}{\sigma_{1,f} - \sigma_3}$$

$$\sigma_{1,f} = \frac{(1 + \sin\emptyset).\sigma_3 + 2.C.\cos\emptyset}{(1 - \sin\emptyset)}$$

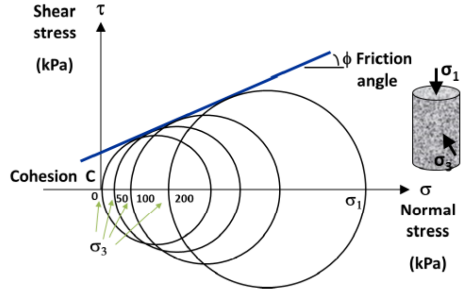
DSR	Deviator Stress Ratio
σ_1	Major principle stress in the layer (KPa)
σ_3	Minor principle stress in the layer (KPa)
$\sigma_{1,f}$	Major principle stress at failure from a triaxial test (KPa)
C	Cohesion value of BSM from project mix design (KPa)
Ø	Friction Angle of BSM from project mix design

Stellenbosch BSM function (NEW)

New Mechanistic Empirical Structural Design Function



Shear parameters of BSM via Triaxial test



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Structural Design

Pavement Name	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Description	E-BSM=800MPa ; E-subgrade=150MP	E-BSM=800MPa ; E-subgrade=150MP	E-BSM=800MPa ; E-subgrade=150MP	E-BSM=800MPa ; E-subgrade=150MP	E-BSM=800MPa ; E-subgrade=150MP	E-BSM=800MPa ; E-subgrade=150MP	E-BSM=800MPa ; E-subgrade=150MP	E-BSM=800MPa ; E-subgrade=150MP	E-BSM=800MPa ; E-subgrade=150MP	E-BSM=800MPa ; E-subgrade=150MP
Pavement Structure Schematic: (Depth (MM): 0–900)	30 MM AC top 230 MM AC underlayer(s) 300 MM BSM800,C265KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	30 MM AC top 200 MM AC underlayer(s) 300 MM BSM800,C265KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	30 MM AC top 170 MM AC underlayer(s) 300 MM BSM800,C265KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	30 MM AC top 160 MM AC underlayer(s) 240 MM BSM800,C265KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	30 MM AC top 140 MM AC underlayer(s) 180 MM BSM800,C265KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	40 MM AC top 120 MM AC underlayer(s) 160 MM BSM800,C265KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	40 MM AC top 100 MM AC underlayer(s) 150 MM BSM800,C265KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	40 MM AC top 90 MM AC underlayer(s) 140 MM BSM800,C265KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	40 MM AC top 90 MM AC underlayer(s) 140 MM BSM800,C265KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa	40 MM AC top 80 MM AC underlayer(s) 130 MM BSM800,C265KPa,Ø38° 350 MM Subbase_E=250 MPa Subgrade_E=150MPa
Total pavement thickness "cover" mm	910	880	850	780	700	670	640	620	620	600
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N = 116 MESAL-100kN (AC layer)	N = 56 MESAL-100kN (AC layer)	N = 26,5 MESAL-100kN (AC layer)	N = 17,6 MESAL-100kN (AC layer)	N = 8,4 MESAL-100kN (AC layer)	N = 5,8 MESAL-100kN (AC layer)	N = 3,3 MESAL-100kN (AC layer)	N = 2,4 MESAL-100kN (AC layer)	N = 2,2 MESAL-100kN (AC layer)	N = 1,7 MESAL-100kN (BSM layer)
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	N > 100 MESAL-100kN (AC layer)	N = 66 MESAL-100kN (AC layer)	N = 33,4MESAL-100kN (AC layer)	N = 23,1 MESAL-100kN (AC layer)	N = 11,8 MESAL-100kN (AC layer)	N = 8,3 MESAL-100kN (AC layer)	N = 4,9 MESAL-100kN (AC layer)	N = 3,6 MESAL-100kN (AC layer)	N = 3,4 MESAL-100kN (AC layer)	N = 2,7 MESAL-100kN (AC layer)
NOTES										

Pavement Name	B6	B7	B8	B9	B10
Description	E-BSM=1200MPa ; E-subgrade=50MPa	E-BSM=1200MPa ; E-subgrade=50MPa	E-BSM=1200MPa ; E-subgrade=50MPa	E-BSM=1200MPa ; E-subgrade=50MPa	E-BSM=1200MPa ; E-subgrade=50MPa
Pavement Structure Schematic: (Depth (MM): 0–550)	40 MM APT-C/APT-D 210 MM BSM1200,C265KPa,Ø38° 350 MM Subbase_E=250MPa Subgrade_E=50MPa	40 MM APT-C/APT-D 180 MM BSM1200,C265KPa,Ø38° 350 MM Subbase_E=250MPa Subgrade_E=50MPa	40 MM APT-C/APT-D 170 MM BSM1200,C265KPa,Ø38° 350 MM Subbase_E=250MPa Subgrade_E=50MPa	40 MM APT-C/APT-D 150 MM BSM1200,C265KPa,Ø38° 350 MM Subbase_E=250MPa Subgrade_E=50MPa	40 MM APT-C/APT-D 140 MM BSM1200,C265KPa,Ø38° 350 MM Subbase_E=250MPa Subgrade_E=50MPa
Total pavement thickness "cover" mm	600	570	560		
Structural Capacity MESAL-100kN (applied loading is a super single wheel 50kN/wheel; Inflation pressure 700KPa)	N = 3,9 MESAL-100kN (Subgrade)	N = 2,27 MESAL-100kN (Subgrade)	N = 1,87 MESAL-100kN (Subgrade		
Verification by The South African mechanistic pavement design method (SAMDM) ; (ref: SAPEM guideline,2014 + TG2 guideline,2020)	BSM 21CM _Critical layer is Subbase (6,3 MESAL)	BSM 18CM _Critical layer is Subbase (2,58 MESAL)	BSM 17CM _Critical layer is Subbas (1,94 MESAL)		
NOTES					

FOAM

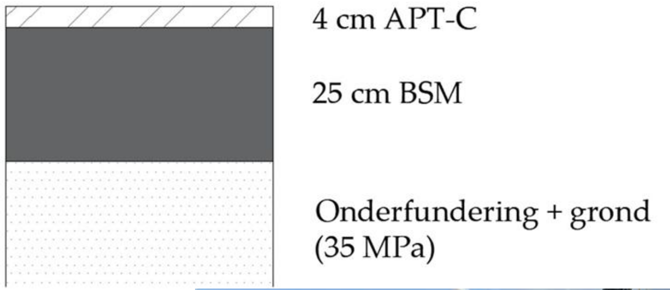
Duurzame funderingen door in situ recycling met schuimbitumentechnologie

PART IV:

Structural design of pavements with BSM

It works… Lareco

- **2022-2025 - Lareco (BK8 <1 MESAL)**



Structural Design - Flanders

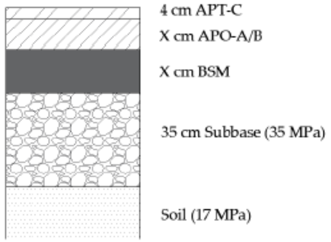
Proposed standard structures Flanders with BSM

1 Assumptions

Subgrade 50 MPa (compressibility modulus 17 MPa) ; Subbase 250 MPa (compressibility modulus 35 MPa) ;

BSM 1.000 MPa, Cohesion = 265KPa and Friction angle = 38°

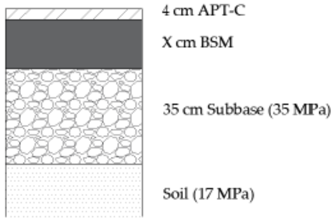
2 Standard structures with asphalt base layer



	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Thickness asphalt base layer	22	19	17	15	13	11	10	9	9	8
Thickness BSM layer	30	28	25	22	18	16	15	14	14	13

+4cm AC-14

3 Standard structures without asphalt base layer

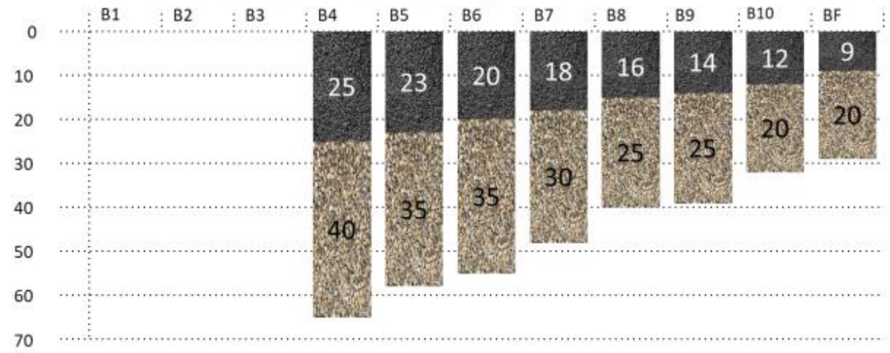


	B6	B7	B8	B9	B10
Thickness BSM layer	23	19	17	15	14

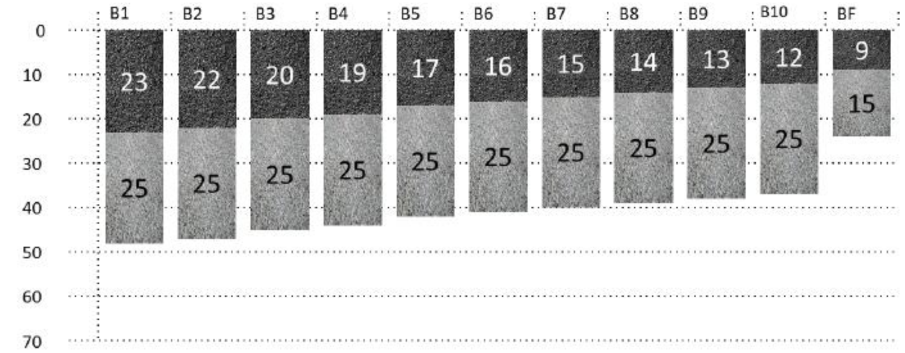
+4cm AC-14

More information in Final Report PART IV: Structural design of pavements with BSM.

Asphalt + unbound base (B5=4..8 MESAL)



Asphalt + cement-base (B7=1..2 MESAL)



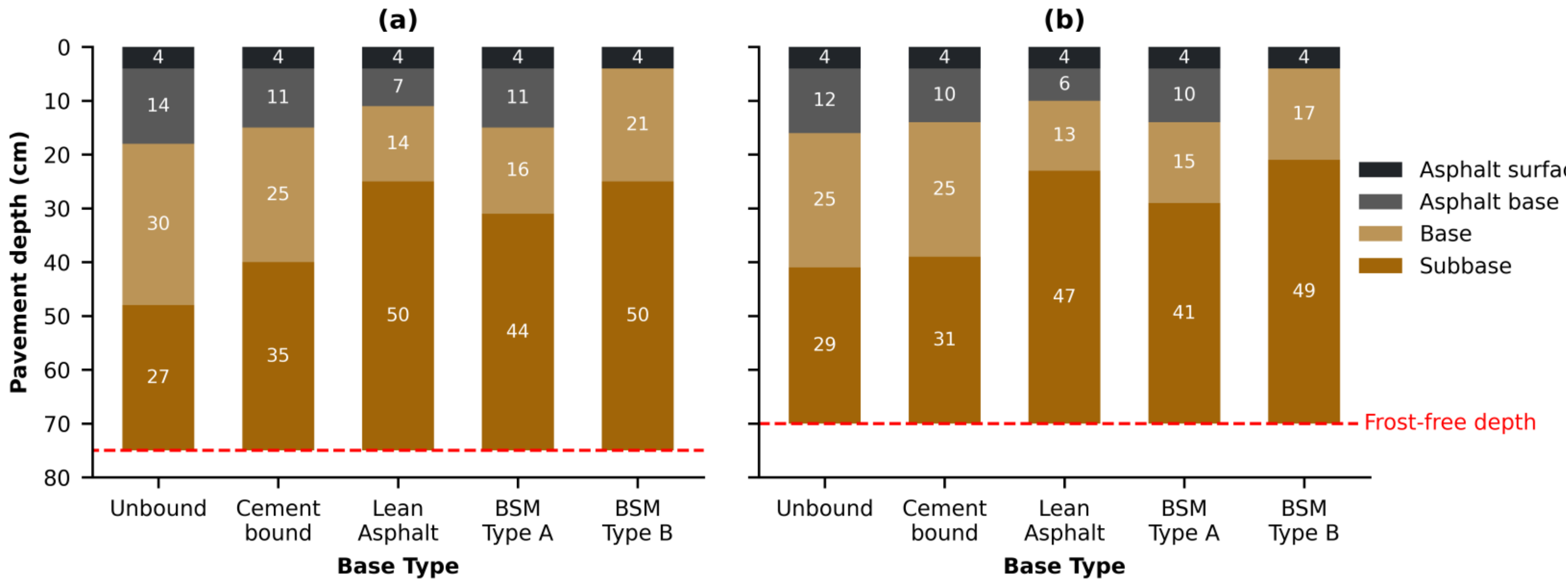
Environmental Impact of Using BSM as Base Material

- **Five alternative pavement structures with varying base layers per test track:**
  - Asphalt pavement with **unbound base** (standard structure);
  - Asphalt pavement with **cement bound base** (standard structure);
  - Asphalt pavement with **lean asphalt base** (standard structure);
  - Asphalt pavement with **BSM type A base** (with asphalt Base Layer);
  - Asphalt pavement with **BSM type B base** (without asphalt Base Layer);

- **Comments:**
  - Constant asphalt surface thickness;
  - Thickness asphalt base and base via (standard) design
  - Thickness of subbase is mainly determined by frost-free depth

https://www.uantwerpen.be/en/research-groups/supar/research/research-projects/foam/

<2M ESAL **<1M ESAL**




FOAM

Duurzame funderingen door in situ recycling met schuimbitumentechnologie

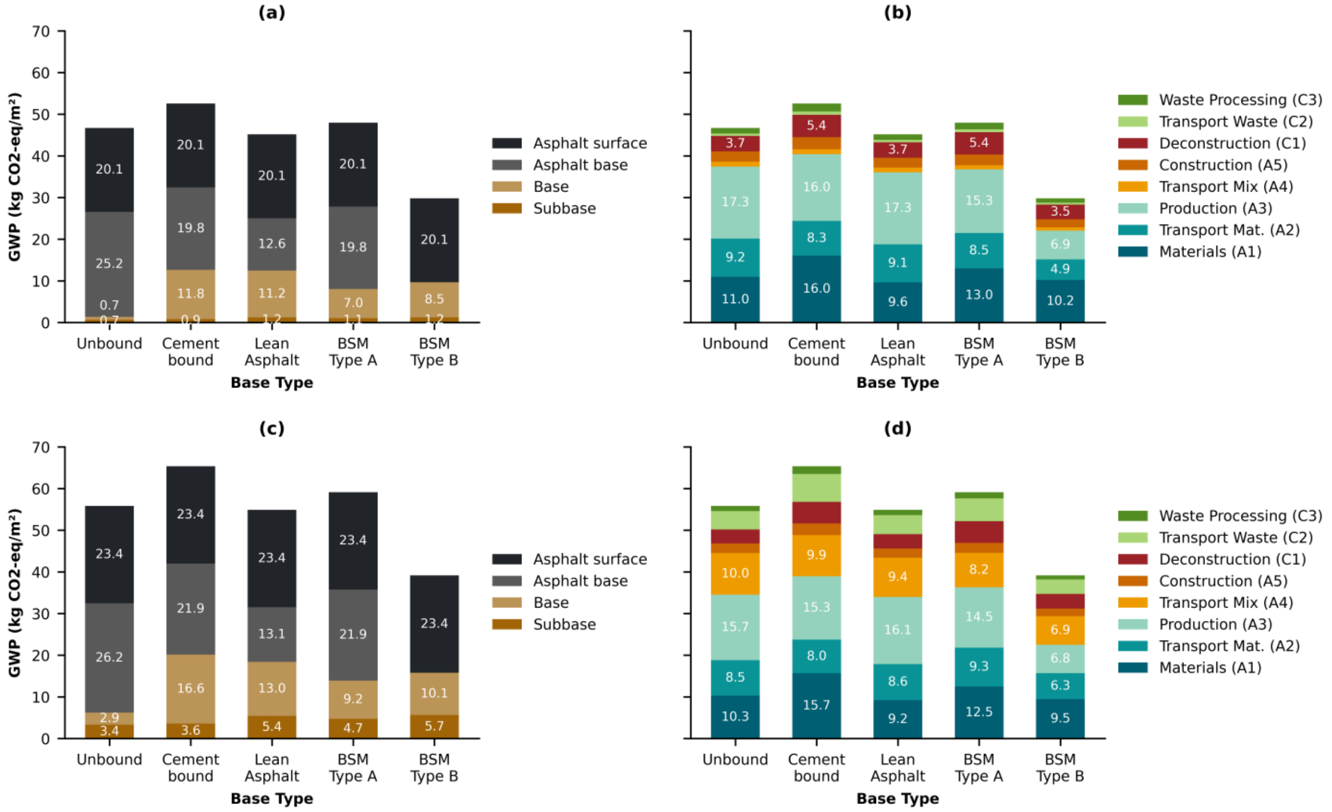
PART V:

SUSTAINABILITY ASSESSMENT OF PAVEMENTS WITH BSM

Environmental Impact of Using BSM as Base Material – Results LCA (2023)

Overall similar conclusion for both test tracks: 1 m2

- **Full structure:**
  - Cement bound structure highest impact;
  - BSM type B structure lowest impact;
- **Focus on base:**
  - Unbound base has lowest impact, but higher impact for asphalt base;
  - BSM base has the lowest impact of bound bases;
- **Life cycle phases:**
  - Material and production phase are main hotspots;
  - Transport to production site;
  - Deconstruction phase (TT1);
  - Transport of mixture to construction site (TT2);



“sustainability index”: case dependant

BSM in Flanders: From Research to Deployment

NEXT

Scaling & Deployment

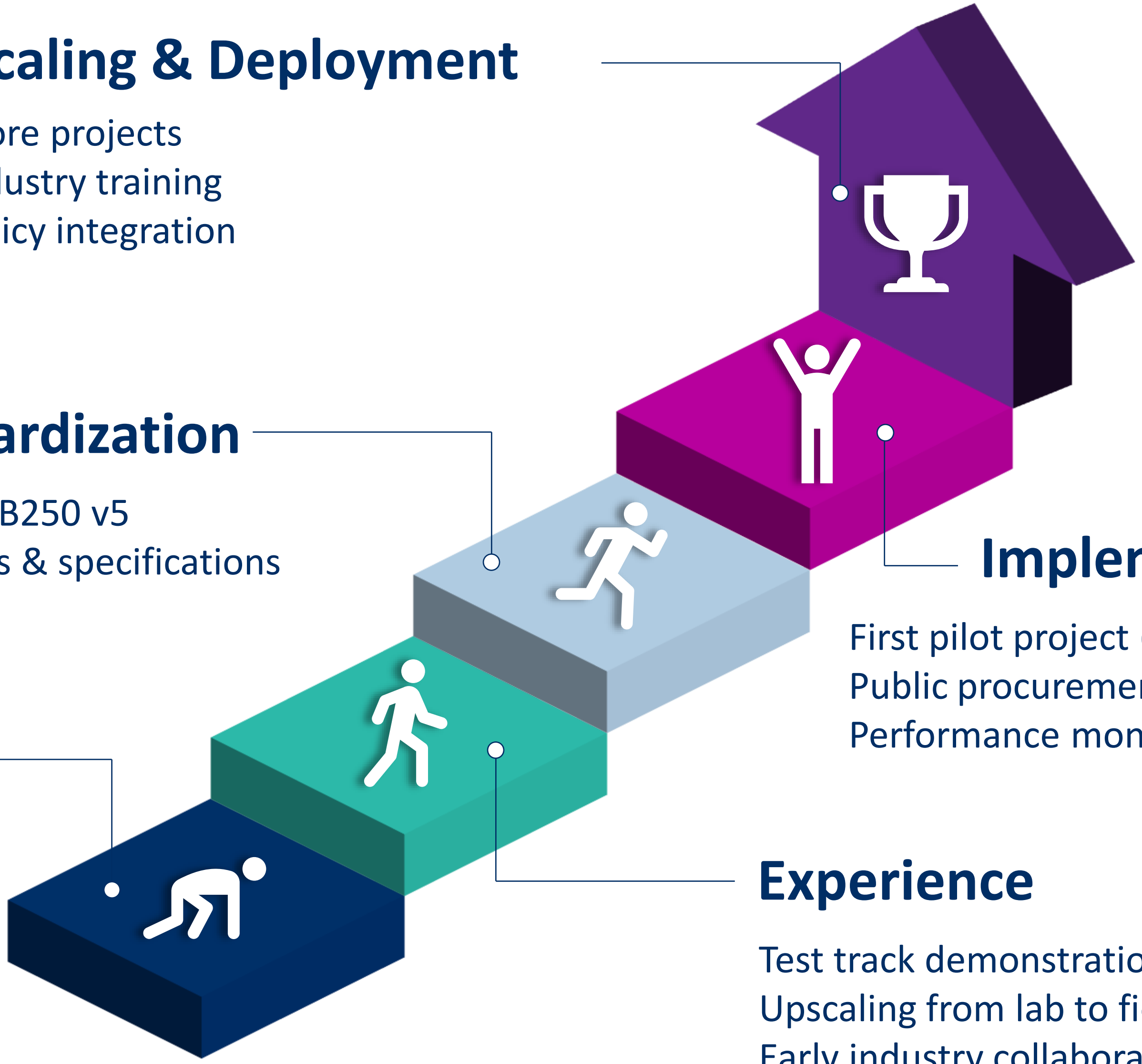
More projects
Industry training
Policy integration

Standardization

Inclusion of BSM in SB250 v5
Defined test methods & specifications
Sector acceptance

Learning

Research & PhD project
Laboratory testing
Material & Structural design studies



Implementation

First pilot project (Kielsbroek - City of Antwerp)
Public procurement using SB250 v5
Performance monitoring

Experience

Test track demonstrations
Upscaling from lab to field
Early industry collaboration

BSM in Flanders: When and Where It Makes Sense

Sustainable GPP projects

Supports Green Public Procurement by lowering CO_2 emissions and life-cycle costs.

Low-cost rehabilitation

More cost-effective than hot recycling or reconstruction, with local material reuse.

Low-traffic roads and sub-base layers

Proven application for municipal and rural networks, with efficient reuse of RAP

Heavily cracked pavements with good subgrade

Restores structure without full-depth reconstruction

Moisture-damaged pavements

Enhances cohesion and water resistance in high groundwater areas (e.g., polders); works best with stabilized subgrade

Heavy-traffic roads (future potential)

With optimized mix design and structural evaluation, BSM can be extended to motorways in Flanders.

BSM is a sustainable, cost-efficient solution for Flemish roads today, with growing potential for heavy-traffic applications

Challenges & Mitigations in BSM Projects

	Challenge	Mitigation Plan
€ ⏱	Inconsistent pavement profile	➢ Detailed pre-investigation ➢ Adjust mix design with local variability ➢ Stabilize weak subgrade sections
€ ⏱	Rainfall during construction	➢ Forecast planning ➢ Fog spray / curing seals immediately after compaction
⏱	Material transfer issue (bridging conveyor failure)	➢ Good truck flow management ➢ Regular equipment checks ➢ Trained / Skilled operators
€ ⏱	High moisture in RAP	➢ RAP protection ➢ Processing close to time of construction
⏱	Manholes	➢ Pre-survey ➢ Mill or patch around manholes ➢ Use a smaller plant on manhole sections
⏱	Testing challenges	➢ Adapted test protocols ➢ Trained staff ➢ Reliable field density checks

Pilot Sections in Flanders

Mixture composition:
100% crushed RAP (0/20) – stockpile
2.2 % Foamed bitumen (70/100)
1% Active Filler: Cement III/A 42.5 N

Towards a Sustainable Base Layer by Cold Recycling Technology with Foamed Bitumen
Tetra Project HBC.2020.2094 FOAM

Test Track 1

Test Track 2

Fresh Findings with BSM

Can we produce BSM with Bio–based binders?

- 30% Bio-based binder (Latexfalt 30-85)

What are the effects of high-quality fillers?

- Improved homogeneity of mixture
- Better moisture regulation
- Enhanced bonding and load-bearing capacity

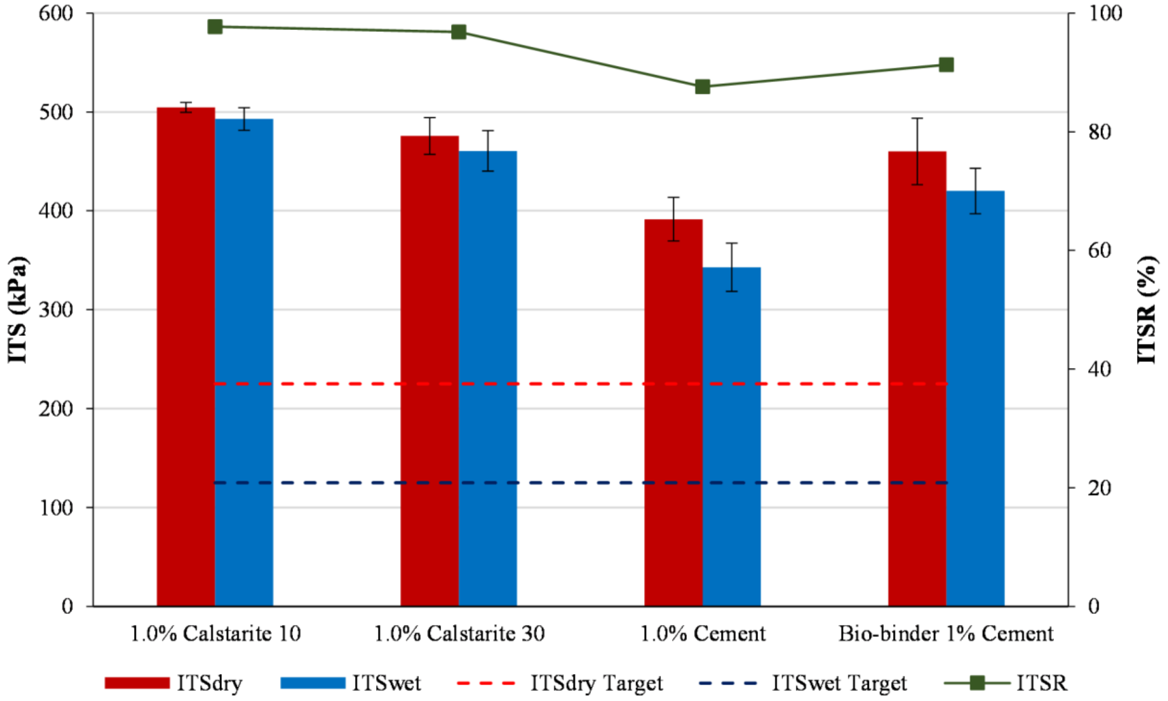
Calstarite: Powdered, lime-containing binders derived from industrial by-products (fly ash)

Calstarite 10

- ~12% free CaO
- moderate reactivity, suitable for general stabilization

Calstarite 30

- ~30% free CaO
- higher reactivity, suitable for challenging situations with high moisture



Fresh Findings on BSM

30% Bio-based binder
+ 1% cement

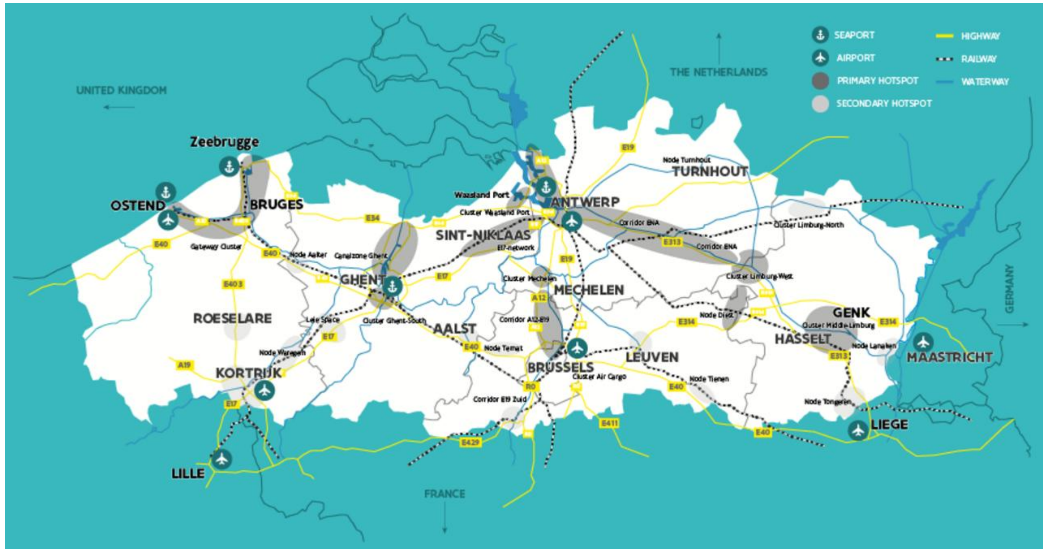
70/100 binder
+ 1% cement

70/100 binder
+ 1% Calstarite 10

70/100 binder
+ 1% Calstarite 30

Conclusions & Next Steps in Flanders

- BSM is a sustainable and cost-efficient road solution.
- Supports **Green Public Procurement** by reducing CO_2 and life-cycle costs.
- Maximizes RAP reuse, lowering waste and transport needs.
- Effective for the rehabilitation of cracked or moisture-damaged pavements.
- **Pilot projects** confirm feasibility and demonstrate performance.
- Standardized in **SB250 v5**, ensuring clear specifications and sector acceptance.
- Research, test tracks, and training provide a strong knowledge base.
- Challenges (e.g., moisture, manholes, RAP variability) can be managed with proper planning.
- **Next step:** scale up projects, expand industry training, and raise awareness.



"BSM is ready for wider deployment in Flanders."

FOAM

THANK YOU

Project Manager

Prof. Wim Van den bergh

wim.vandenbergh@uantwerpen.be

PhD Student

M.Sc. Ecem Nur Barisoglu

ecemnur.barisoglu@uantwerpen.be

University of Antwerp
SuPAR I Sustainable Pavements and Asphalt Research