What is happening in the mixing drum?

RAP/RAS recycling studied at small length scale

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WG1: Hot Recycling of RAP

TU Delft

Introduction to RAP

Asphalt pavement is recycled into new pavement material

Scarcity of raw material (aggregate), waste disposal problem: recycling is inevitable

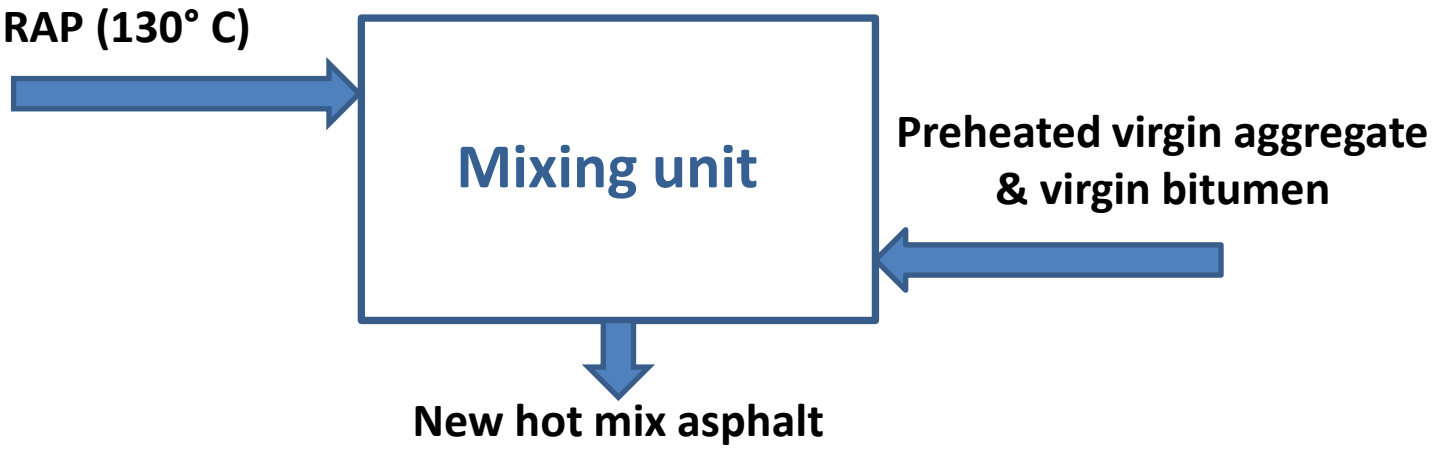
Netherlands:

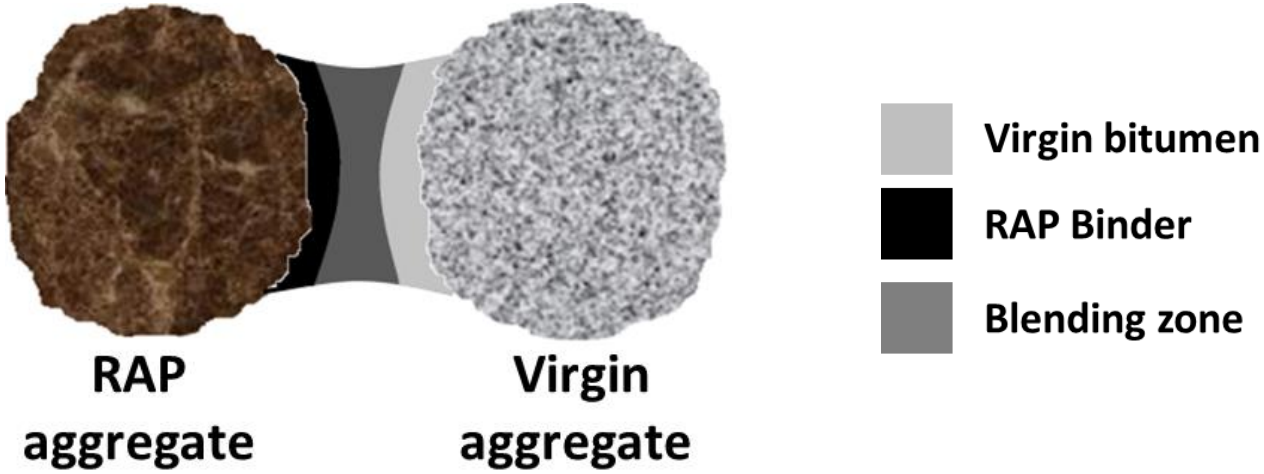
- ~ 4 million tons of reclaimed asphalt in 2010
- 80% of available RAP is recycled
- 50% RAP allowed in dense asphalt

Challenge

Increase RAP content without compromising mechanical properties.

The recycling process





Blending scenarios for RAP

- Complete mixing
- Partial mixing
- No mixing (‘black rock’)
- Blending (= materials rearrange into ‘new’ material)

Performance of asphalt containing RAP

From literature:

Asphalt pavements containing RAP perform better w.r.t.:
+ elastic modulus
+ tensile strength
+ rutting resistance

But
-RAP deteriorates in fatigue characteristics
→ **attributed to 'degree of blending' of RAP with fresh bitumen**

(McDaniel 2000, Aurangzeb 2012)

Means of probing the mixing of RAP with virgin binder

Indirect method

Mechanistic approach: based on rheology (DSR)

Interface detection: based on measuring the diffusion of components between two binders (FTIR)

Direct Method

Nano-indentation: To detect the interface between two binders

Limitation-

- Hard to find interface (scatter)
- Allowable sample temperature very low (-10°C)

Optical microscopy: not possible

→ Scanning probe microscopy (AFM)

Binder Properties

RAP binder extraction:

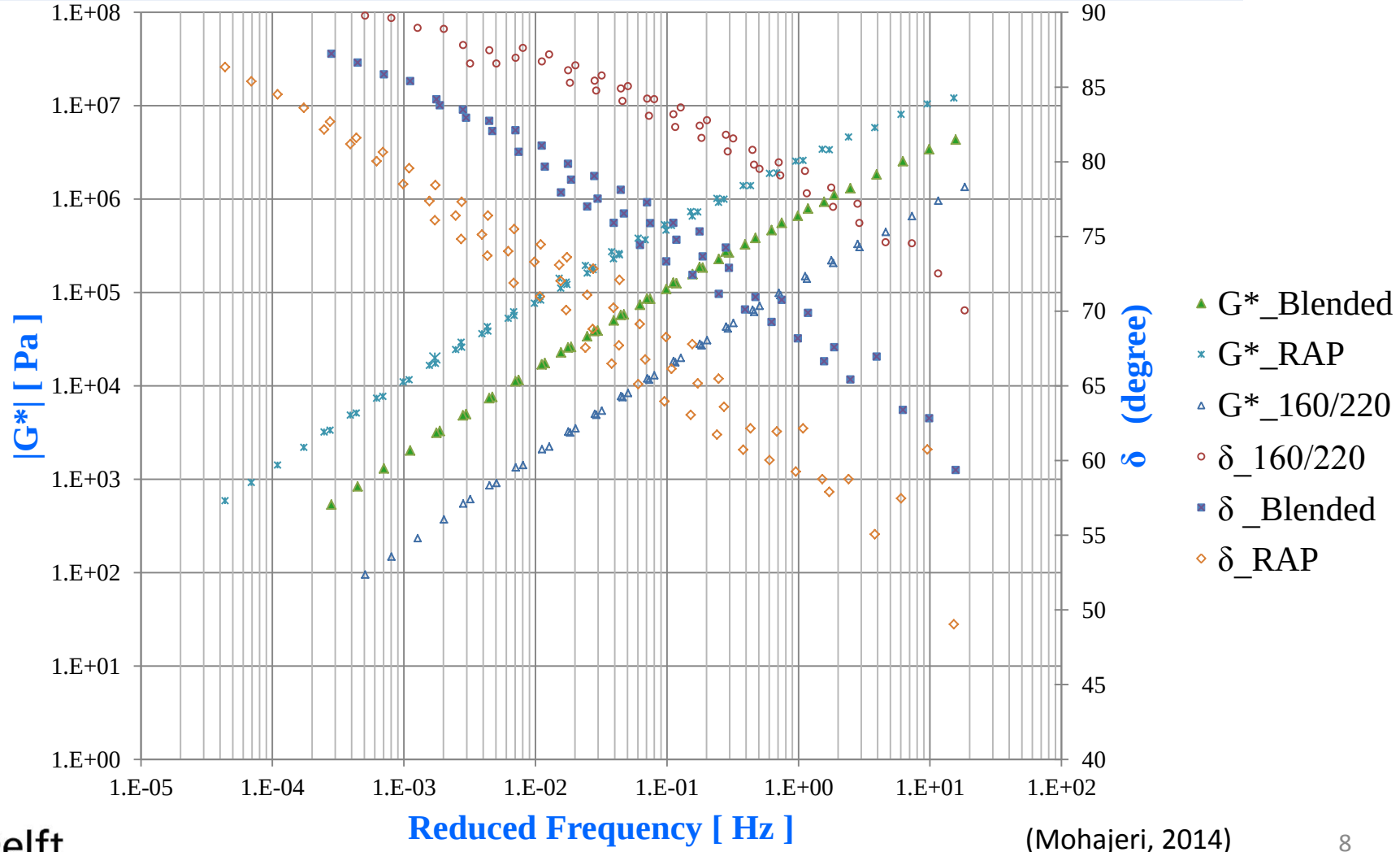
- Solvent extraction by methylene chloride (EN 12697-1)
- Rotary evaporation (EN 12697-3)

	RAP binder	Virgin bitumen (160/220)
Pen-grade (25°C)	21	164
Softening point (°C)	60	43
Mass density (g/cm^3)	1.035	1.020

Mechanistic approach:
The effect of blending on binder stiffness

Log pen rule : $a \log pen_{RAP} + b \log pen_{virgin} = (a + b) \log pen_{mix}$, $a + b = 1$

RAP binder +virgin bitumen (1:1 ratio, 5 min,160°C) = blended bitumen



(Mohajeri, 2014)

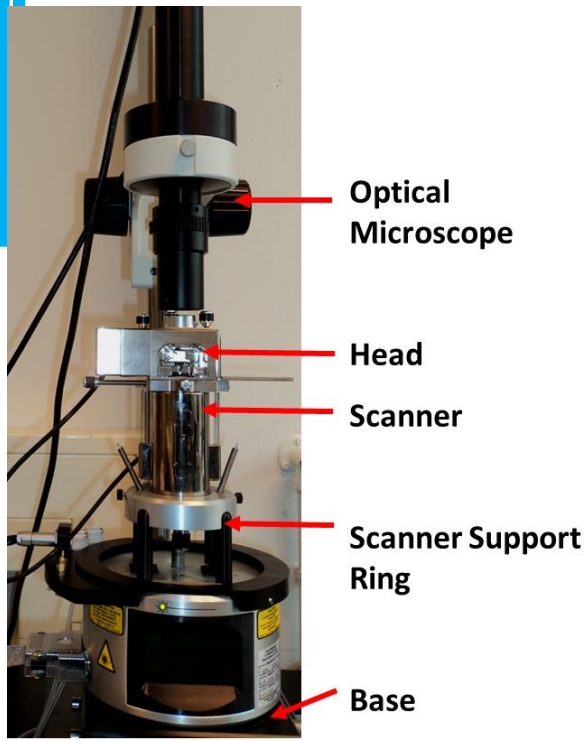
Atomic Force Microscope

Primary operating modes:

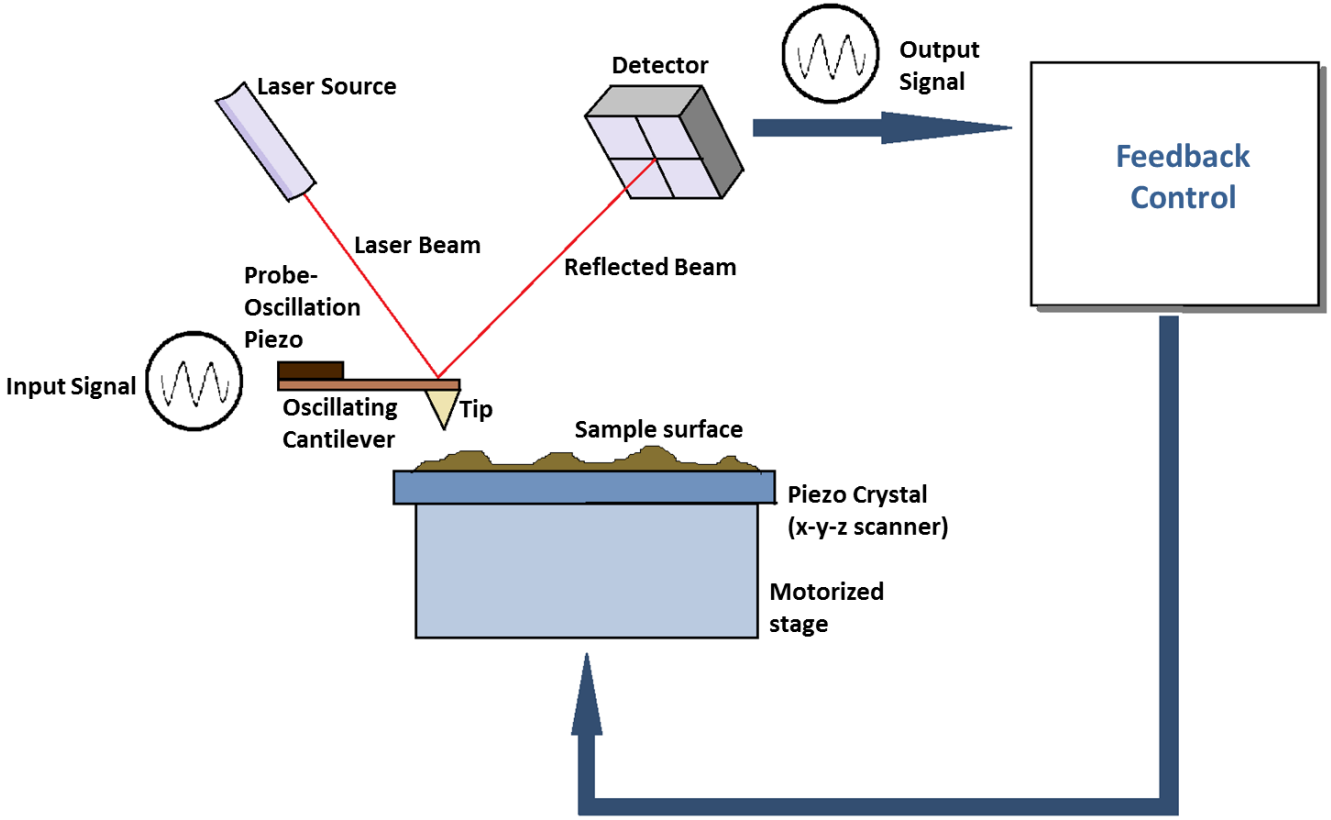
Contact (rigid samples)

Intermittent contact (soft and adhesive samples)

Non-contact (extremely soft samples)



Multimode V



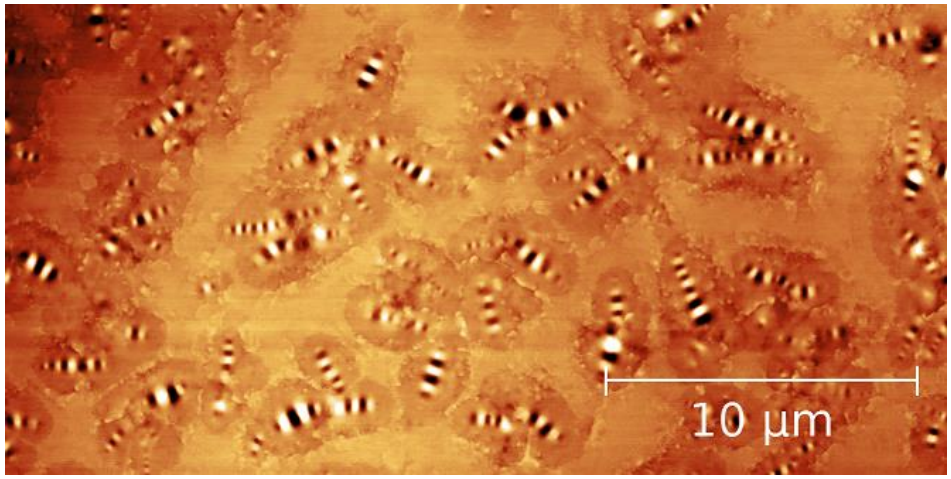
Bitumen observed with AFM

- Bitumen exhibits discontinuities at micrometer scale;

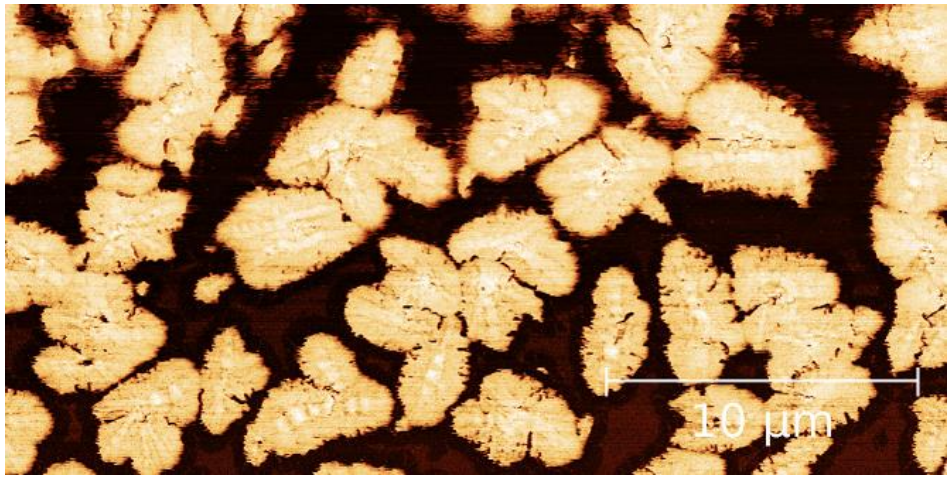
  2/3-phase morphology → microstructure

- Microstructural details depend on:

- molecular composition (crude origin, production parameters)
- thermodynamic history
- environmental conditions (aging, oxidation)

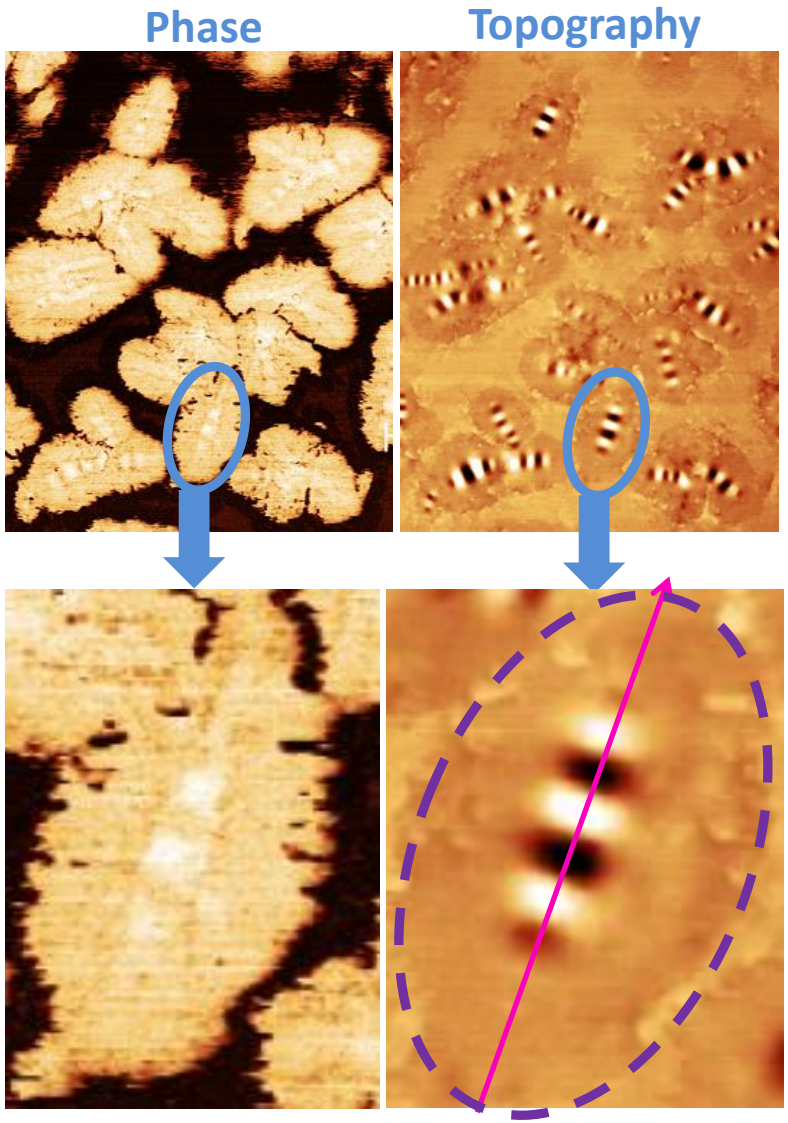


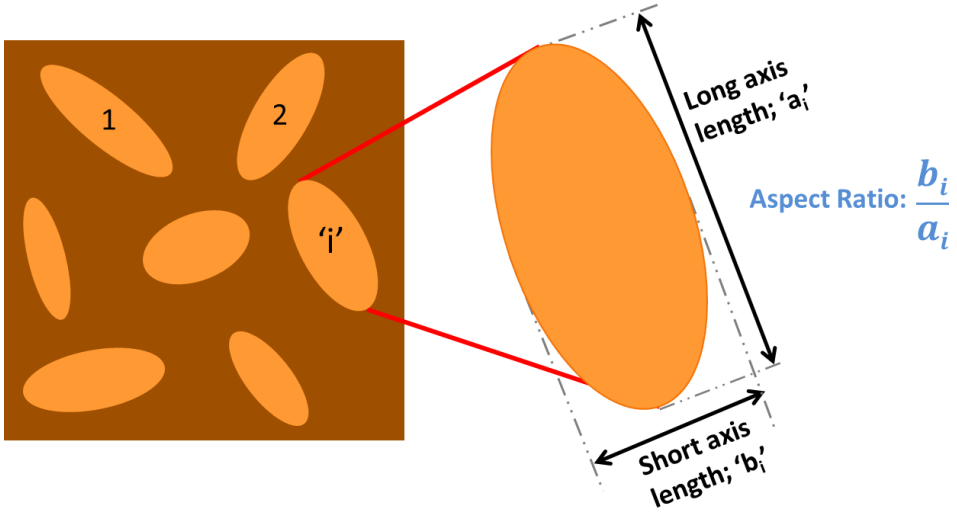
Topography

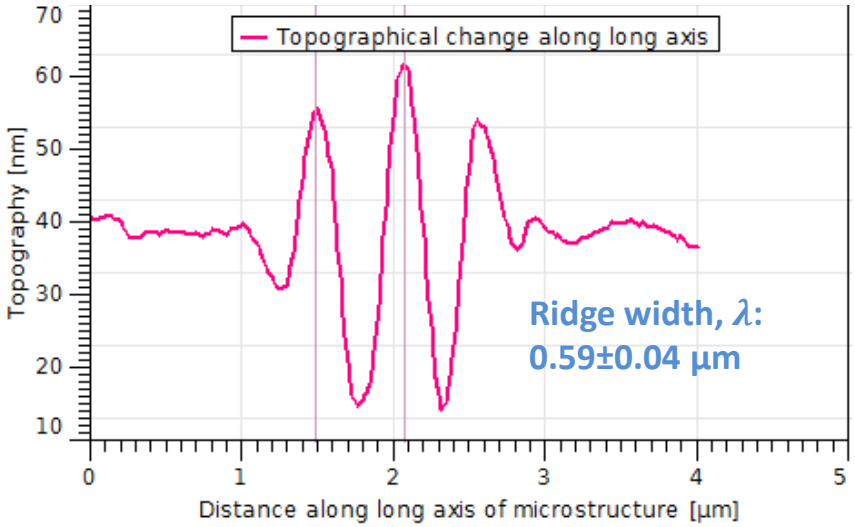


Phase

Microstructural details observed by AFM

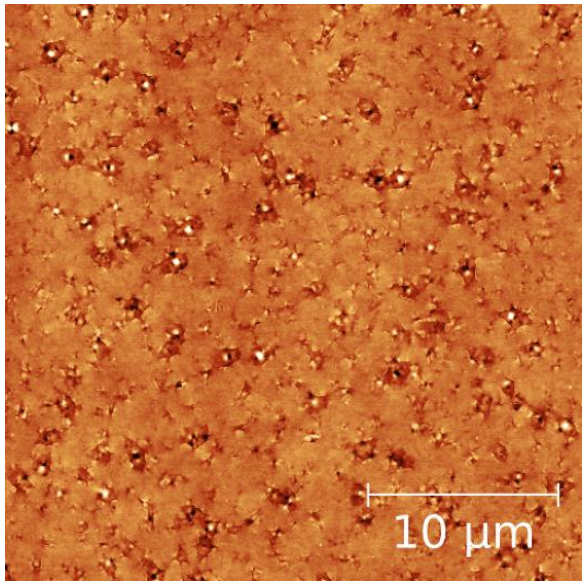


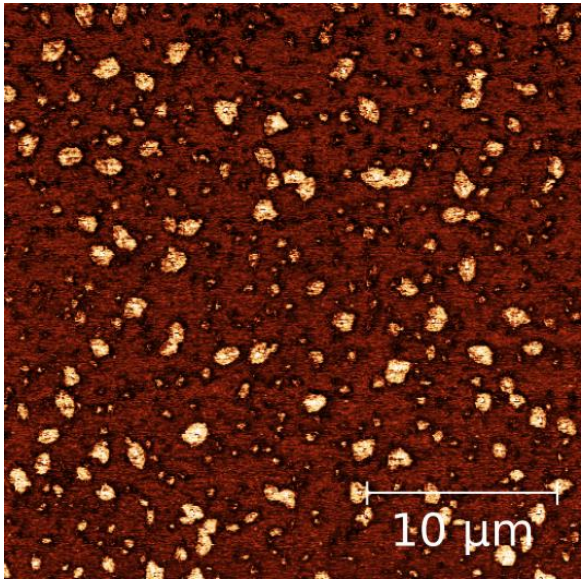




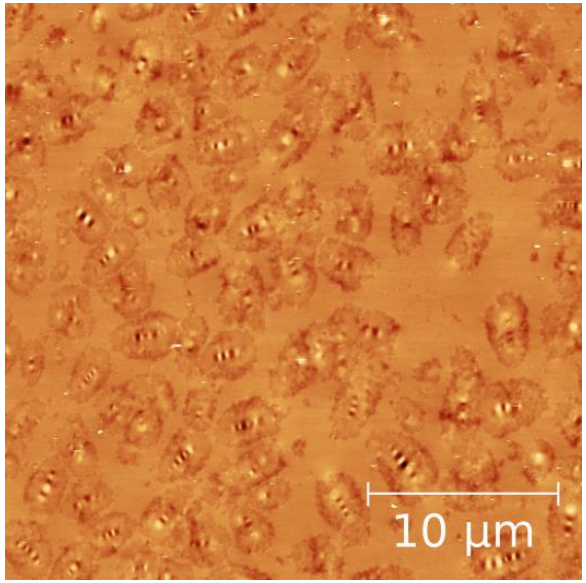
Microstructure of RAP & virgin binder

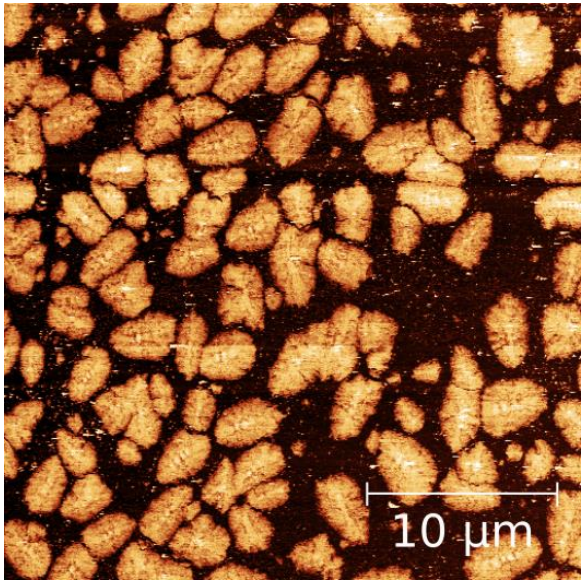
RAP-binder





Virgin-binder

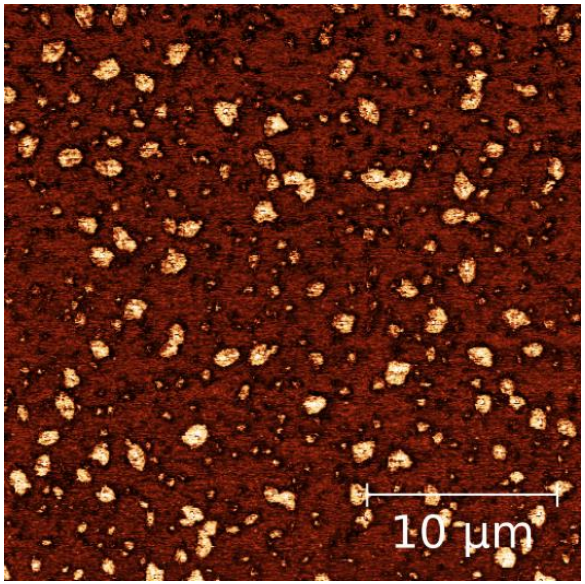




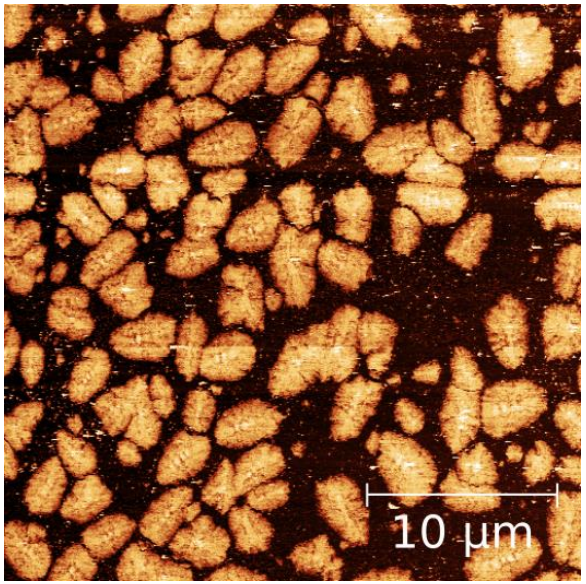
Topography **Phase**

Qualitative comparison of the microstructure

RAP- binder



Virgin bitumen
(160/220 pen grade)

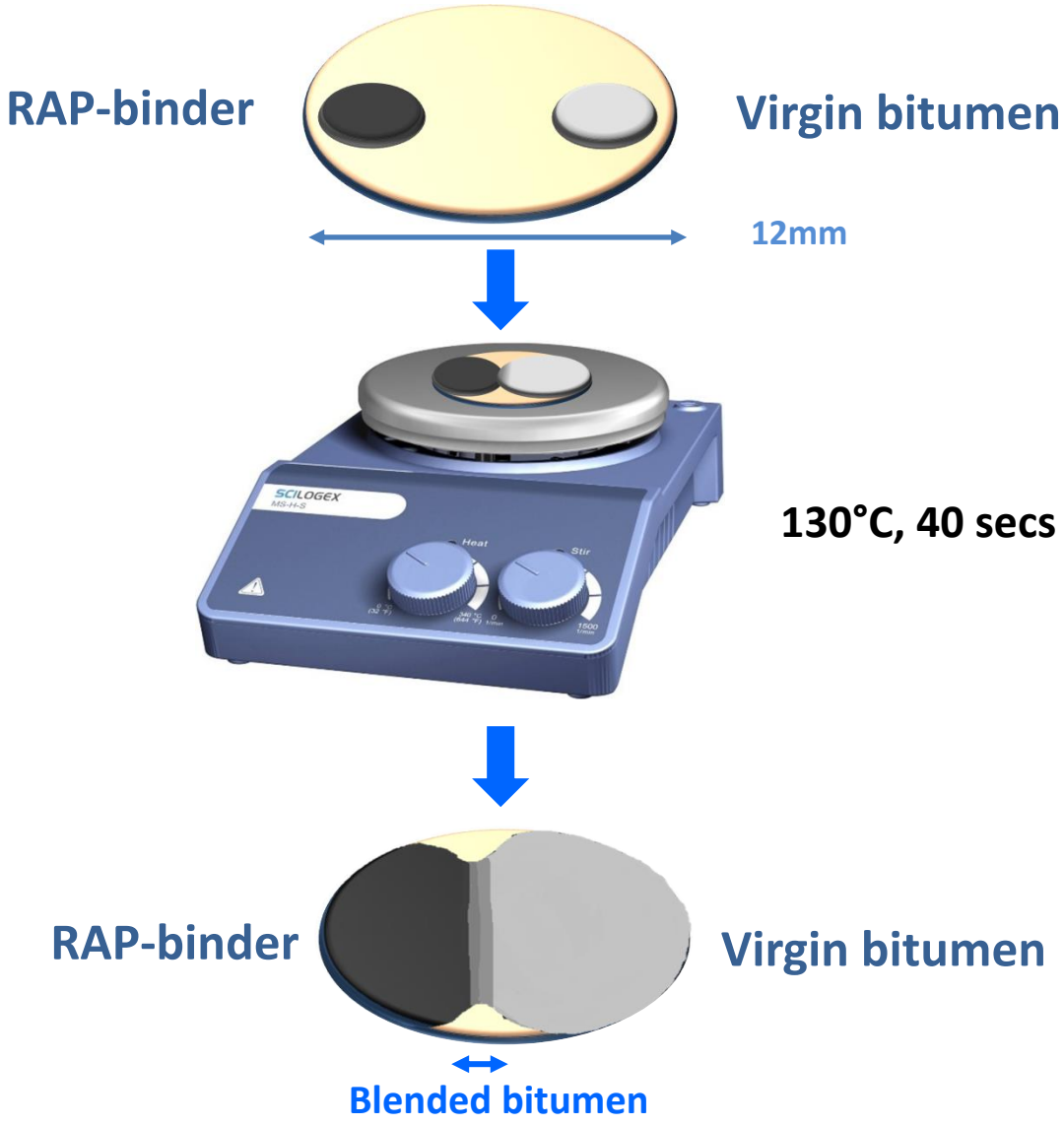


Scan size: 30µm

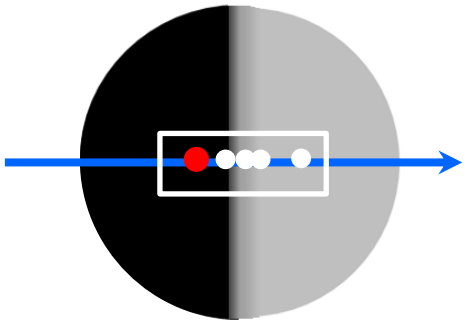
Comparison of domain phases of the microstructures:

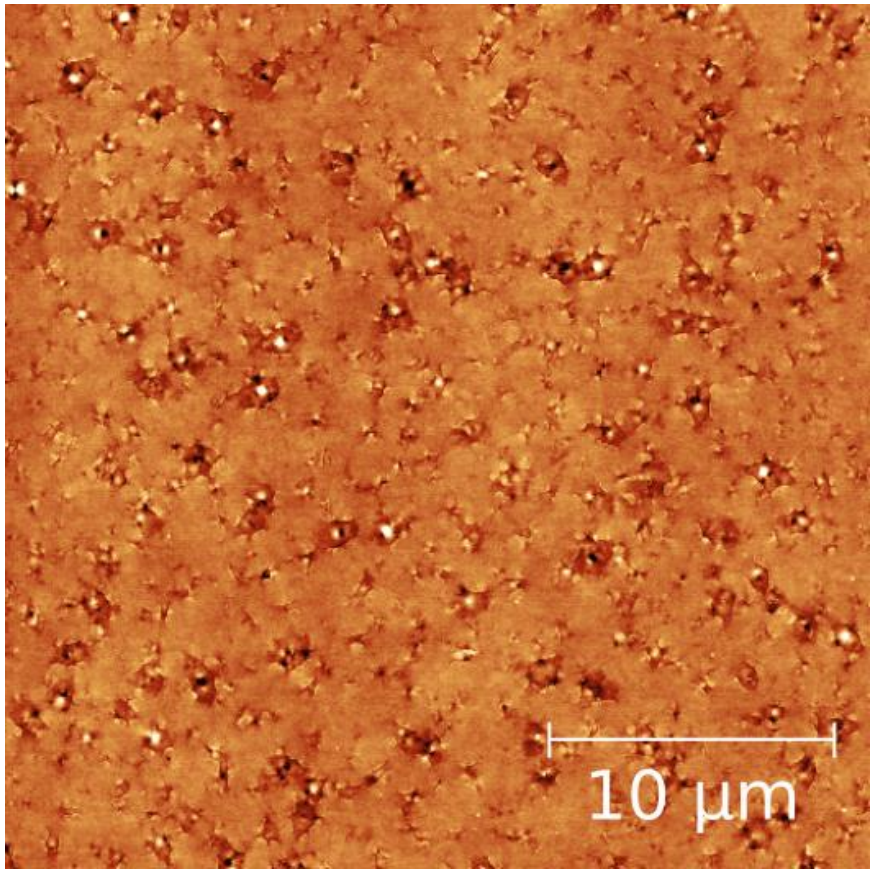
	RAP binder	Virgin bitumen
Size	Small	Large
Shape	Round	Elliptical
Surface coverage	Lower	Higher

Laboratory mimicking of blending and interface formation

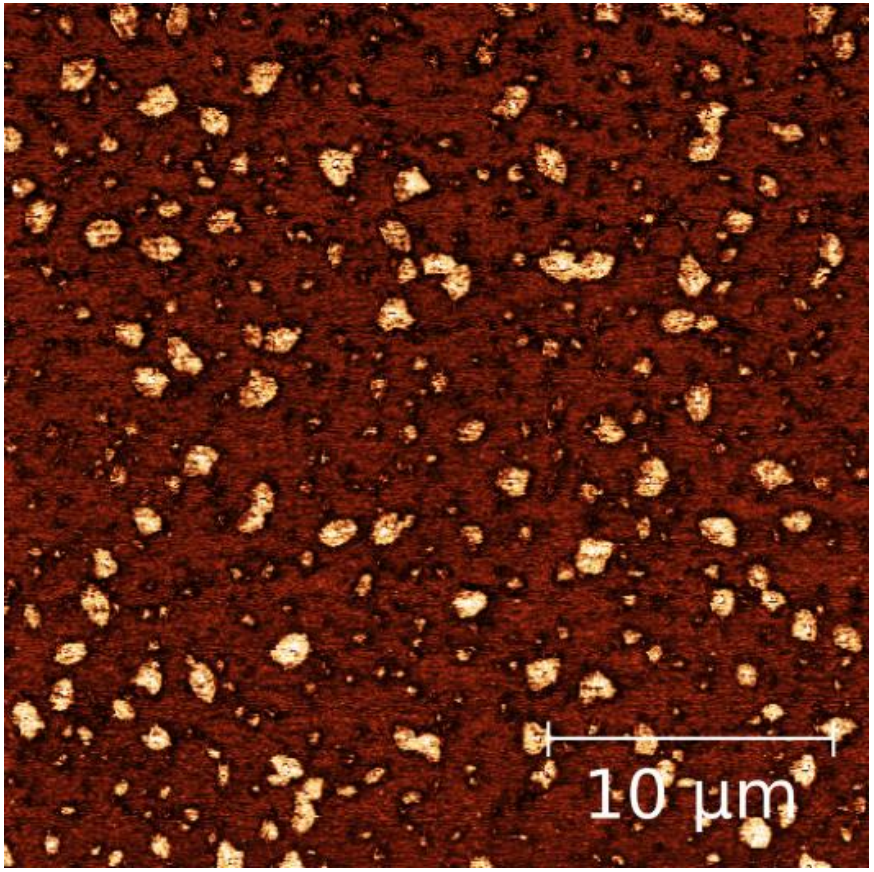


RAP-binder morphology





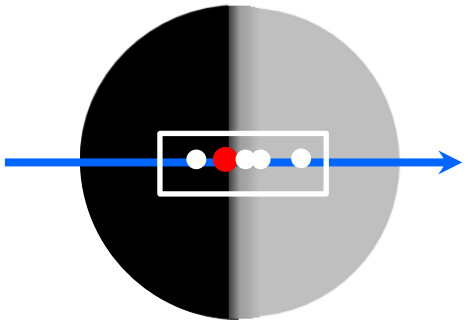
Topography

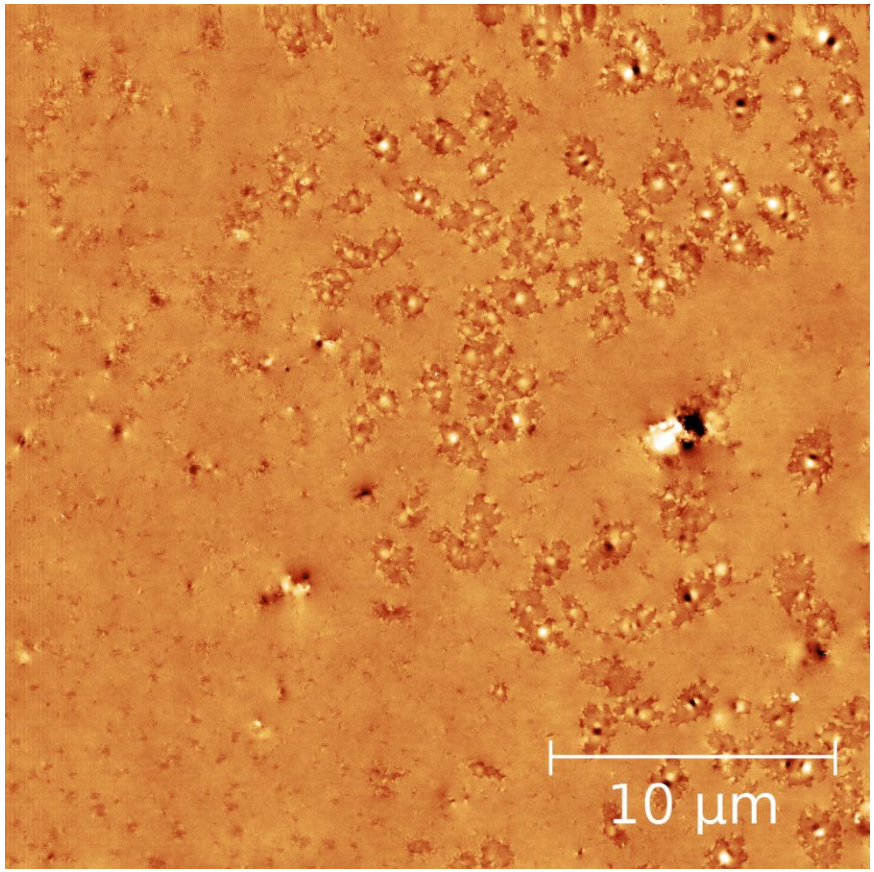


Phase

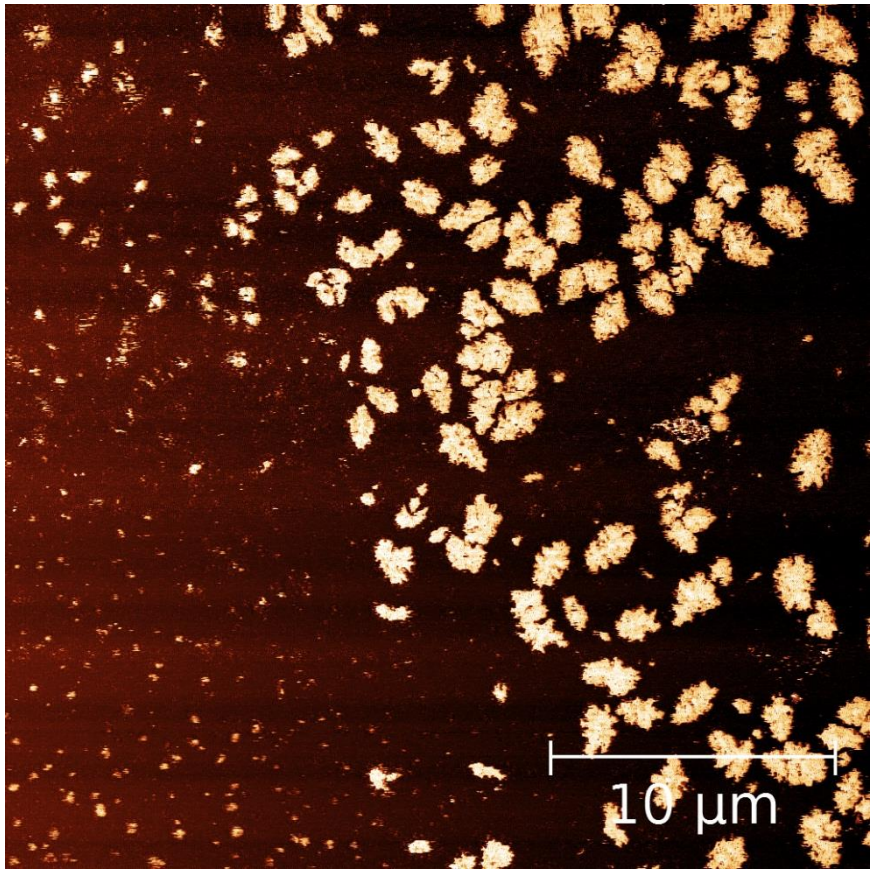
Scan size: 30µm

RAP-binder towards interface (Transition zone)





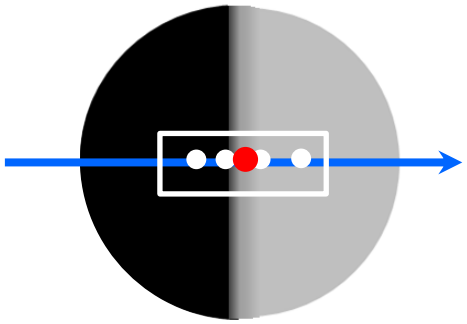
Topography

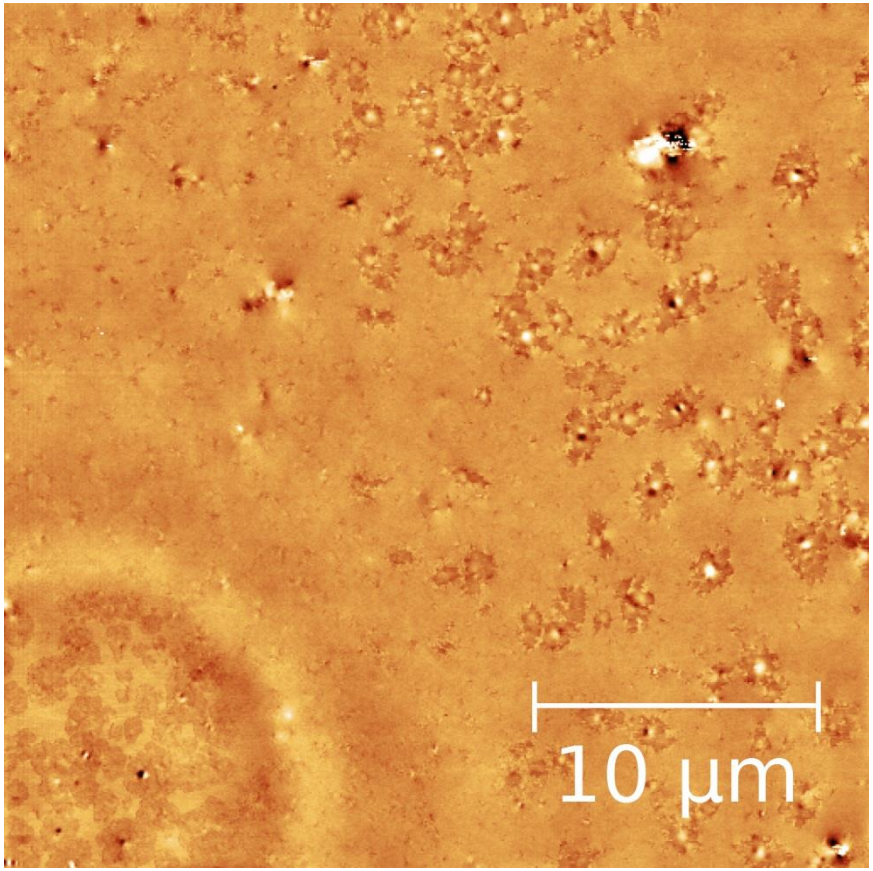


Phase

Scan size: 30µm

‘Blended’ zone





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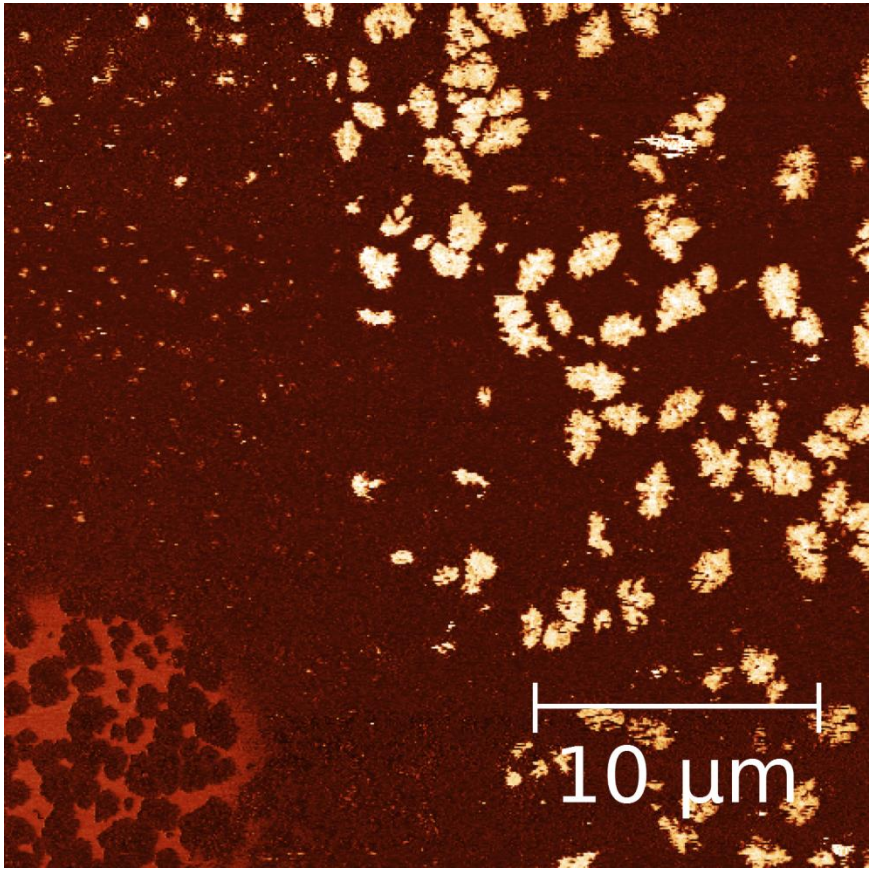
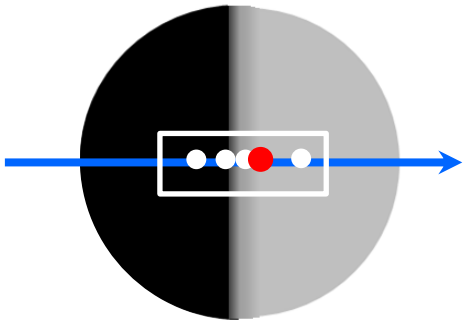
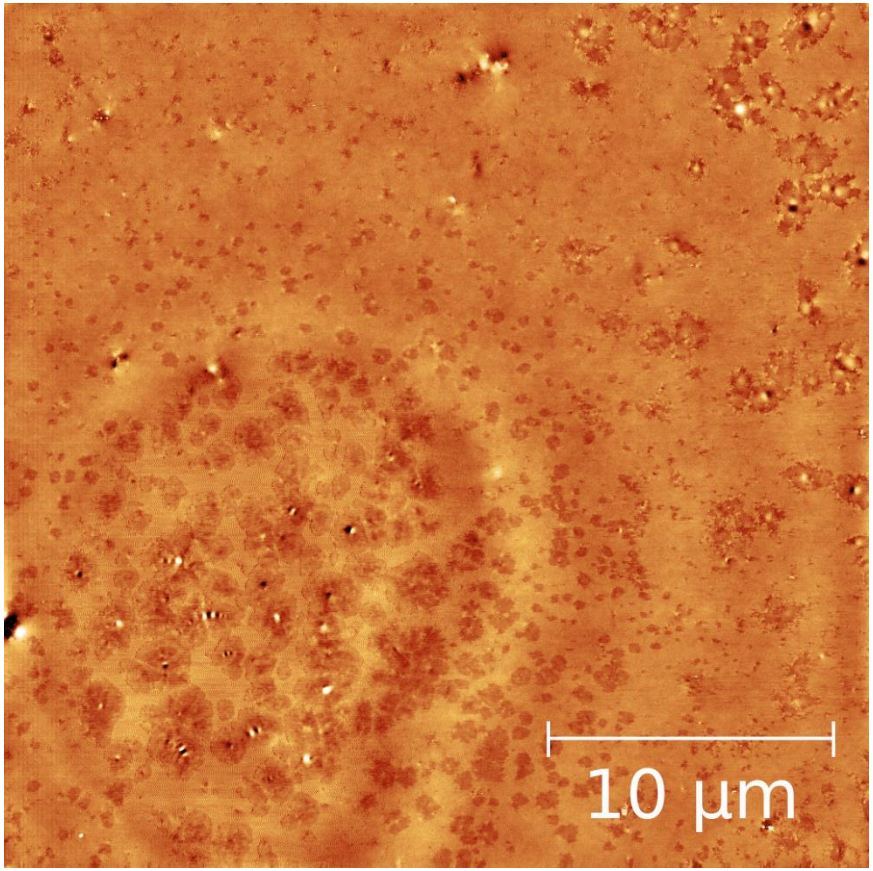


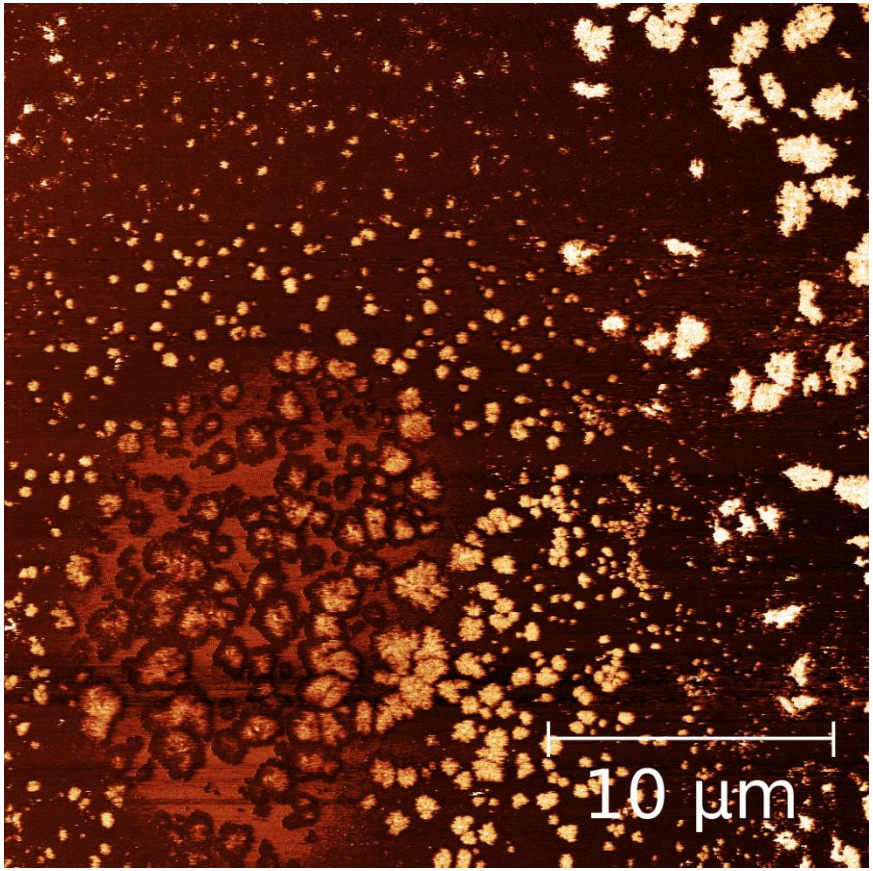
Phase

Scan size: 30µm

'Blended' zone





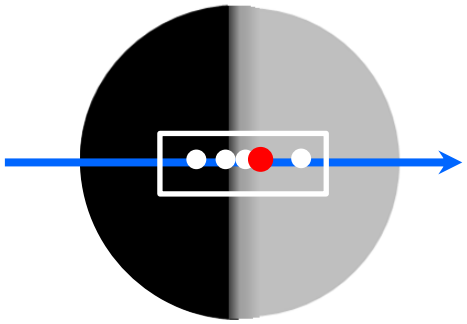


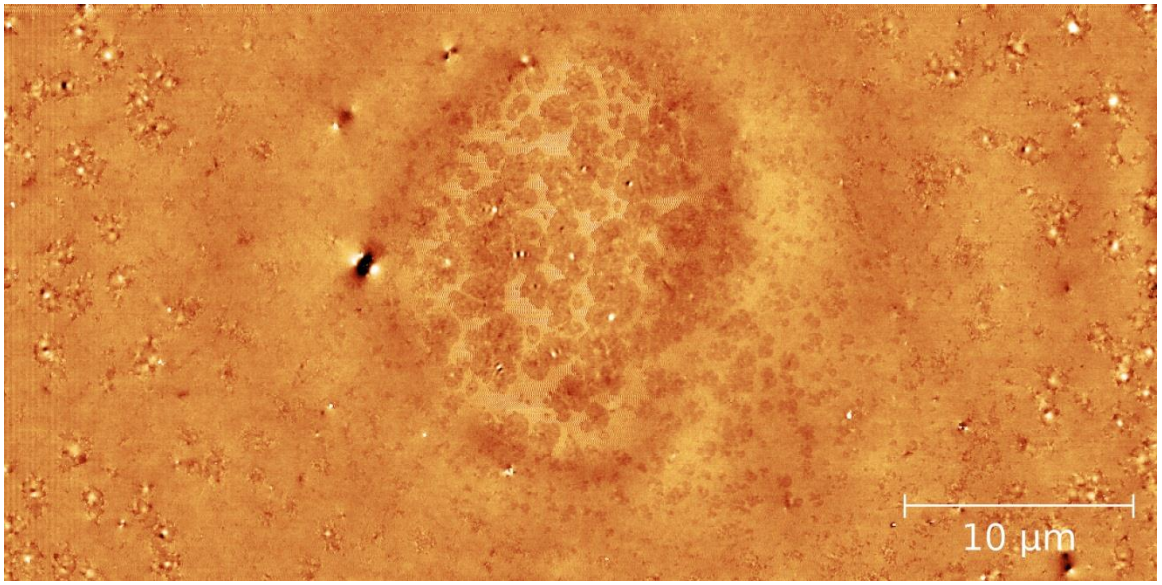
Topography

Phase

Scan size: 30µm

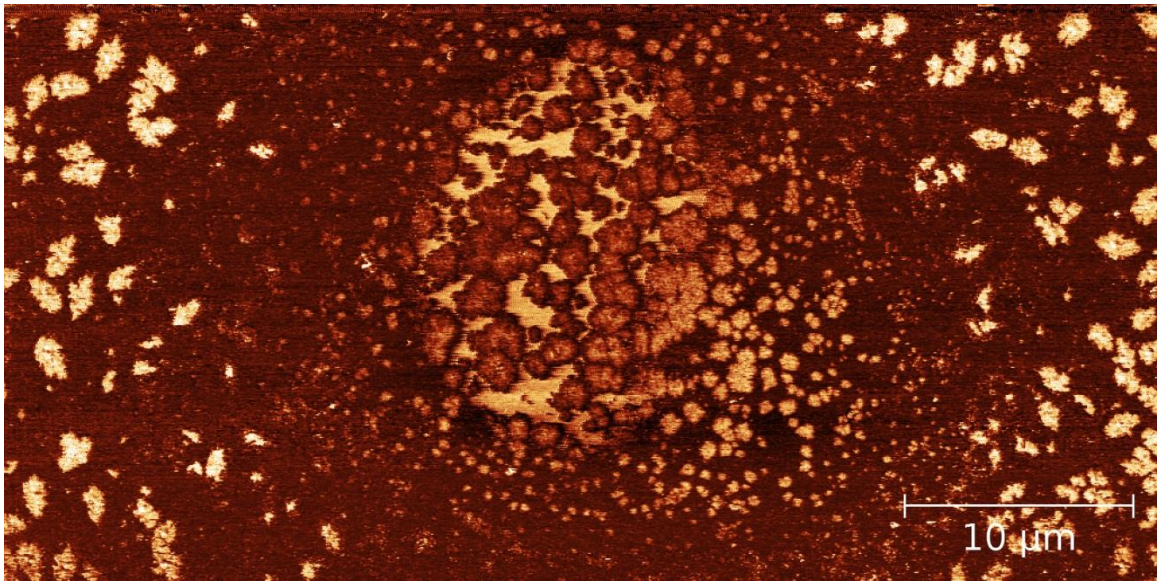
‘Blended’ zone (detail)





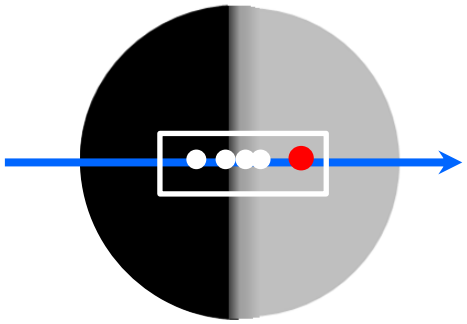
Topography

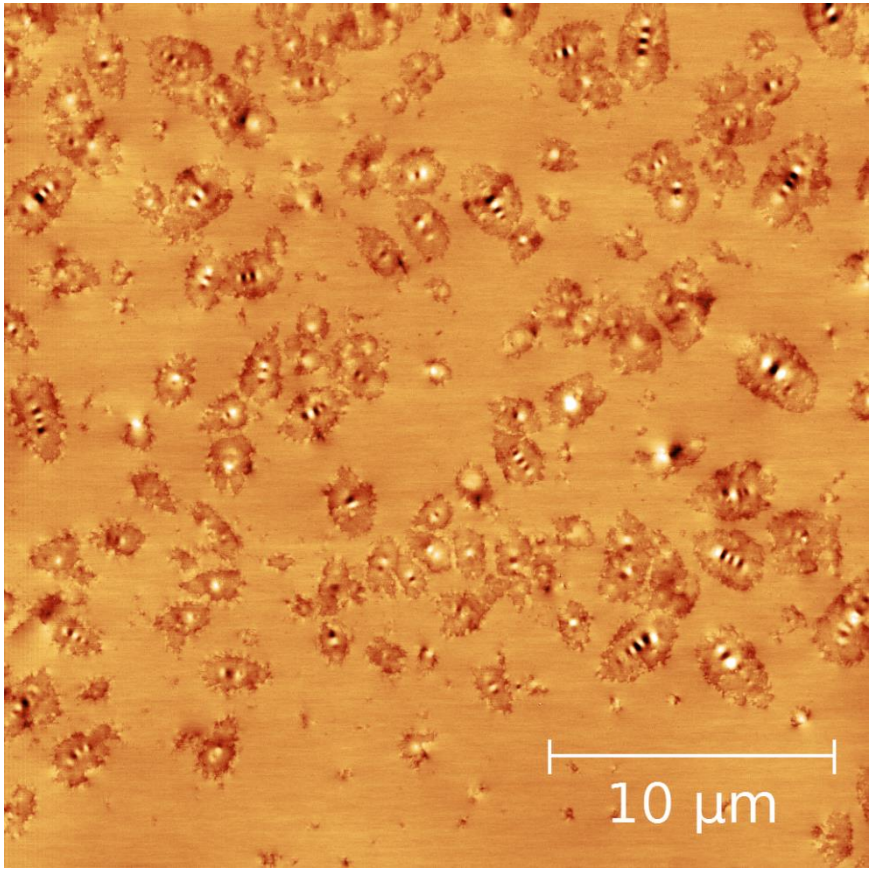
Scan size: 50µm



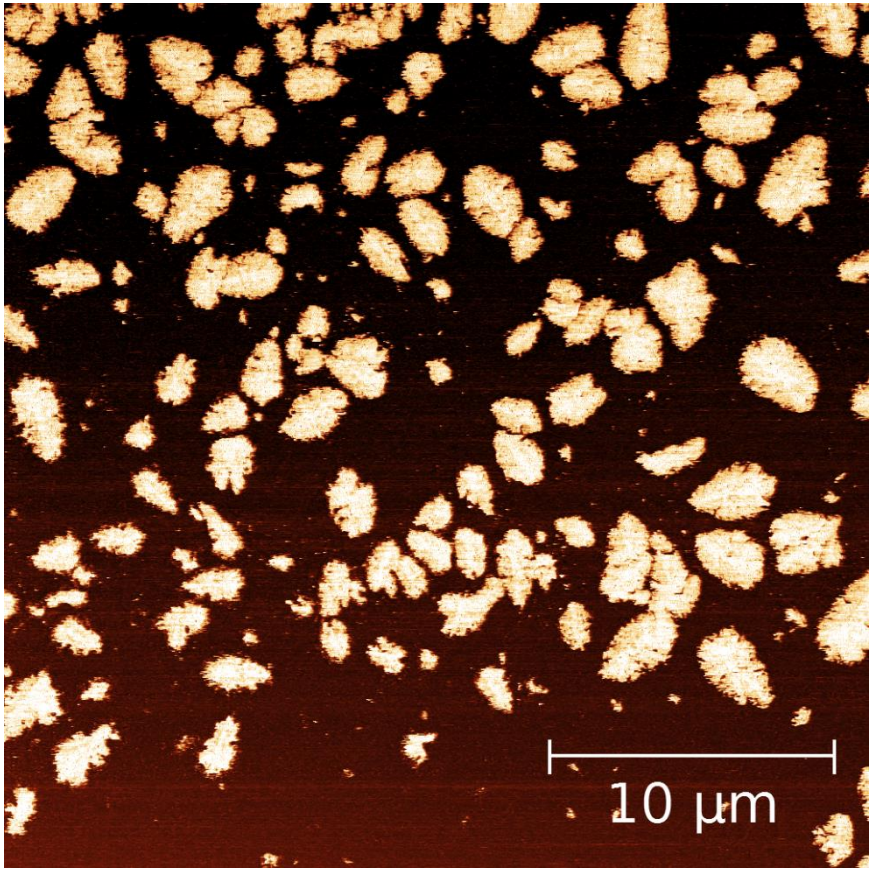
Phase

Transition to virgin 160/220 bitumen





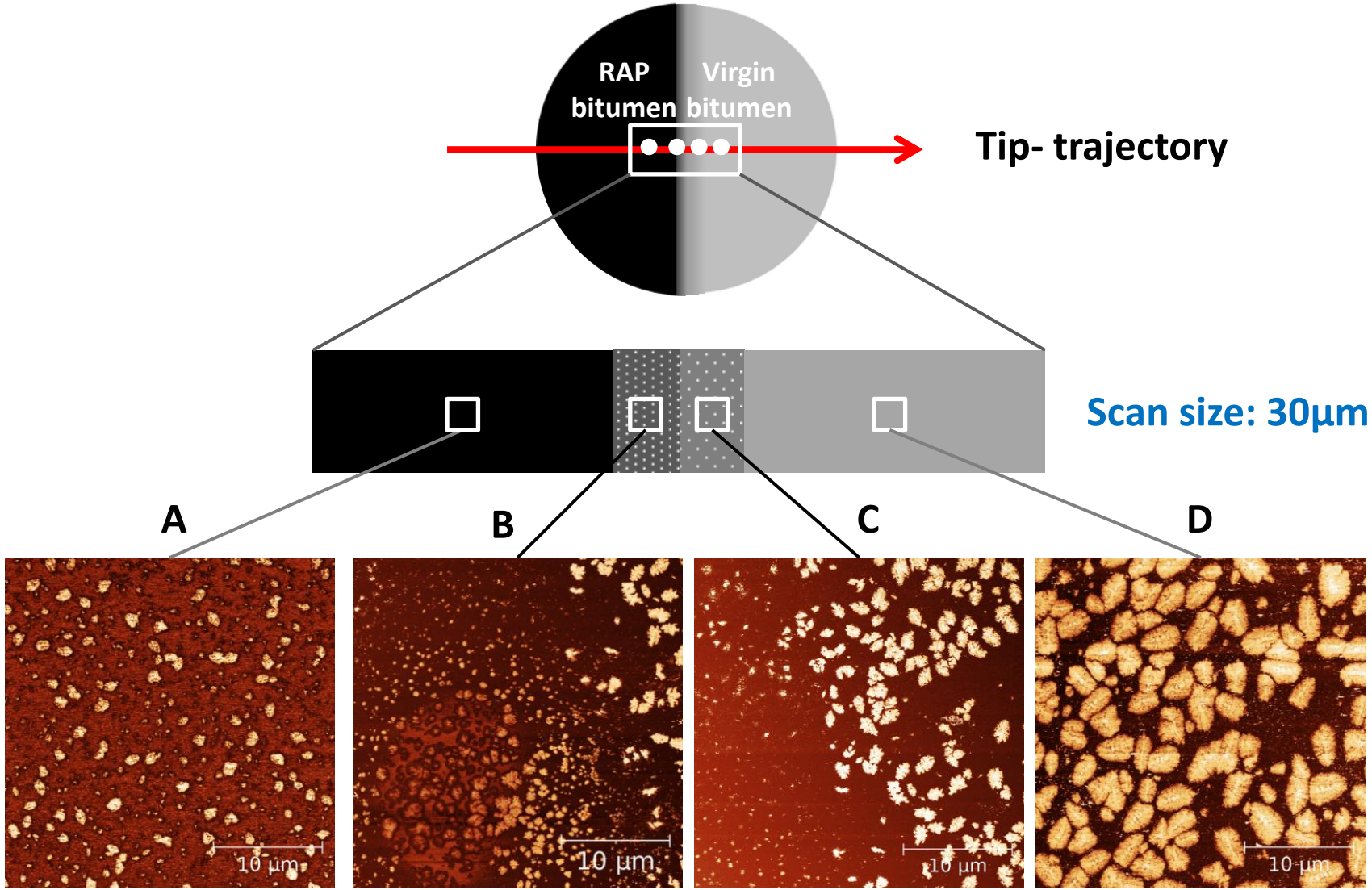
Topography



Phase

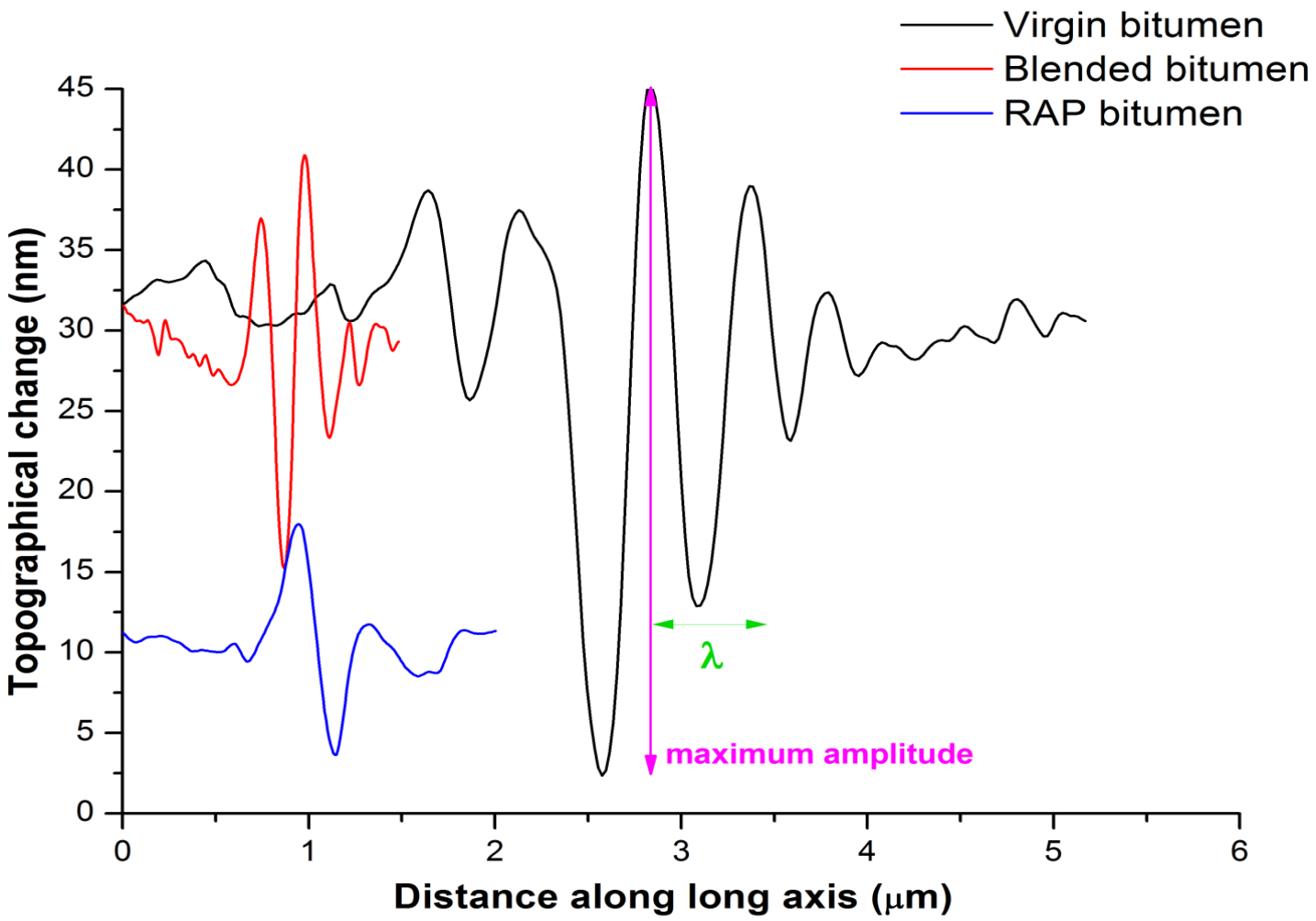
Scan size: 30µm

Measurement scheme and results at a glance

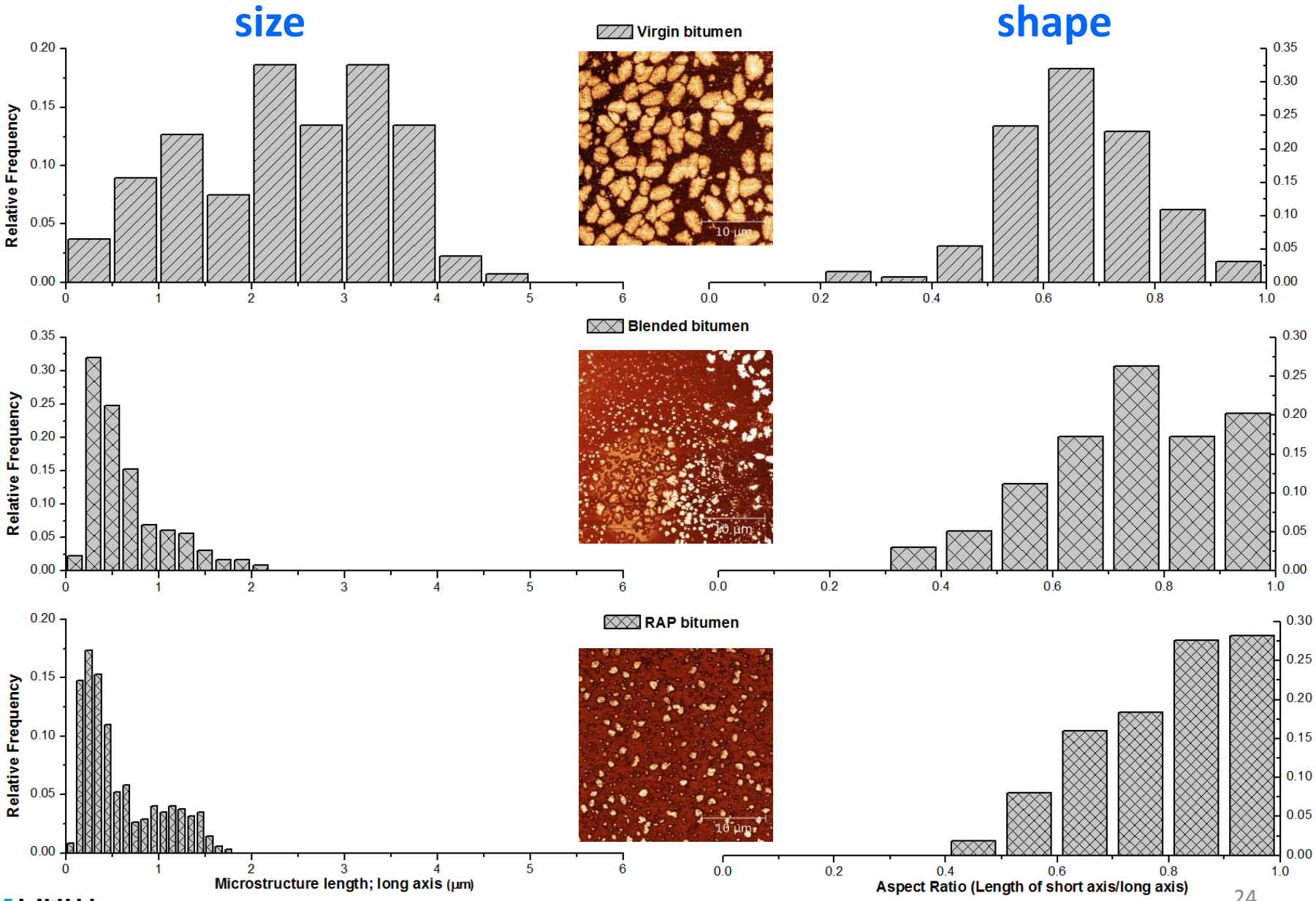


A : RAP-bitumen | B : Blended zone | C : Transition zone | D : Virgin bitumen

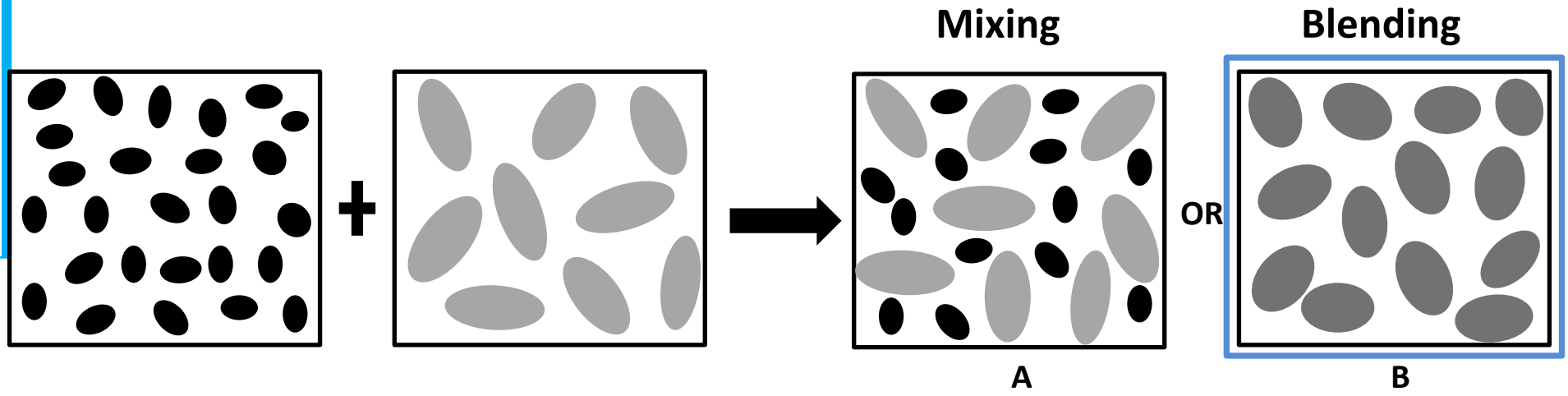
Comparison of Topographical profiles



Microstructural characteristics

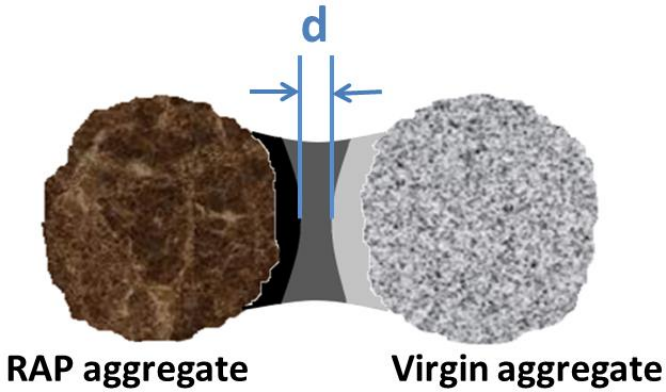


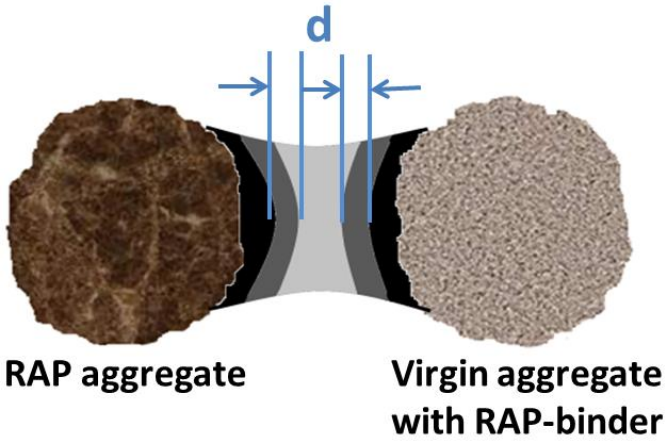
Scenarios on combining RAP and virgin bitumen



RAP-bitumen Virgin-bitumen Interaction scenarios

Blending zone thickness





d: Blending zone thickness
Design parameter

Virgin bitumen

RAP Binder

Blending zone

d = d(T,t)
T = process temperature
t = residence time

D = average bitumen coating thickness
Complete blending occurs, *D ≤ ½d*

We find d(T,t) = 50µm with T= 130°C, t= 40s

Conclusions
(Extent of interaction between RAP and Virgin binder)

- Interfacial zone between RAP-binder and virgin bitumen is observed directly for the first time
- The interfacial zone displays a gradual transition of microstructural properties
- Completely blended binder microstructural properties are found to be the averaged of the two
- The extent of the zone is d(t,T) = d(40s, 130°C) = 50µm
- AFM and DSR experimental findings are consistent
- The time, temperature dependence of the interfacial thickness (d(t,T)) can be regarded as mix design parameter for RAP containing asphalt mix

Blending degree of Recycled Asphalt Shingles (RAS) to virgin binder

Recycled Asphalt Shingles (RAS)

Post-manufactured Shingles

Post-consumer Shingles (Tear-offs)

Powdered Shingles

RAS Binder

Benefits of Recycling Shingles

- Recycling bitumen and fine aggregates
  - High bitumen content (20-35%)
- Environmental and economic need
  - 11 M tons of waste shingles/year (USA)
  - Disposal fee: ~ 100 $/ton
- Improved performance of asphalt mixtures
  - Improved rutting resistance

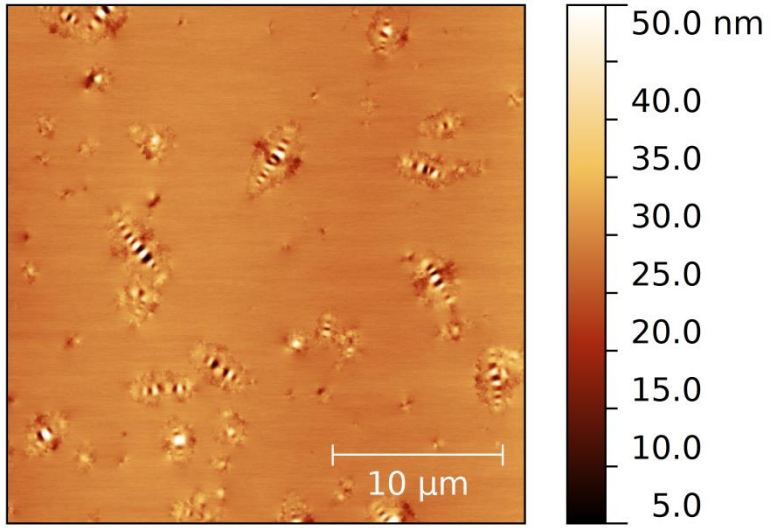
Blending scenarios of RAS to virgin binder

- Complete mixing
- Partial mixing
- No mixing (‘black rock’)

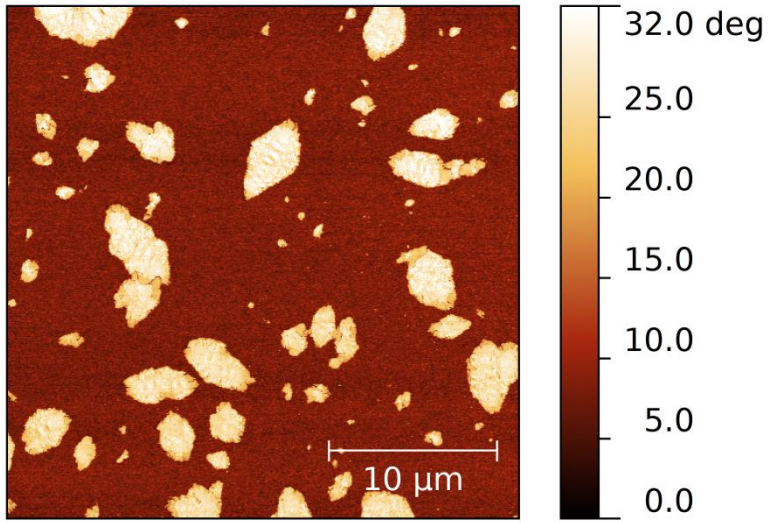
Again: Extent of blending is believed to steer material’s performance

RAS and Virgin binder microstructures

Virgin binder: A 52-28



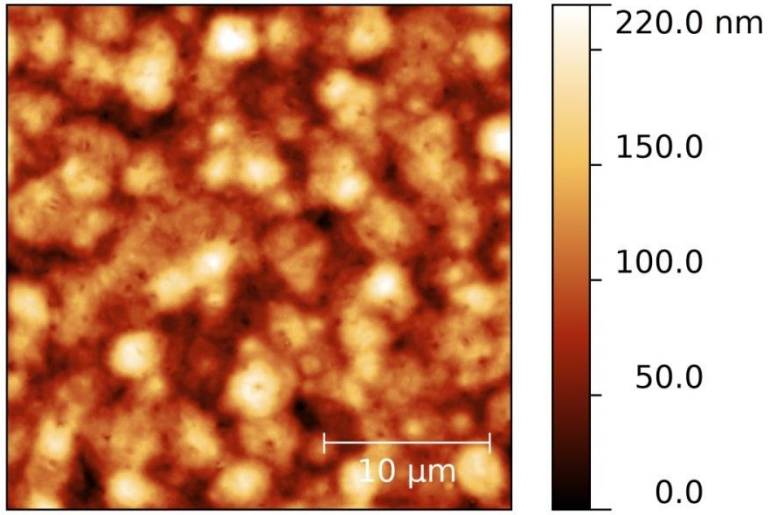
Topography



Phase

30µm

TT-RAS binder: Tennessee tear offs



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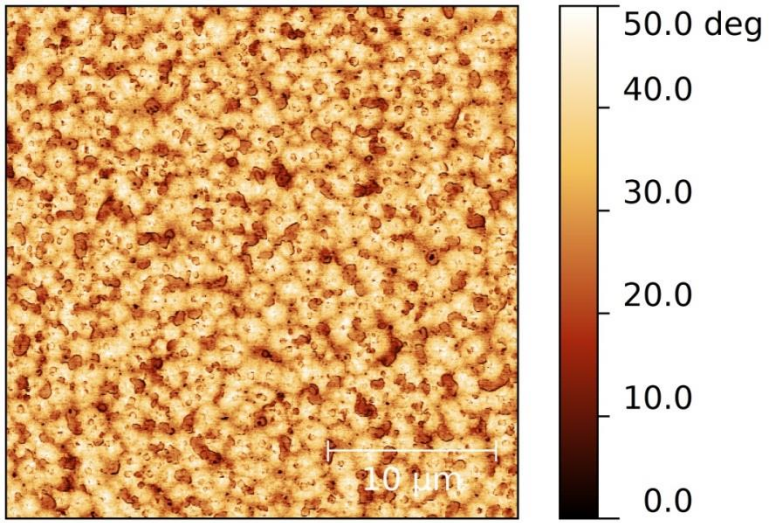


Phase

30µm

RAS and Virgin binders' extent of interaction experiment

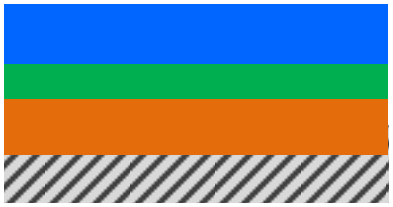
- Does RAS interact like RAP?
- What is the optimal mixing T?
- New specimen: probing the binder layer mixing

Separate layers

t, T_1

T, t_1

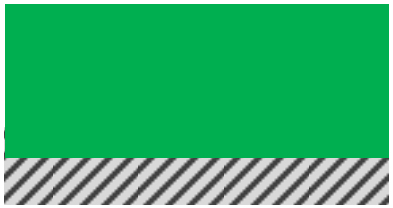
Partial mixing



t, T_2 ($T_2 > T_1$)

T, t_2 ($t_2 > t_1$)

Complete mixing

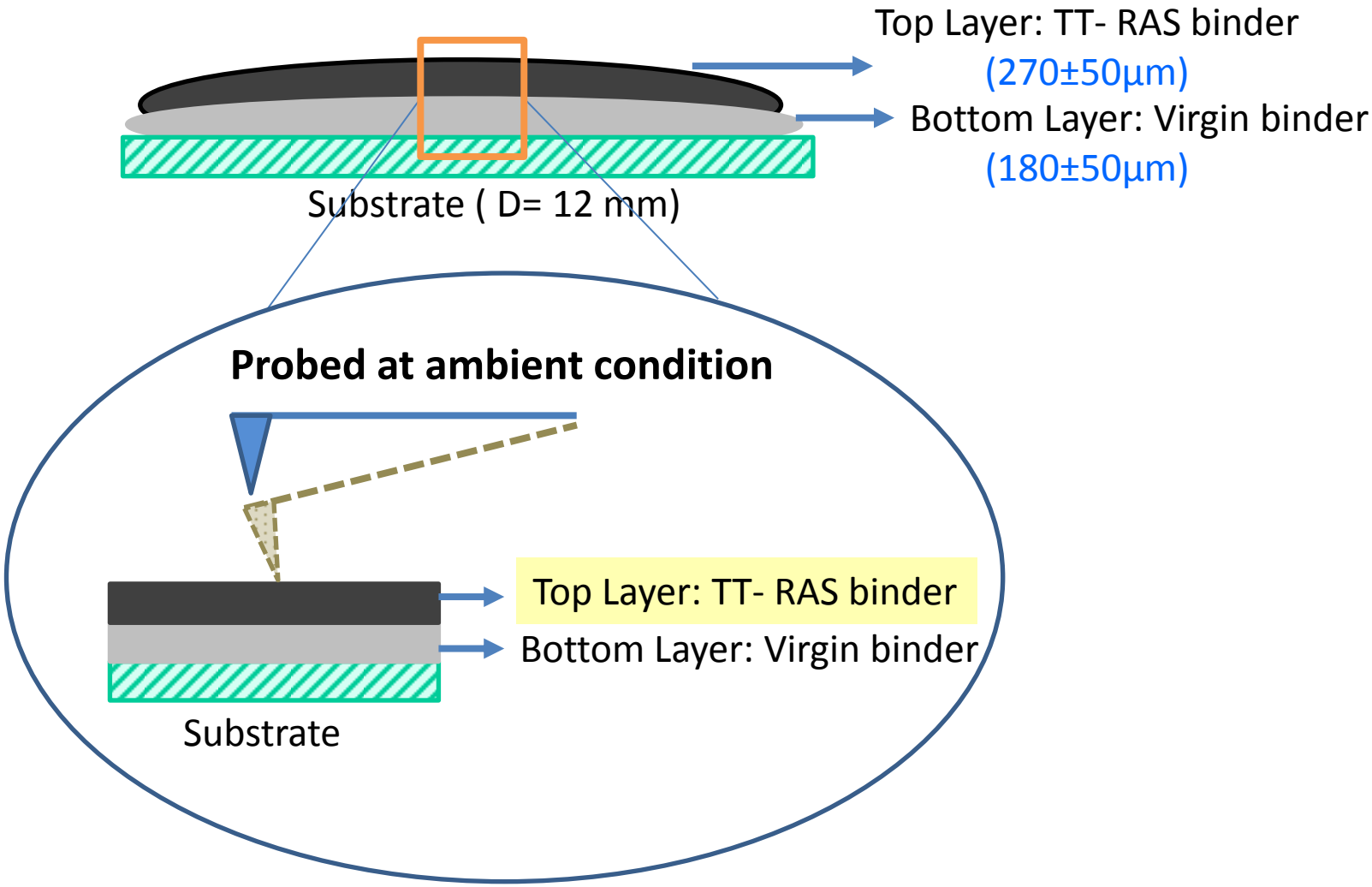


t, T_3 ($T_3 > T_2$)

T, t_3 ($t_3 > t_2$)

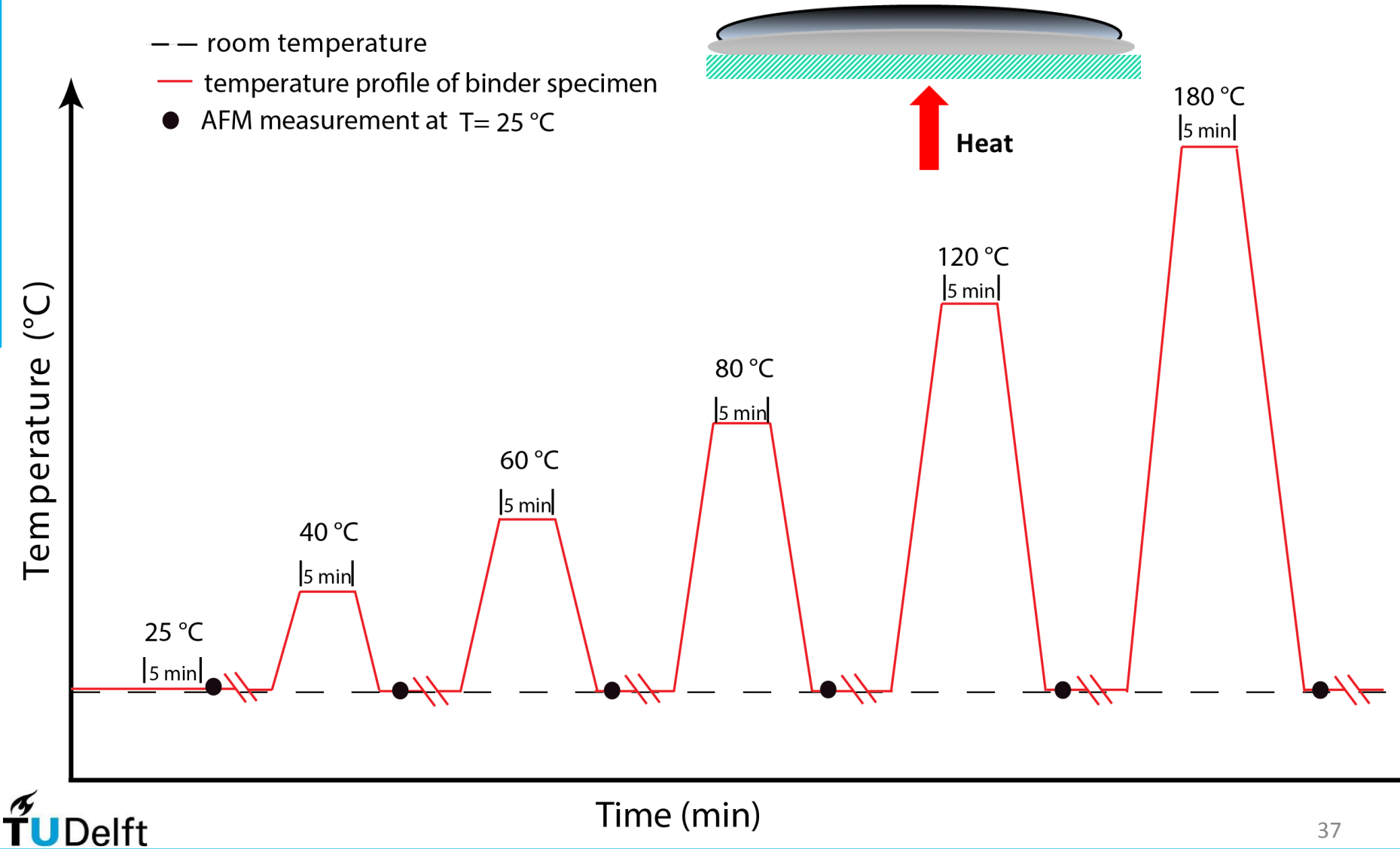
T = Temperature
t = Time
RAS binder
Virgin binder
Mixing zone

2-layer binder specimen preparation and probing zone



Thermal conditioning and measurement scheme

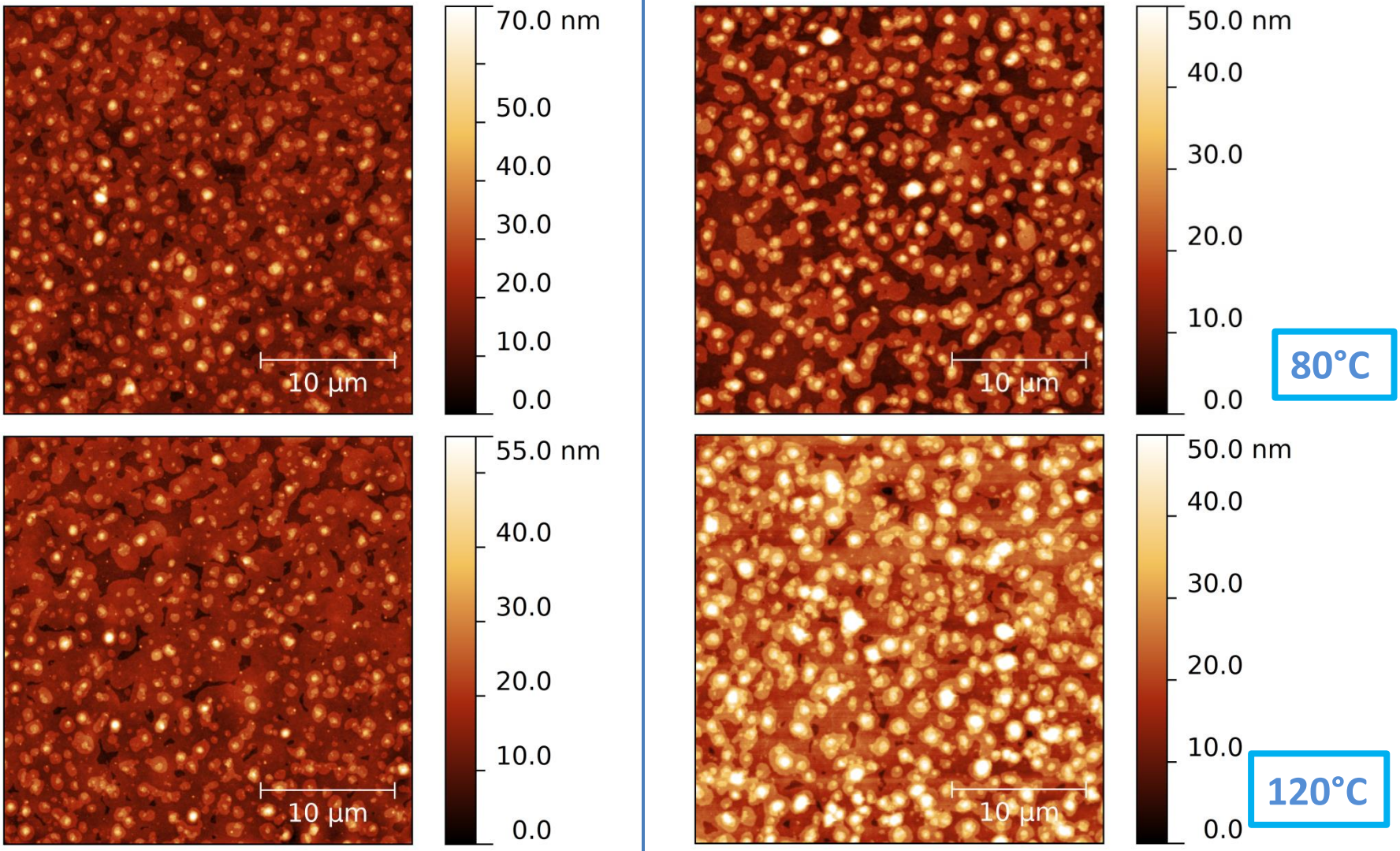
(Top layer of 2 layer binder specimen and control,TT-RAS binder)



Microstructural change with temperature

Top layer: RAS binder

Control : RAS binder

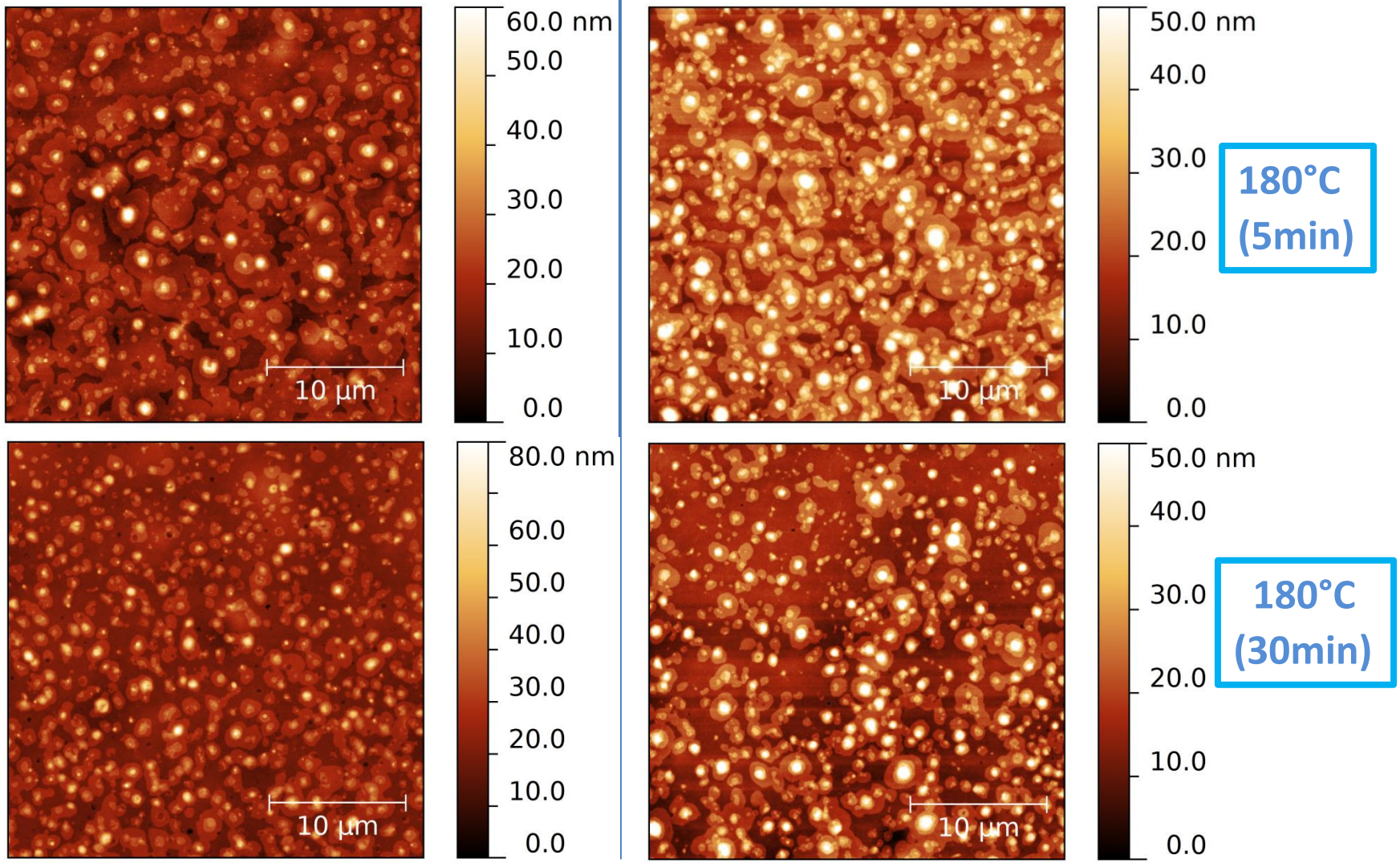


AFM Topography images (30µm)

Microstructural change with temperature

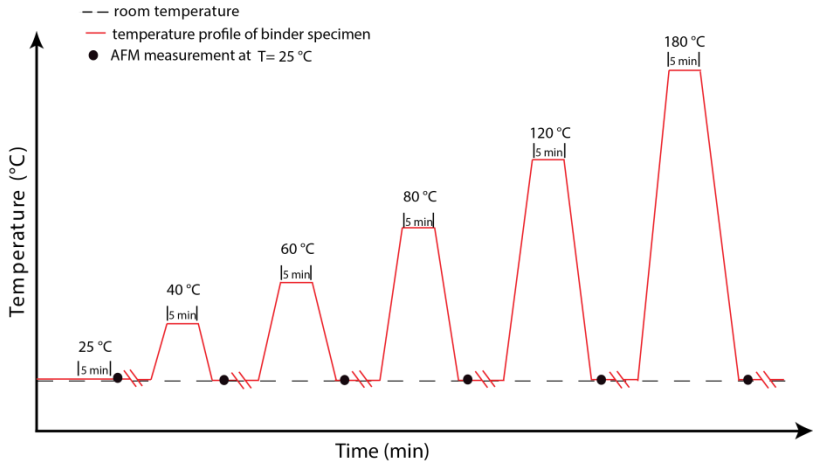
Top layer: RAS binder

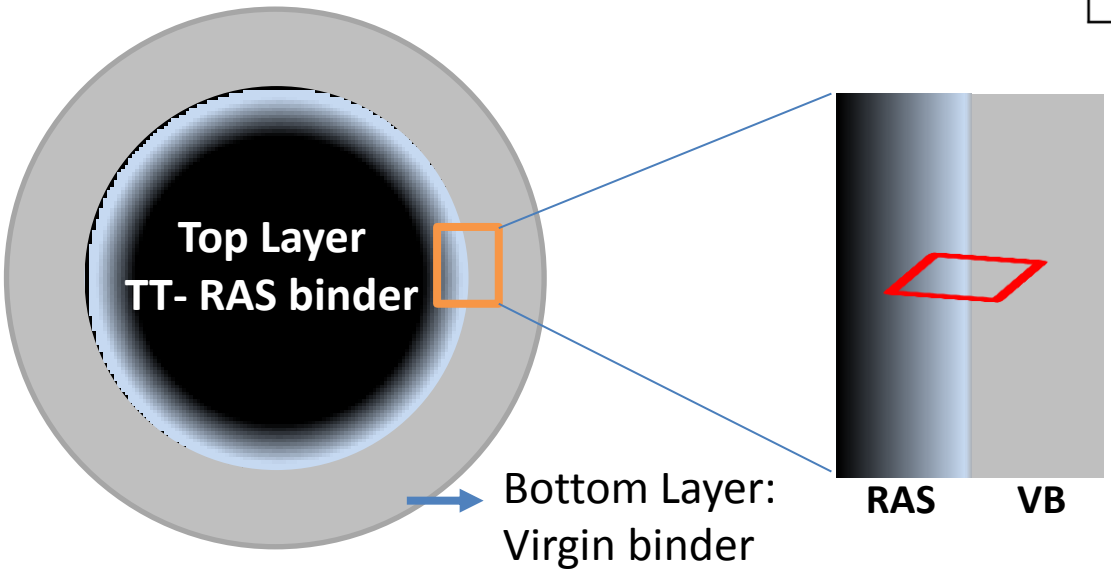
Control : RAS binder

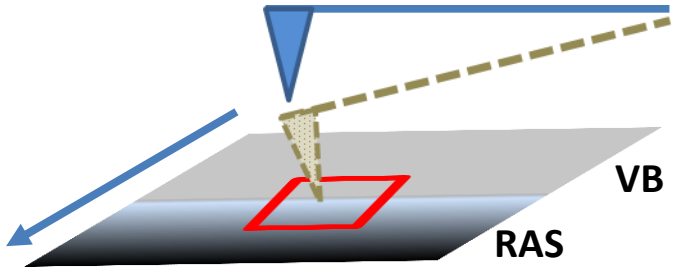


AFM Topography images(30µm)

Interface detection of RAS and virgin binder



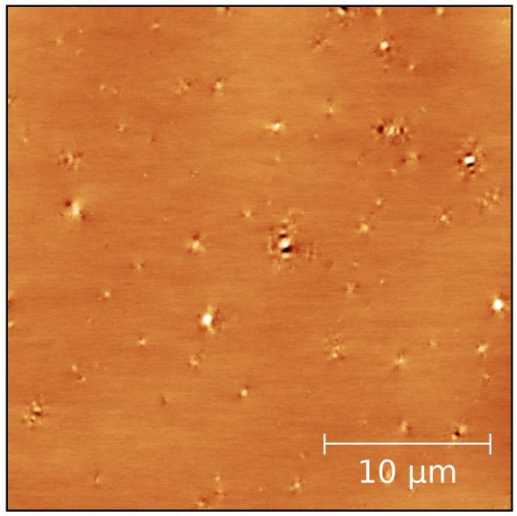


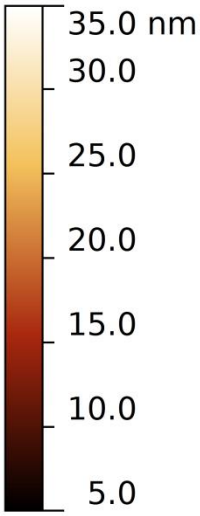


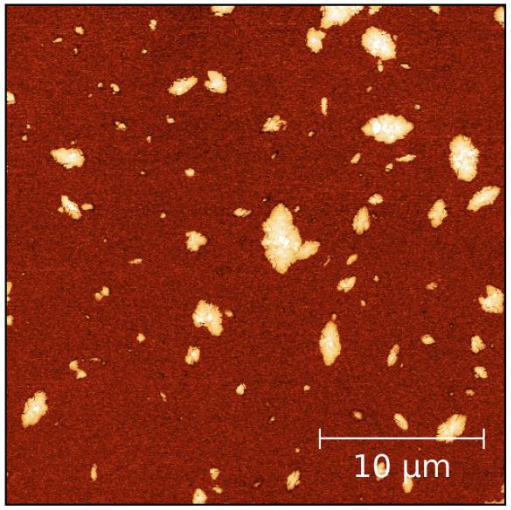
Top view of specimen

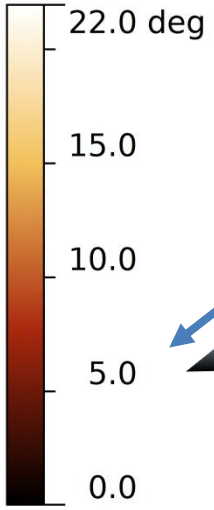
Probing scheme

RAS and virgin binder interface

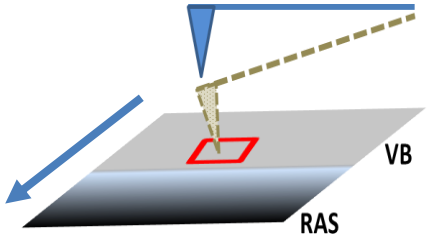




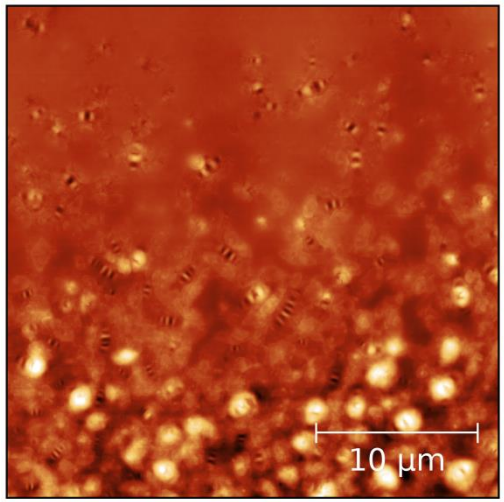




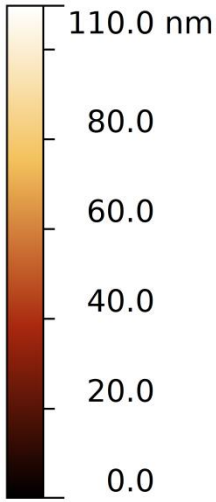
Virgin binder

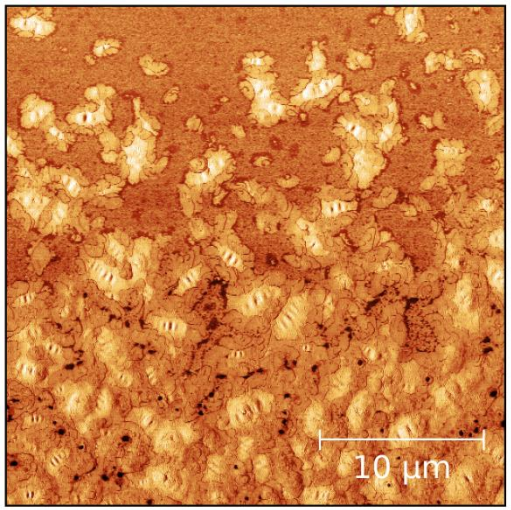


30µm

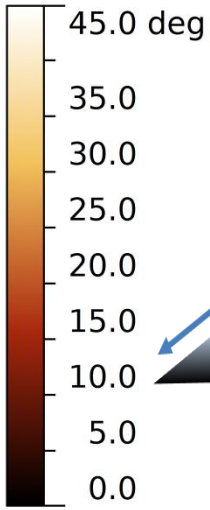


Topography

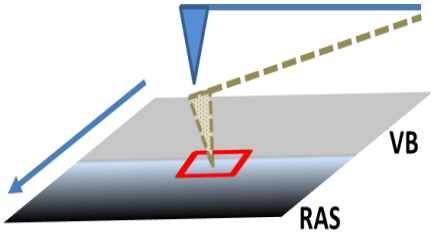




Phase

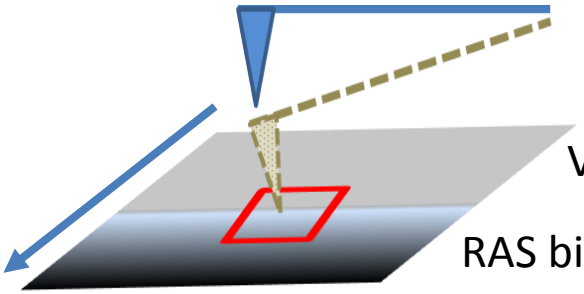


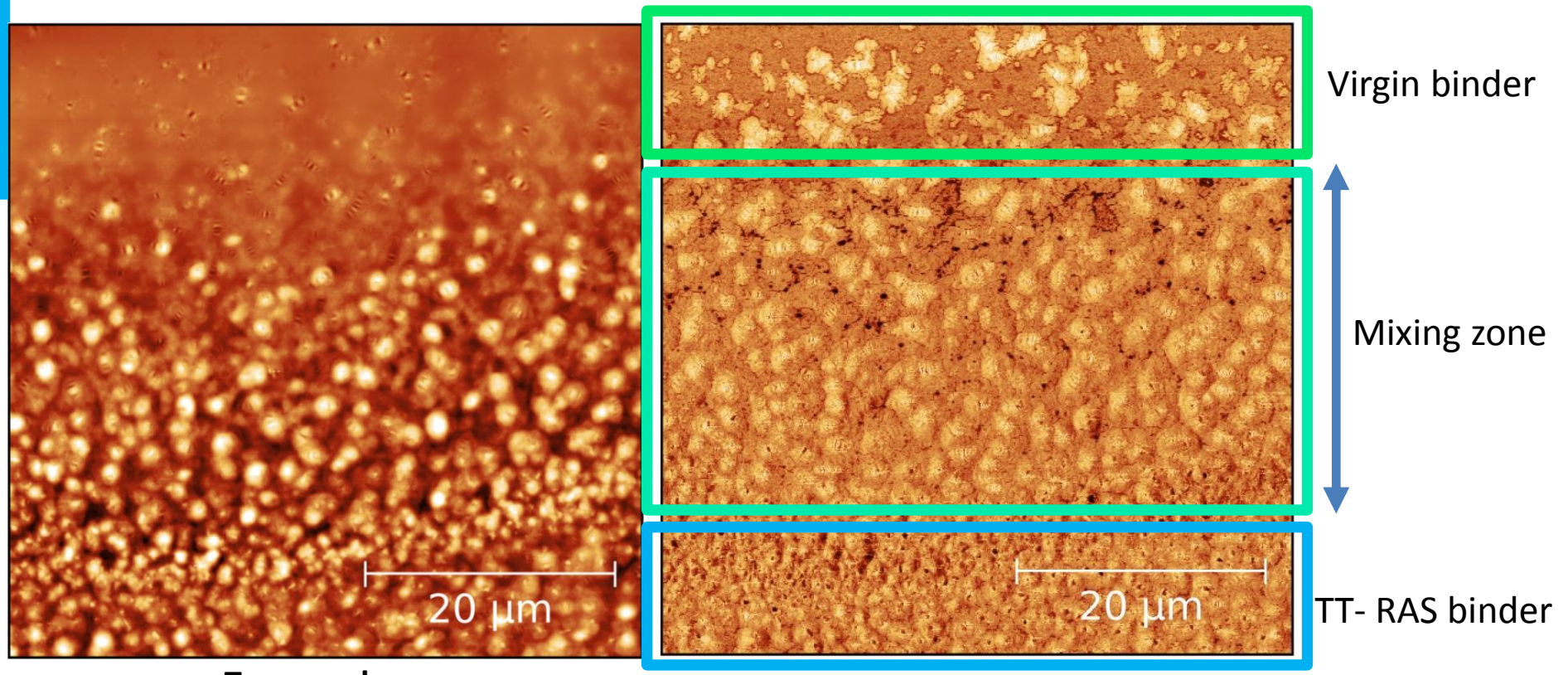
Interface



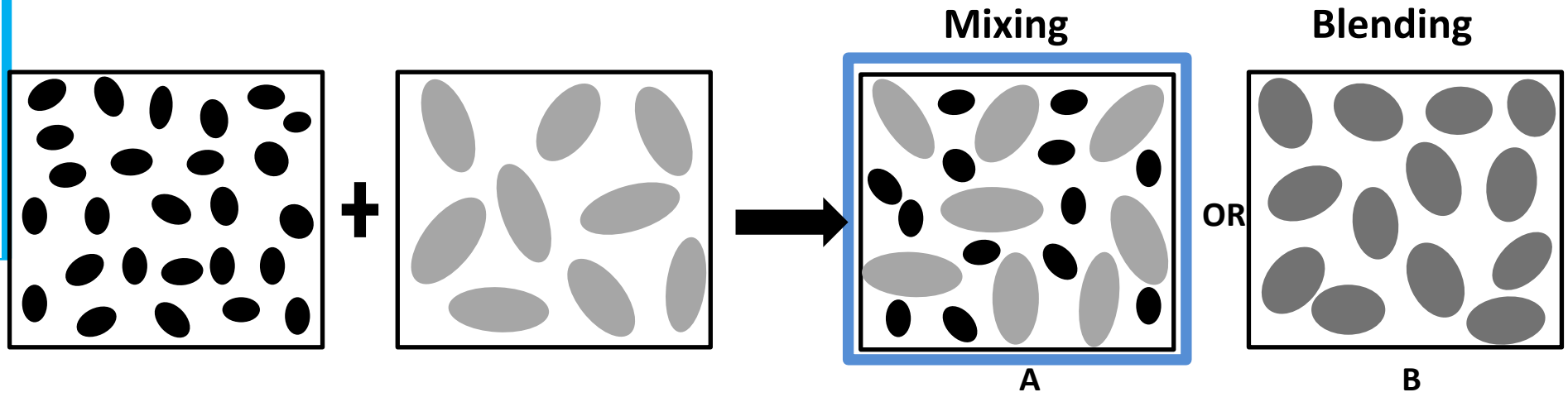
30µm

RAS and virgin binder interface





Scenarios on combining RAS and virgin bitumen



RAS-binder

Virgin-bitumen

Mixing/Blending scenarios

Conclusions

- Interfacial zone between aged RAS-binder and virgin bitumen is probed directly for the first time
- mixing zone ~ 25 to 30 µm
- Domain phase segregation is observed at the interface
- High polymer modification of RAS may limit blending
- The thickness of the RAS binder layer around the aggregate is the limiting parameter for the degree of interaction

Take home message

- Bitumen is an ‘association’ of ‘self-assembled’ colloids

- RAP + virgin binder → Blending (metastable colloids)
- RAS + virgin binder → Mixing

(high polymer modification of RAS hinders the mobility of the colloidal particles, as a result they stabilizes locally)

Thank You