# Recycling Using High Percentages of RAP and Rejuvenation of PAC wearing courses

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**based on PhD work by Mohamad Mohajeri (Iran) and Yuan Zhang (China)**
**co-supervisor: Martin van de Ven**
**and work by Jian Qiu (China) BAM contractors (former PhD)**
**sponsors: van der Lee contractors; Ministry of Transport; Chinese Scholarship Council**
**BAM contractors; Ministry of Transport and Delft University of Technology**

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# A Dutchman in SA: what does he experience ?

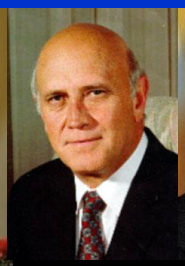
- Nature

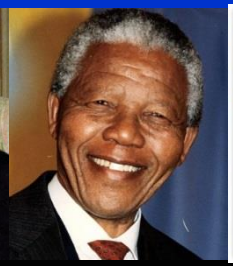
- Language

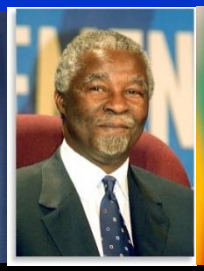
- Food and wine

- Culture

- History and Politics







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# AND .....

# ..... RUGBY .....

**Rugby skills = a*muscles + b*speed + c*braai + d*boerewors + e*castle**


**not to be confused with Lintworm or a brown Mamba!**



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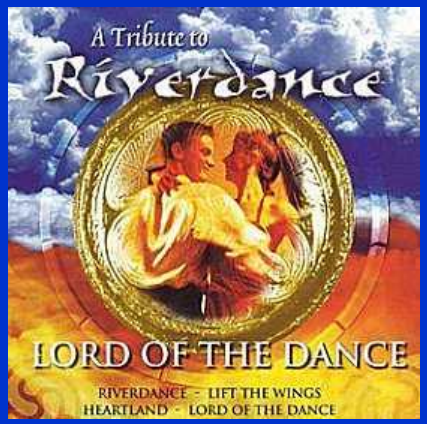
# This also seems to be a potent combination !







**29 – 15**



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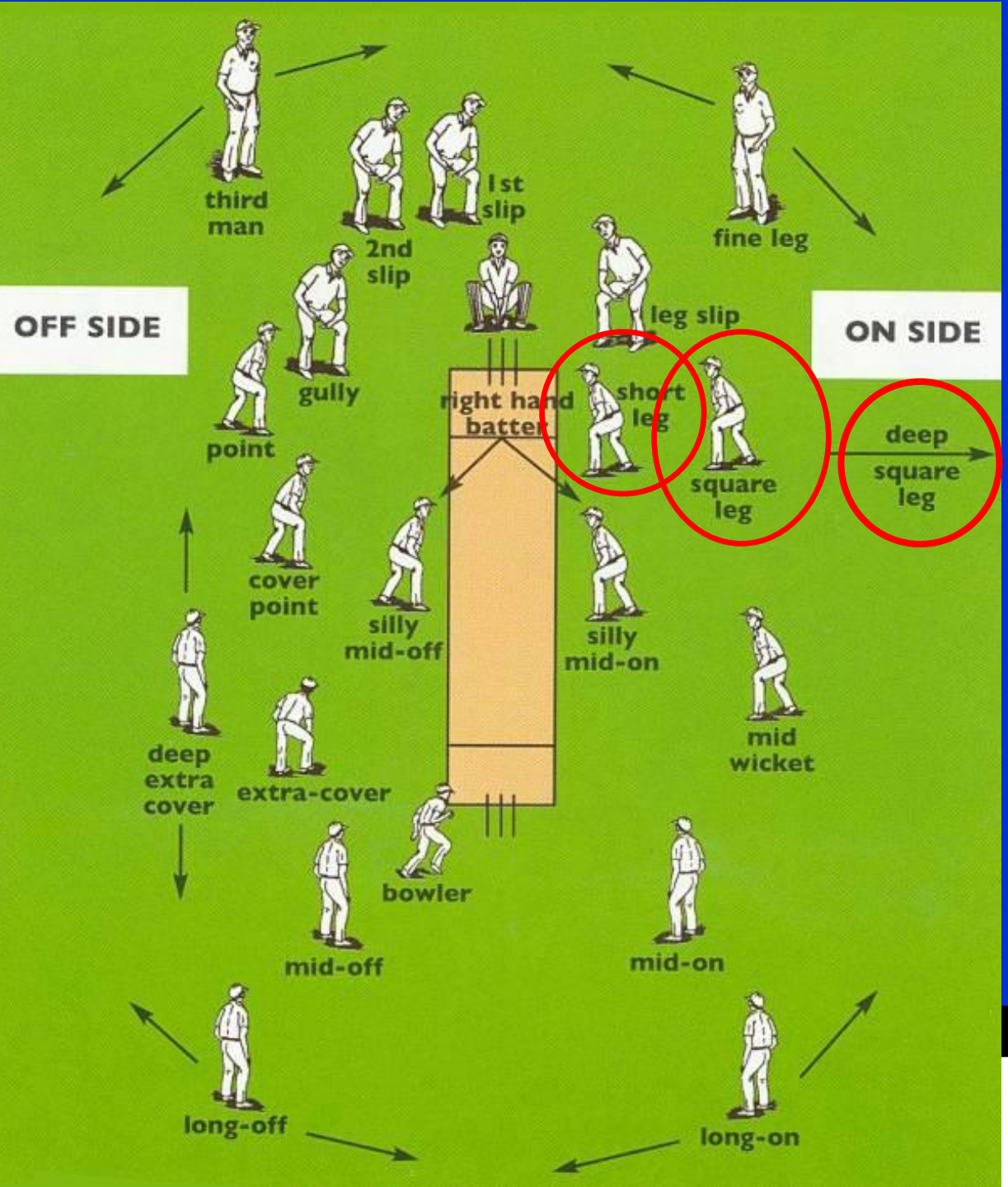
# AND THERE IS ANOTHER AMAZING THING WHICH IS CALLED ….

# CRICKET !!




**Is it a game for disabled men ??!!**

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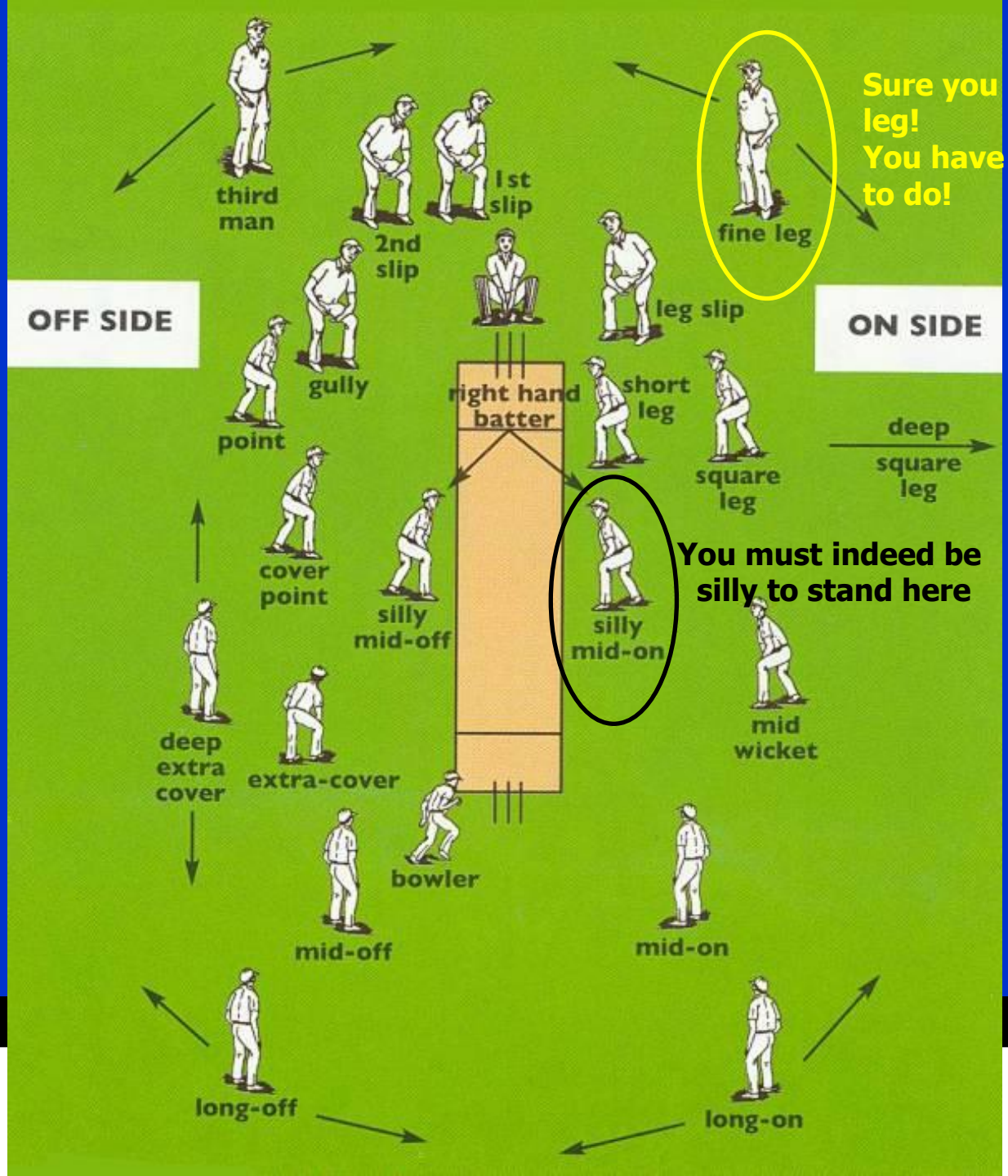
third man
1st slip
2nd slip
fine leg
Sure you have a fine leg!
You have nothing to do!
OFF SIDE
ON SIDE
leg slip
gully
point
right hand batter
short leg
square leg
deep square leg
cover point
silly mid-off
silly mid-on
You must indeed be silly to stand here
deep extra cover
extra-cover
mid wicket
bowler
mid-off
mid-on
long-off
long-on

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# Coverage is “hocus pocus” for a normal person.

**“Younus used his feet to good effect, laundring Lyon over wide long-on for the only six of the day”**

# Google translate English - Dutch

**"Younus used his feet to good effect, laundring Lyon over wide long-on for the only six of the day"**

**"Younus gebruikt zijn voeten met goed resultaat , was doen Lyon over een breed lange -on voor de slechts zes van de dag"**

# HELP, THIS IS EVEN WORSE !!

- **Lyon ?? Does he mean the Lion king or what ??**
- **You say “yis” instead of “yes” and “thisis” instead of “thesis” so “six” = …**

# So this is what I understood !!!

**Younus used his feet to good effect, laundring Lyon over wide long-on for the only six of the day**

**Younus was dancing while he was washing a lion's wide long-john for the only sex of the day**

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# Additional Rules

- LBW is proper way to defend a wicket; should be allowed
- Batsman should be allowed to kick the ball or make a header in order to prevent the wicket to fall
- Bonus: kicking 2 runs and heading 18 runs
- Batsman should be allowed to catch the ball; then the bowler is out

# Hot Mix Recycling, Blending and Rejuvenation

**(RheoFalt HP-EM$^{tm}$; Rasenberg Contractors and van Wezenbeek Specialties)**

**Resin** **Roofing material** **RAP**


**Courtesy: Rasenberg Contractors**

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# Importance of Recycling and Rejuvenation in the Netherlands

- Recycling: this is a MUST and we need to use high RAP percentages because of environmental and economical (RAP = €€€) reasons and lack of space
- Rejuvenation: could be a cost effective and environmental friendly way to extend life of PAC wearing courses on highways

# RECYCLING

# State of the art in the Netherlands with respect to recycling (EAPA 2012)

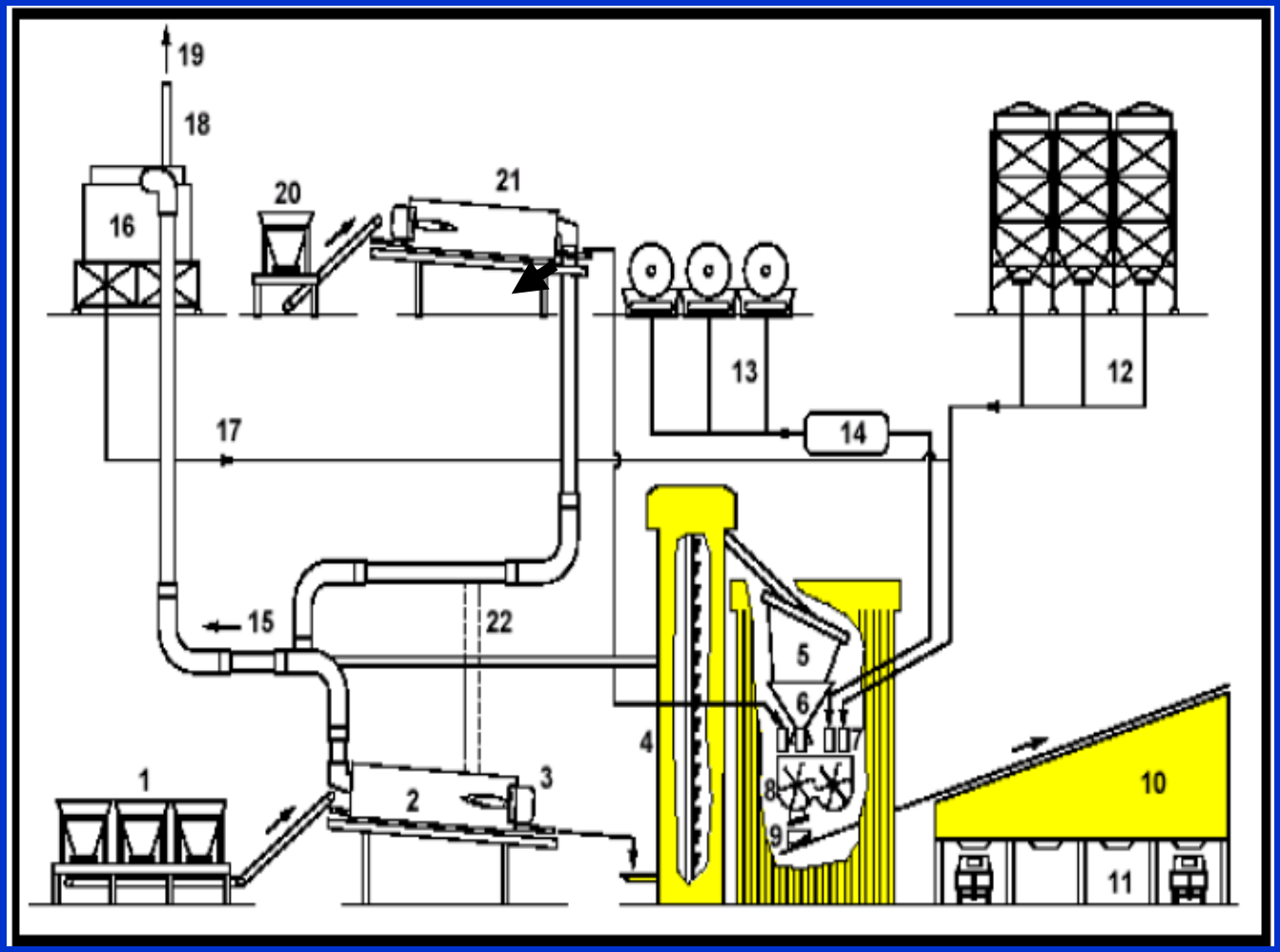
- At the moment 4 * $10^6$ ton/year of RAP is available.
- 80 % of the RAP is used in hot and warm recycling; 15% in cold recycling.
- WMA still not very popular.
- 73 % of new HMA and WMA production contains RAP.
- Consumption of bitumen in 2006 : 0.3*$10^6$ ton (on 9.2*$10^6$ ton HMA and WMA).
- Recycled mixtures containing high % of RAP must comply to same specs set for mixtures made of virgin materials.
- 0% RAP in SMA; 20% in PAC; 50% in all other mixtures.

# Hot mix asphalt plants in the Netherlands (2012)

**Number of stationary plants 41**
**Number of mobile plants 1**

**Number fit for hot recycling 40**
**One of them is a double drum mixer and the others are batch plants equipped with parallel drum**

# Parallel drum (RAP pre-heated to 130 $^{0}$C)



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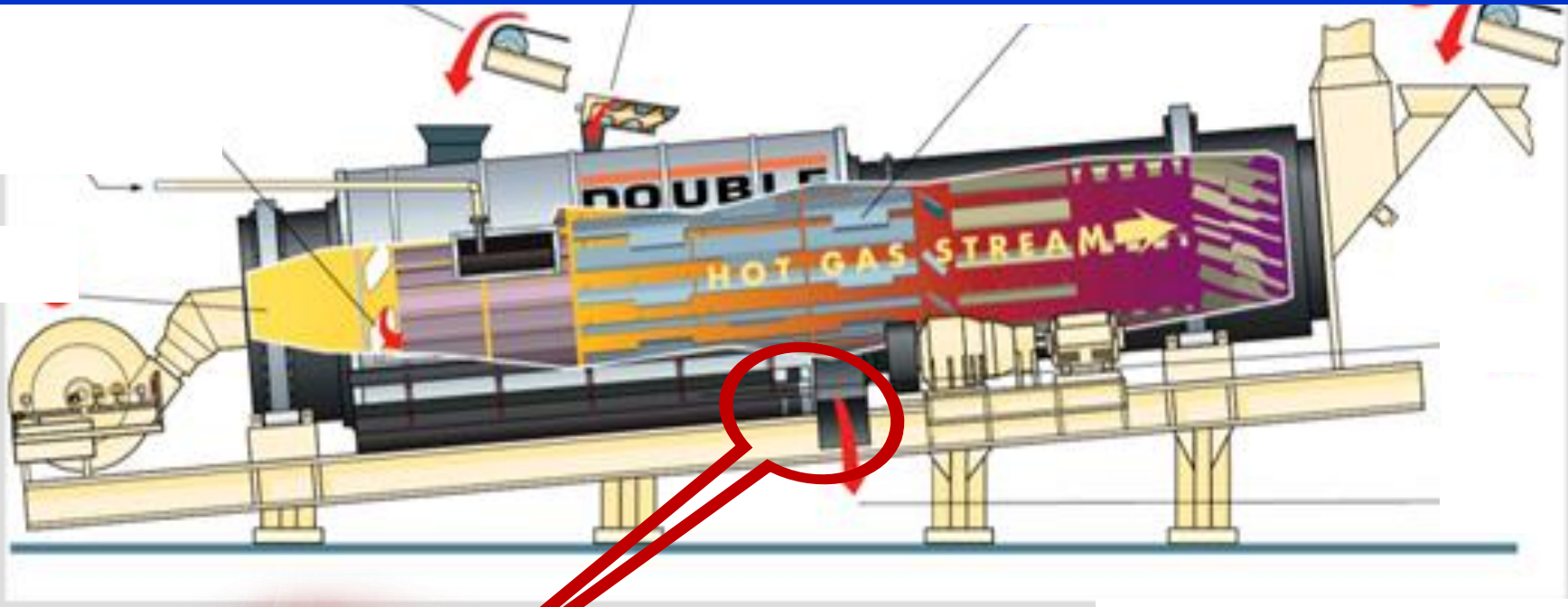
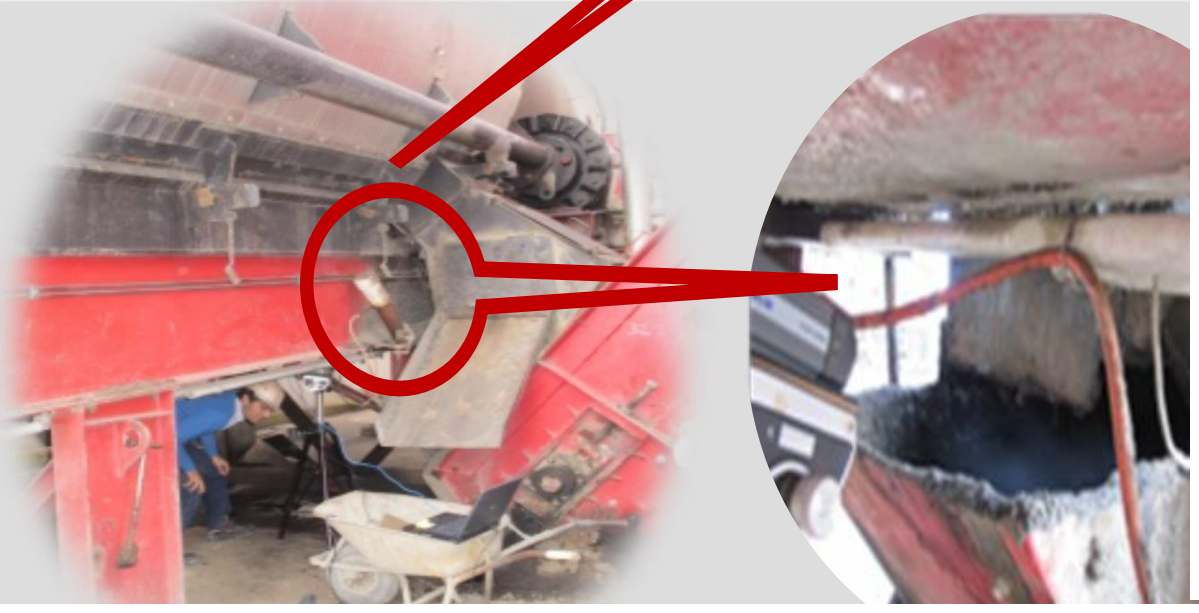
# Double Drum mixer



**if**
**50% RAP at ambient temperature and 4% moisture**
**then**
**virgin aggregates pre-heated to 500 °C**

# Questions

- Can we rejuvenate old bitumen?
- How well do old and virgin bitumen blend?
- What are the consequences of imperfect blending?

- How do super-heated aggregates blend with RAP at ambient temperature with 4% moisture?
- What are the consequences on mixture quality

# Rejuvenators

- Types available
  - Petroleum-based: paraffinic, naphthenic, aromatics, used motor/lubricating oil, etc.
  - Bio-based: cashew nut shell resin, palm oil, shale oil, sesame oil, soybean oil, used cooking oil, etc.

- Are rejuvenators materials with simply a lower viscosity or do they also have a "repairing" effect on the aged bitumen ???

# Special Resin to "Upgrade" (rejuvenate) Bitumen (natural product, cashew nuts)

**100% recycling is possible**

**Courtesy:**
**Rasenberg Contractors**
**Van Wezenbeek Specialties**

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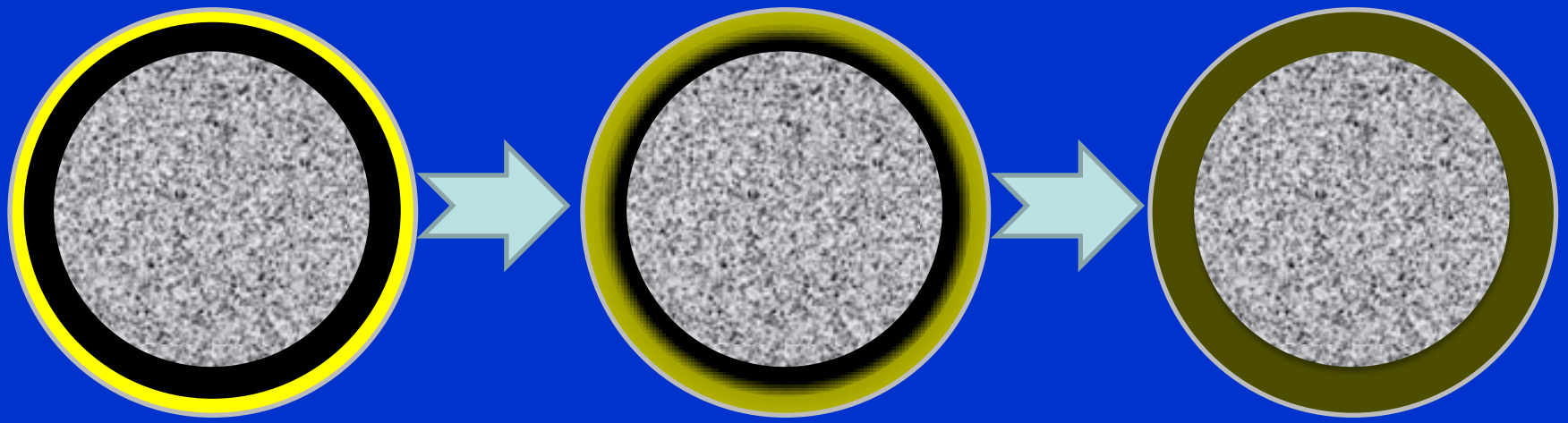
# Rejuvenating process

- Step 1: no blending (black stone) →avoid
- Step 2: partial blending +time dependent diffusion →practice
- Step 3: full blending →final aim



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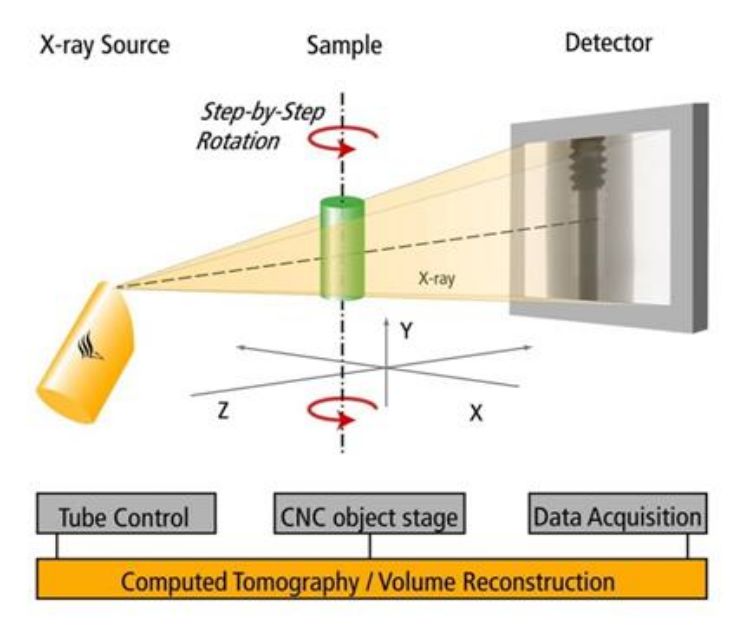
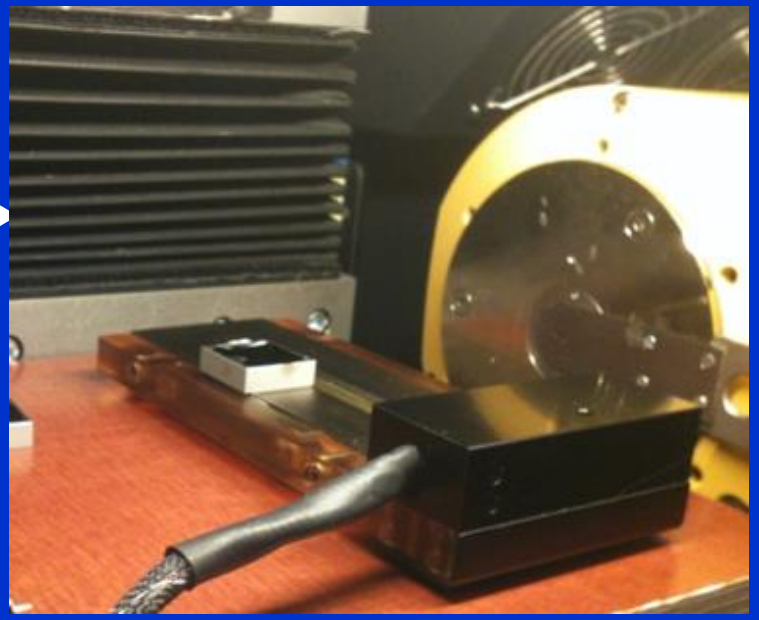
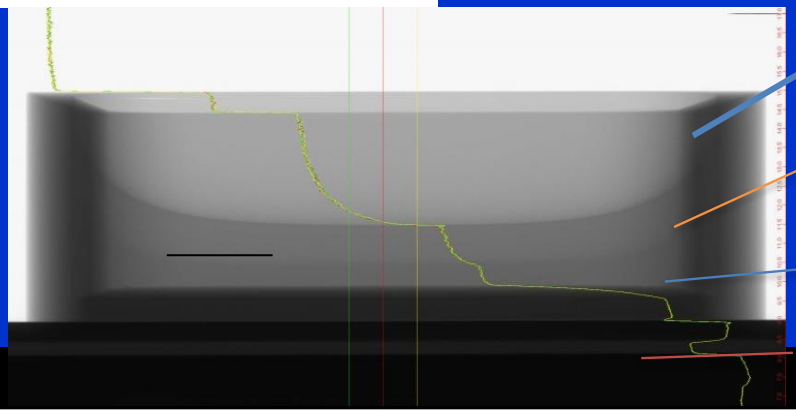
# Nano CT scans to test effect of rejuvenator





Aluminum container

Rejuvenator

Aged bitumen

Heating unit

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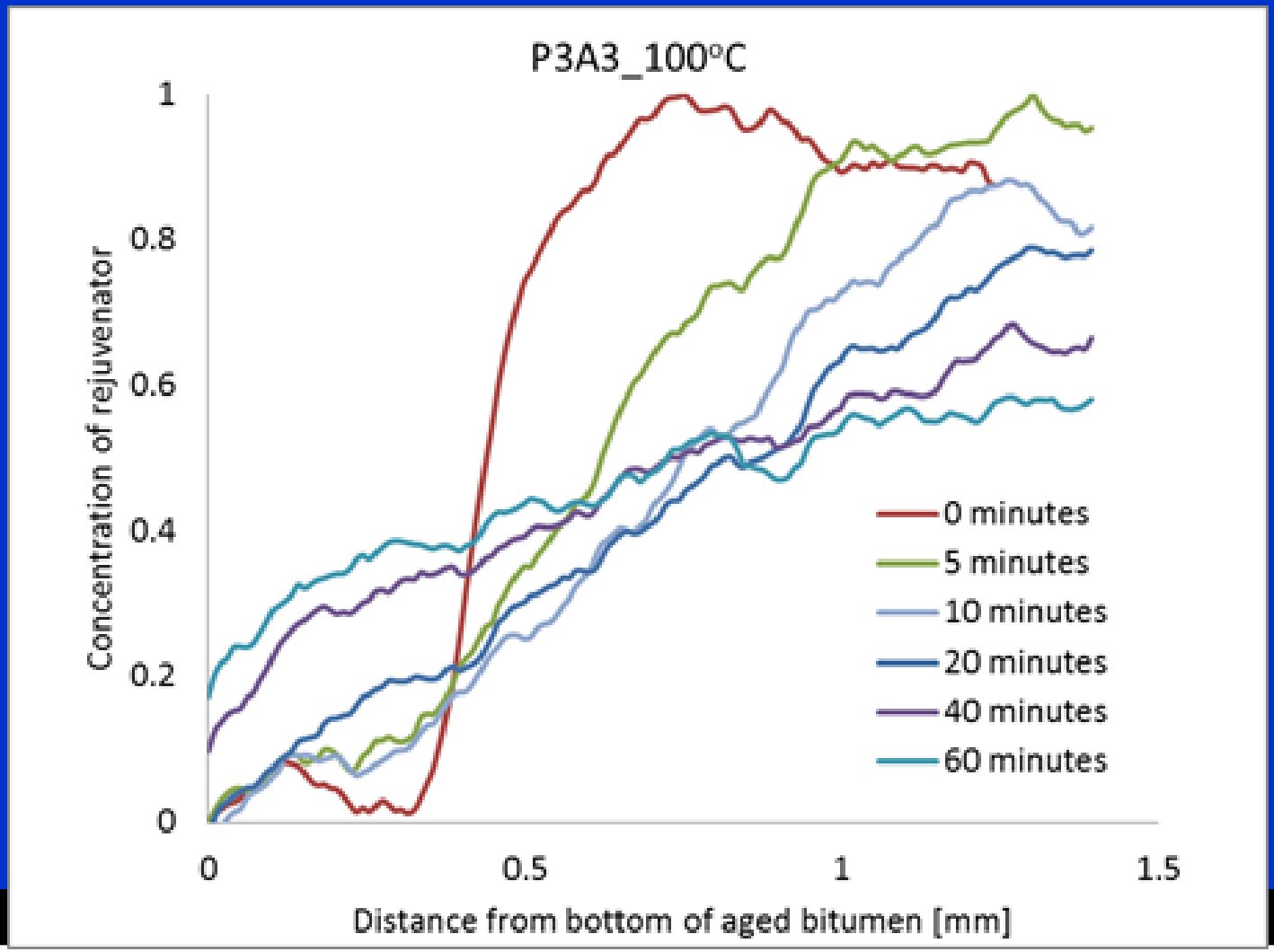
# Example of diffusion results

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# Conclusion

- Diffusion certainly takes place but it is a slow process
- Later on we will see effect of temperature
- Most probably full blending will not occur

# Most of time

- Mixing RAP with softer virgin bitumen to obtain desired characteristics
- We are relying on complete blending of old and new bitumen

# How to determine degree of blending

- "Layer by layer" recovery of bitumen from recycled mixture
- "Glass bead" study
- Mechanical characteristics of recycled mixtures prepared in different ways

# RAP fractions & binder content

| Fraction size [mm] | 0 - 2 | 2 - 5 | 5 - 8 | 8 - 11 | 11 – 16 | 16 - 22 |
|---|---|---|---|---|---|---|
| Mass percentage of total aggregate fraction | 22 | 21 | 15 | 18 | 16 | 8 |
| Percentage of binder in that fraction | 33 | 25 | 11 | 13 | 13 | 5 |

**Main portion of the binder is at finer fractions**

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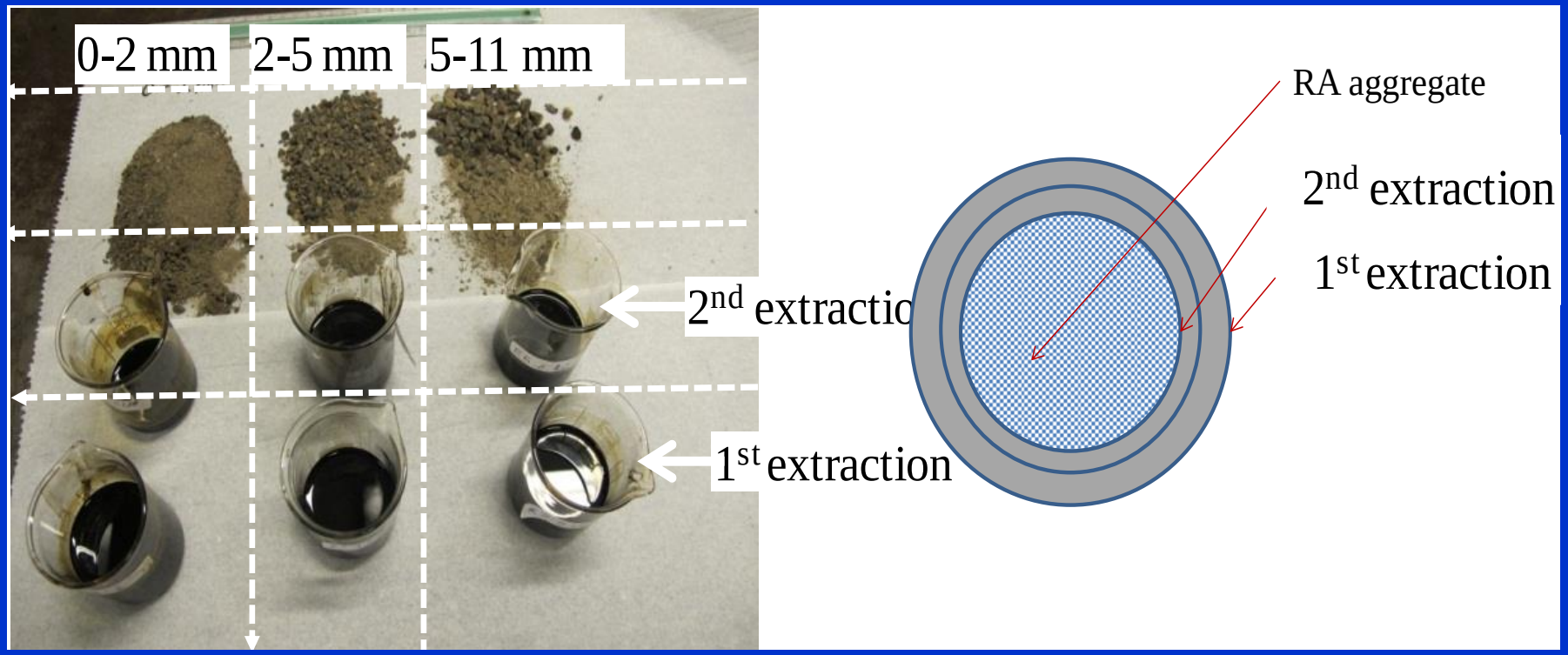
# Layer by layer recovery of RA binder



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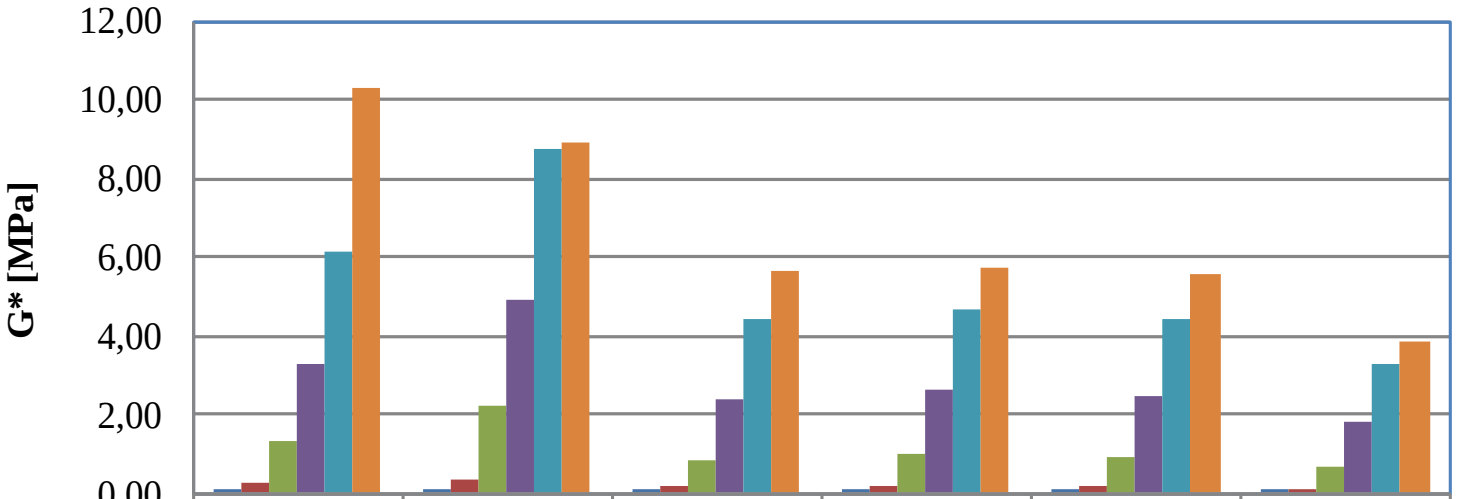
# G* of extracted binder layers




| | 0-2mm first extraction | 0-2mm second extraction | 2-5mm first extraction | 2-5mm second extraction | 8-11mm first extraction | 8-11mm second extraction |
|---|---|---|---|---|---|---|
| 0.001Hz | 0,032 | 0,048 | 0,017 | 0,023 | 0,020 | 0,016 |
| 0.01Hz | 0,218 | 0,326 | 0,135 | 0,166 | 0,152 | 0,115 |
| 0.1Hz | 1,312 | 2,225 | 0,864 | 0,982 | 0,904 | 0,668 |
| 1Hz | 3,301 | 4,886 | 2,404 | 2,595 | 2,430 | 1,780 |
| 4Hz | 6,097 | 8,714 | 4,430 | 4,684 | 4,446 | 3,241 |
| 10 | 10,269 | 8,901 | 5,650 | 5,694 | 5,547 | 3,818 |



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# Conclusions

- Differences between successive stages are not significant
- Bitumen recovered from larger fractions seems to be softer
- In general: the recovered bitumen does not seem to be a homogeneous mass

**In order to get a better understanding of what is happening when mixing cool RAP with superheated aggregate, blending simulations were made**

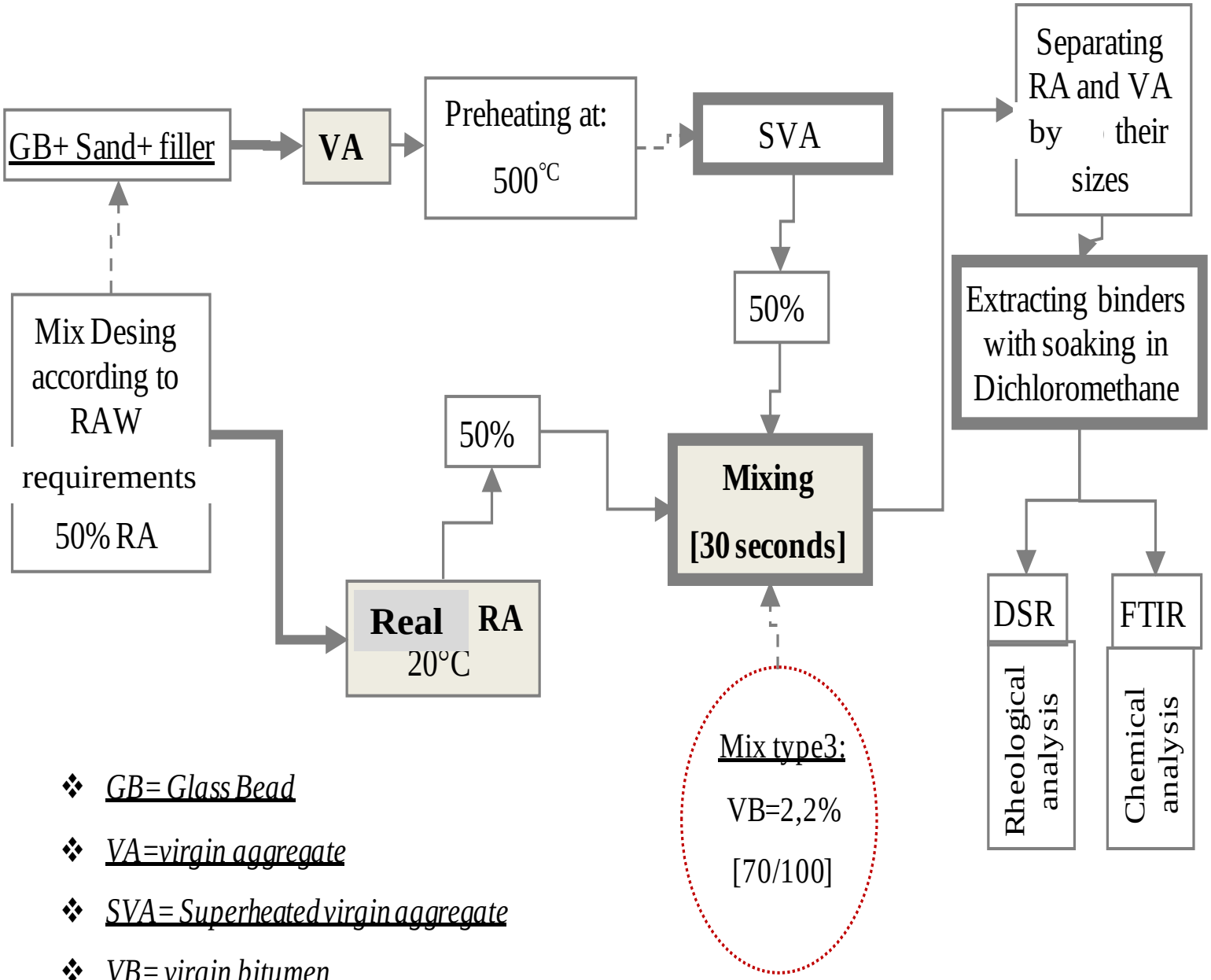
# Blending simulation

- Cold RAP was mixed with same amount of super-heated virgin fines, sand, glass beads (representing the coarse aggregates) and virgin bitumen (RAP : new = 1 : 1)

# If blending occurs then Log pen rule applies

$$\text{Log pen}_{\text{mixture}} = a\ \text{Log pen}_{\text{RA bitumen}} + b\ \text{Log pen}_{\text{virgin bitumen}}$$

a = fraction of RA bitumen
b = fraction virgin bitumen
a + b = 1


GB+ Sand+ filler
VA
Preheating at:
500°C
SVA
Separating RA and VA by their sizes
Mix Desing according to RAW requirements
50% RA
50%
Extracting binders with soaking in Dichloromethane
50%
Mixing
[30 seconds]
Real RA
20°C
DSR
FTIR
Rheological analysis
Chemical analysis
Mix type3:
VB=2,2%
[70/100]
GB= Glass Bead
VA=virgin aggregate
SVA= Superheated virgin aggregate
VB= virgin bitumen



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# Mixture with 50% RAP (ambient temperature and 4% moisture) and superheated virgin sand, filler, glass beads (coarse aggregate) and bitumen






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# G*, δ and estimated Pen values at 25 °C

| | RAP | | GB binder | | Stone binder | | virgin 70100 | |
|---|---|---|---|---|---|---|---|---|
| f [Hz] | G* [Mpa] | δ[degree] | G* [Mpa] | δ[degree] | G* [Mpa] | δ[degree] | G* [Mpa] | δ[degree] |
| 0,01 | 0,323 | 66,6 | 0,113 | 72,7 | 0,064 | 75,7 | 0,006 | 85,6 |
| 0,4 | 4,112 | 56,7 | 1,731 | 61,2 | 1,078 | 63,8 | 0,169 | 78,6 |
| 1 | 7,089 | 54,9 | 3,118 | 58,9 | 1,979 | 60,9 | 0,361 | 76,1 |
| 10 | 23,578 | 51,7 | 11,566 | 54,3 | 7,678 | 54,7 | 2,033 | 68,9 |
| 20 | 32,302 | 51,0 | 16,372 | 53,2 | 11,010 | 53,3 | 3,250 | 66,7 |
| 100 | 61,836 | 49,7 | 33,789 | 51,3 | 23,418 | 50,5 | 8,780 | 61,7 |
| * predicted penetration | 16 | | 26 | | 33 | | 88 | |
| ** log pen rule base on 50% RAP | 38 | | | | | | | |



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# Conclusions

- Log pen rule predicts pen of RA binder after recycling fairly well
- Bitumen recovered from superheated glass beads is harder than bitumen recovered from RAP
- Complete blending did not occur

# Double Drum Mixer

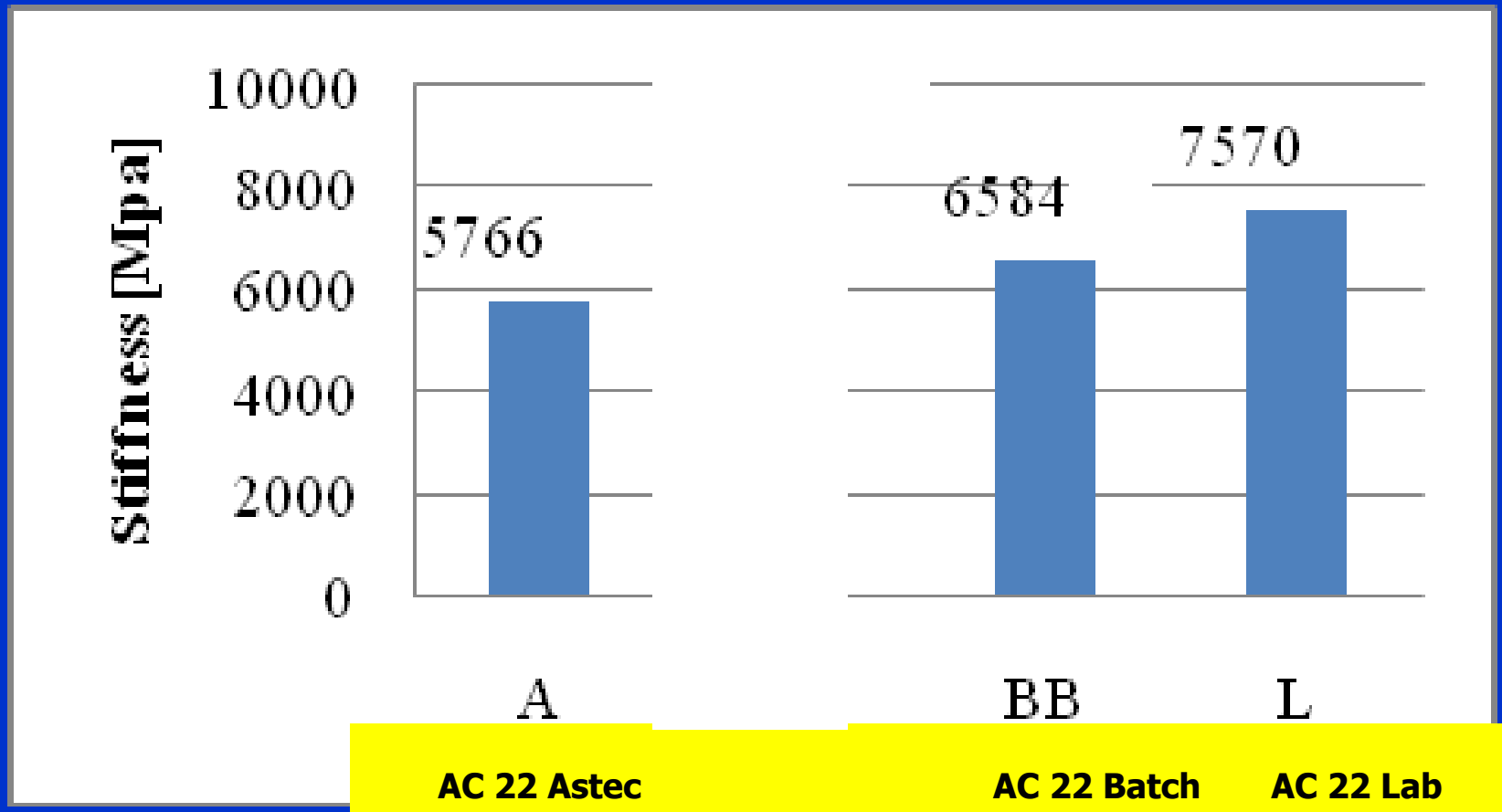
- High amount of RAP (50%) containing 4% moisture at ambient temperature is mixed with virgin aggregates which are preheated to very high temperatures.
- What is the effect on mechanical characteristics

# Produced mixture and test methods

- AC 22 base course mixture
- 50% RAP from base course mixture
- 4% moisture
- IPC PressBox was used to compact blocks from which specimens were taken
- Tests included:
  - mixture stiffness using 4 point bending
  - fatigue using 4 point bending

| Mixture Type | RAP % | Code |
|---|---|---|
| Moist base course RAP (4%) at ambient temperature is mixed with superheated aggregate (500 °C) in an Astec Double Drum mixer | 50 % | A ASTEC Double Drum |
| Moist base course RAP (4%) preheated at 130°C in parallel drum is mixed with hot virgin aggregate (270 °C) in batch plant pugmill mixer (Batch Plant) | 50 % | BB Batch plant |
| Preheating (3hrs) and mixing RAP and virgin aggregate at the same temperature in laboratory pugmill mixer (170 °C) | 50 % | L LAB |

# Mixture stiffness at 20 ºC and 8 Hz




**AC 22 Astec 50% RAP**

**AC 22 Batch 50% RAP**

**AC 22 Lab 50% RAP**



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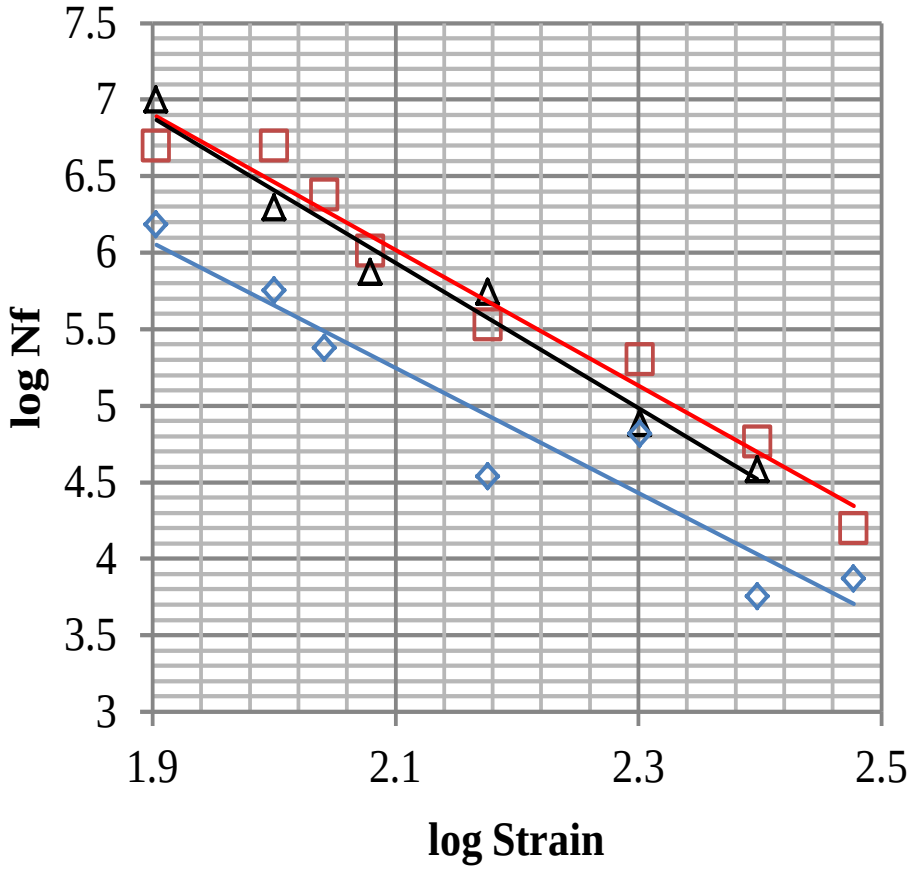
# Fatigue relationships at 16.9 ºC / 8 Hz




y = -4.7378x + 15.883
R² = 0.9754

y = -4.4333x + 15.328
R² = 0.967

y = -4.0906x + 13.838
R² = 0.9121

ASTEC

BATCH

LAB



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# Conclusions

- For this type of mixture there is no significant difference in characteristics between double drum and batch plant with parallel drum produced mixtures
- Lab produced mixture showed significantly different behavior!
- Using results obtained on lab produced mixtures for pavement design purposes should therefore be reconsidered!

# REJUVENATION
# of
# PAC WEARING COURSES

# Porous Asphalt Concrete

- Single layer porous asphalt concrete
  - 50 mm layer with 0/16 mm aggregate
  - bitumen 70/100 pen, void content > 20%
  - noise reduction ≈ 3 dB(A)
- Double layer porous asphalt concrete
  - 30 mm top layer 2/6 or 4/8 mm aggregate, with pmb
  - 45 mm bottom layer 11/16 mm aggregate
  - noise reduction ≈ 6 dB(A)
- PAC is used on 90% of motorways

# Another advantage of porous asphalt concrete



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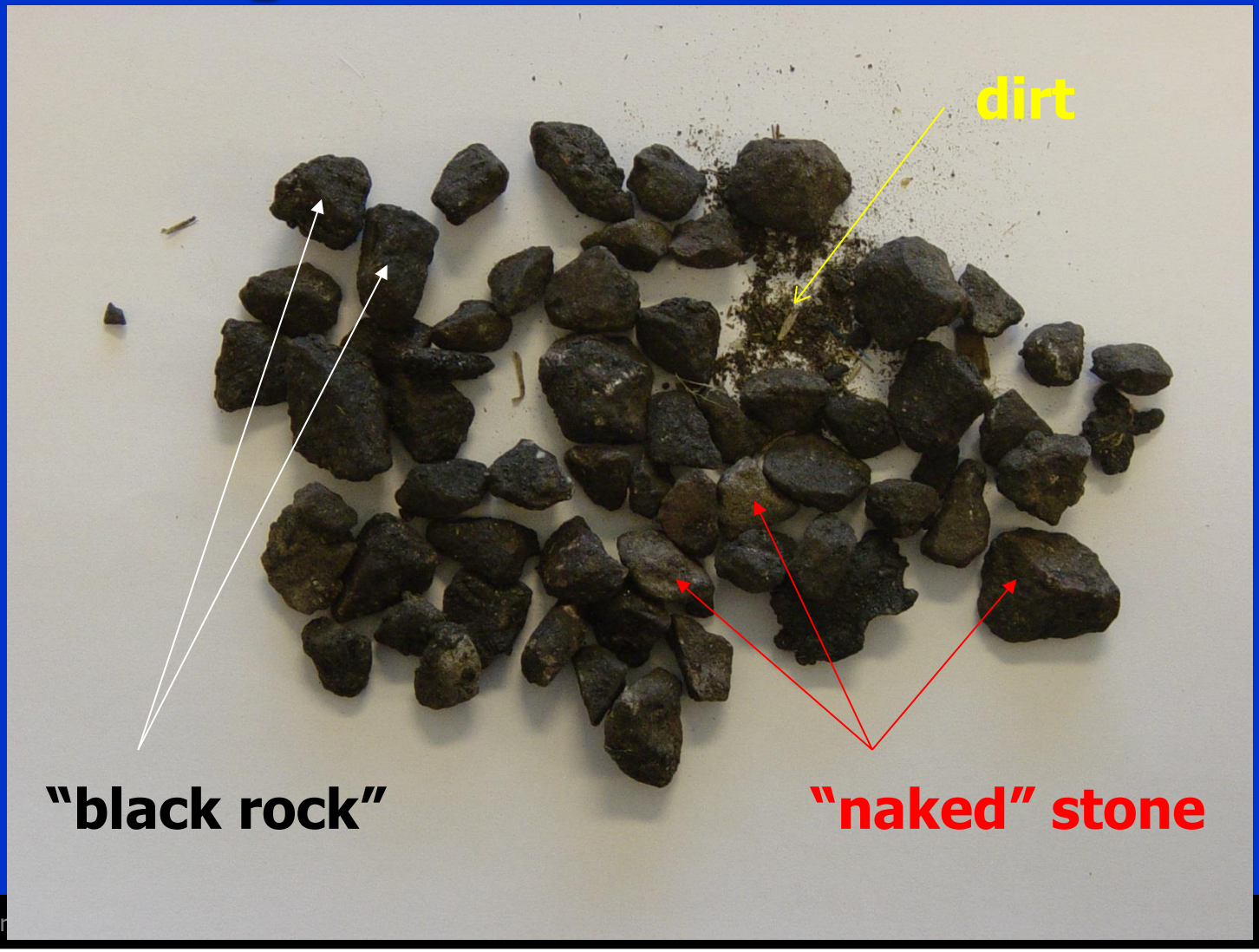
# Major damage type is ravelling, potential reasons are:

- Traffic
- Temperature, UV, Oxygen → Aging
- Moisture
- De-icing
- Oil spillage
- Working conditions during placement
- Skills of the paving crew

# Ravelling



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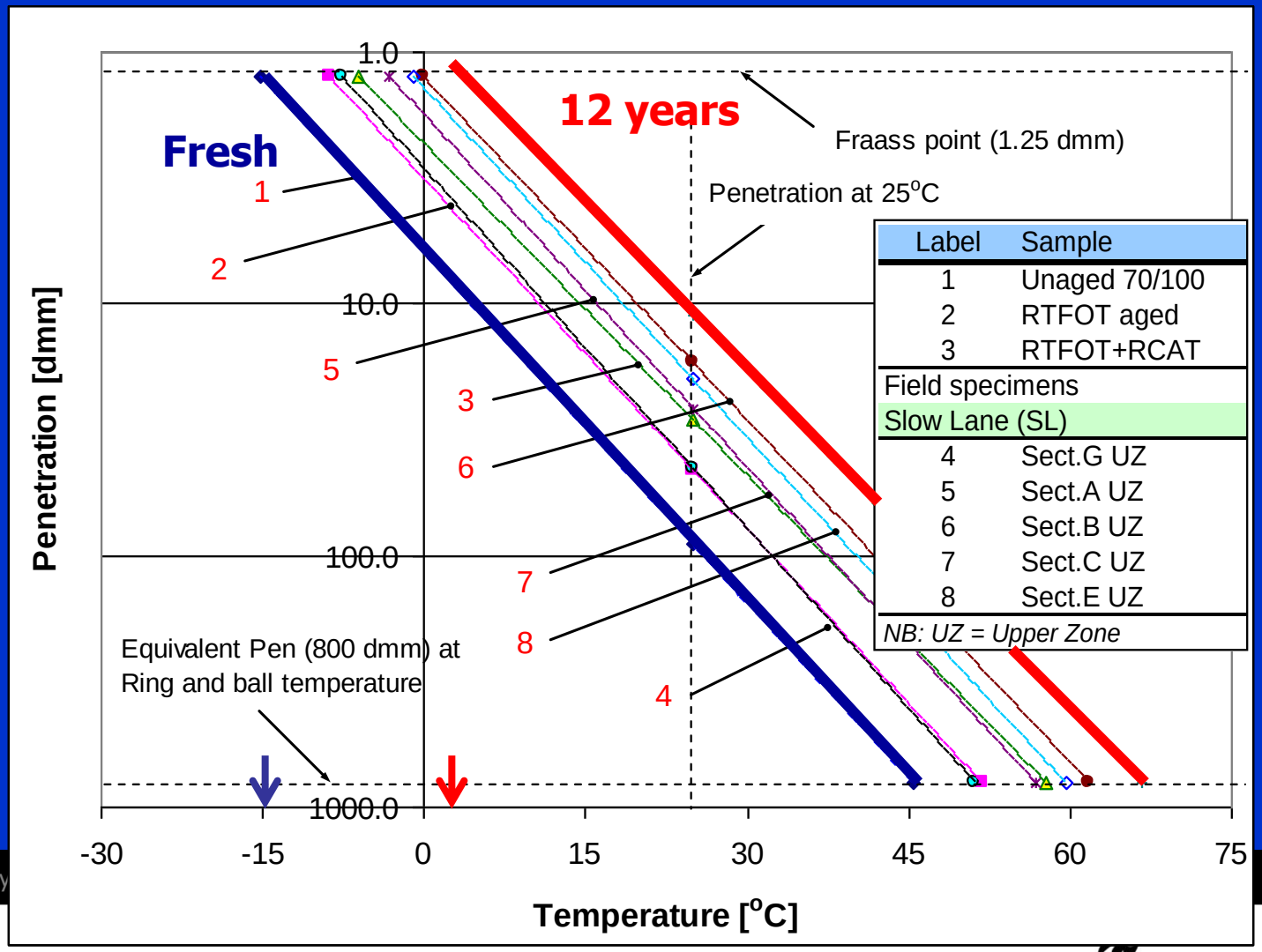
# Severe aging of bitumen in Porous Asphalt Concrete



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# Preventive maintenance

- Spraying "rejuvenation" products in thin films (800 gr/$m^2$) on porous asphalt layers is being considered as a cost-effective and environmentally sustainable strategy for preventive maintenance.
- Goal is to add extra binder material and to promote rejuvenation.

**All products are propriety products and no information about composition is given by producers**

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# Spraying of products



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# Jet blower after spraying a certain product

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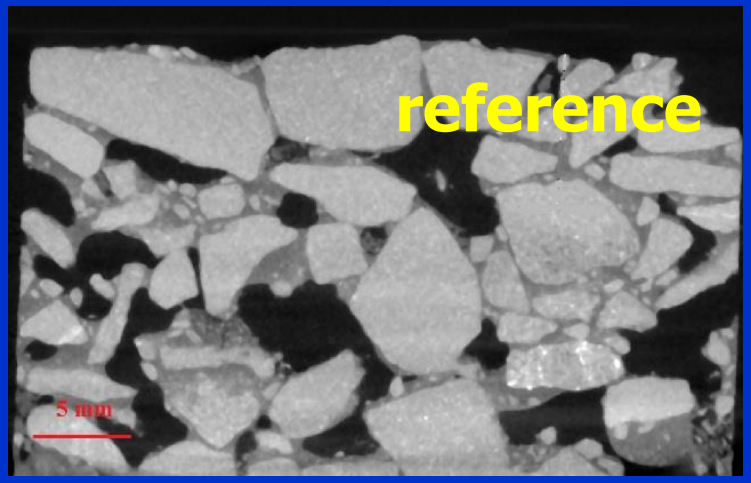


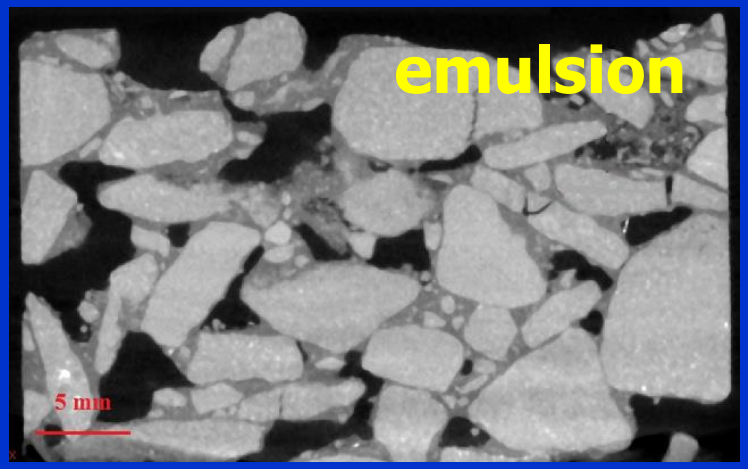


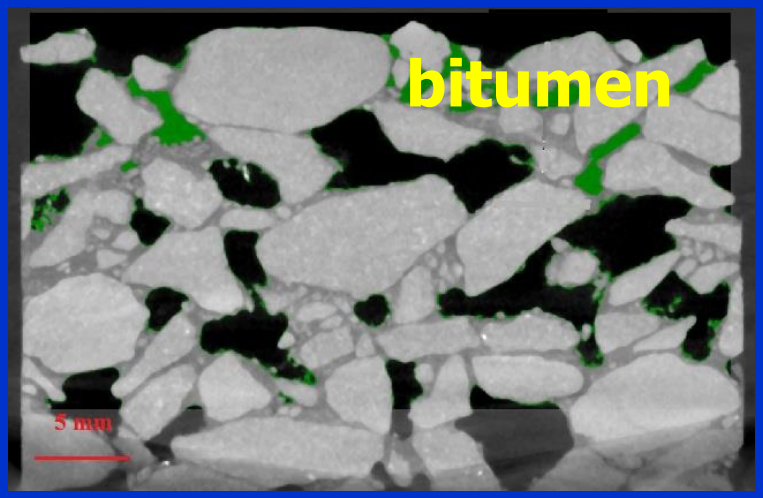


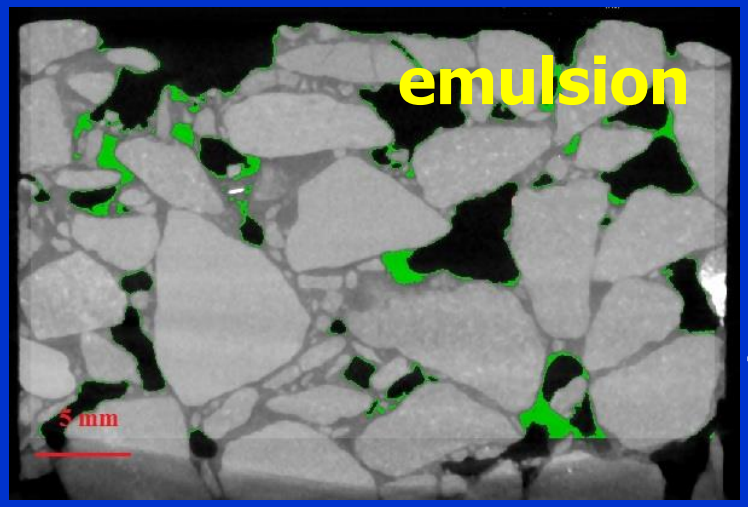


Emulsion, penetration is deeper because of use of jet blower

CT scans on reference mix identified two materials (different density): stone and mortar; some cores treated with "rejuvenation" products show additional binder.

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# Optical Microscopy test


**Specimens were polished to a thin slice 35 mm x 25 mm x 30 μm**

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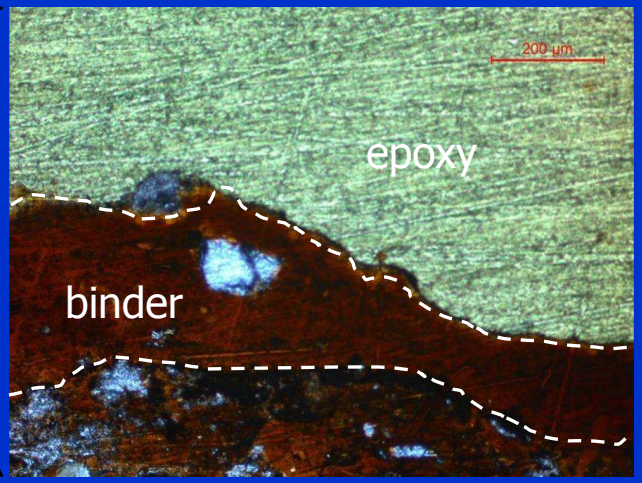


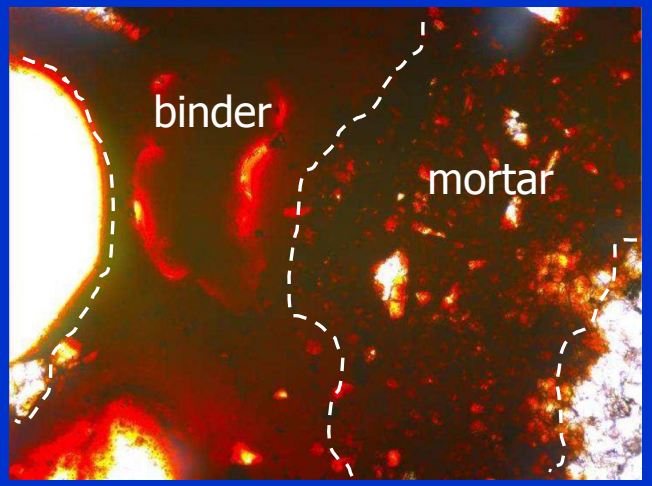


**An additional binder layer without shiny particles (filler or sands) was observed on surface of the mortar**

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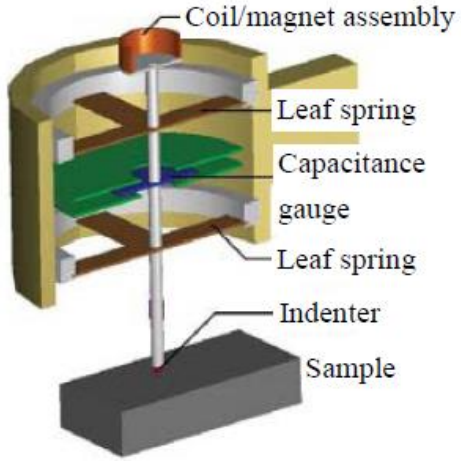
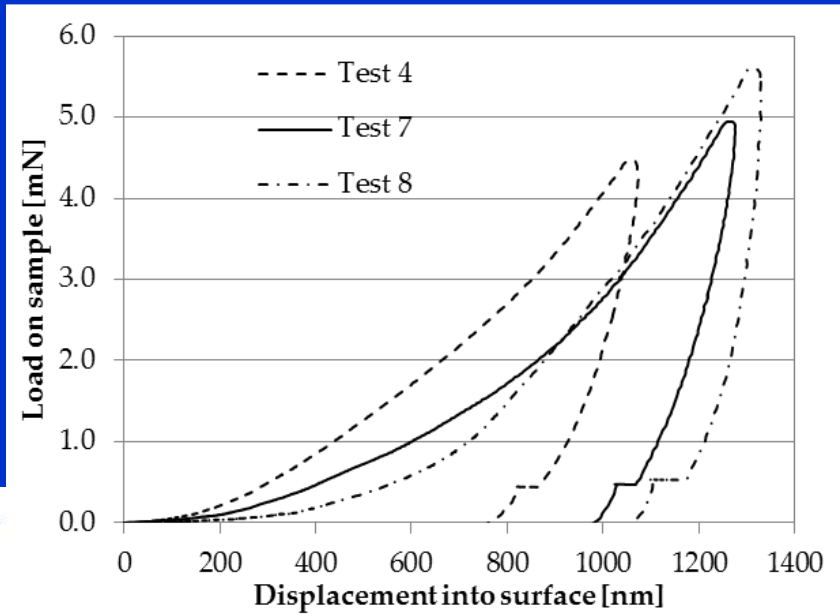
# Nano-indentation tests

**An indenter loads the mortar surface with a displacement rate of 5 nm/s until an indentation depth of 1000 nm at -20 °C**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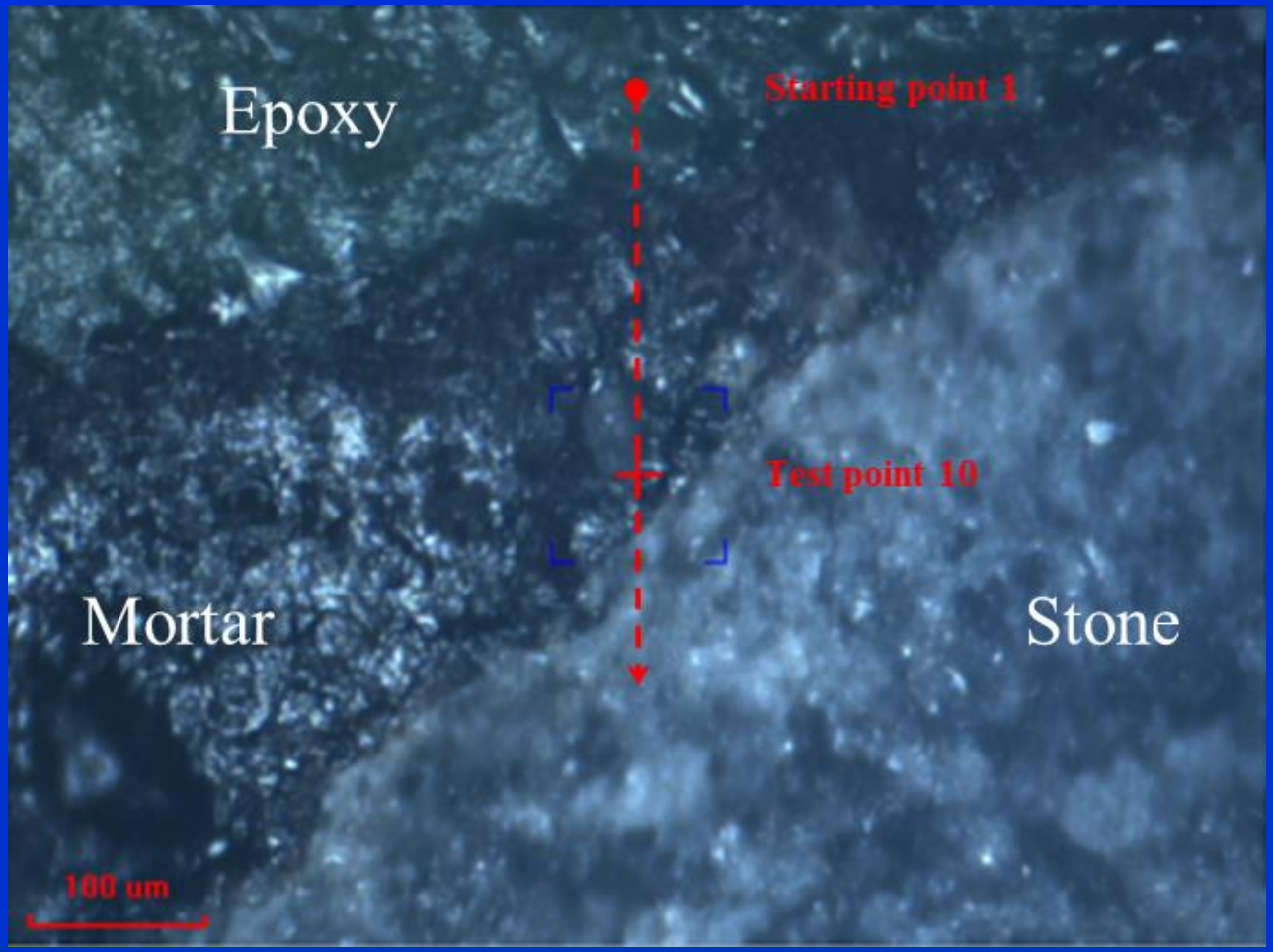
# Example of indentation results

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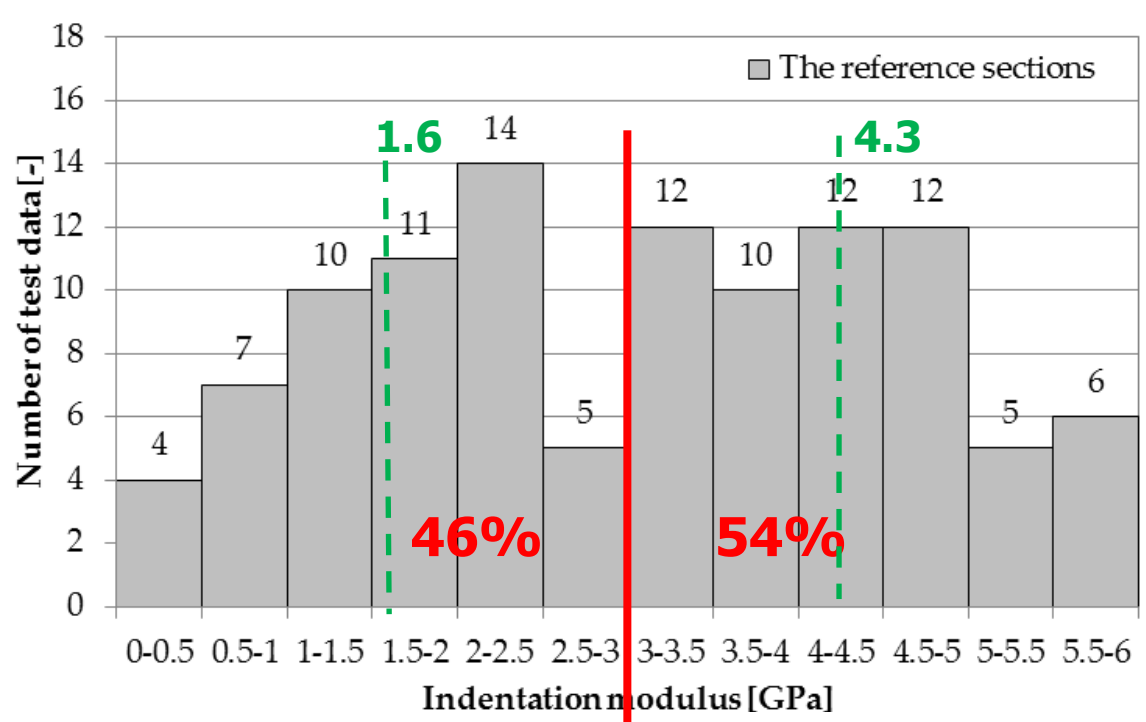


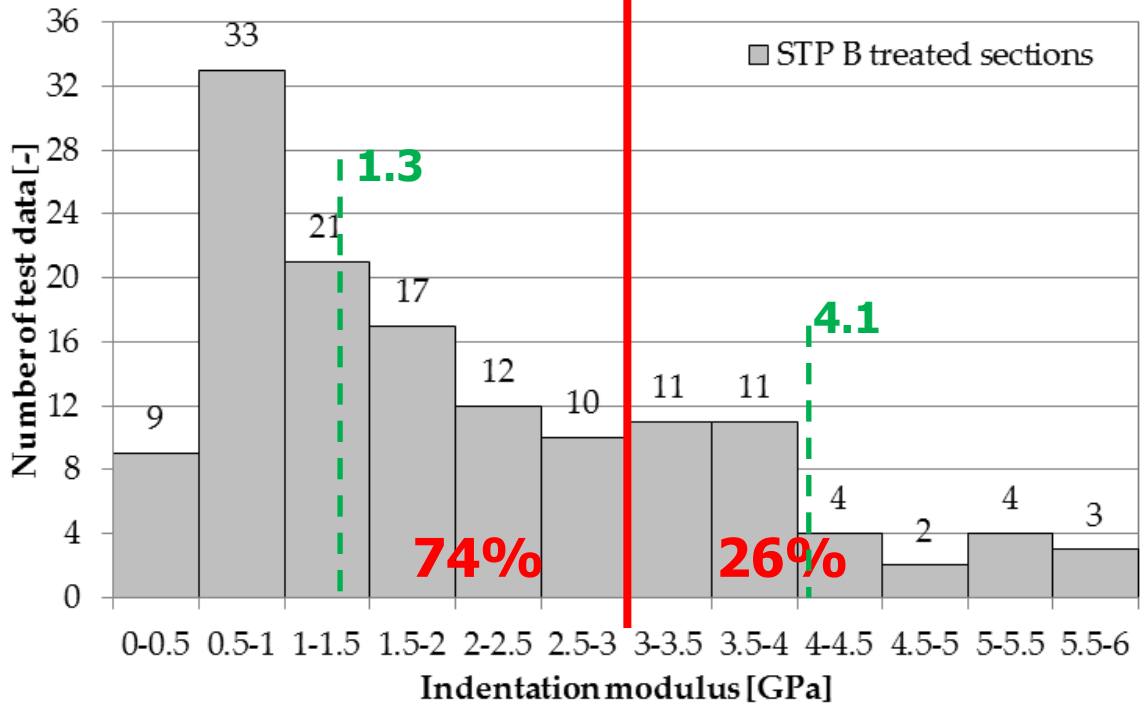


# Effect product B

**Indentation Modulus (IM)**

**IM < 3 Gpa**
**Bitumen rich phase**

**IM > 3 Gpa**
**Filler rich phase**

**Effect of adding bituminous material is clearly visible**



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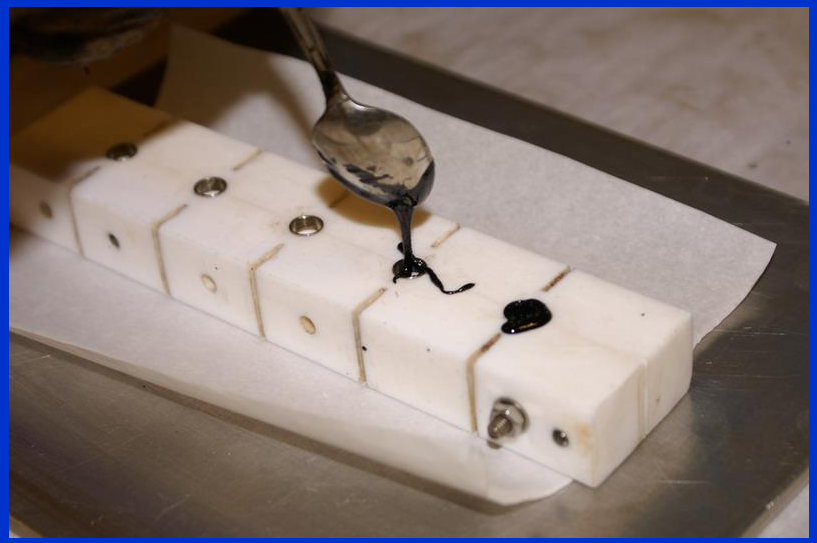
# Conclusions so far

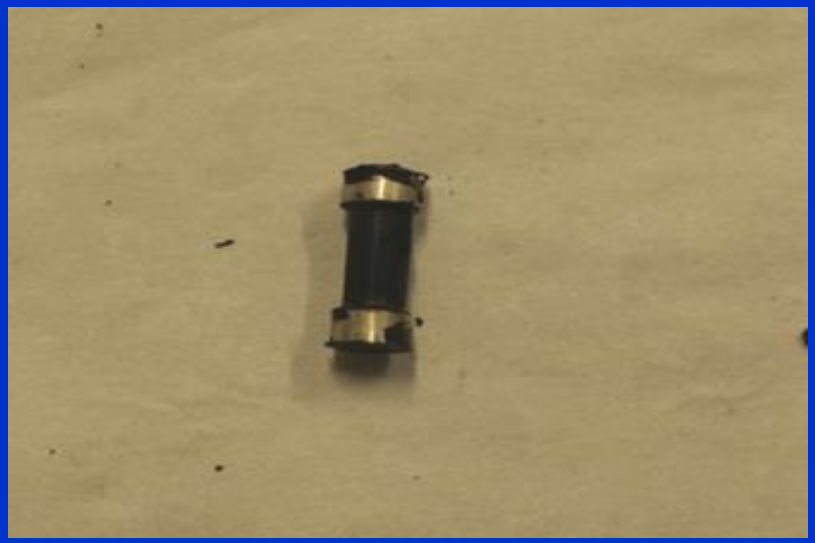
- Nice that we see an effect but what is effect on mechanical properties of the "glue" that sticks the coarse particles together
- Mortar needs to be tested and NOT the bitumen because the mortar is the real glue

# Definition of mortar

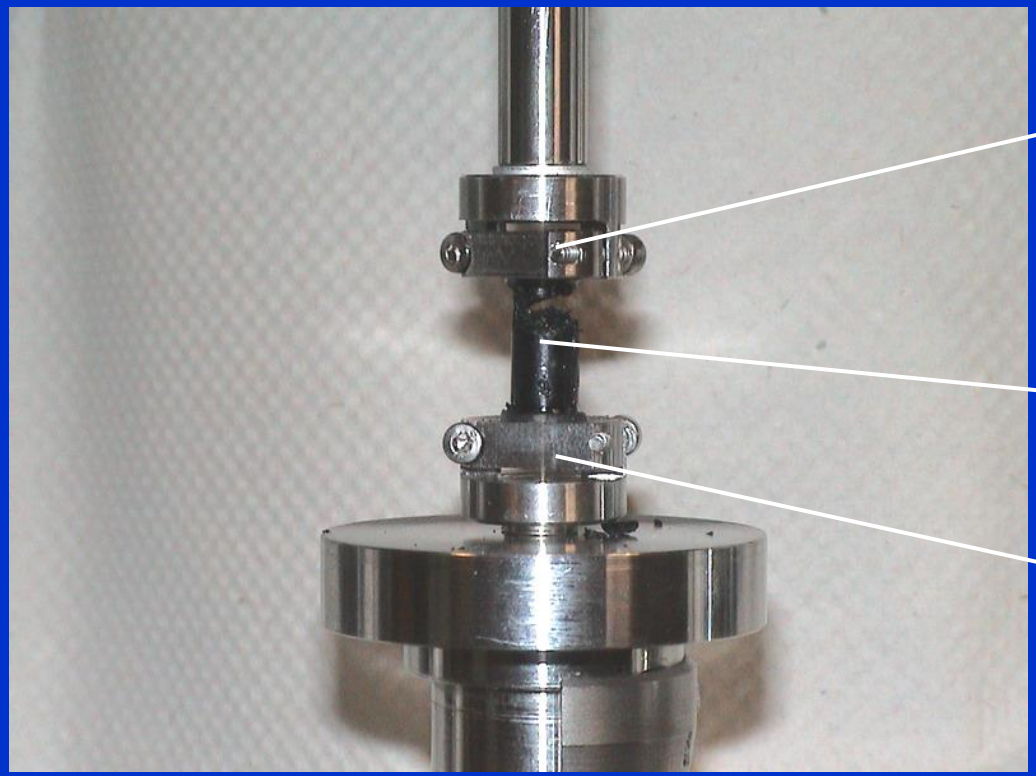
- **Bitumen.**
- **Filler (fines) < 63 μm includes 25% hydrated lime.**
- **Fine sand fraction (< 425 μm).**
- **How do you test a mortar? Use a DSR!**

# Preparation of mortar column samples





# DSR is used for modulus and fatigue testing



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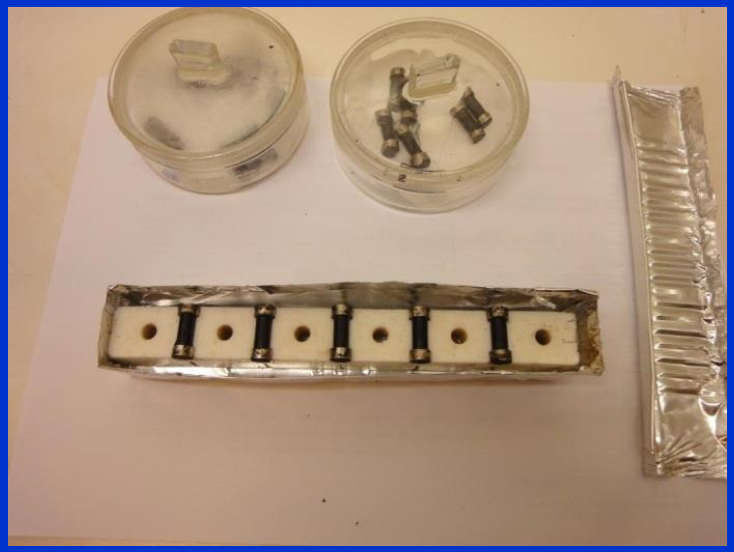
# Rejuvenation procedure

**Application of emulsion type rejuvenation product on laboratory aged mortar columns**



- **Step 1: soaking in emulsion bath for 15 minutes at 25 $^{o}$C**
- **Step 2: curing in air for 7 days at room temperature**

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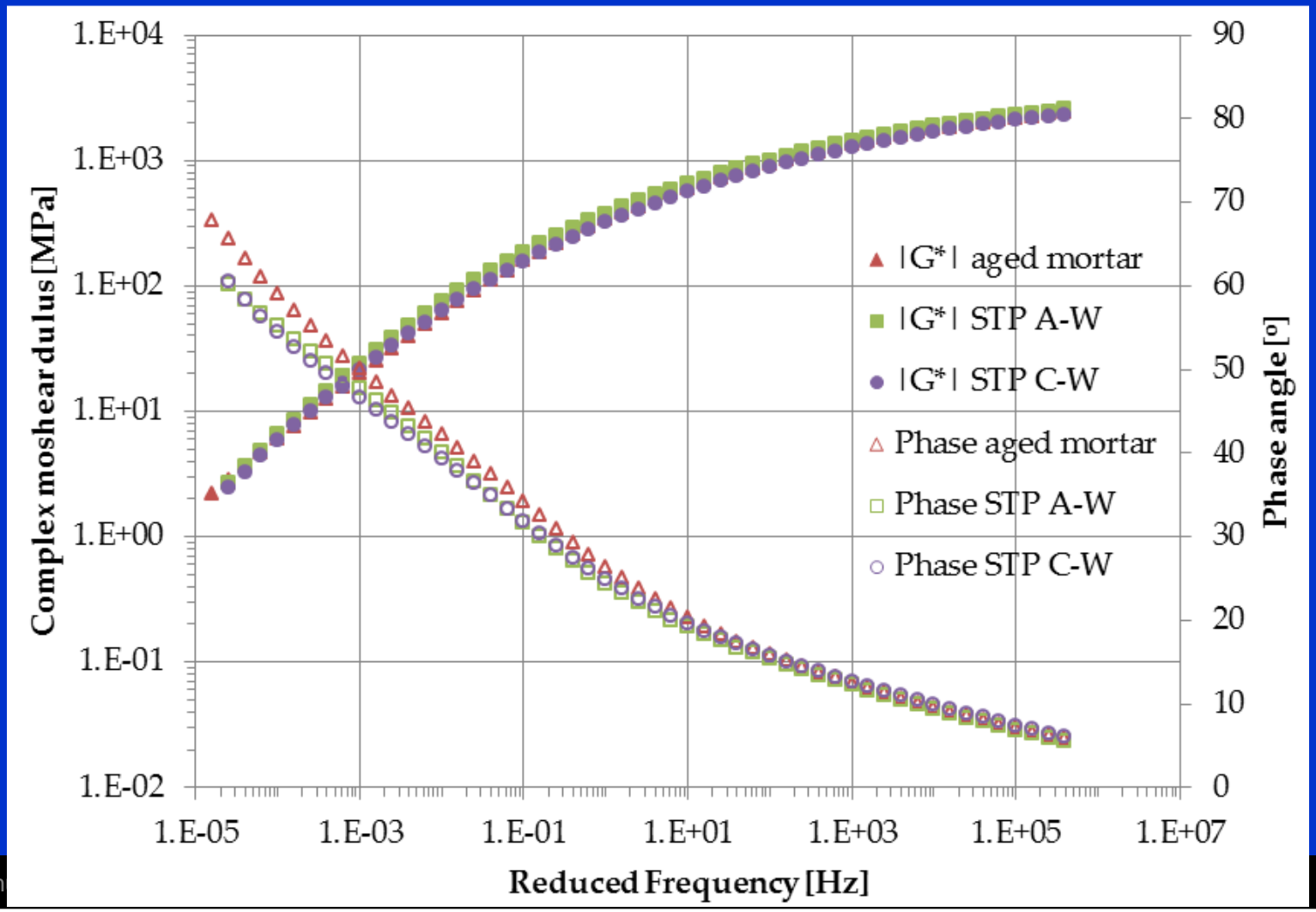
# Master curves aged and treated mortar






**STP X = product; W= one week curing**

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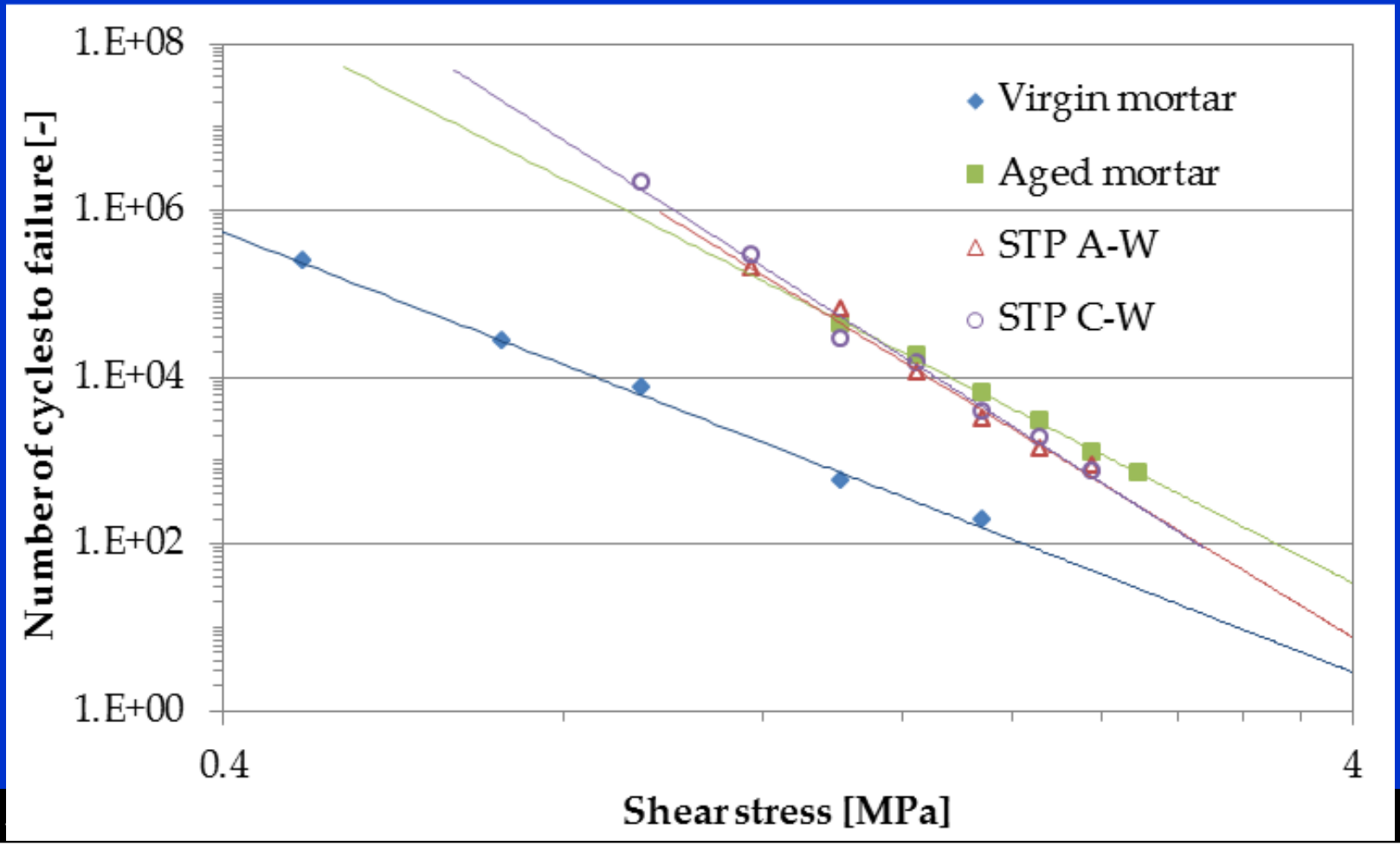
# Fatigue aged and treated mortar

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# Conclusions

- **Effect of rejuvenation on $G^*$, $\delta$ and fatigue could not be shown**

# Why don't we measure effect on mechanical properties?

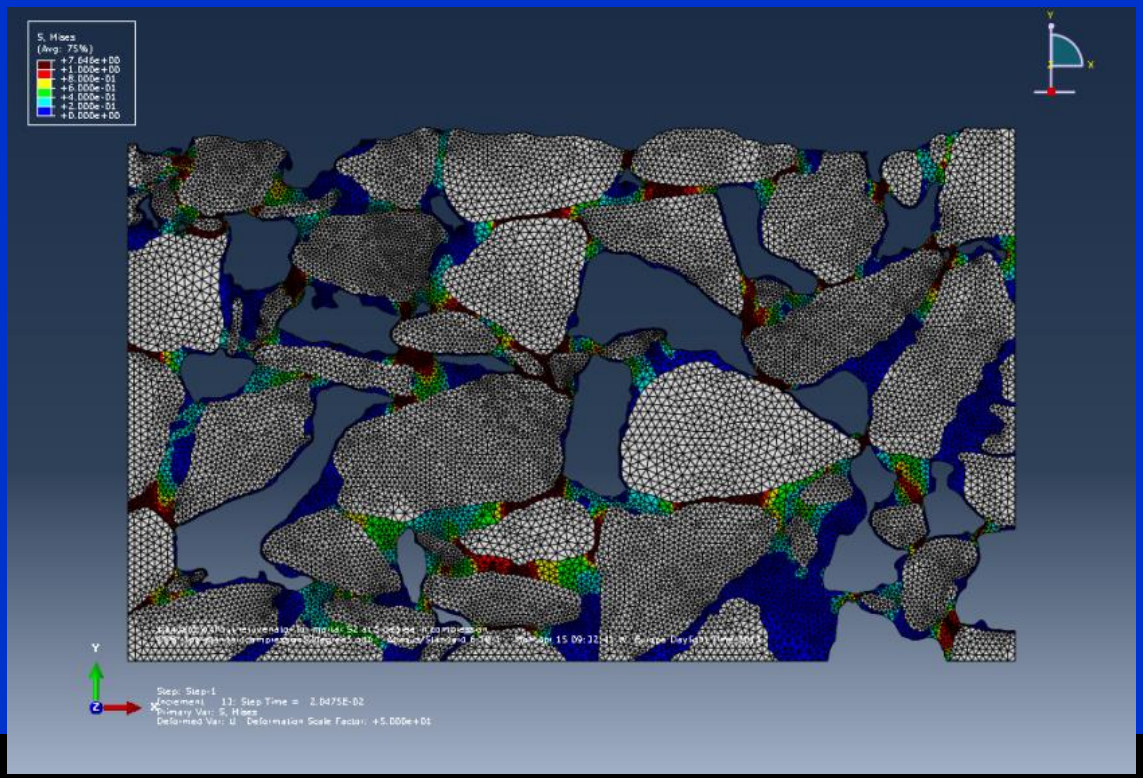
- **Rejuvenation is driven by diffusion**
  **- main "handicap" - temperature is too low**

# Additional comments

- Effects of diffusion were also measured using the DSR for testing multilayer bitumen systems at 65 $^{o}$C
- Some diffusion was measured but it was negligible
- This supports the finding that counting on diffusion when using spraying techniques is a “no no”

# So these products will not be effective?

**To some extent they will be effective because new, fresh material is added. This effect has been proven in the lab and by means of FE analyses**



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# Thank you for your attention



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# But …

**an Irish South African might help next time !!**



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# However

**Soccer skills = f (1 / rugby skills)**





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# Some Statistics

**2500 km main highway system**

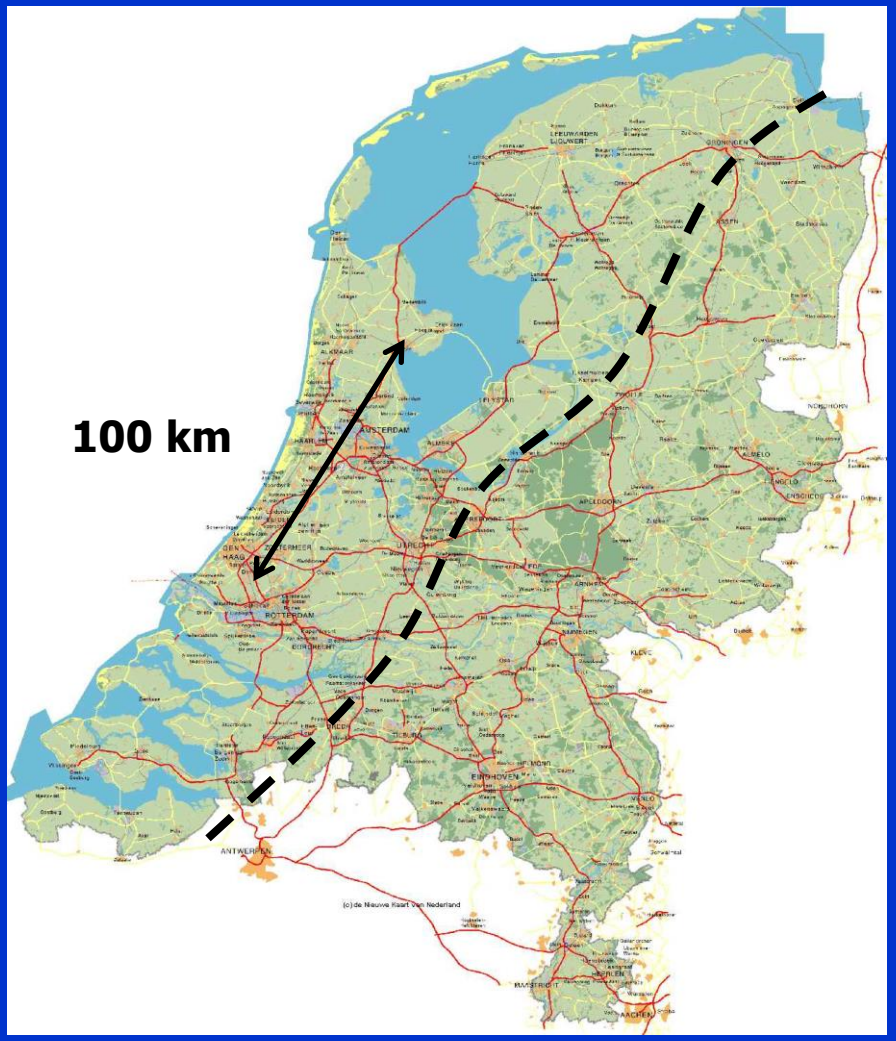
**100.000 vehicles/day**
**15 % trucks**
**3.5 axles of 100 kN/truck**
**9 % overloaded**
**axle loads as high as 24 tons**

**time slot for maintenance 21u – 5u**

**20 % inhabitants hindered by traffic noise**

**6 dB(A) reduction of noise level**

**2 % < CBR < 5 % in western part of the country**



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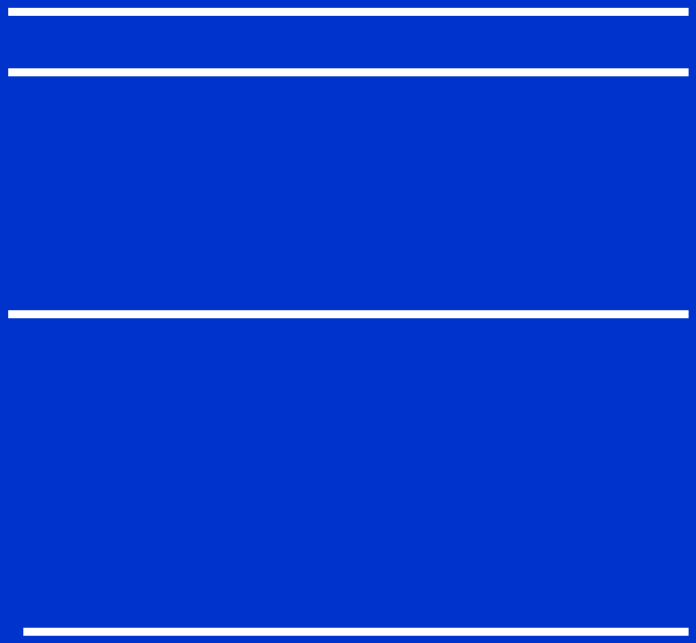
# Typical highway structure



50 mm porous asphalt concrete

250 mm asphalt concrete
4.5% 40/60 bitumen, 6% voids

300 mm unbound base of recycled construction demolition waste

sand subgrade

# Blending

*"to combine or mix so that the constituent parts are indistinguishable from one another"*

**But does it occur?!**

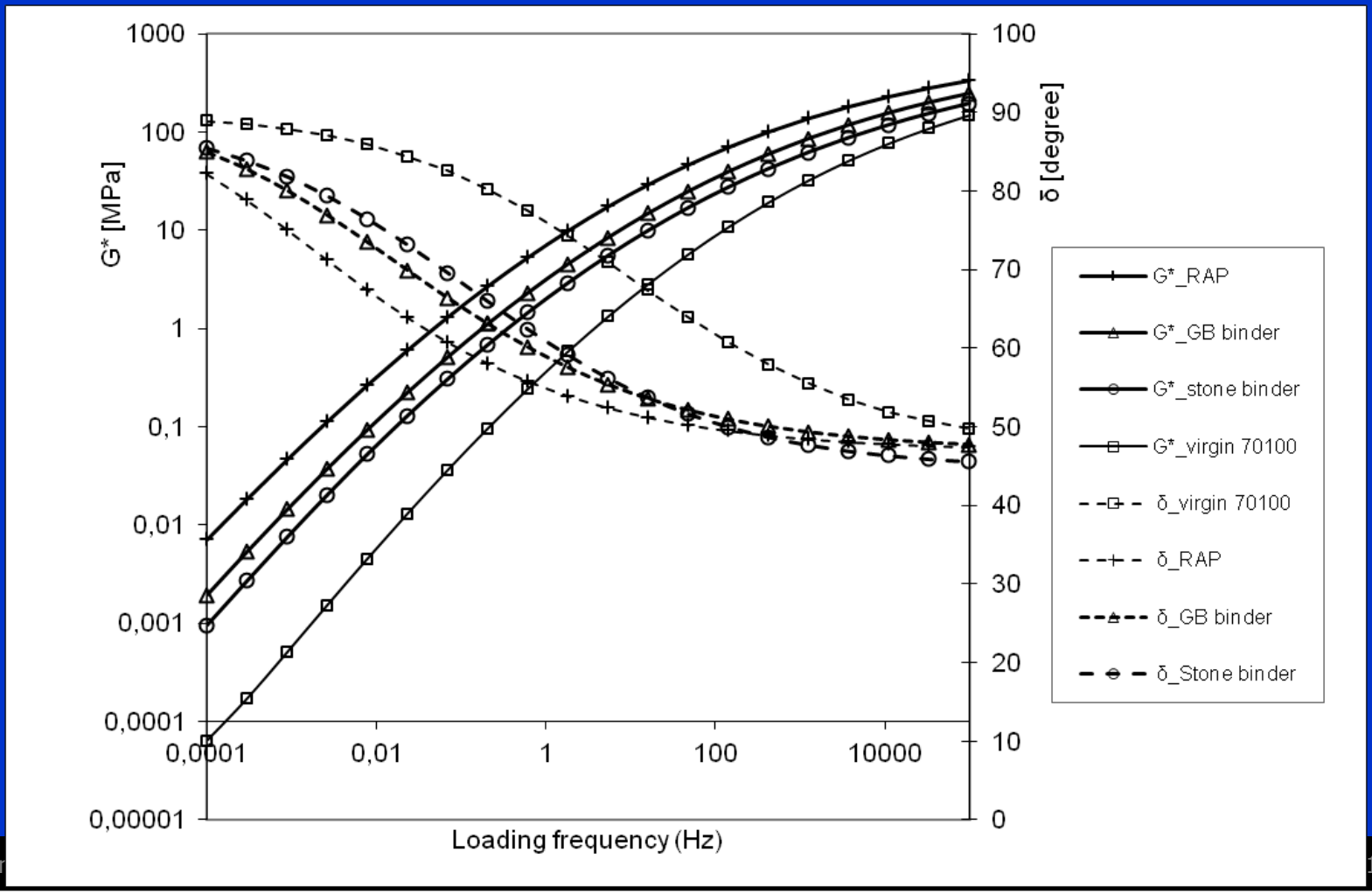
# If blending occurs then Log G*cq Log pen rule applies

$$\text{Log } G^*_{\text{mixture}} = a \text{ Log } G^*_{\text{RA bitumen}} + b \text{ Log } G^*_{\text{virgin bitumen}}$$

$$\text{Log pen}_{\text{mixture}} = a \text{ Log pen}_{\text{RA bitumen}} + b \text{ Log pen}_{\text{virgin bitumen}}$$

a = fraction of RA bitumen
b = fraction virgin bitumen
a + b = 1

# G* and δ of virgin, stone and GB binders



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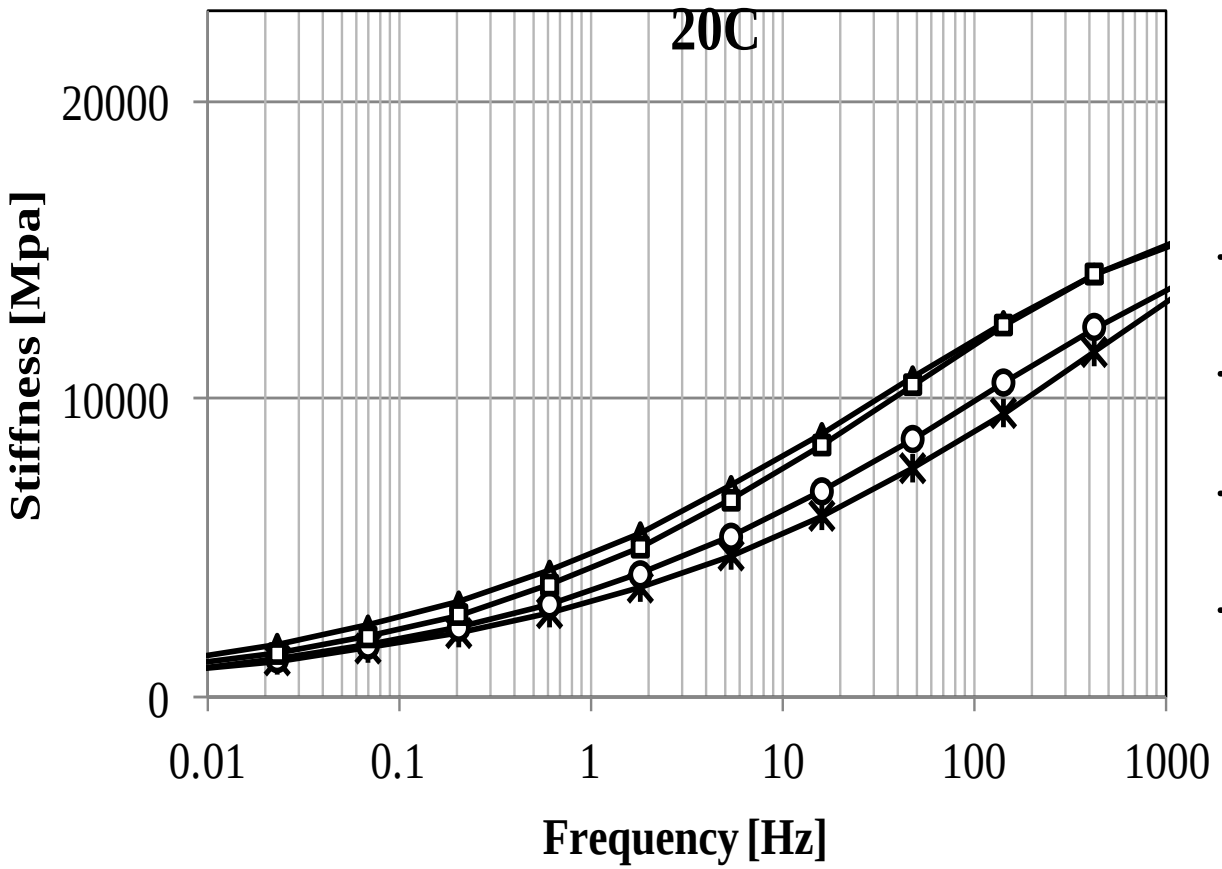
| Mixture Type | RAP % | Code |
|---|---|---|
| Moist base course RAP (4%) at ambient temperature is mixed with superheated aggregate (500 °C) in an Astec Double Drum mixer | 50 % | A ASTEC Double Drum |
| Moist base course RAP (4%) preheated at 130°C in parallel drum is mixed with hot virgin aggregate (270 °C) in batch plant pugmill mixer (Batch Plant) | 50 % | BB Batch plant |
| RAP (25% base RAP+25% reclaimed porous asphalt PARAP) preheated at 130°C in parallel drum is mixed with hot virgin aggregate (270 °C) in batch plant pugmill mixer (Batch Plant) | 50 % | B Batch plant |
| Preheating (3hrs) and mixing RAP and virgin aggregate at the same temperature in laboratory pugmill mixer (170 °C) | 50 % | L LAB |

# Master curves at 20 °C for different mixtures




**AC 22 Astec 50% RAP**

**AC 22 Batch 25% PARAP + 25% RAP**

**AC 22 Batch 50% RAP**

**AC 22 Lab 50% RAP**

**PARAP = RAP of porous asphalt concrete; binder has very low pen ≈ 12**

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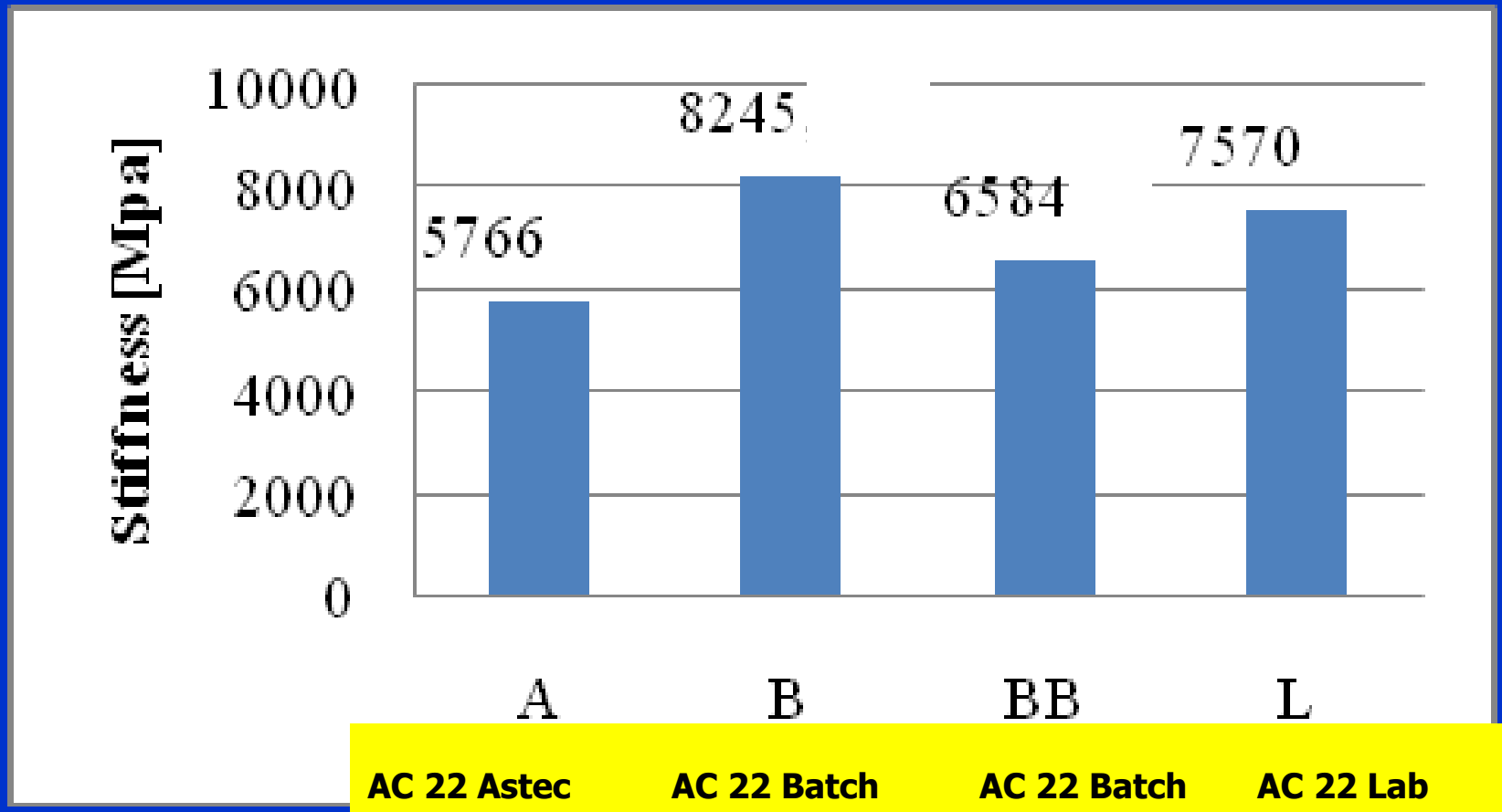
# Mixture stiffness at 20 °C and 8 Hz




| A | B | BB | L |
|---|---|---|---|
| AC 22 Astec 50% RAP | AC 22 Batch 25% PARAP + 25% RAP | AC 22 Batch 50% RAP | AC 22 Lab 50% RAP |



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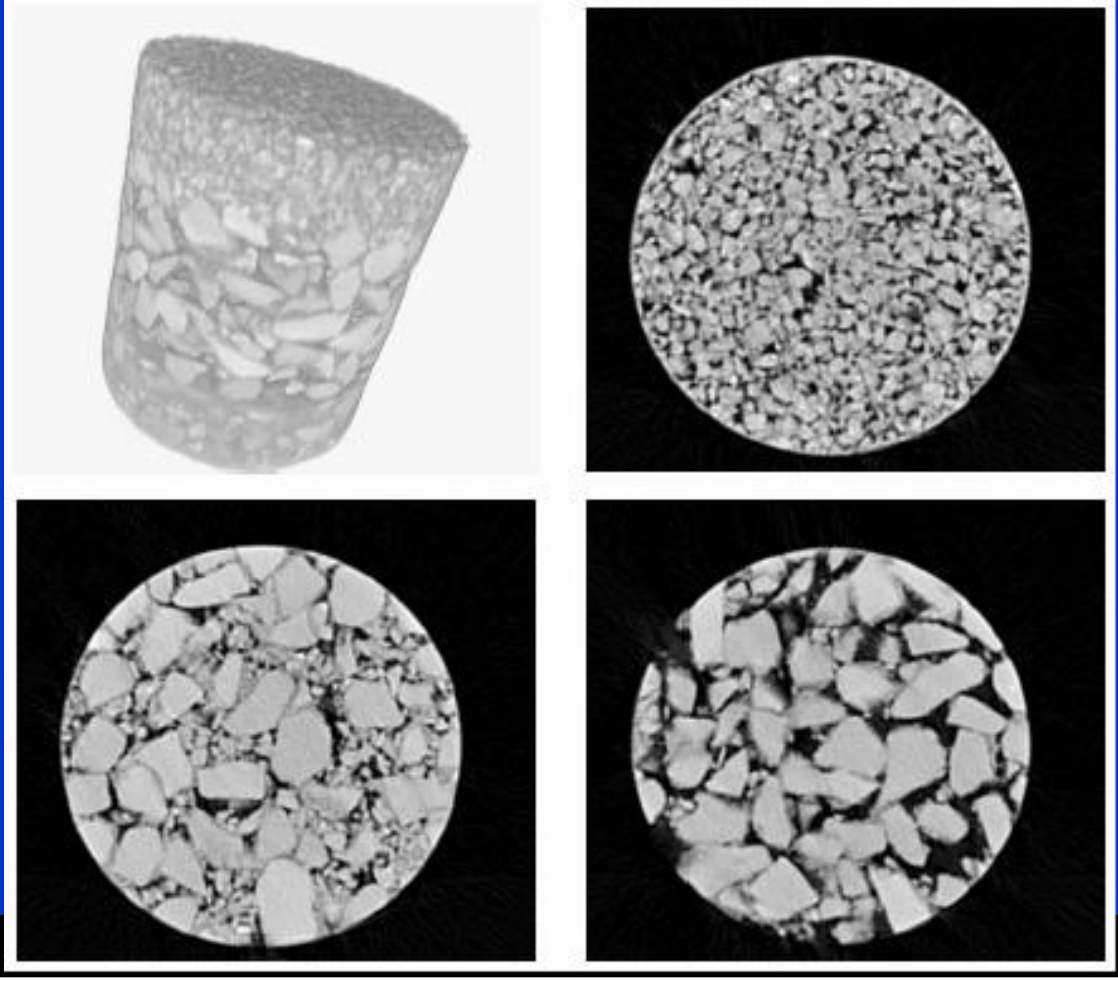
# Why do we use very porous asphalt wearing courses

- 25 % of inhabitants are hindered by traffic noise.
- Noise reduction is therefore a hot topic.
- Measures taken at the source are the most effective.
- Sound barriers are not only very costly but also don’t reduce noise production.
- Solutions should be found in tire and in pavement surface.

# Double layer porous asphalt concrete or twinlay



Top layer 25 mm
4/8 mm aggregate.

Bottom layer 40 mm
11/16 mm aggregate.

# What is ravelling



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# Rejuvenation

- Goals of rejuvenation is to give the binder its original properties
- Diffusion is to play a major role when rejuvenator is sprayed
- Diffusion *"the intermingling of substances by the natural movement of their particles"*
- Key parameters controlling diffusion
  - time
  - temperature