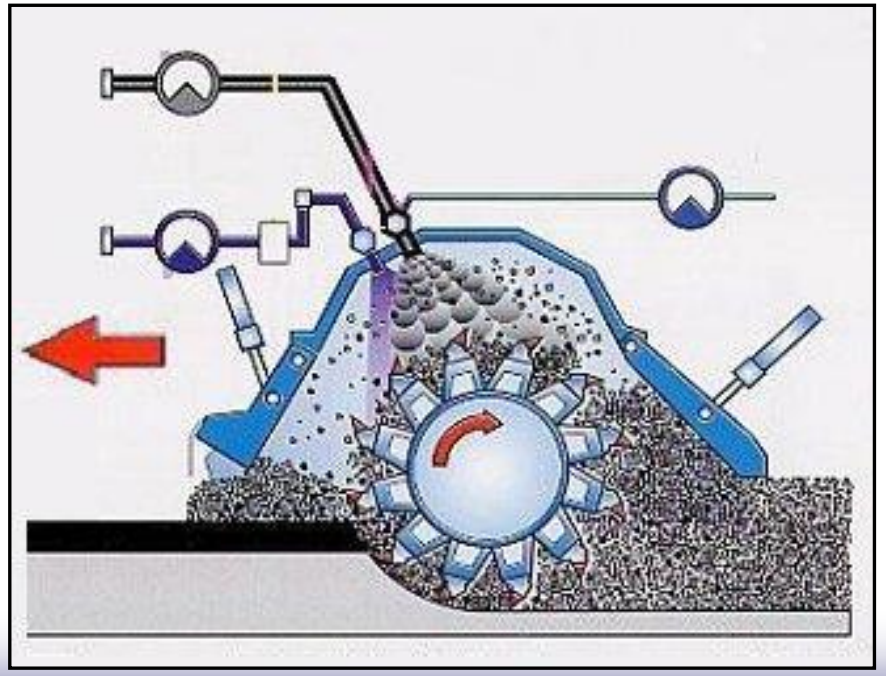
INNOVATION

IN COLD RECYCLING TECHNOLOGIES

COLD RECYCLING AND LIME



ACKNOWLEDGEMENTS

- **Kim Jenkins**
- **Gordon Airey**
- **Alessandro Marradi**
- **Martin Diekmann**
- **Elena Romeo**

BACKGROUND

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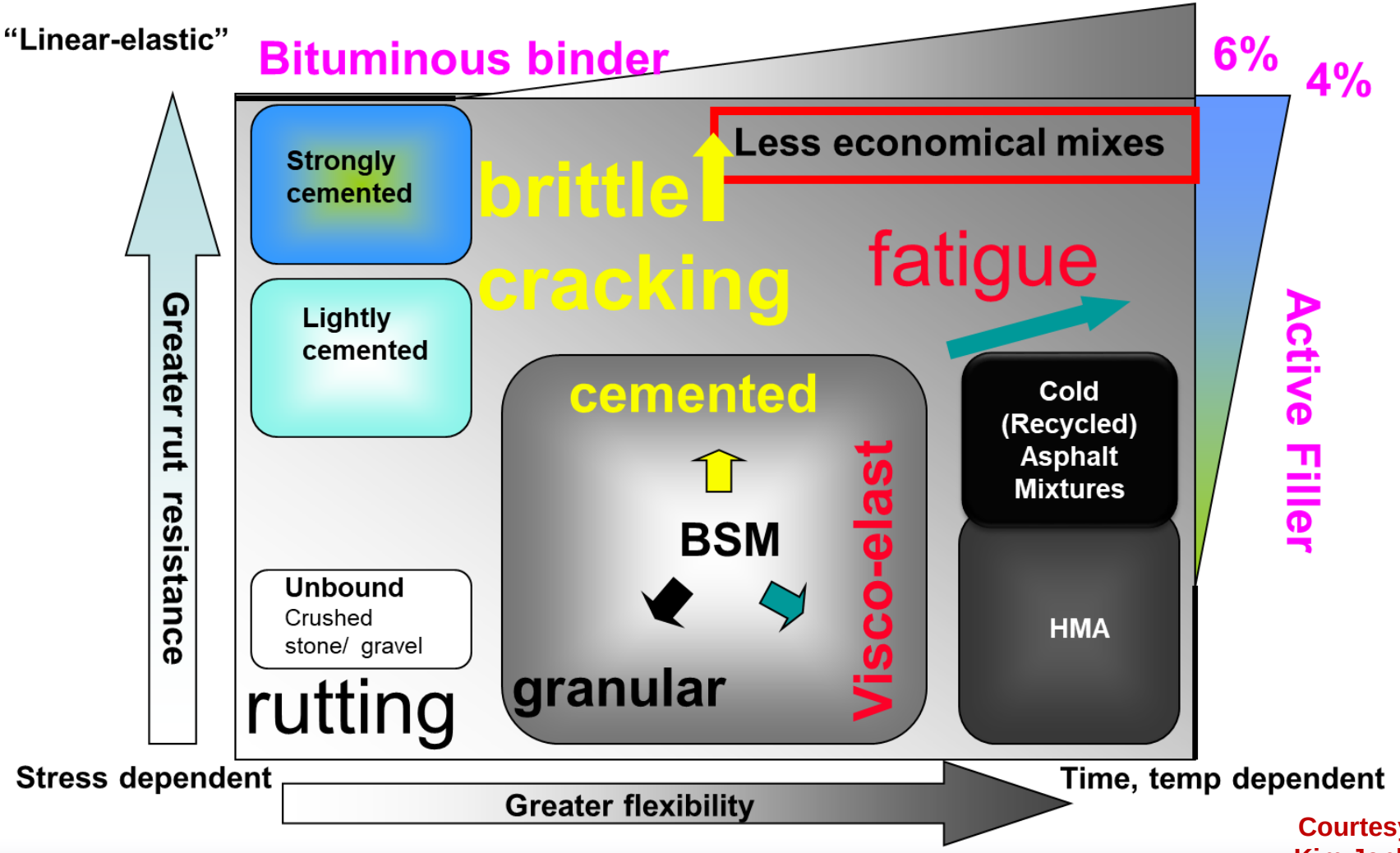

Courtesy of Kim Jenkins

BACKGROUND

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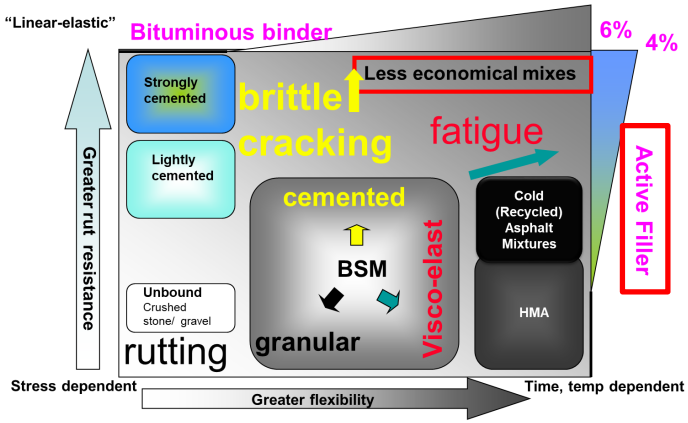
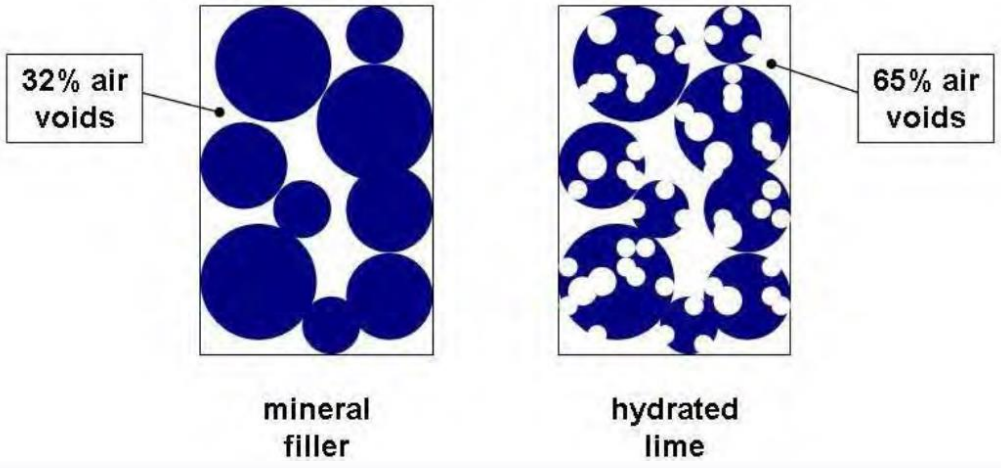


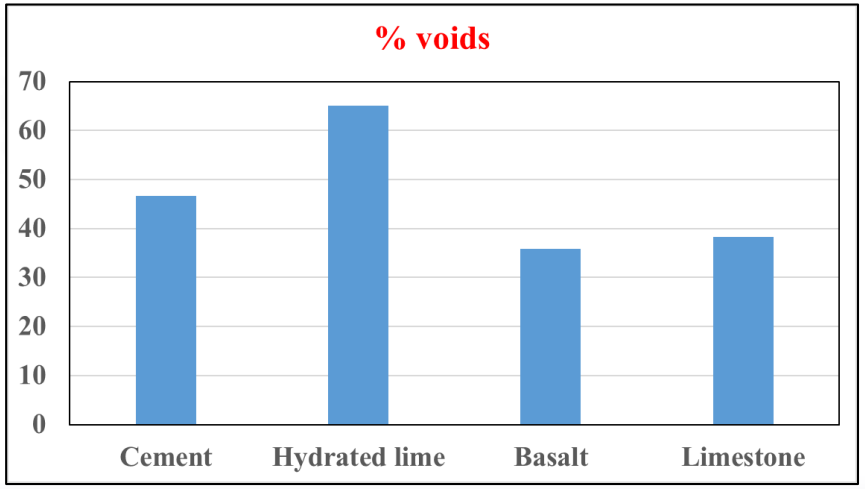
Active filler

The term active filler is used to define fillers that **chemically alter** the mix properties. This includes fillers such as lime, cement and fly ash but excludes natural fillers such as rock flour.

The purpose of incorporating active filler in BSM is to:

- Improve adhesion of the bitumen to the aggregate
- Improve dispersion of the bitumen in the mix
- *Modify the plasticity of the natural materials*
- Increase stiffness & strength of mix
- Accelerate curing of compacted mix
- Control emulsion's breaking time





BACKGROUND

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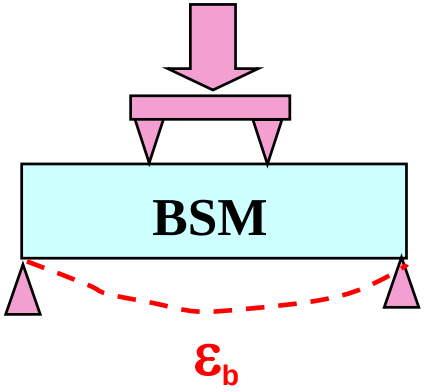
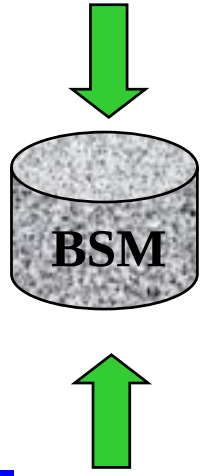
Cement Contents

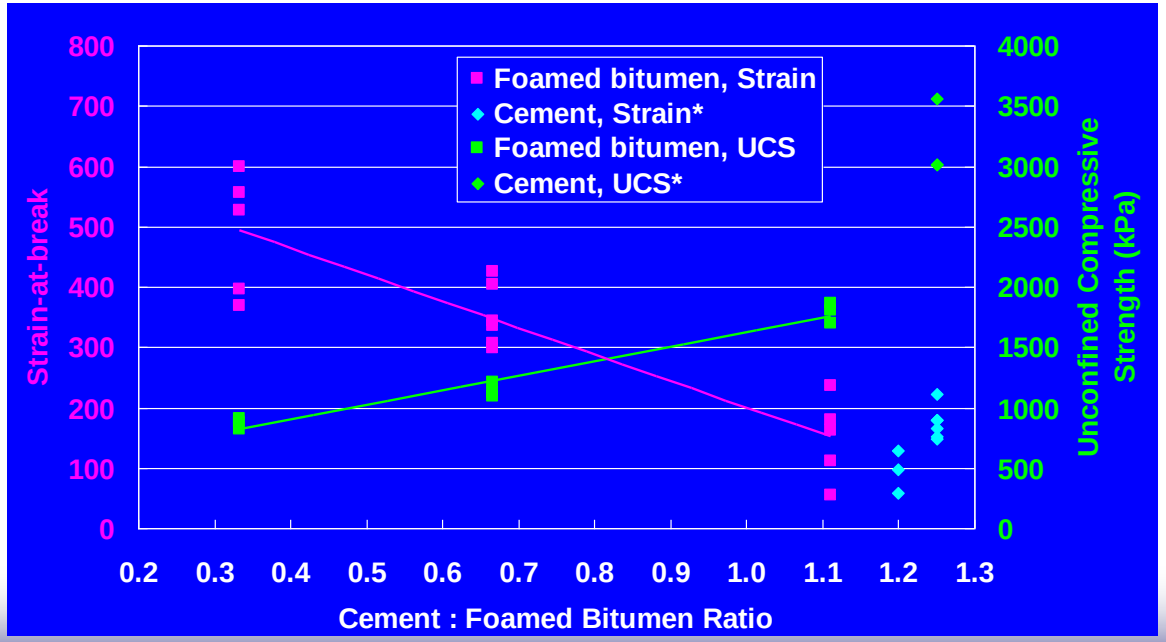
The cement content of BSMs should be ≤ 1%, and the cement content should not exceed the bitumen content.

……→ ≤ 1,5%……





Strength and flexibility



Courtesy of Kim Jenkins

BACKGROUND

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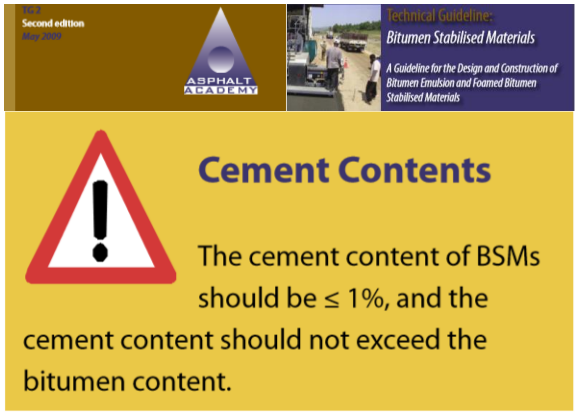
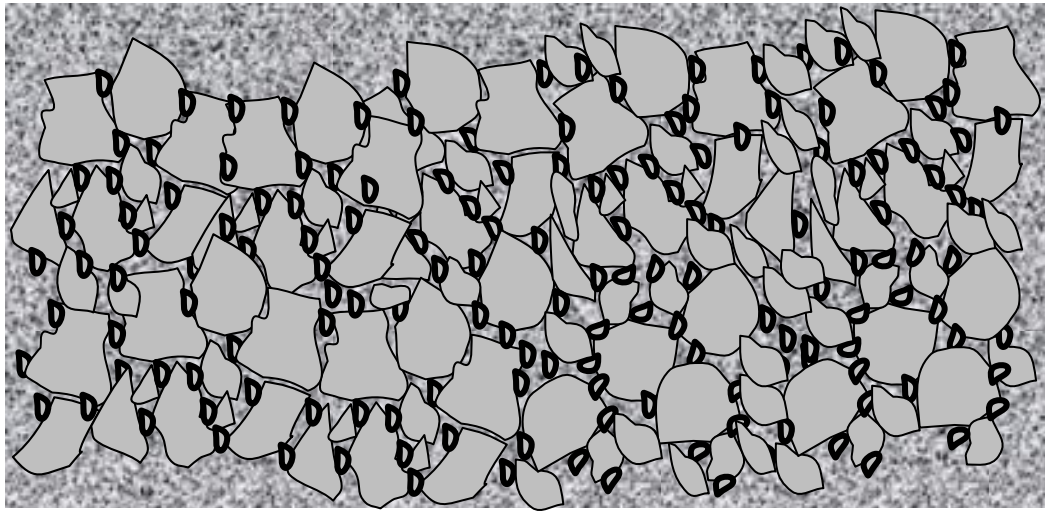


……..→ ≤ 1,5%.....

A Bitumen Stabilized Material is an half bounded material: a material with a behavior "at half way" between a granular material and a bounded material

"..a granular material with steroids……." [Dave Collings]



…with high amount of cement the Bitumen Stabilized Material loses the characteristics of a granular material: it becomes a Cement Bound Material

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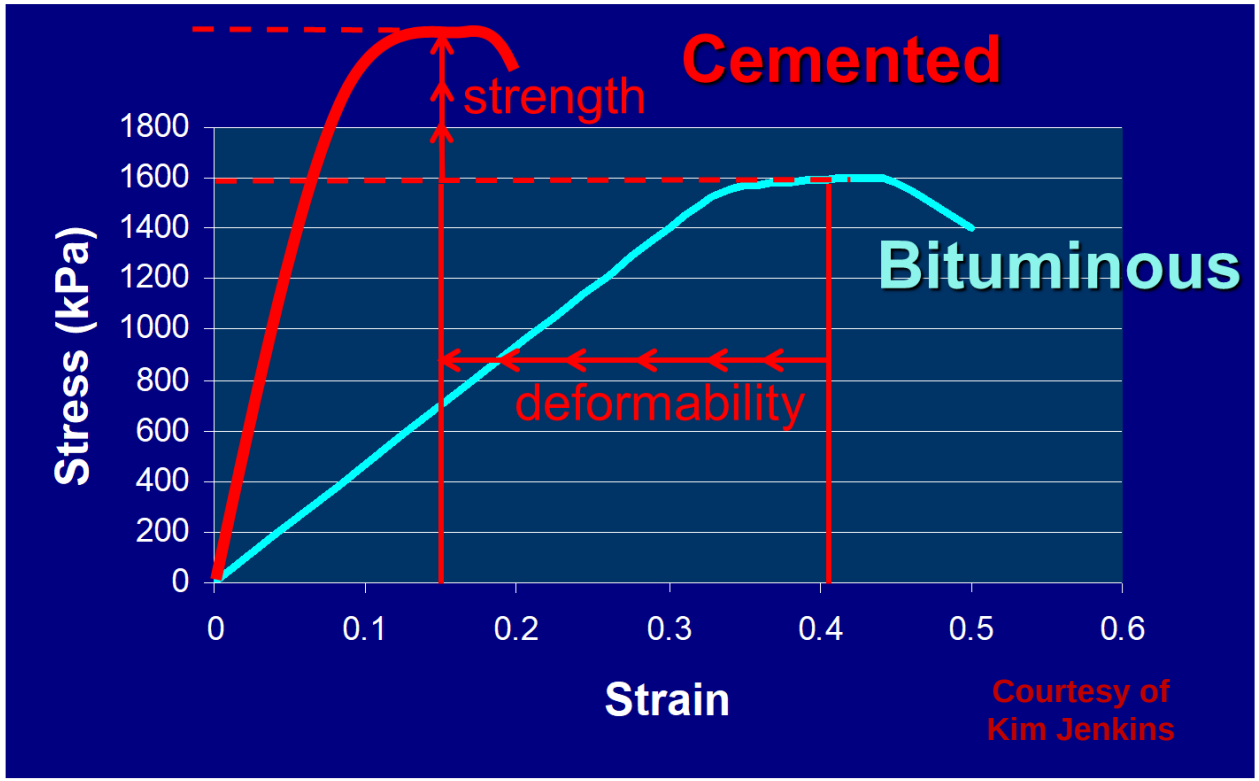

…with high amount of cement the Bitumen Stabilized Material loses the characteristics of a granular material: it becomes a Cement Bound Material

BACKGROUND

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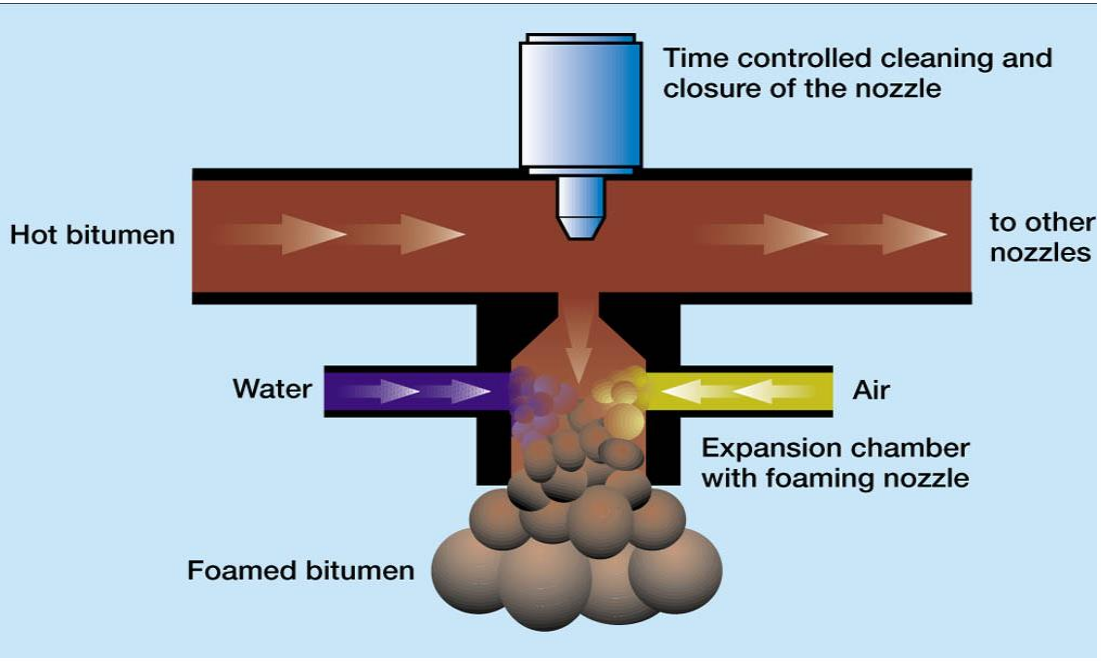
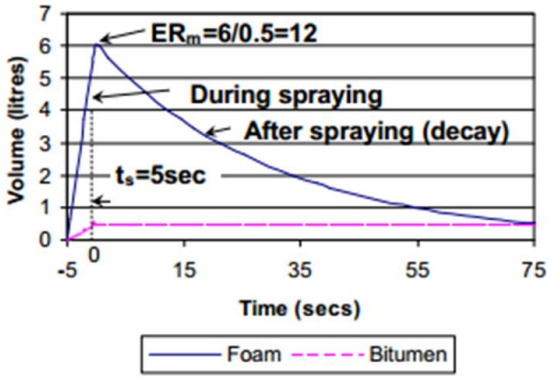
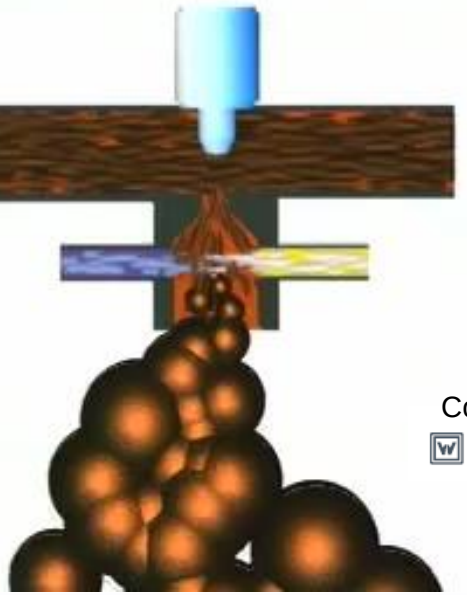
Foam bitumen

Cold water and air are injected simultaneously into the hot asphalt.

The hot asphalt foams explosively and shoots down into the mixing chamber.







Courtesy of WIRTGEN

BACKGROUND

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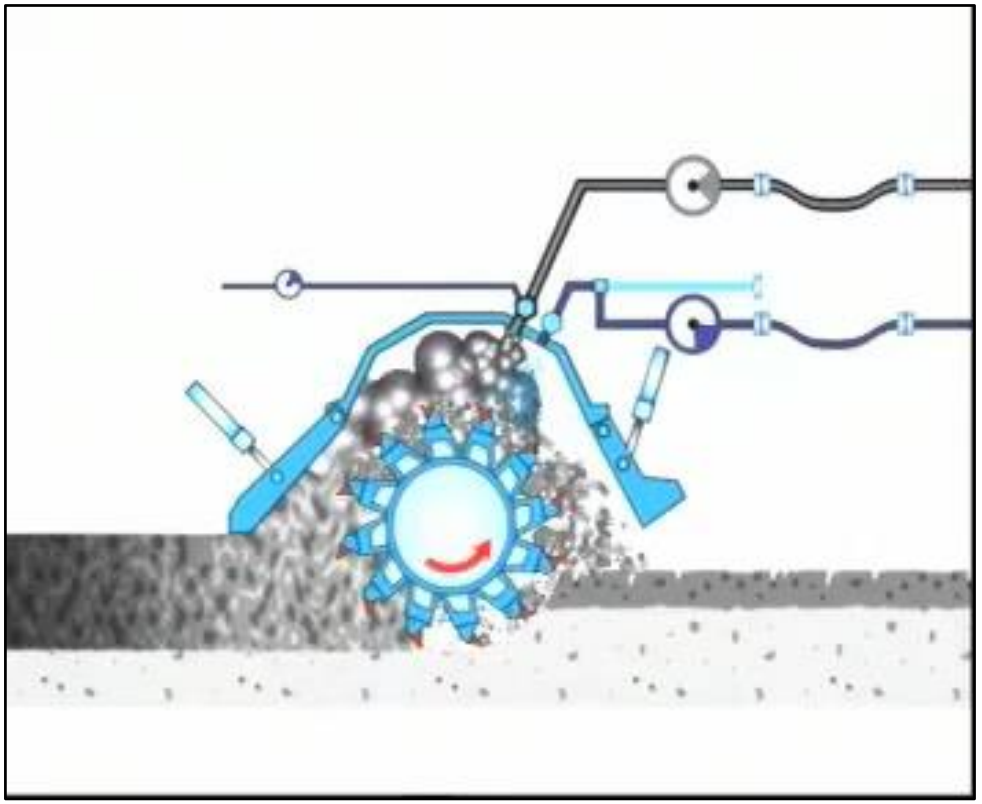
Foam bitumen



Courtesy of WIRTGEN

BACKGROUND

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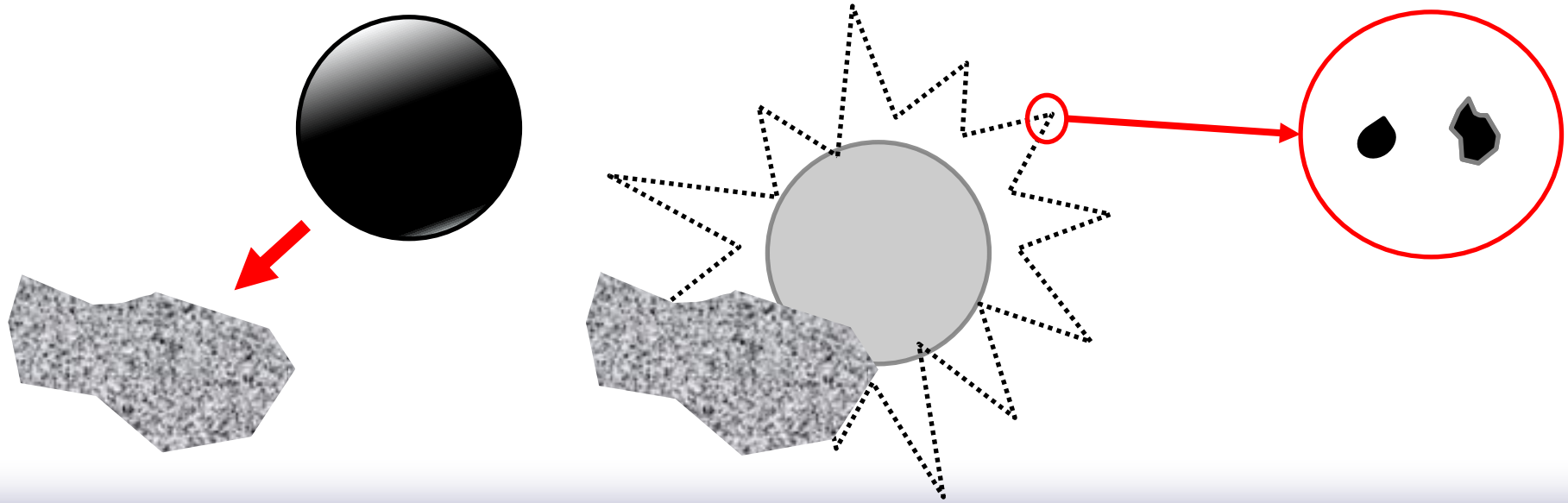
Foam bitumen

Foamed bitumen is a mass of bubbles. Each bubble is a thin (very thin) film of bitumen surrounding steam (water vapor)

Because the film of bitumen is so thin, if a stone is thrown at one of these bubbles, it will shatter into thousands (maybe millions?) of tiny bitumen splinters Each bitumen splinter has only sufficient heat energy to warm a dust particle (+moisture) and adhere to it (or attach itself onto another bitumen splinter)

The blasting and the dust particles are the carriers of bitumen



BACKGROUND

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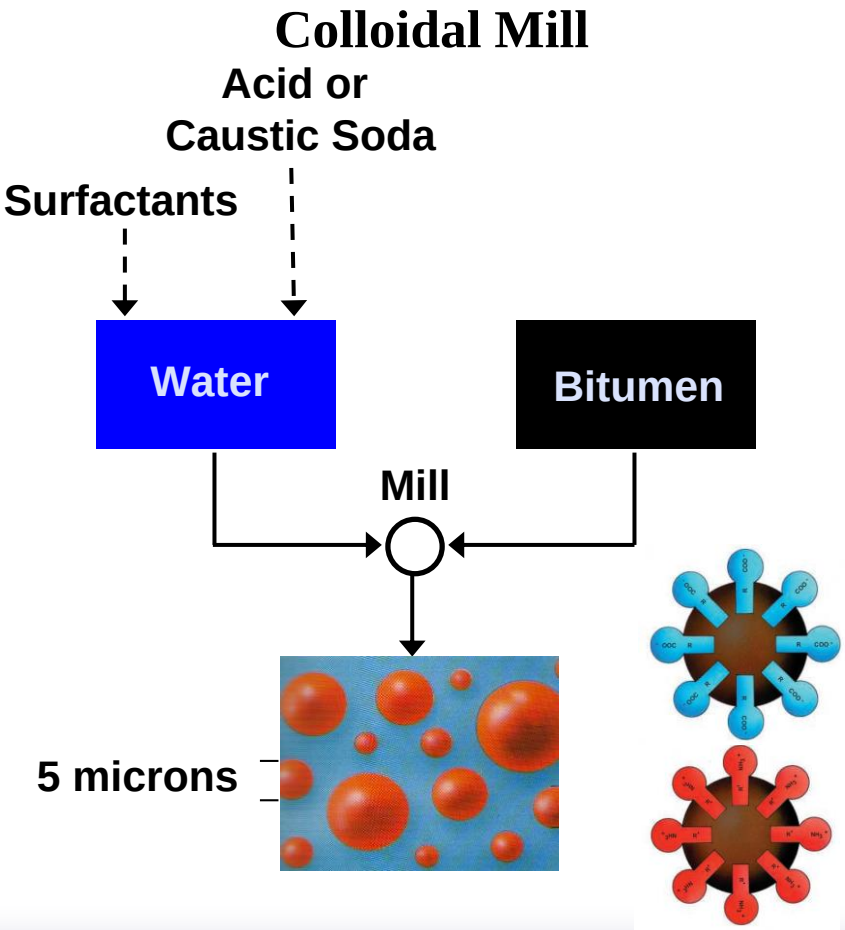
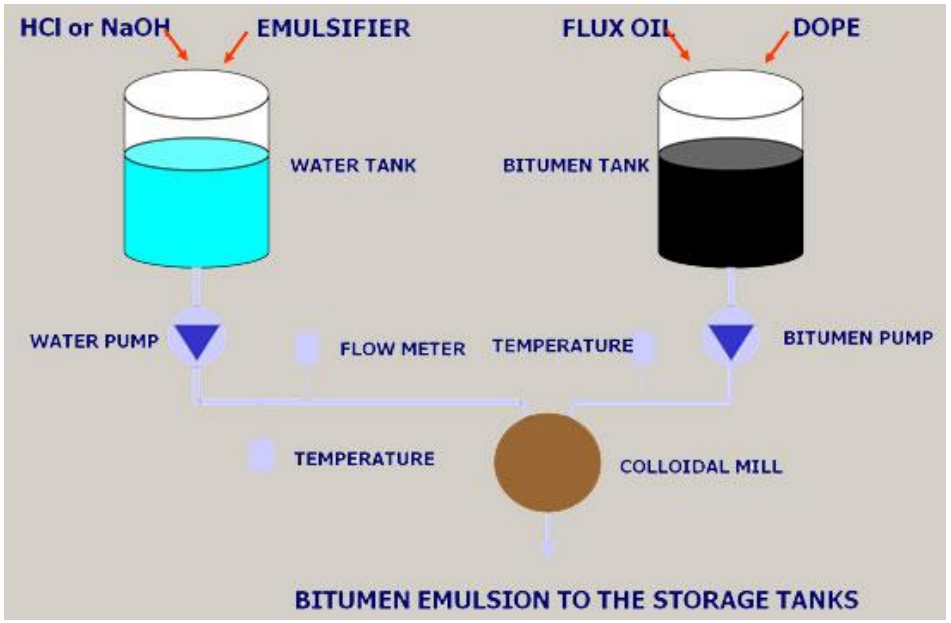
Bituminous emulsion





BACKGROUND

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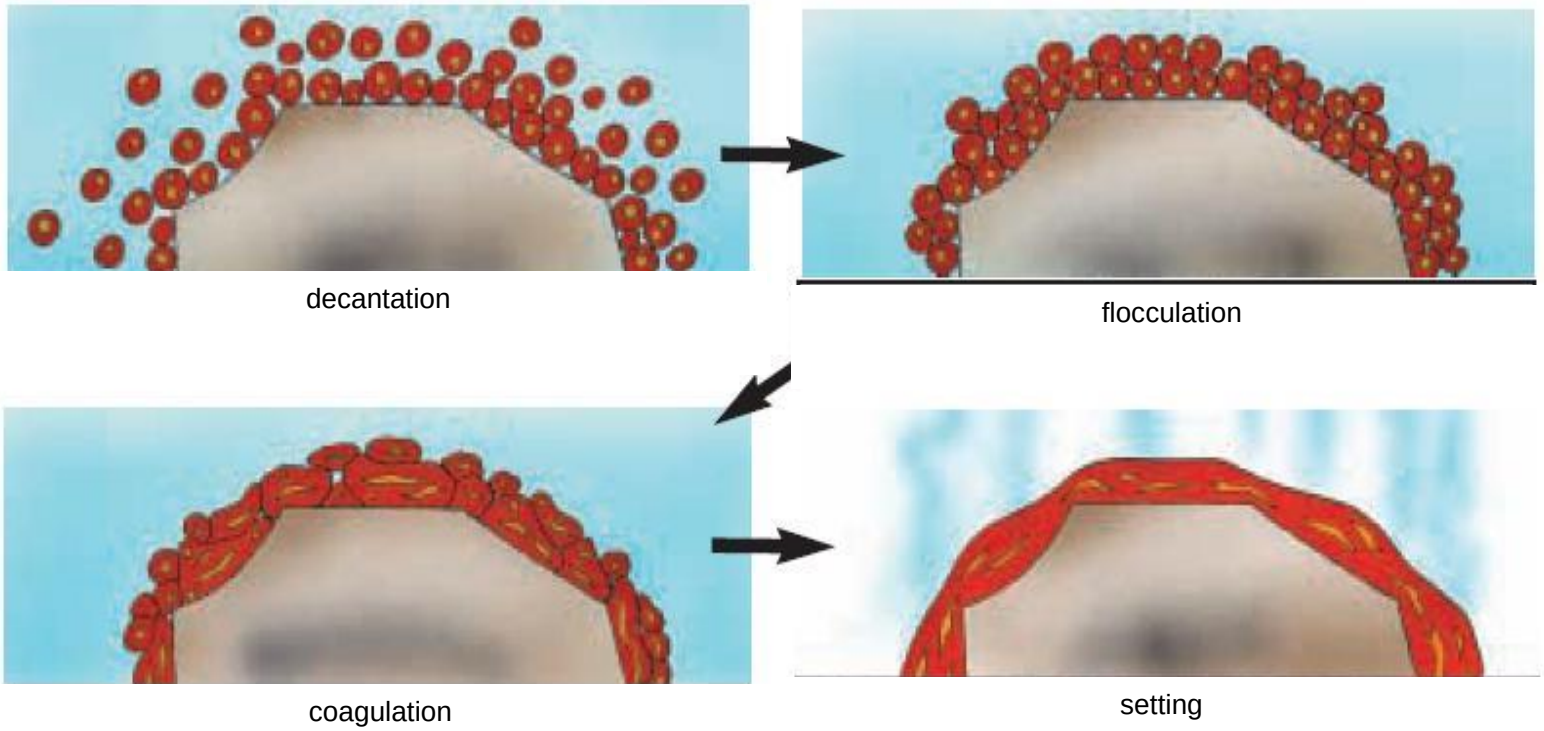
Bituminous emulsion



BACKGROUND

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Bituminous emulsion

Bitumen emulsion is a form of paint, so it “wet” the surface of all particles of the mixture of aggregates

The water is the carrier of bitumen

Courtesy of Kim Jenkins

BACKGROUND

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Bituminous emulsion

Because the surface area of the fines aggregates it is much bigger than the surface area of coarse aggregates, the emulsion will be concentrated on the fines fraction.

Particle size (mm)	Surface area factor (m^2/kg)
19	0.13
13.2	0.18
9.5	0.24
6.7	0.31
4.75	0.43
2.36	0.82
1.18	1.64
0.6	2.87
0.3	6.14
0.15	12.24
0.075	32.77

252 times higher

BACKGROUND

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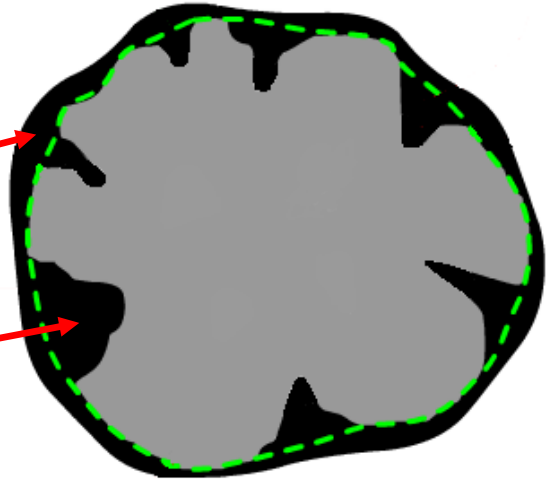
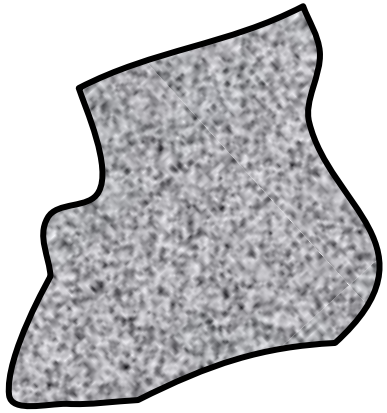
Bituminous emulsion



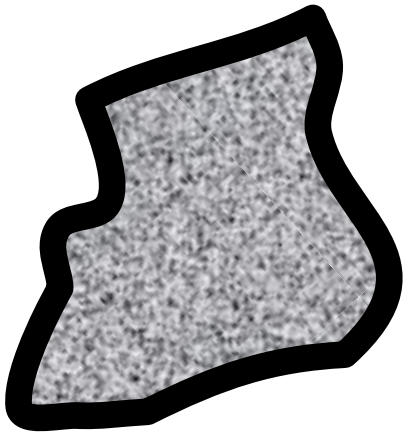
Non-continuously bounded material



Bituminous emulsion stabilized material

A bituminous emulsion stabilized materials has the aggregates fully covered by the emulsions, but the film made by the emulsion (in total around 2-3% of the weight of aggregates) it is not enough thick to make a fully bounded material

Continuously-bounded material



Hot (cold) asphalt mixture

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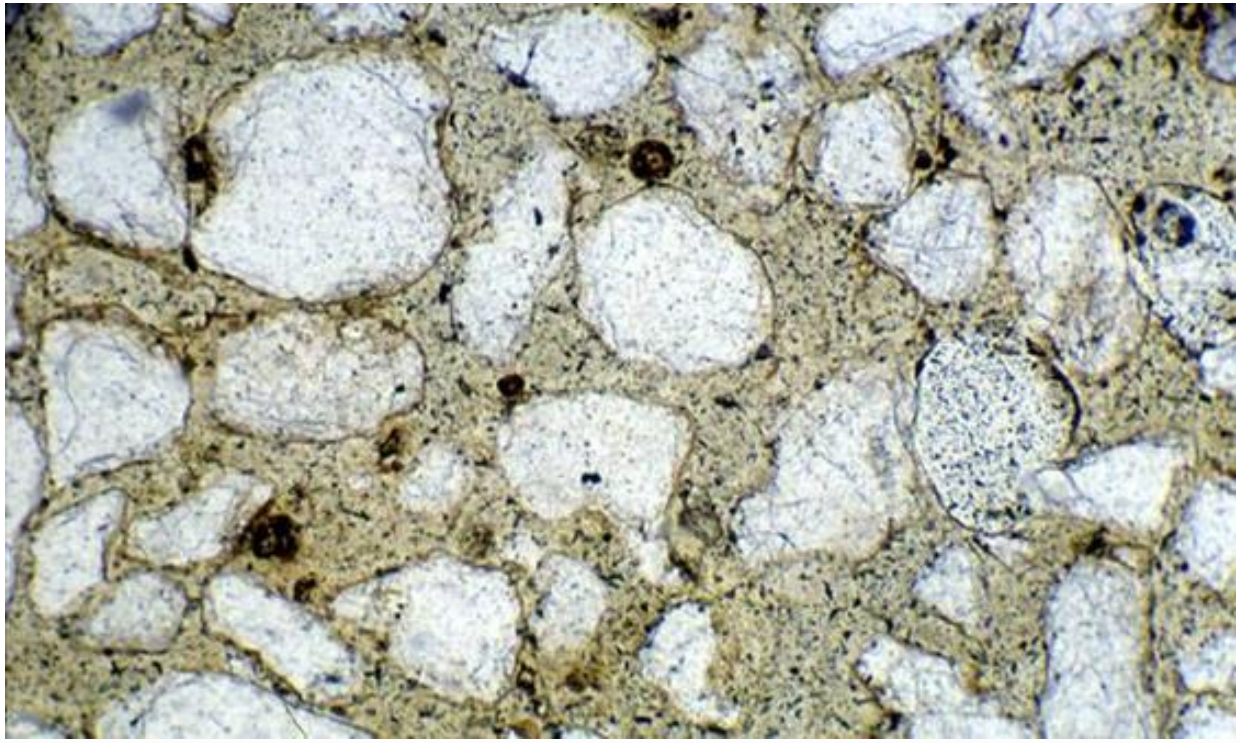
BSMs are non-continuously bounded materials

The bitumen carried by fine aggregates (mainly by filler) it makes an adhesive mastic disperse inside the mixture



PROBLEM STATEMENT

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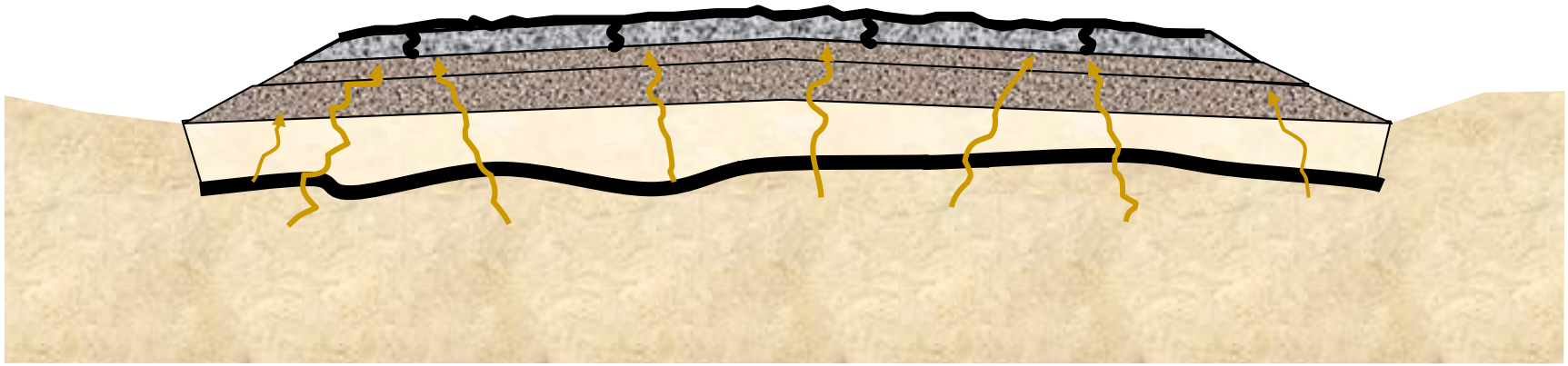
Rising of clay particles:
it requires to join lime stabilization and cold in place recycling



PROBLEM STATEMENT

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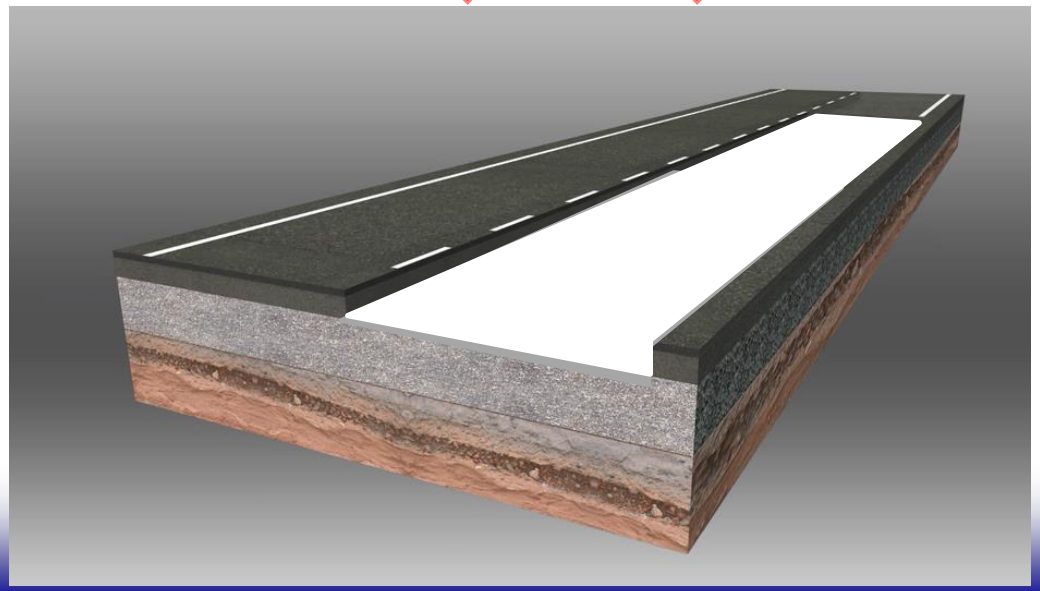
Can we use the lime as active filler to have only one lay down phase?
Can make sense a «combined lime-bitumen stabilization»?

1. Lime to stabilize the clay

2. Cement as active filler

3. mixing, foaming, …..



PROBLEM STATEMENT

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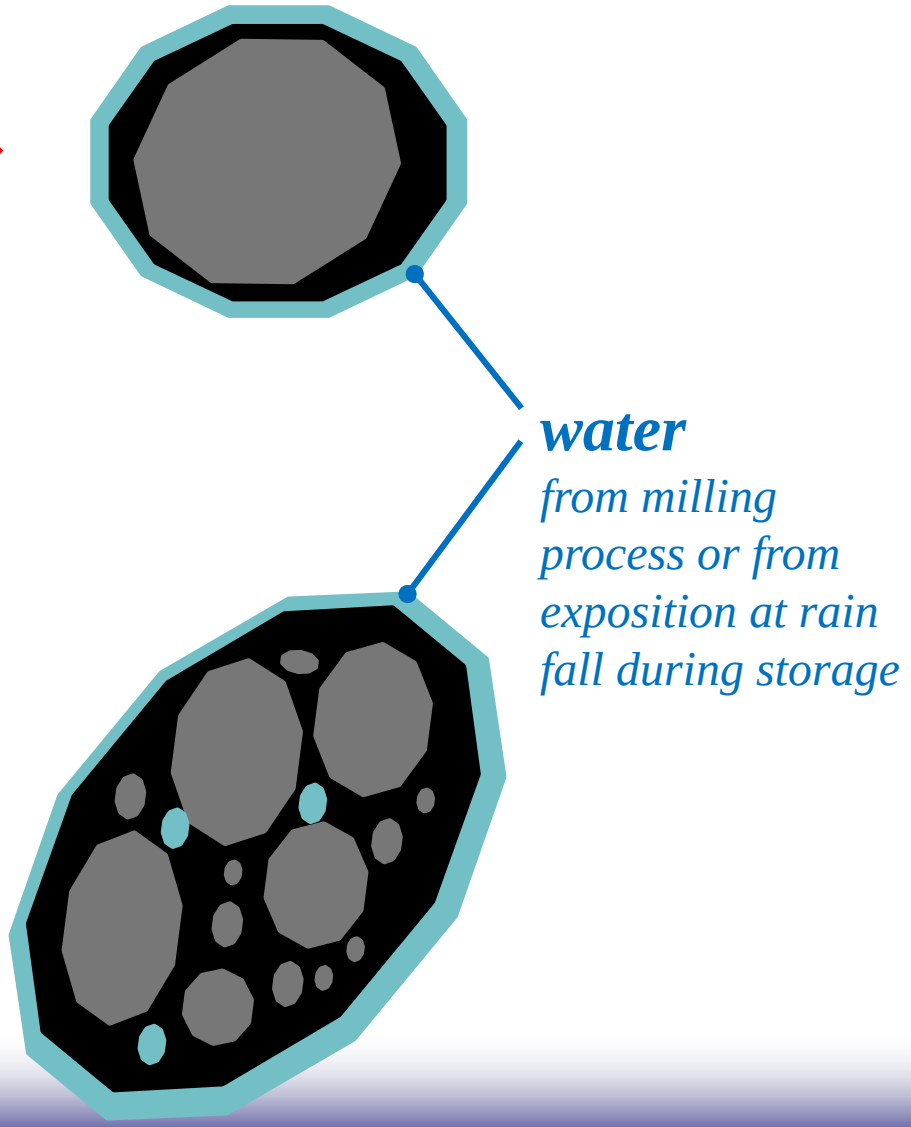
RAP



water

from milling process or from exposition at rain fall during storage

PROBLEM STATEMENT

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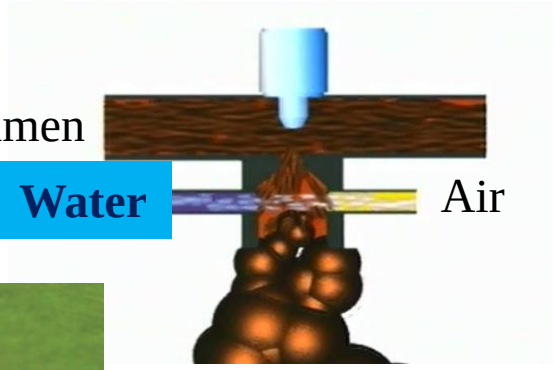

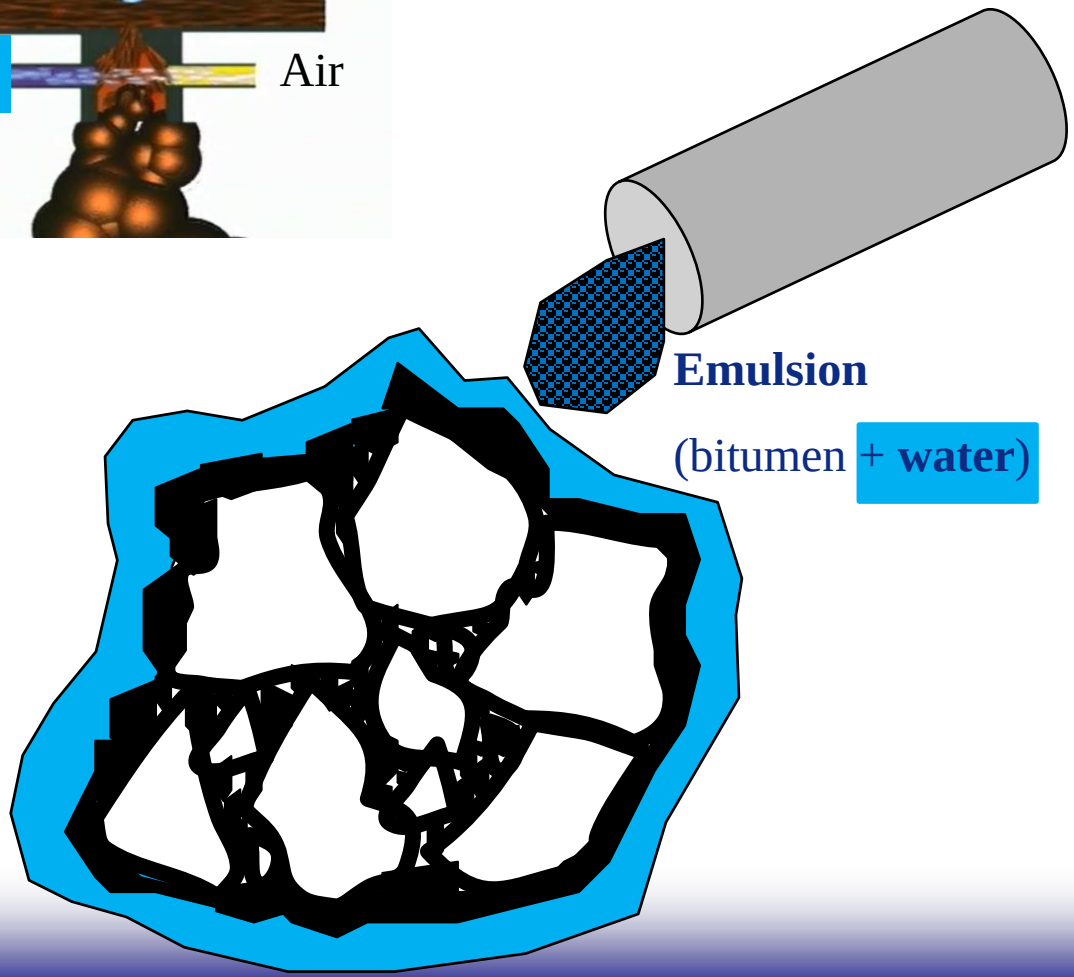

Emulsion

(bitumen + **water**)

PROBLEM STATEMENT

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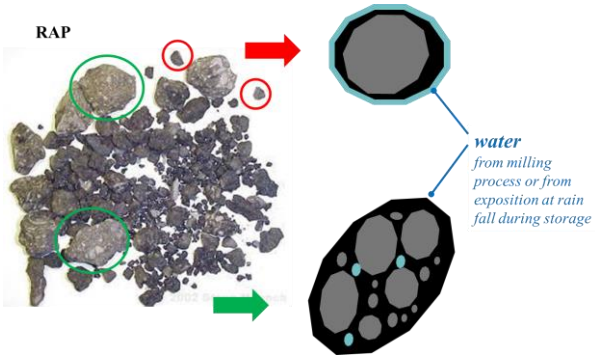
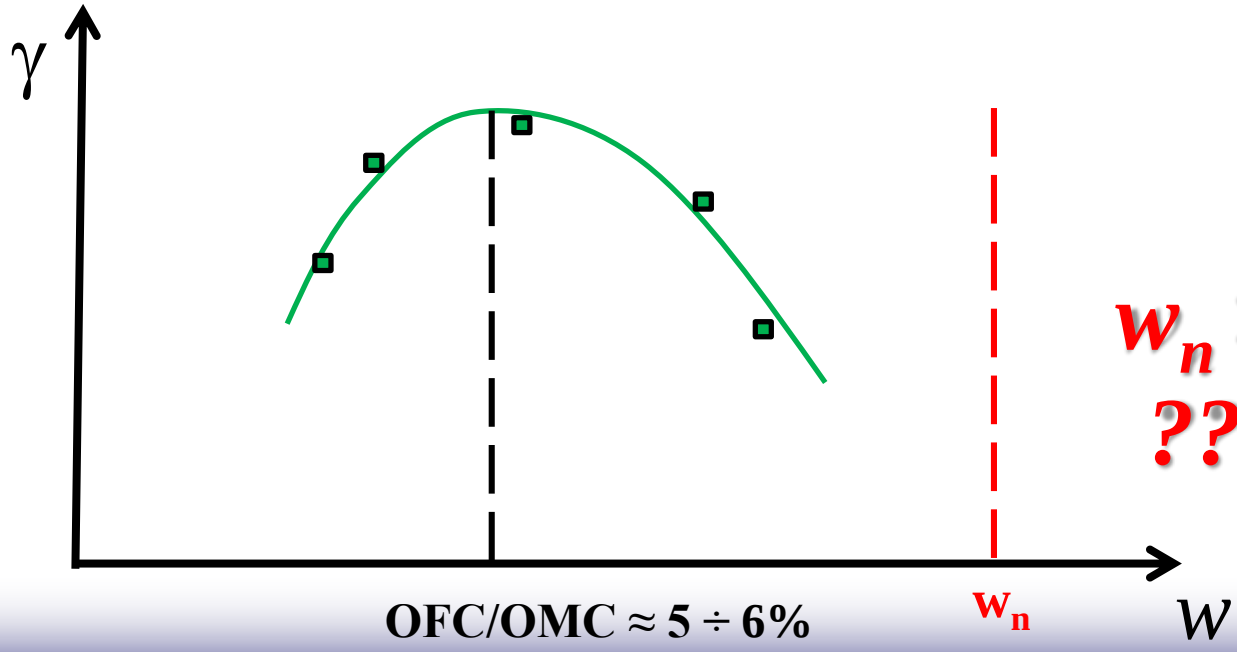


Water



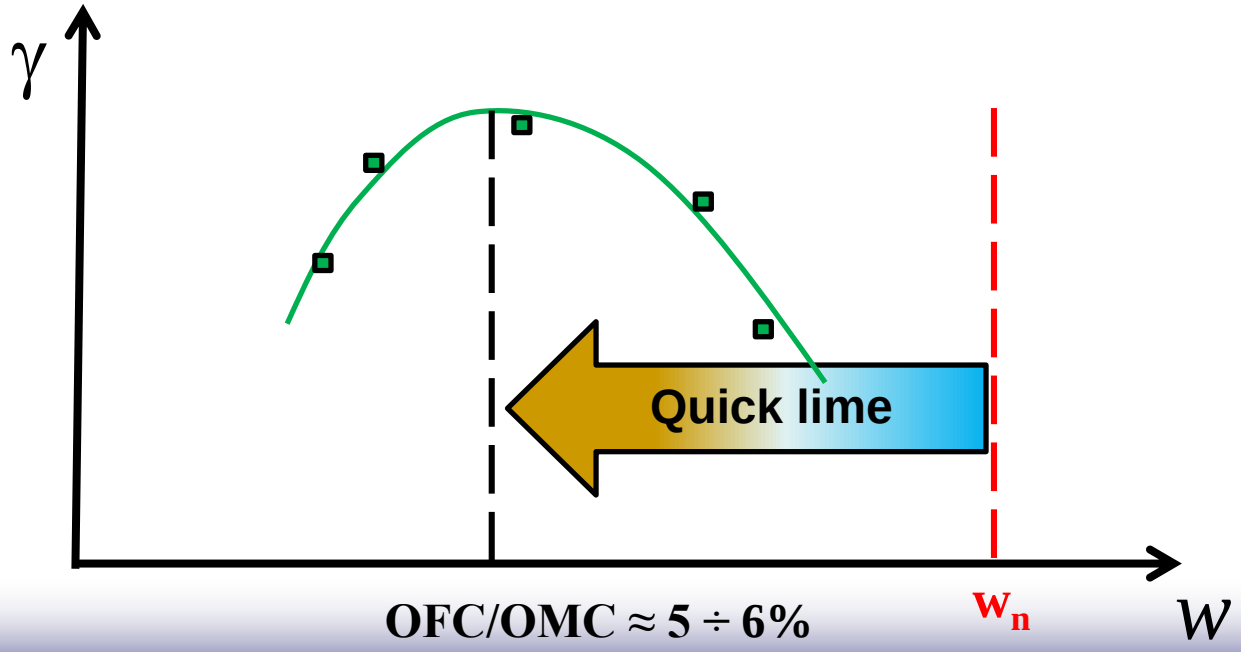
$w_n >> OFC$

???????

PROBLEM STATEMENT

Can we use this hydrated lime as active filler?

$$CaO + H_2O \rightarrow Ca(OH)_2 + 15.5\ kCal \rightarrow \approx -1 \div 1.5\%\ water$$



PROBLEM STATEMENT

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- **Can the lime be used instead of cement?**
- **Can the lime partially replace the cement in the total amount of active fillers?**

OBJECTIVE AND SCOPE

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- **Evaluate the influence on bearing capacity of introducing lime in bitumen emulsion recycled mixtures**
- **Evaluate the influence on bearing capacity of introducing lime in foam bitumen recycled mixtures**
- **Evaluate the influence on bearing capacity of use of lime instead of cement in foam bitumen recycled mixtures**

BINDERS CHARACTERISTICS

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Emulsion

Over stabilized emulsion

→ *1% it is the minimum amount of cement to start the breaking process*

Bitumen content: 60%

Bitumen's characteristics

Pen@25°C: 100 dmm
$T_{R\&B}$: 60°C
Elastic recovery: 75%

Bitumen for foaming

Pure bitumen
Pen@25°C: 70 -100
$T_{R\&B}$: 51°C

RAP

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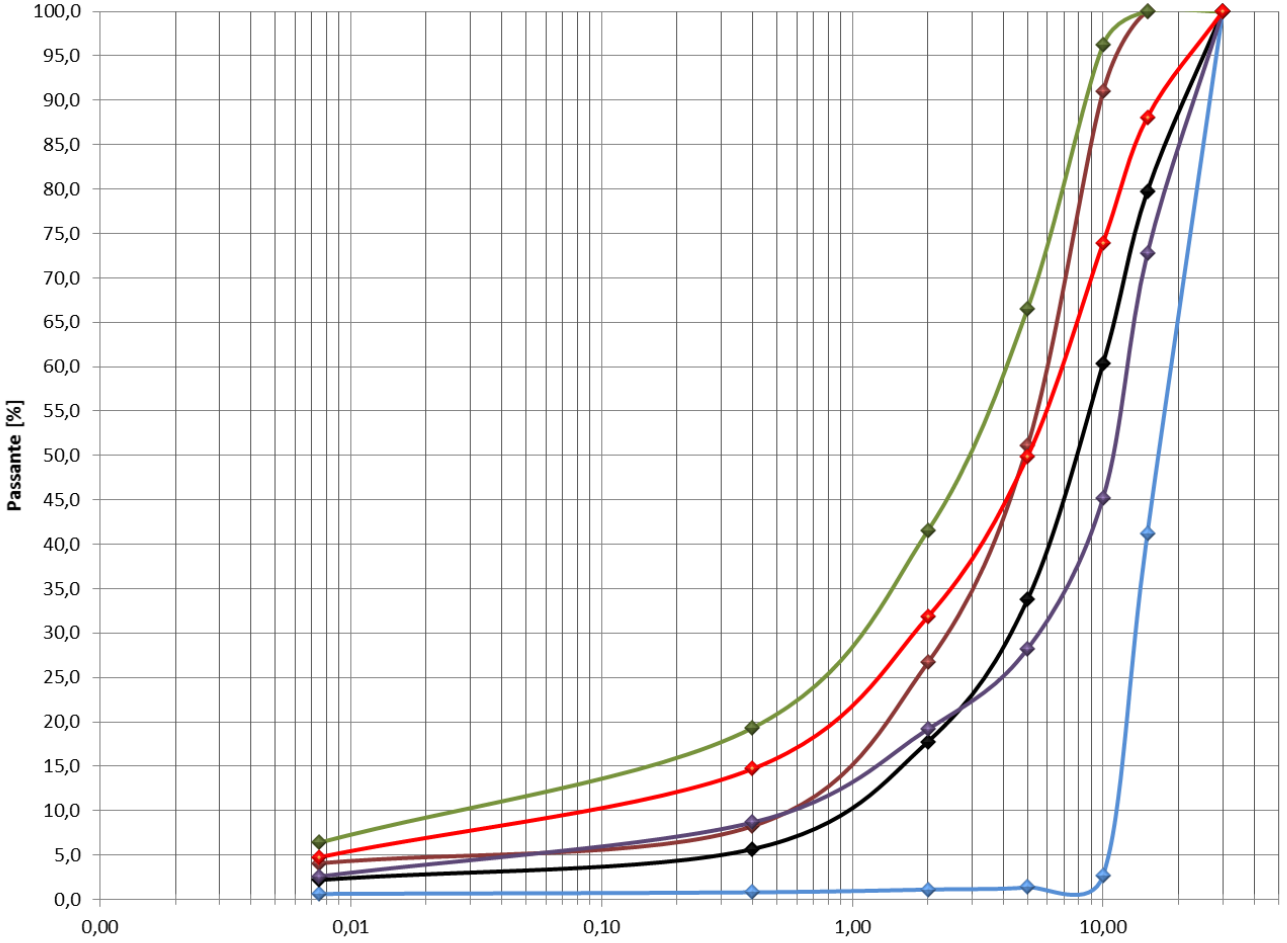

Specimen	% bitumen
1	7,5
2	10,7
3	5,9
4	6,0
5	5,6
6	4,7
8	4,3
9	4,3

MIXTURES

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Total amount of filler: 4.5%

	Mix	%binder	%cement	%lime	%mineral filler
Emulsion	2A	3	1.0	2.0	1.5
	2B	3	1.0	0	3.5
	4D	3	2.5	0	2.0
Foam bitumen	3A	2	1.0	2.0	1.5
	3B	2	1.0	0	3.5
	5C	3	2.5	2.0	0
	5D	3	2.5	0	2.0
	5E	3	0	2.0	2.5
	5F	3	0	3.0	1.5

TRIAL SECTION - FLORENCE (ITALY)

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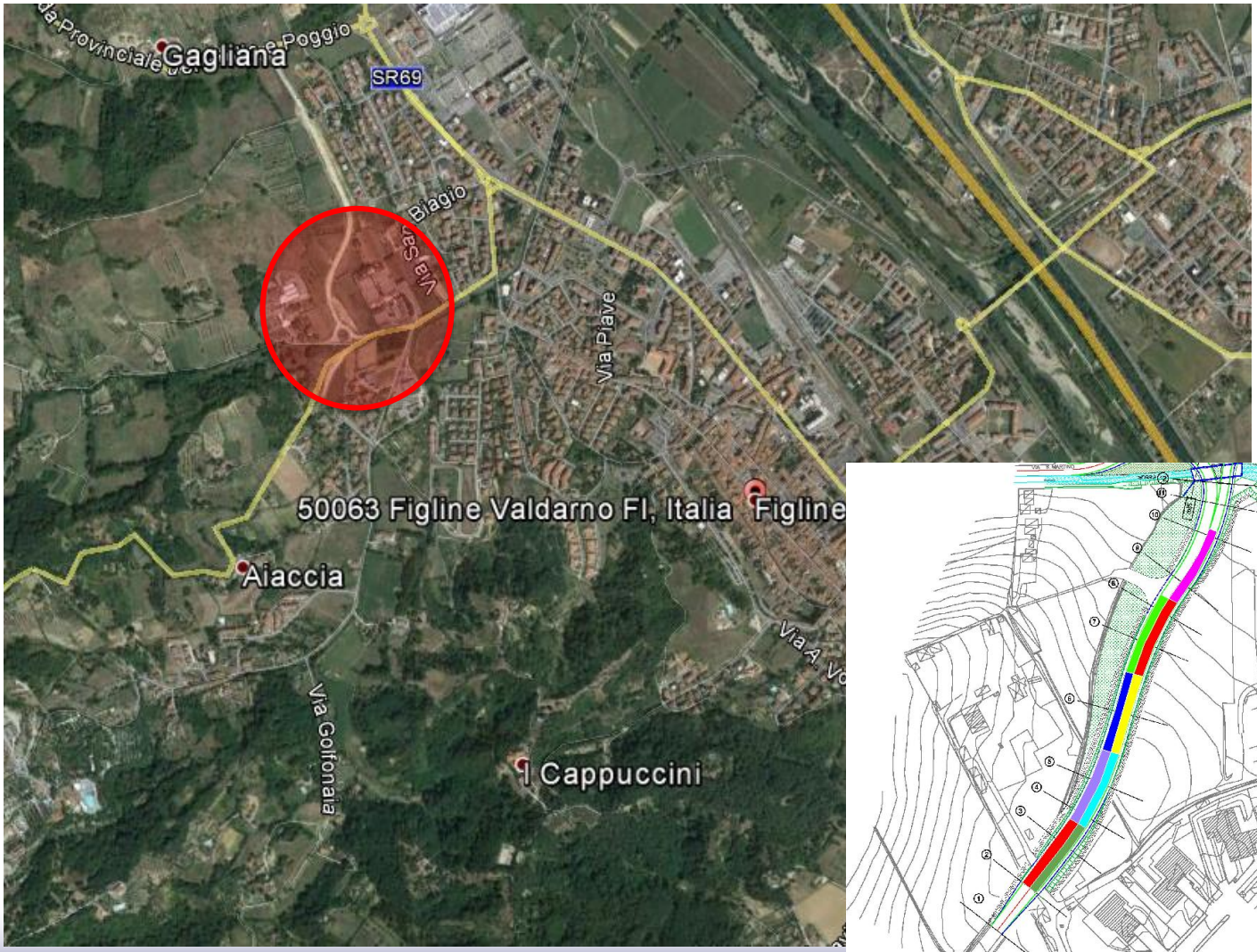

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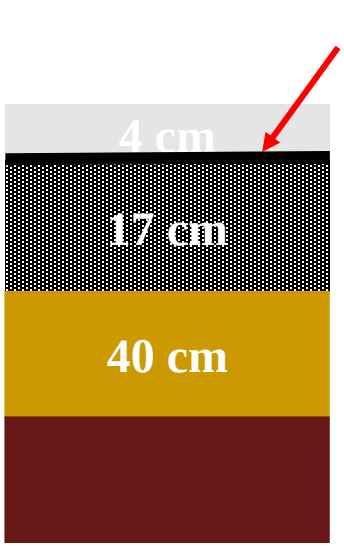

Protective tack coat

Wearing course

Base - Cold Recycled Mixture (bituminous emulsion/foam bitumen)

Subbase – lime stabilized soil

Subgrade

Thanks to a particular work plan the wearing coarse was layed down 10 months after wearing course

All mixtures had the curing process without traffic load

First LWD/FWD test campaign directly on CRM layer

LWD & FWD Tests Results

Mix 5D_3%FB_2,5%C_0% L_2% MF

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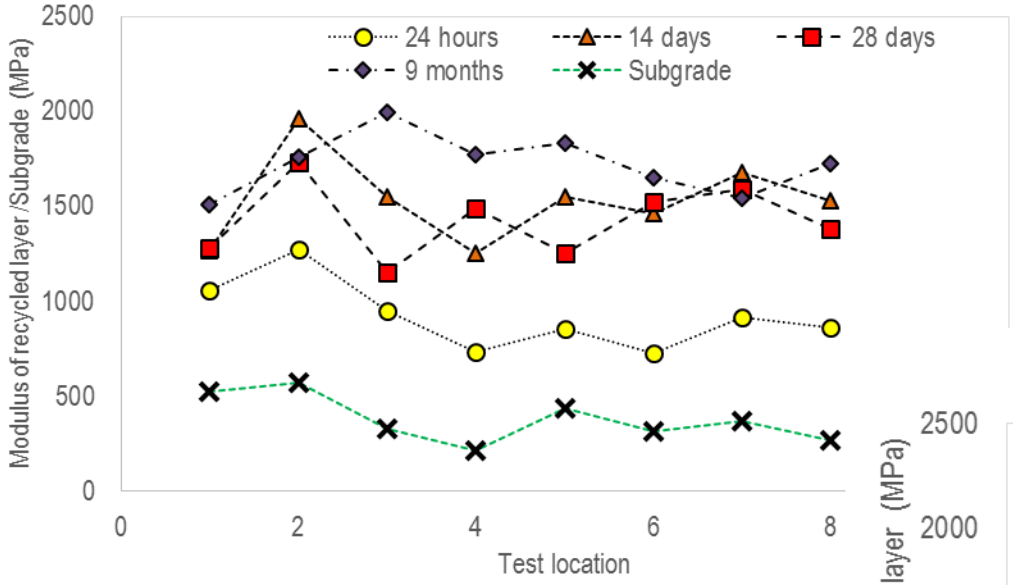
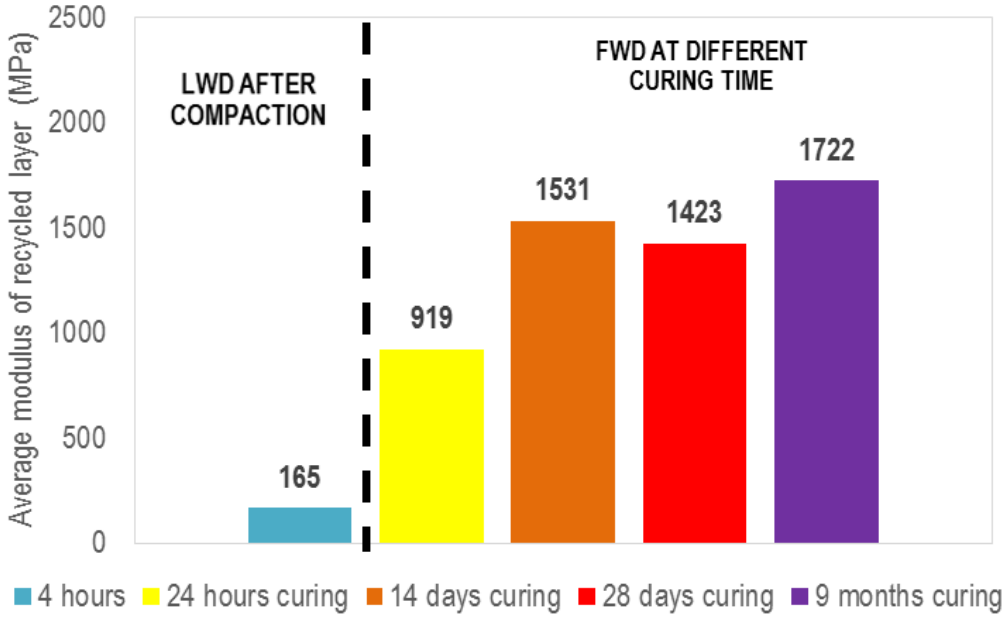


Minimum requirement of Italian Road Authority (ANAS)

- **45 MPa 4 hours after compaction**
- **170 MPa 24 hours after compaction**



LWD & FWD TESTS RESULTS

MIX_5E_3%FB_0%C_2%L_2,5%MF

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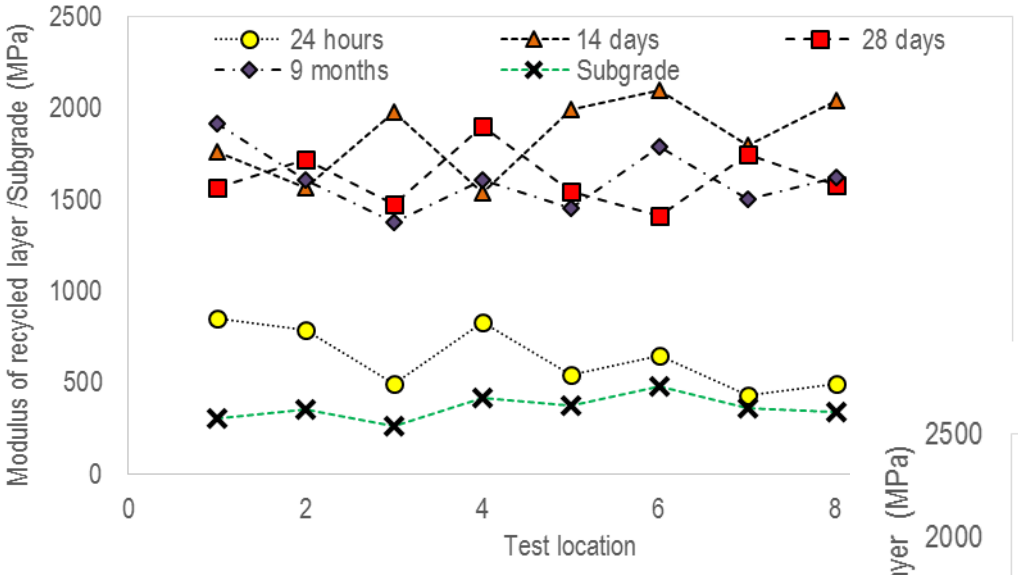

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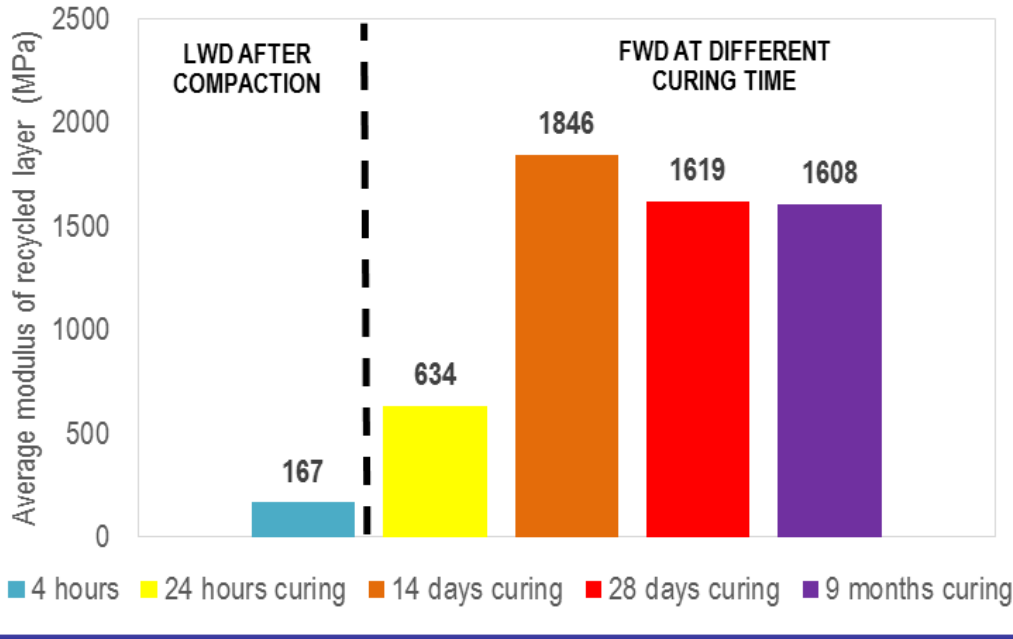

LWD & FWD TESTS RESULTS

MIX_3B_2%FB_1%C_0%L_3.5%MF

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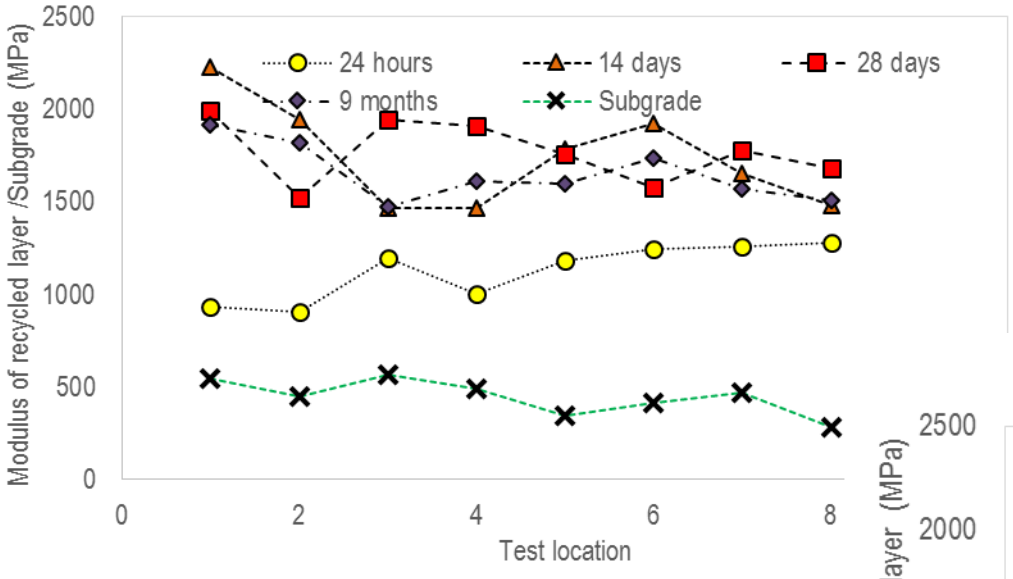

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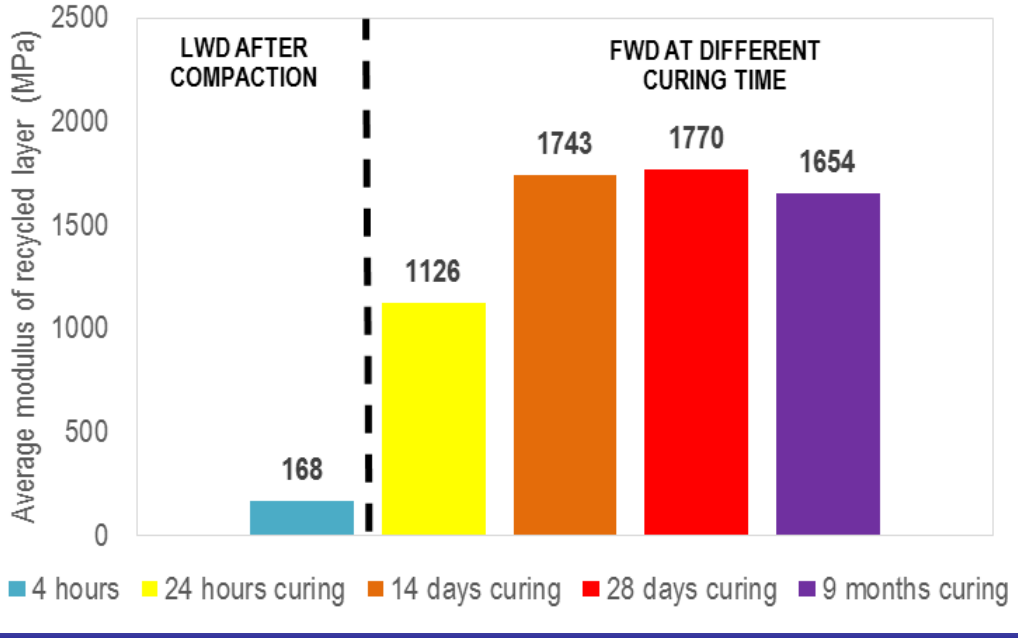

LWD & FWD TESTS RESULTS

MIX_3A_2%FB_1%C_2%L_1.5%MF

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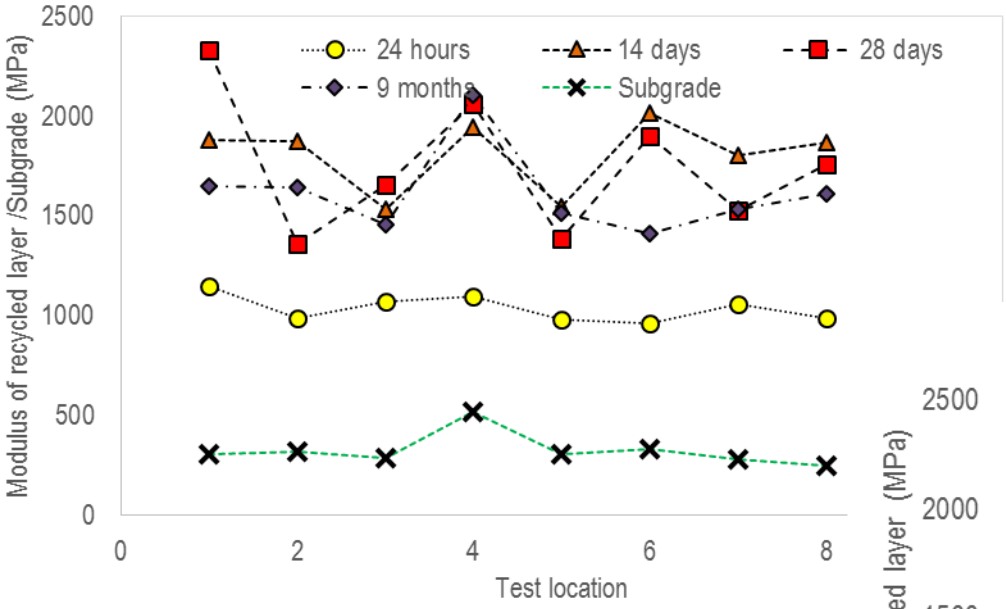

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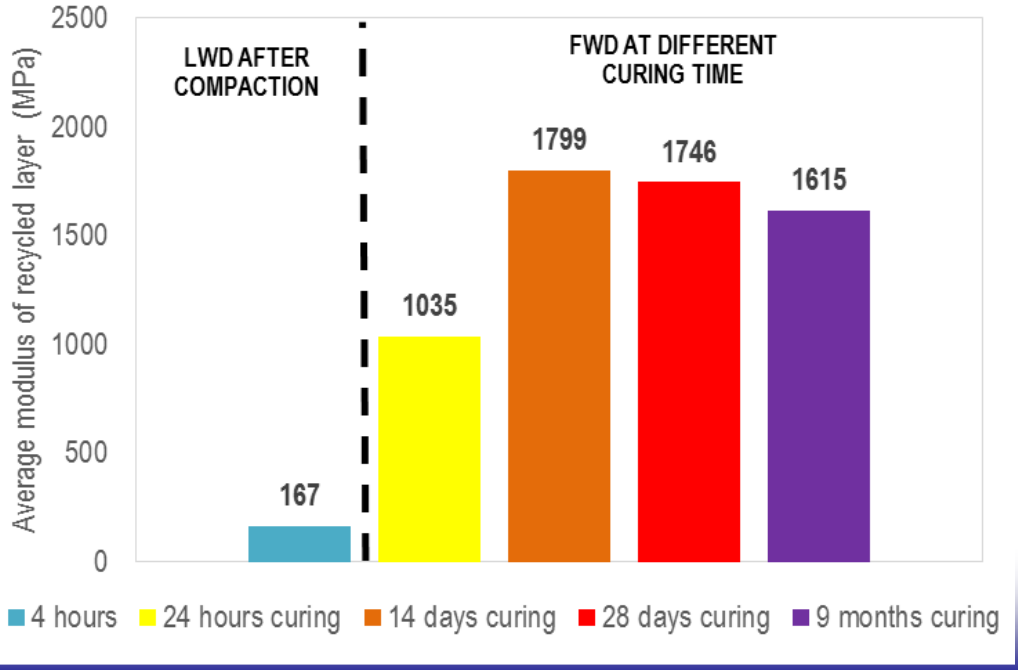

LWD & FWD TESTS RESULTS

MIX_5C_3%FB_2.5%C_2%L_0%MF

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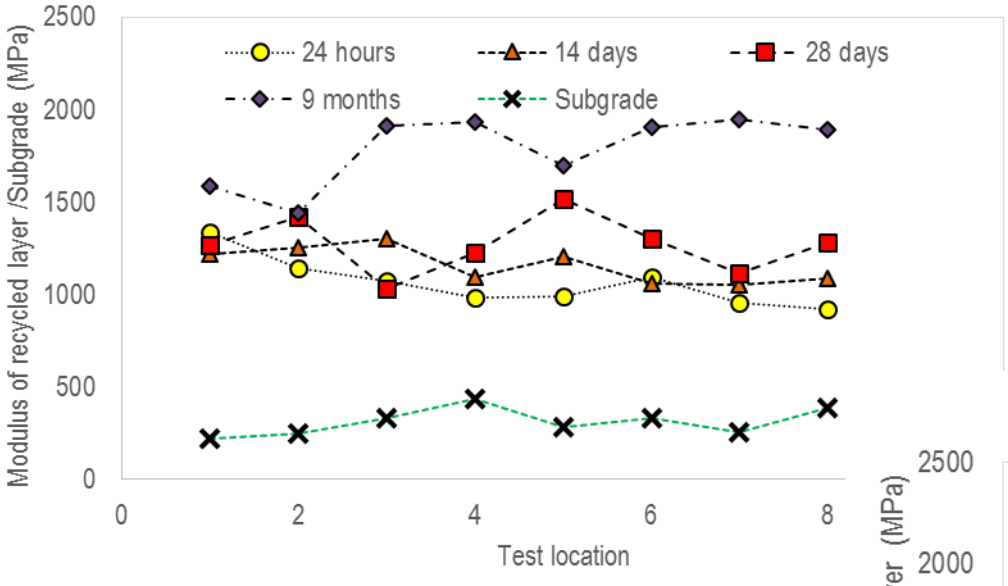

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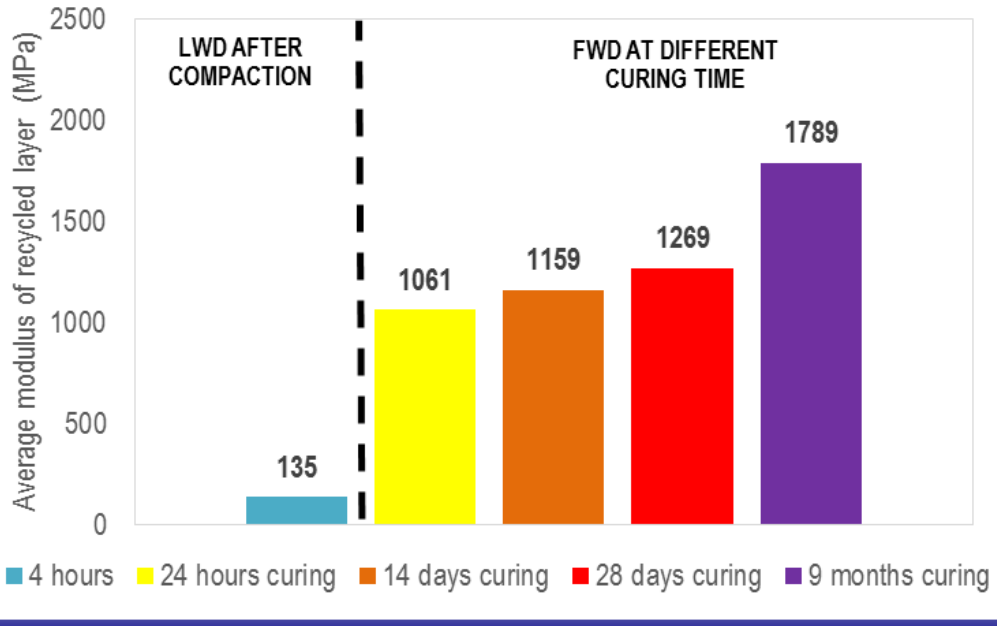

LWD & FWD TESTS RESULTS

MIX_5F_3%FB_0%C_3%L_1,5%MF

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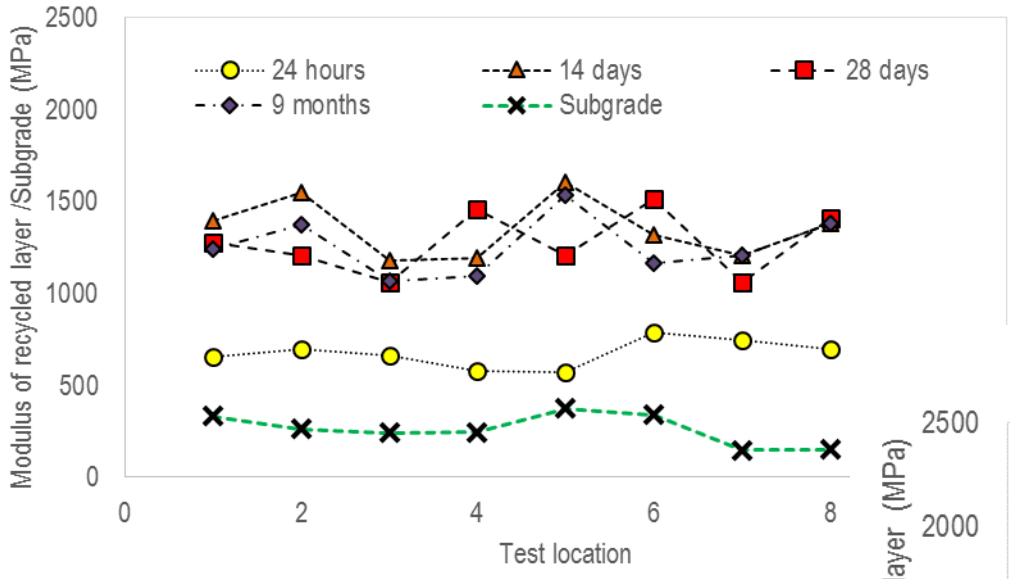
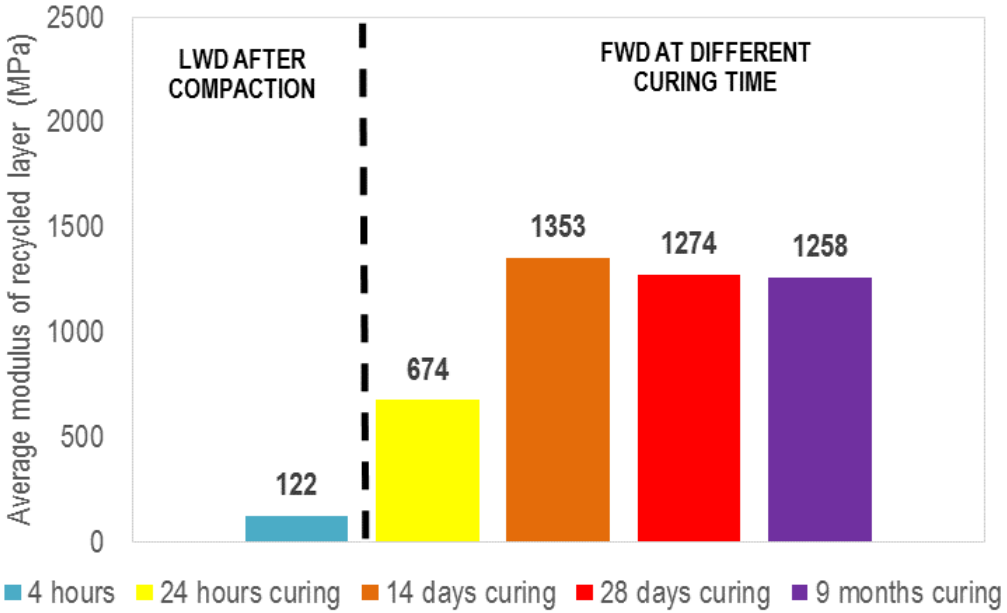


Minimum requirement of Italian Road Authority (ANAS)

- **45 MPa 4 hours after compaction**
- **170 MPa 24 hours after compaction**



LWD & FWD TESTS RESULTS

MIX 2A 3%BE-1%C-2% L-1,5% MF

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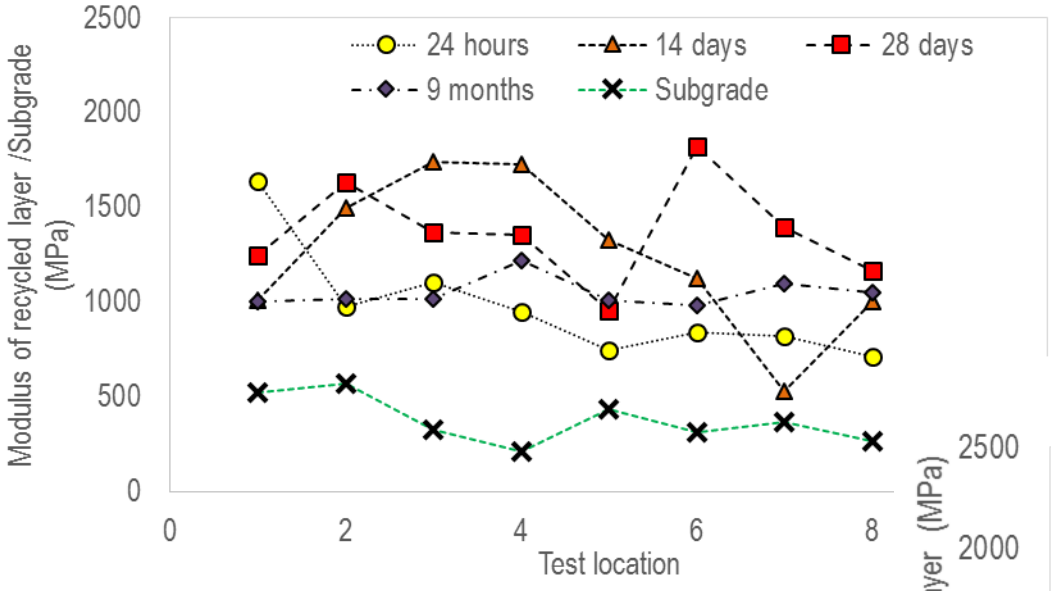
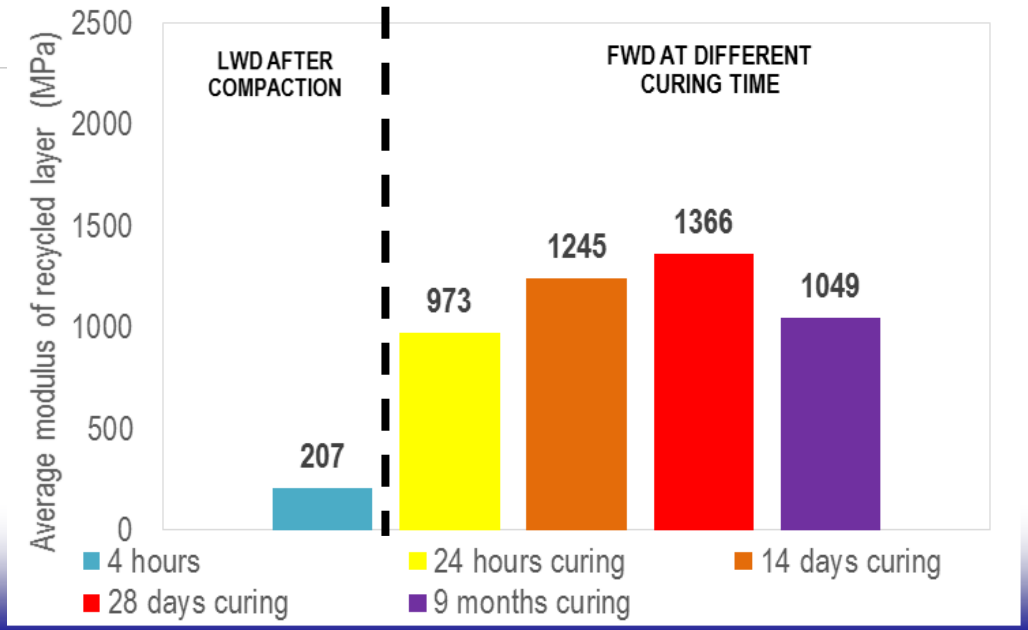


Minimum requirement of Italian Road Authority (ANAS)

- **45 MPa 4 hours after compaction**
- **170 MPa 24 hours after compaction**



LWD & FWD TESTS RESULTS

MIX 2B 3%BE-1% C-0% L – 3.5% MF

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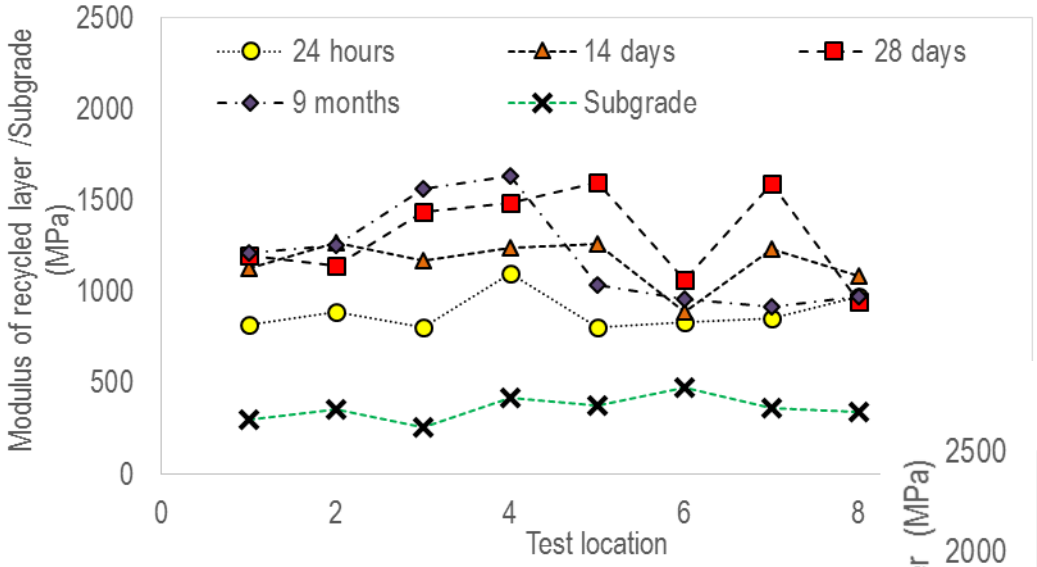
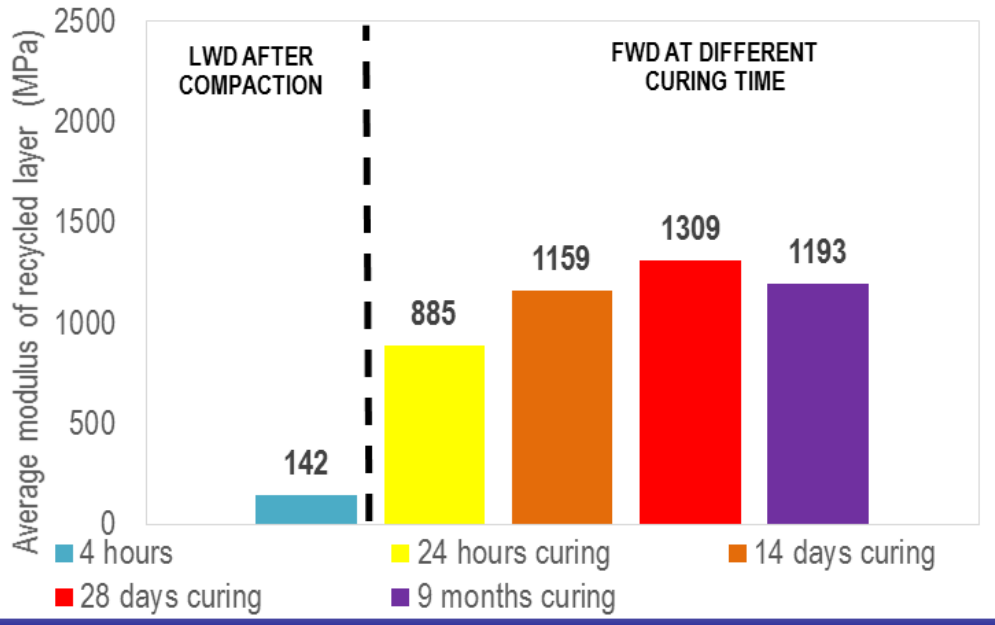


Minimum requirement of Italian Road Authority (ANAS)

- **45 MPa 4 hours after compaction**
- **170 MPa 24 hours after compaction**



LWD & FWD TESTS RESULTS

MIX 4D 3%BE-2.5% C-0% L – 2% MF

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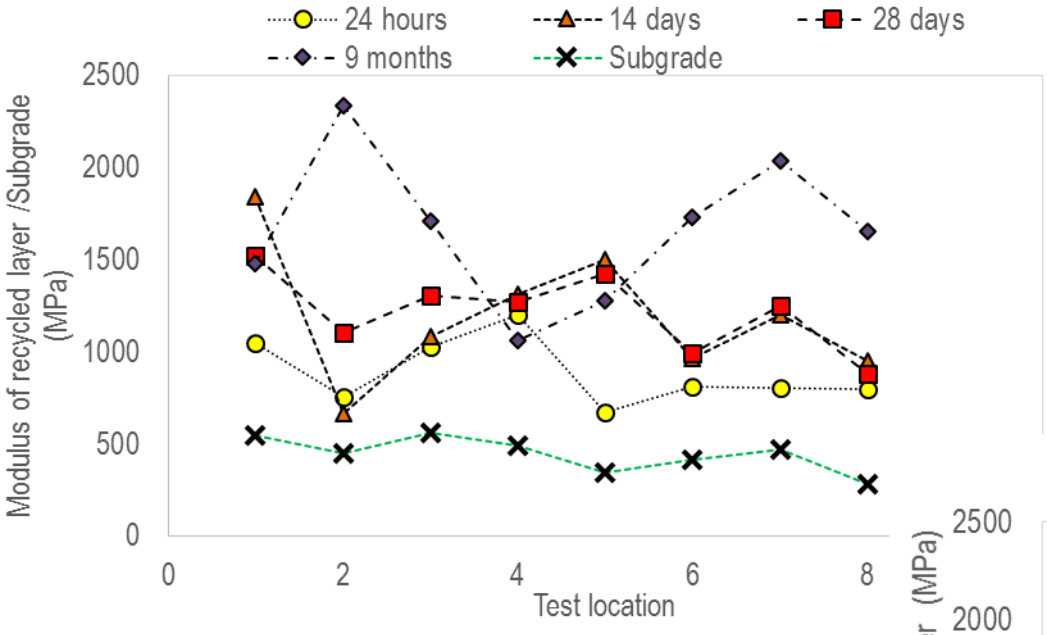
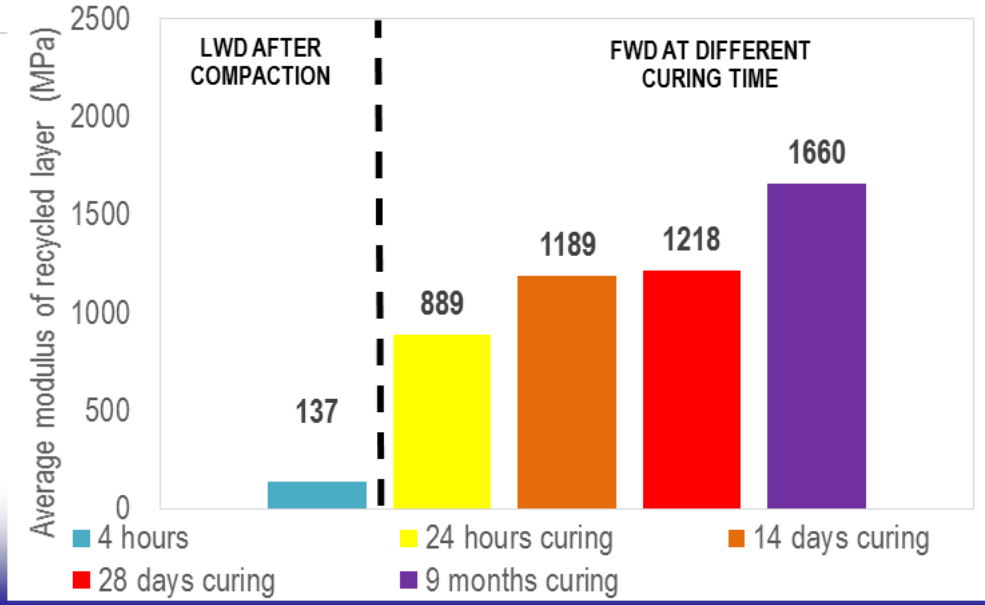


Minimum requirement of Italian Road Authority (ANAS)

- **45 MPa 4 hours after compaction**
- **170 MPa 24 hours after compaction**



LWD & FWD TESTS RESULTS

LIME & CEMENT

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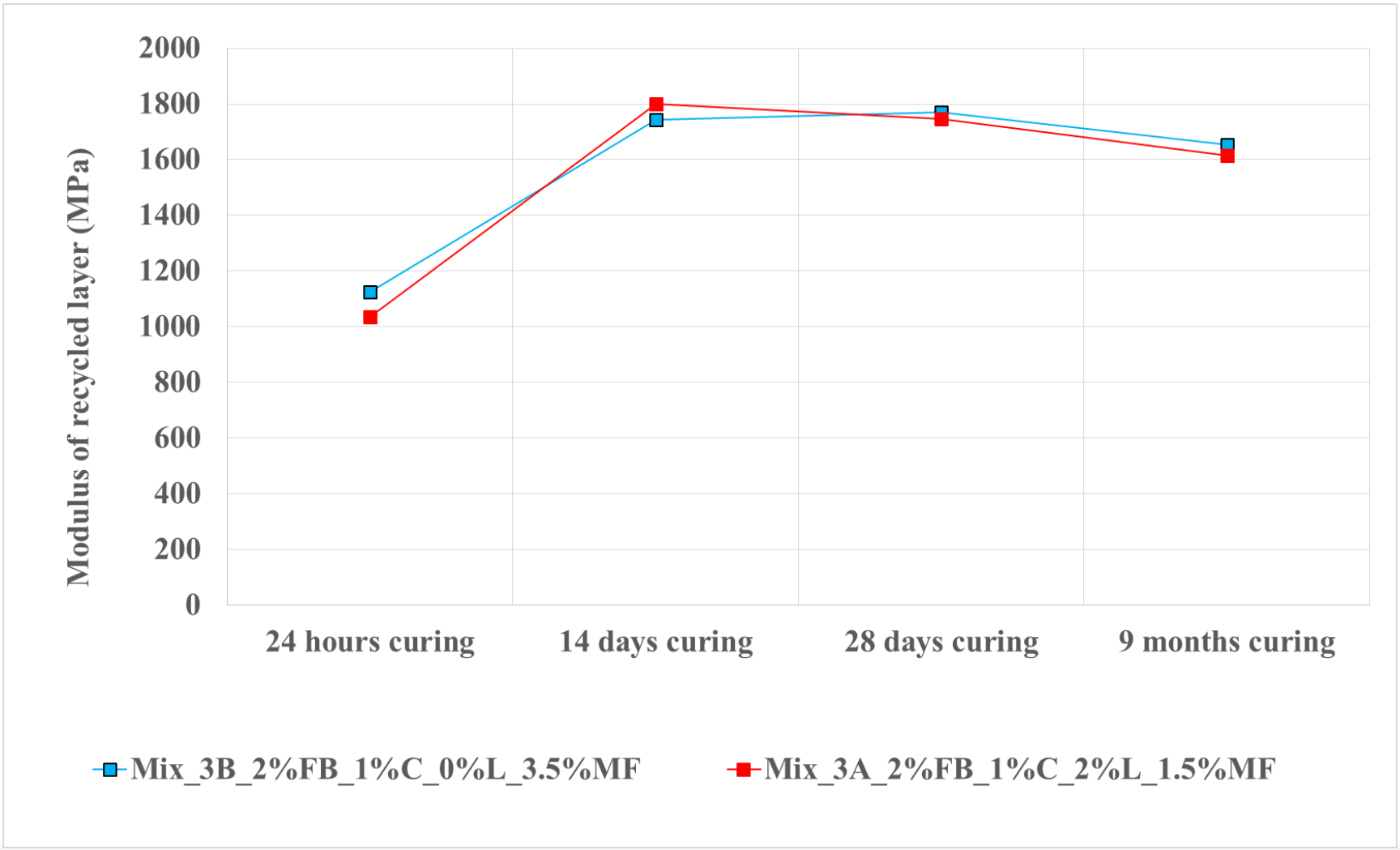

LWD & FWD TESTS RESULTS

LIME VS CEMENT

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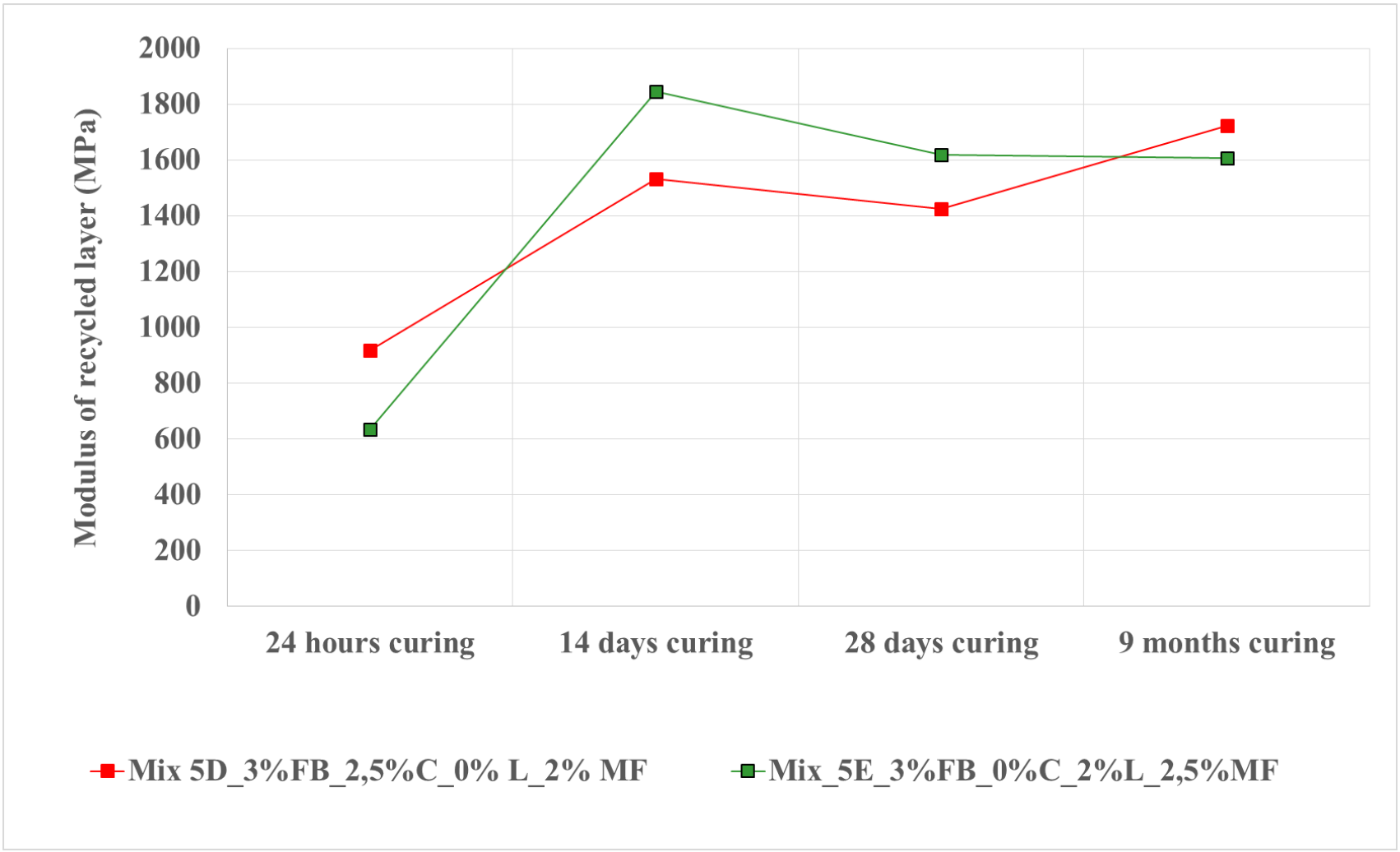

FRACTURE ENERGY

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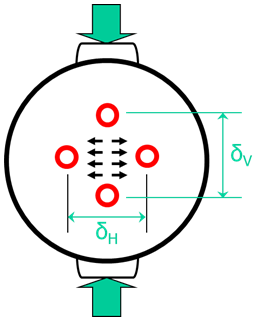
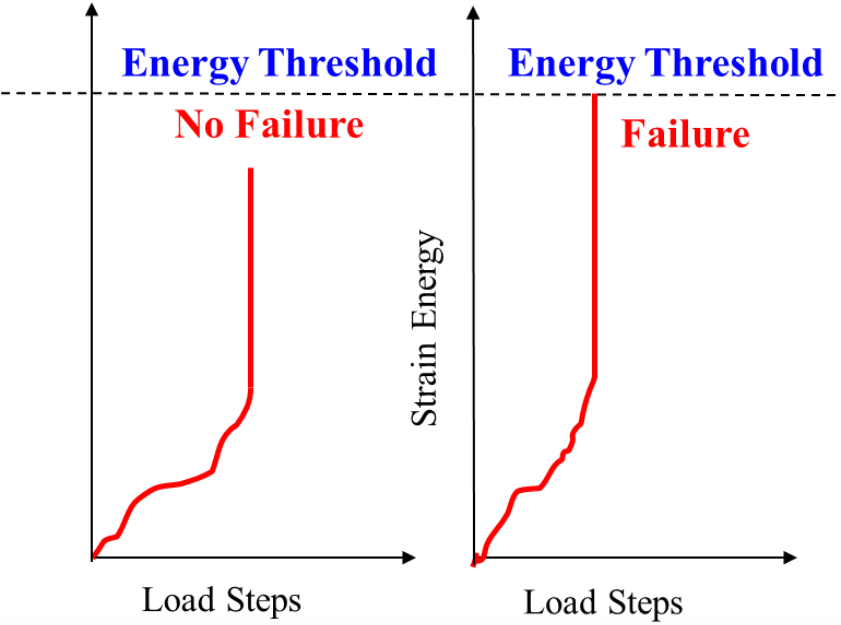
HMA Fracture Mechanics [Roque et alt., 2011]

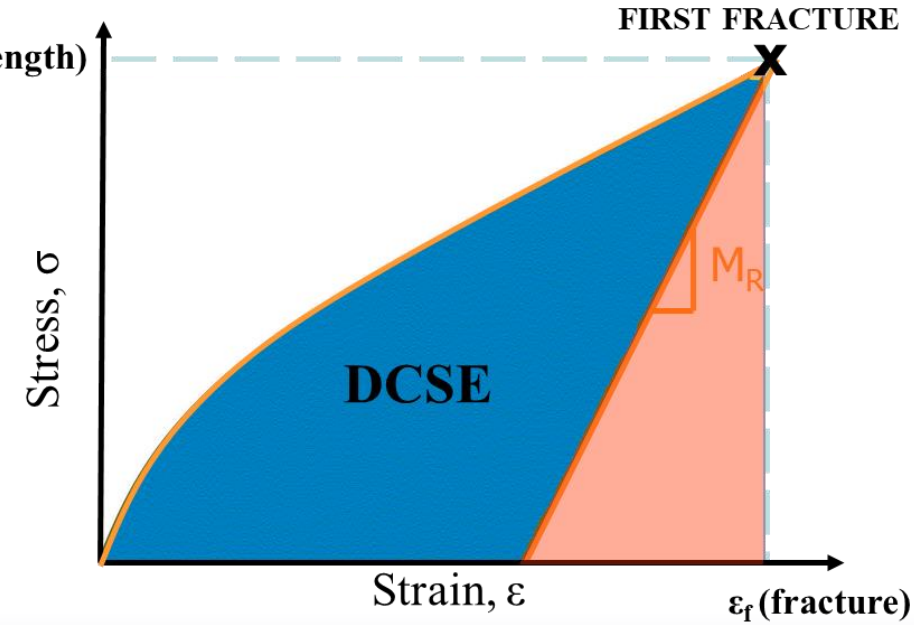


Total Fracture Energy (FE) → creep + elastic

Creep Strain Energy (DCSE) → creep only

FE = DCSE + EE

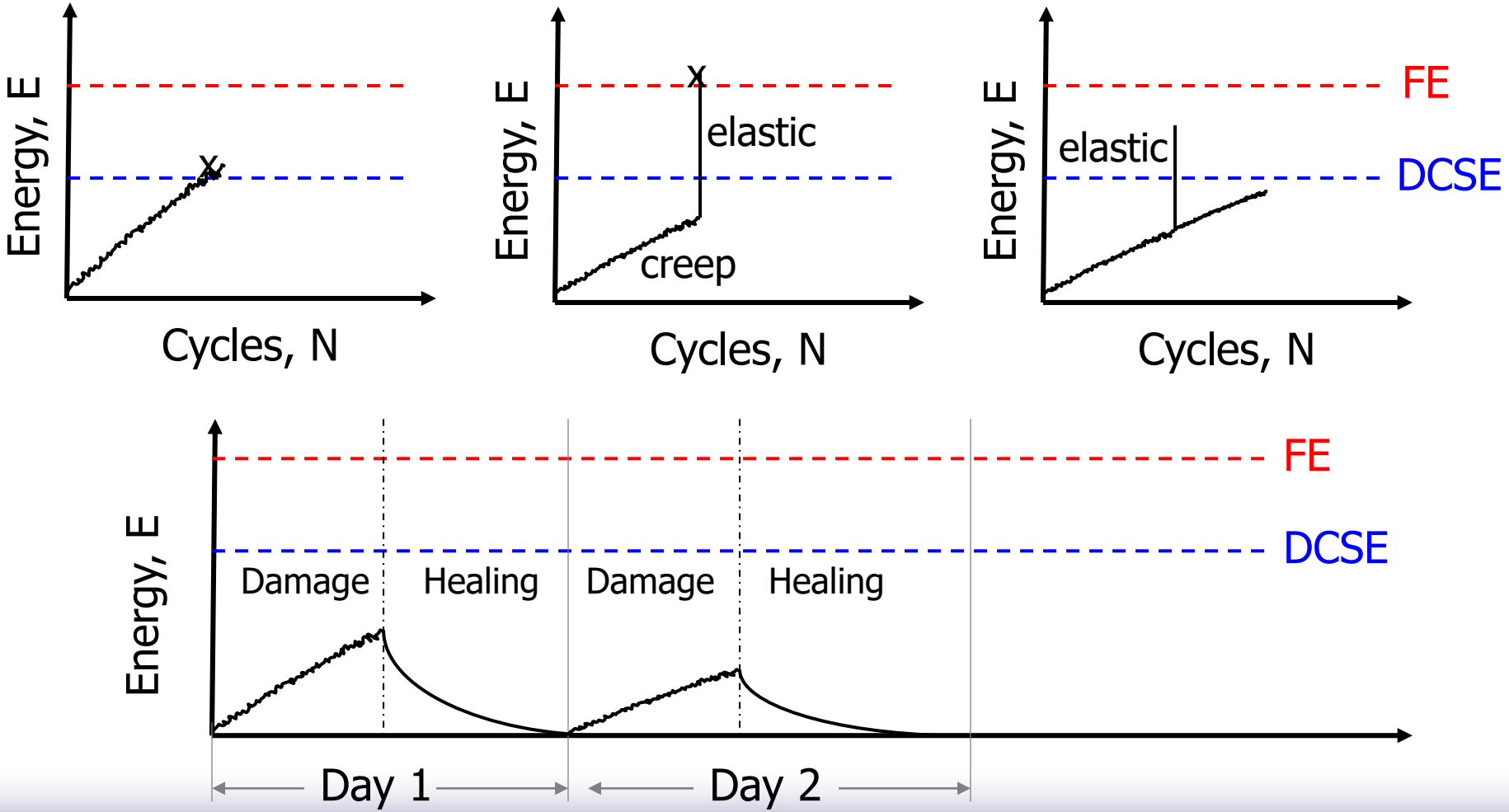




FRACTURE ENERGY

University of Parma

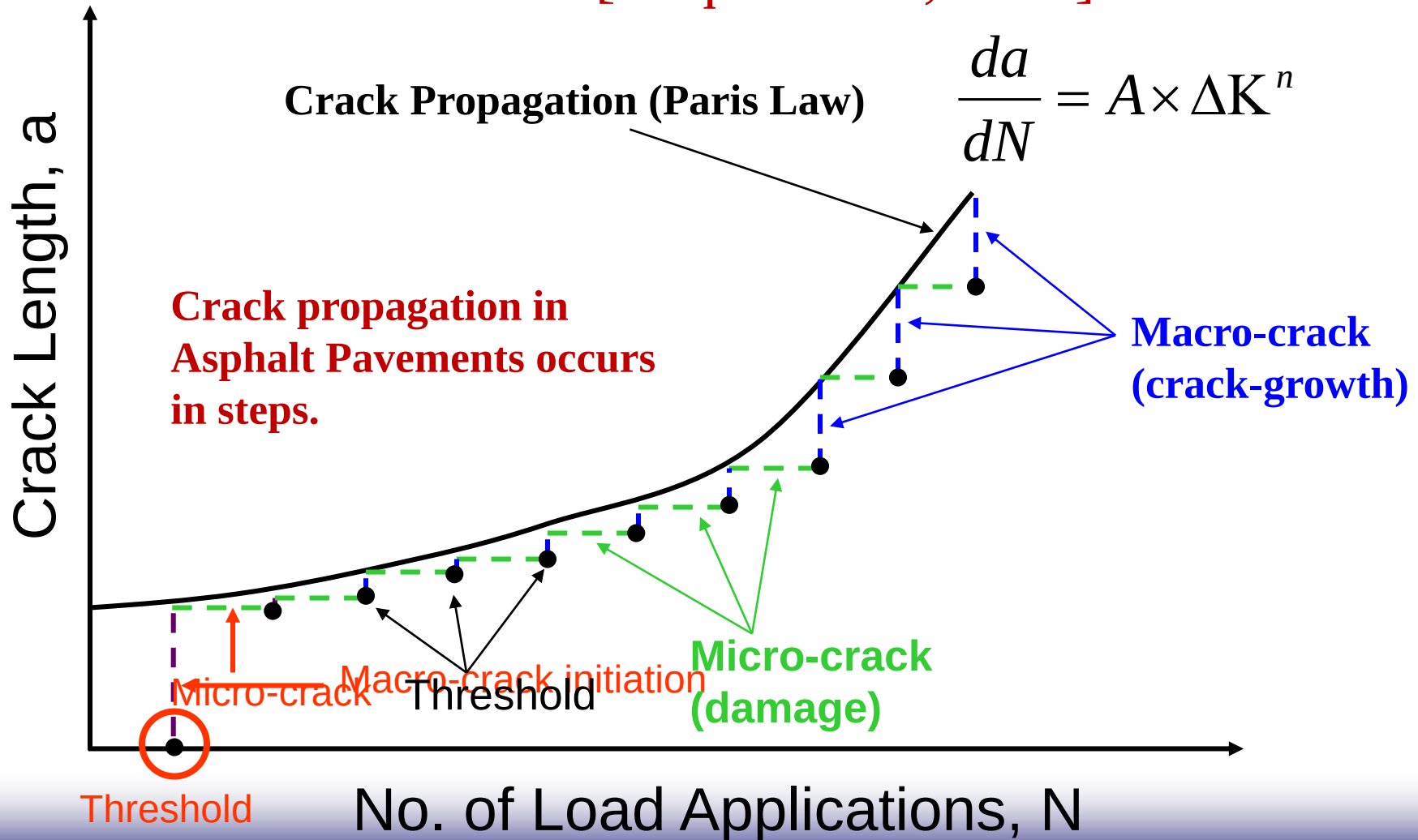
HMA Fracture Mechanics [Roque et alt., 2011]



FRACTURE ENERGY

University of Parma

HMA Fracture Mechanics [Roque et alt., 2011]



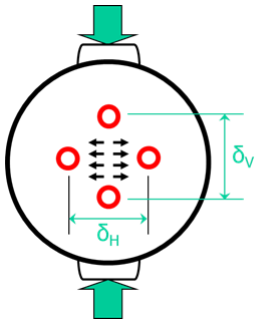
FRACTURE ENERGY

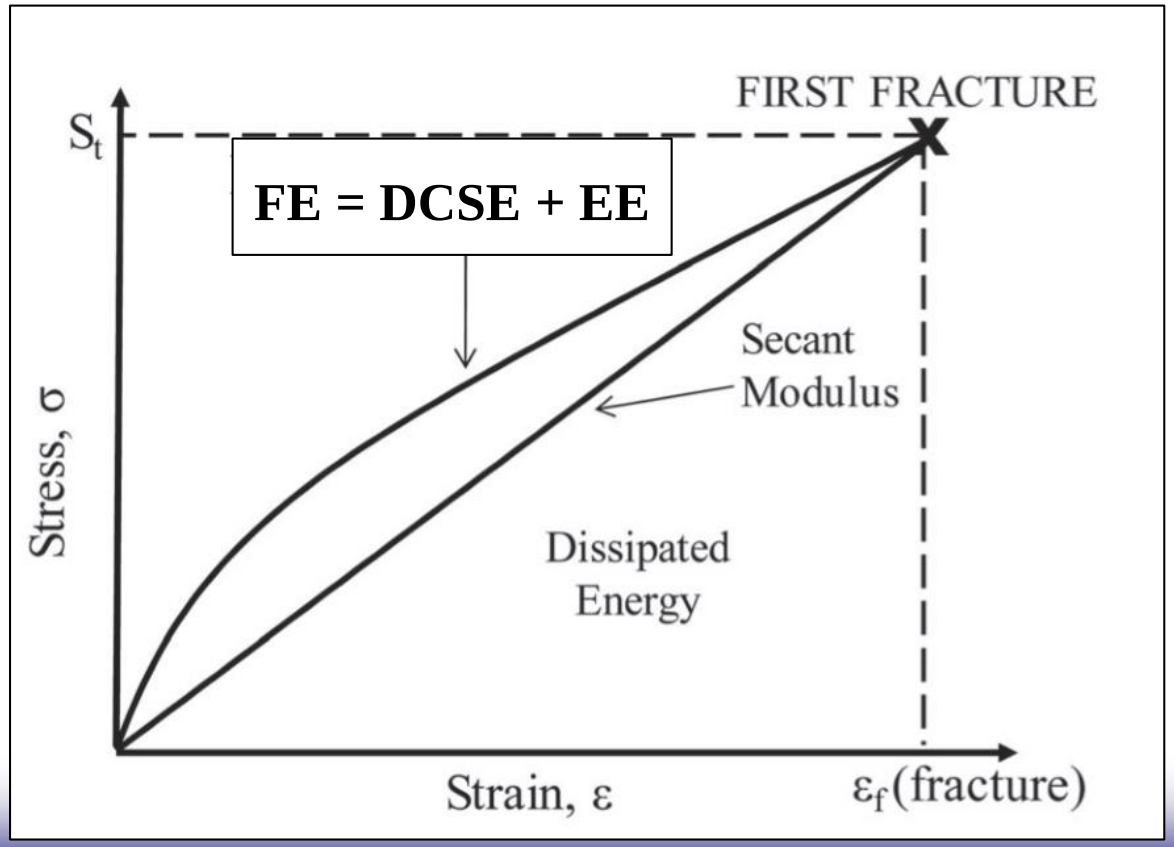
University of Parma

HMA Fracture Mechanics [Roque et alt., 2011]

approach for quasi-brittle materials

Total Fracture Energy (FE) → dissipated energy + strain energy





FRACTURE ENERGY

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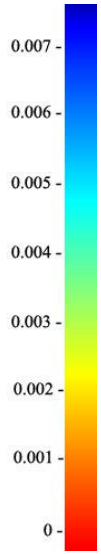
Bituminous emulsion

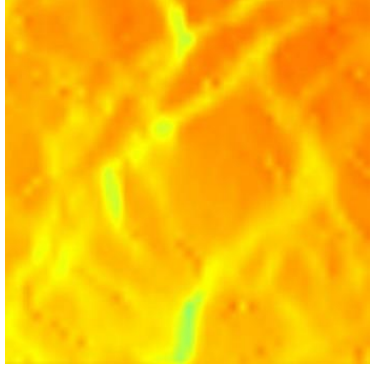
MIX	% bitumen emulsion	% cement	% hydrated lime	St [MPa]	Failure Strain [με]	FE [Kj/m³]	Dissipated Energy [Kj/m³]	Strain Energy [Kj/m³]
2A	3	1	2	0.30	910	0.29	0.136	0.153
2B	3	1	0	0.12	814	0.12	0.049	0.070
4D	3	2.5	0	0.21	571	0.18	0.061	0.117

HORIZONTAL

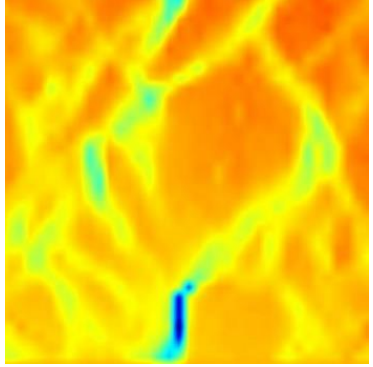
Bituminous emu

MIX	% bitumen emulsion	% cement	% hydrated lime
2A	3	1	2
2B	3	1	0
4D	3	2.5	0

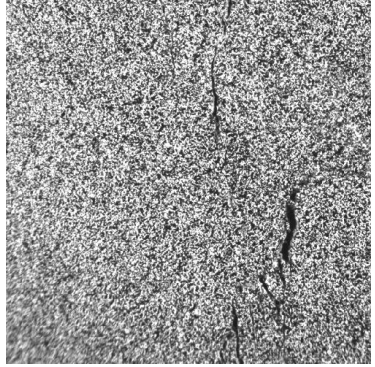




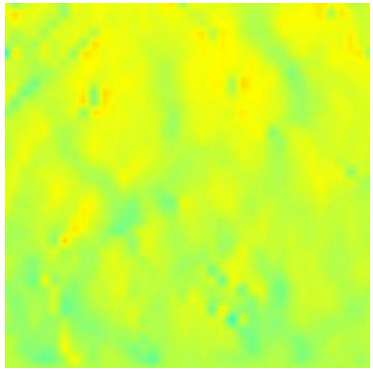
Mix 2A – macrocrack



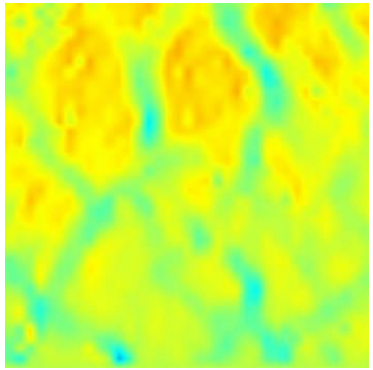
Mix 2A – peak load



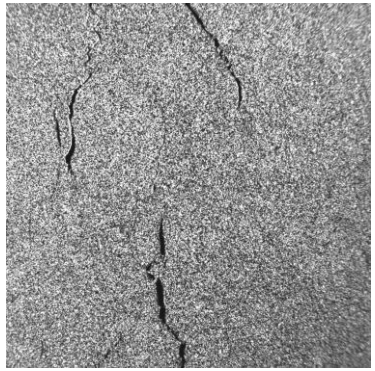
Mix 2A – visible cracks



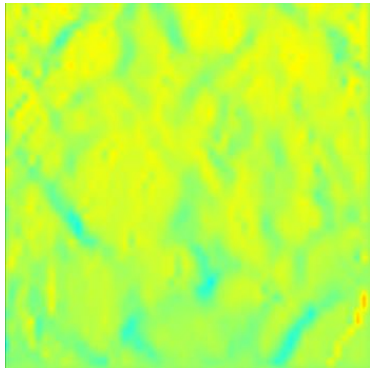
Mix 2B – macrocrack



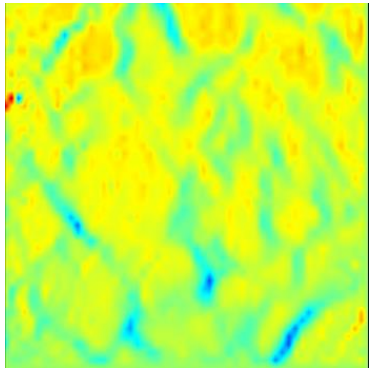
Mix 2B – peak load



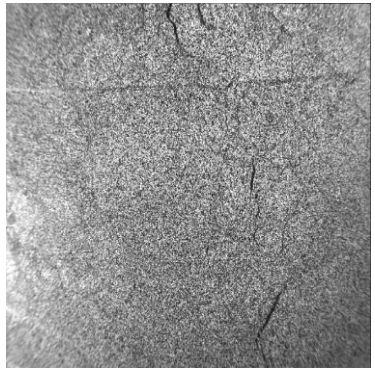
Mix 2B – visible cracks



Mix 4D – macrocrack



Mix 4D – peak load



Mix 4D – visible cracks

HORIZONTAL FULL FIELD STRAIN MAPS

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Foam bitumen

MIX	% foam bitumen	% cement	% hydrated lime	St [MPa]	Failure Strain [με]	FE [Kj/m^3]	Dissipated Energy [Kj/m^3]	Strain Energy [Kj/m^3]
3A	2	1	2		1624	0.81	0.261	0.552
3B	2	1	0	0.29	938	0.40	0.138	0.258
5C	3	2.5	2.0	0.29	702	0.61	0.103	0.504
5D	3	2.5	0	0.36	636	0.47	0.114	0.359
5E	3	0	2.0	0.19	1092	0.51	0.103	0.408
5F	3	0	3.0	0.23	1091	0.59	0.123	0.464

HORIZONTAL FULL FIELD STRAIN MAPS

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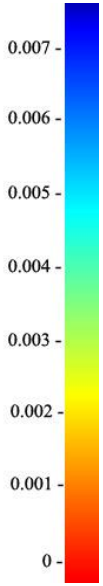
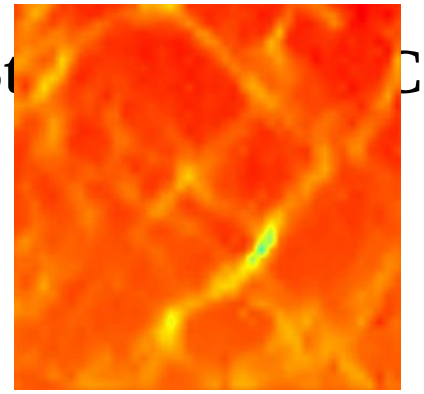
Foam bitumen

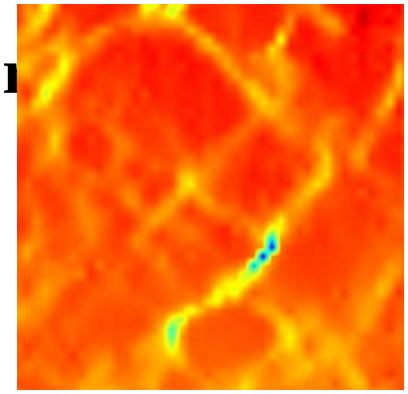
with lime

MIX	% foam bitumen	% cement	% hydrated lime
3A	2	1	2
3B	2	1	0
5C	3	2.5	2.0
5D	3	2.5	0
5E	3	0	2.0
5F	3	0	3.0

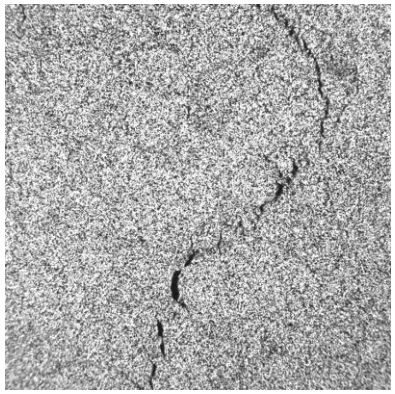




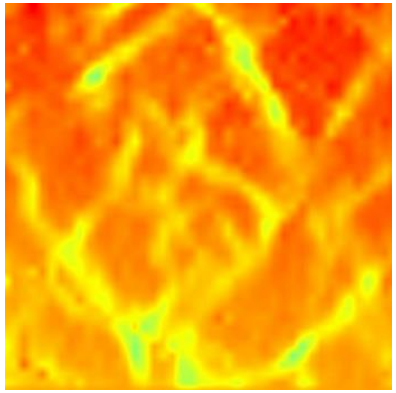
Mix 3A – macrocrack



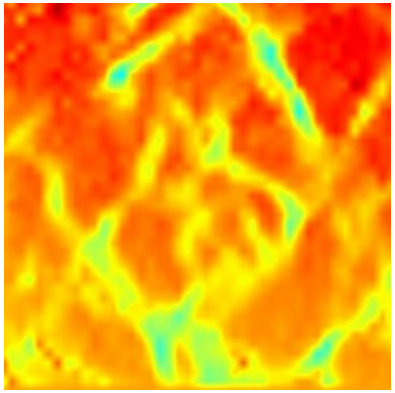
Mix 3A – peak load



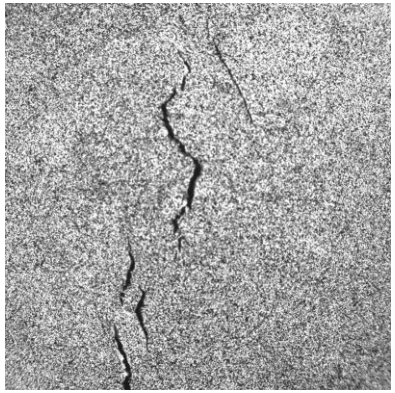
Mix 3A – visible cracks



Mix 5D – macrocrack



Mix 5D – peak load



Mix 5D – visible cracks

without lime

CONCLUSIONS

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- Lime can be used instead of cement and together with cement as an active filler for bitumen stabilized materials
- Active fillers have limited influence on bearing capacity
- Active fillers have influence in the redistribution of the stress after crack initiation (*lime increases failure strain and fracture energy, cement reduce fracture energy*)
- Moderate amount of cement + lime may represent the optimal blending for bitumen stabilized mixtures

COLD RECYCLING & LIME

University of Parma

THANKS !!

QUESTIONS??