University of Parma

PAVEMENTS/MATERIALS CONFERENCE

Cold Recycling

Gabriele Tebaldi, Ph.D., P.E.

Assistant Professor

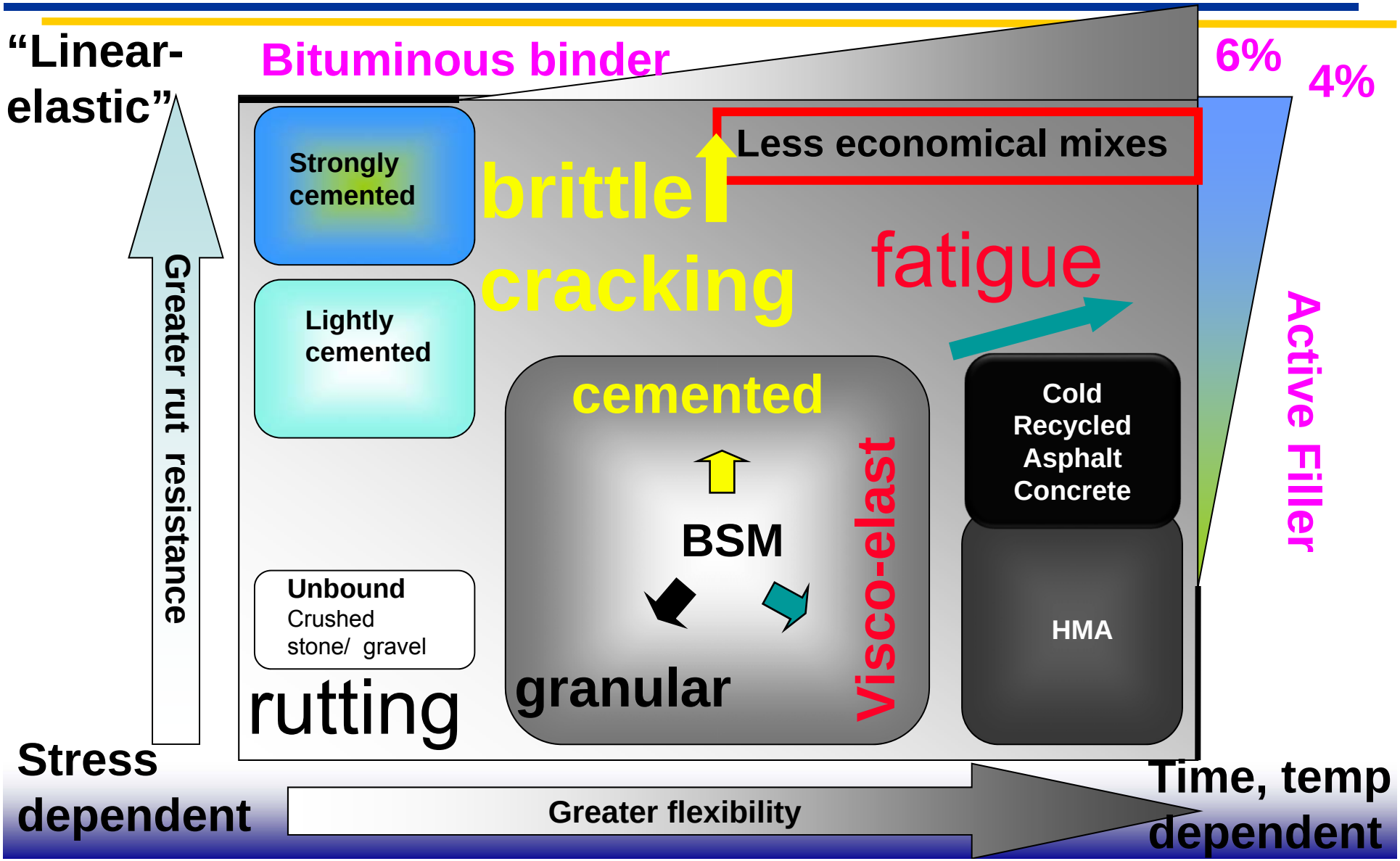
University of Parma - Department of Civil and Environmental Engineering and Architecture

Adjunct Professor

University of Florida – E.S.S.I.E., Department of Civil & Coastal Engineering

Cold Recycled Material with Bitumen

University of Parma



Foam Asphalt

University of Parma

Foam Asphalt

University of Parma

Source material for foamed asphalt is ordinary hot asphalt cement (AC-5 or PG 52-28).

Foam is produced using hot asphalt with a temperature between 325° to 340° F and a precisely defined amount of water (2.5% by weight of asphalt).

When the water comes in contact with the hot asphalt it evaporates explosively, causing the asphalt to “Foam”.

The asphalt expands up to 15% of its original volume.

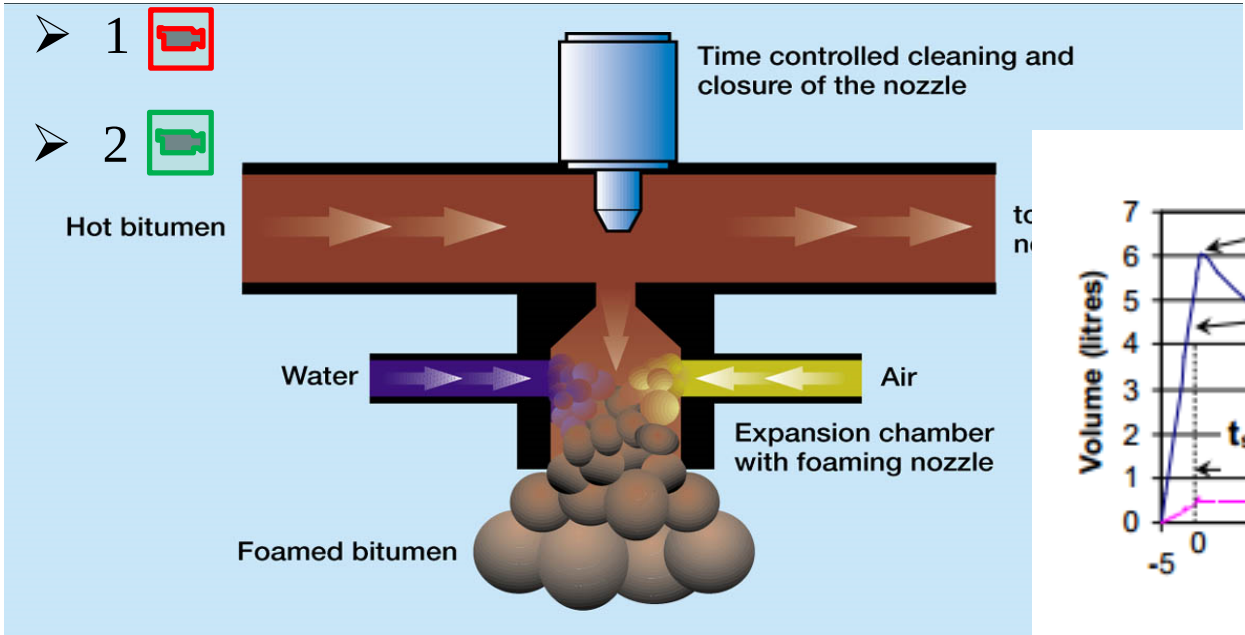
When foamed, the asphalt has a very large surface area making it ideal for mixing with aggregates.

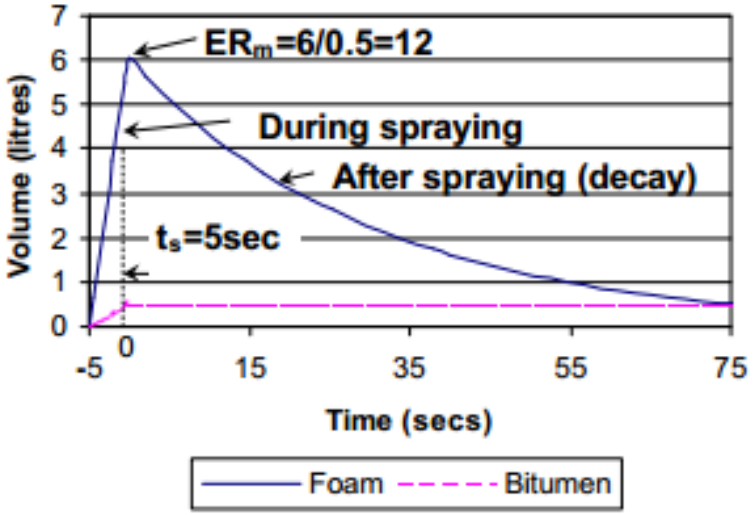
Foam Asphalt

University of Parma

Expansion Chamber

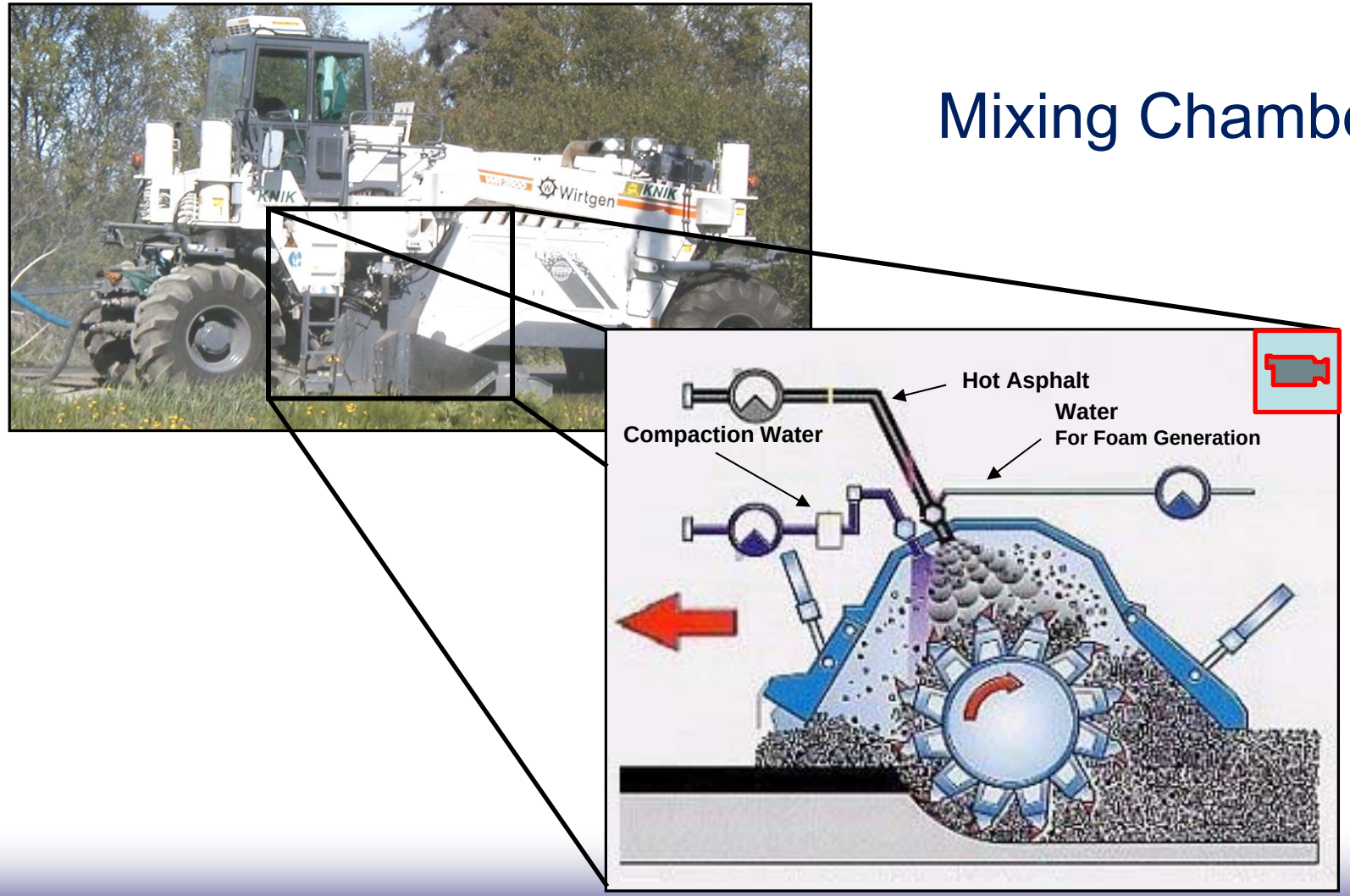
Cold water and air are injected simultaneously into the hot asphalt. The hot asphalt foams explosively and shoots down into the mixing chamber.





Foam Asphalt

University of Parma



Mixing Chamber

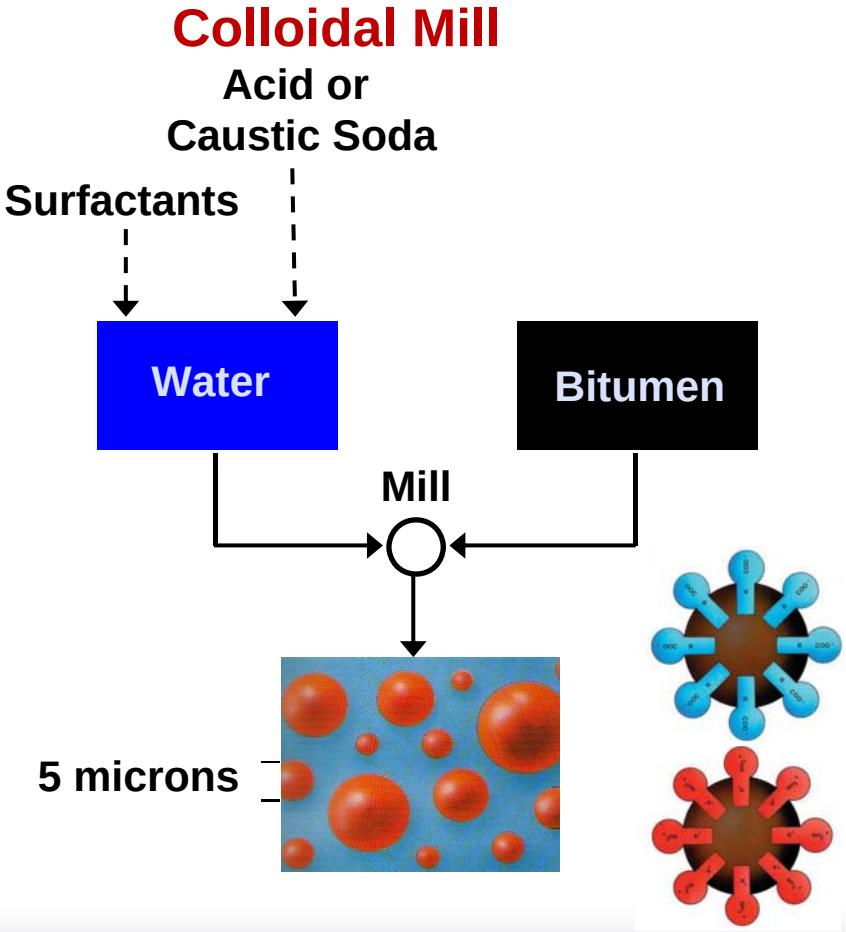
Foam Asphalt

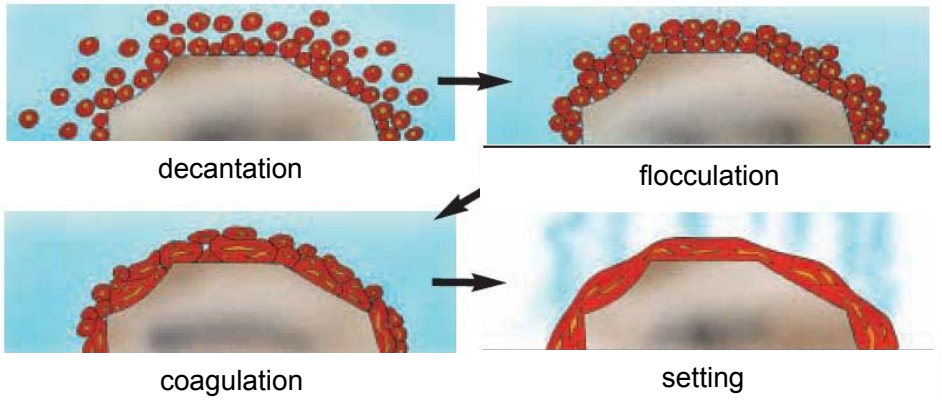
University of Parma

Asphalt Emulsion

University of Parma

Colloidal Mill





Asphalt Emulsion

University of Parma

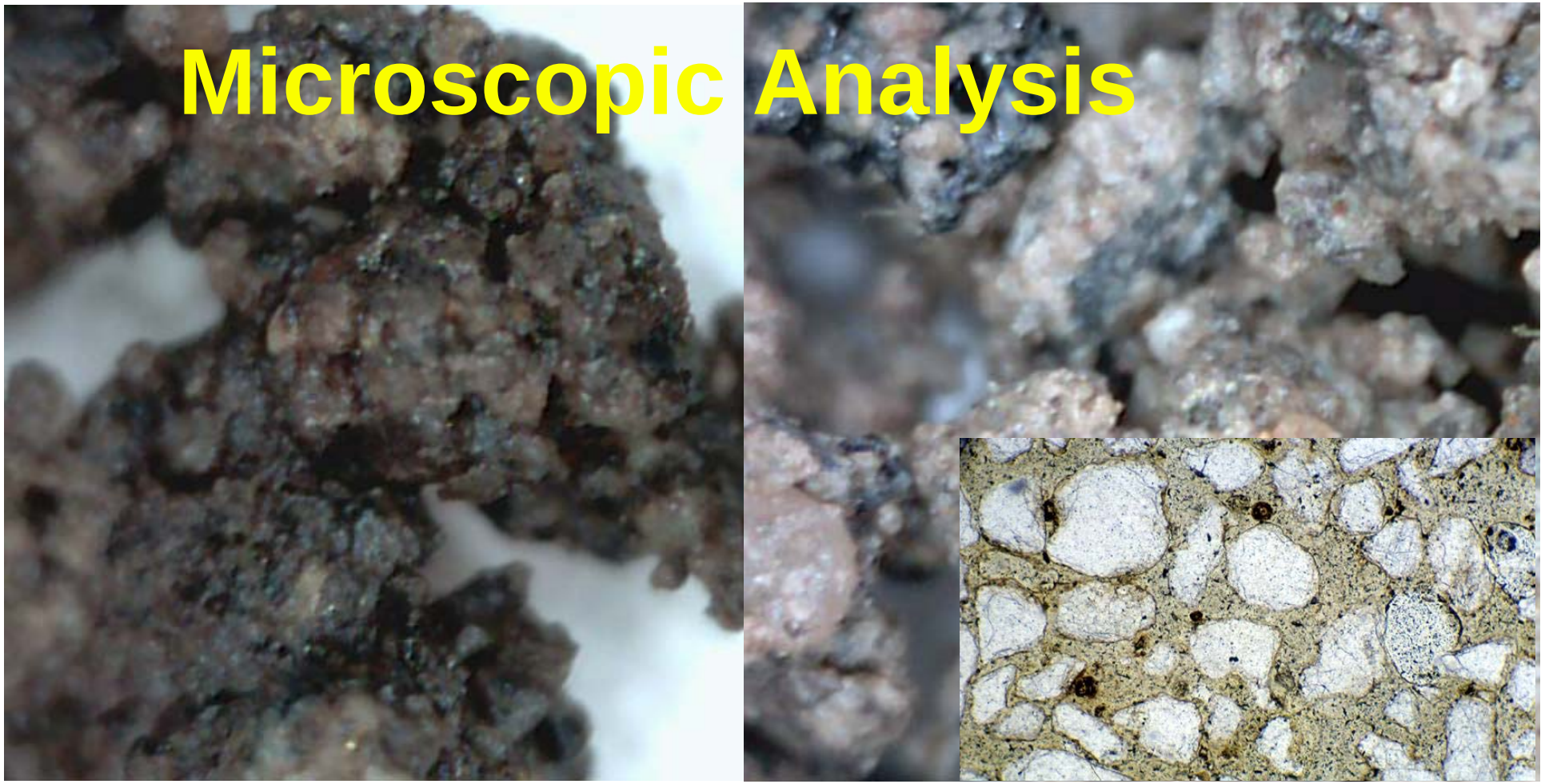
Asphalt Emulsion (an Italian example)

University of Parma

Emulsion characteristics	Water content [EN 1428] 40 ± 2%
	Amount of bitumen [EN 1431] 60 ± 2%
	Homogeneity [EN 1429] max 0,2%
	Sedimentation @ 7 dd [EN 12847] max 10%
	pH (acidity) [EN 12850] 2 ÷ 6
Bitumen characteristics	Penetration @ 25°C, 100 g / 5” [EN 1426] 50 ÷ 70 dmm
	R&B [EN 1427] > 60°C
	Fraaß point EN 12593 ≤ - 15°C

Bitumen Dispersion

University of Parma



Emulsion

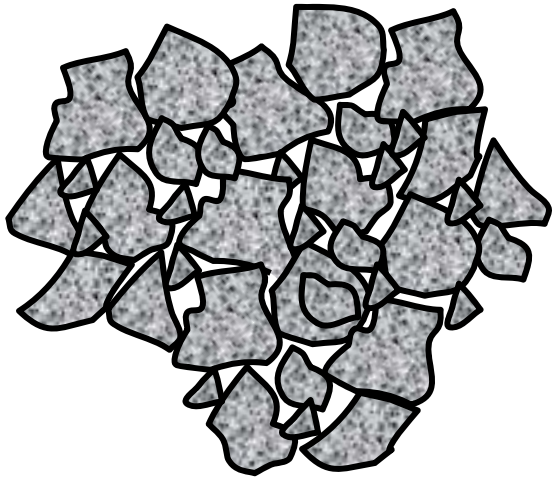
Foam

Bitumen Dispersion

University of Parma

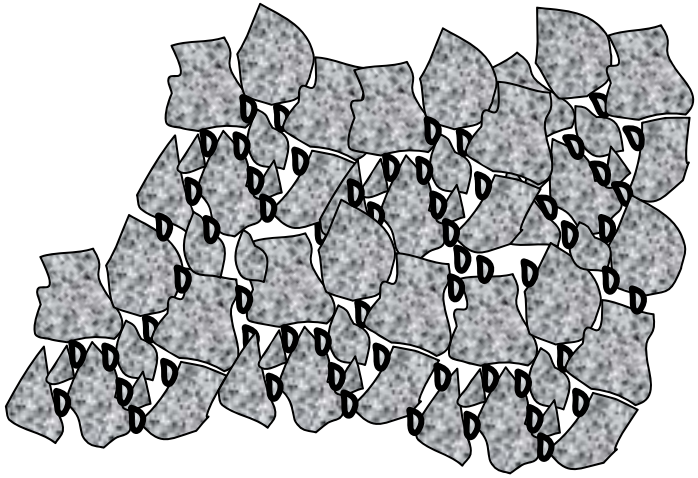
Asphalt emulsion

Continuously bound



Foam asphalt

Non-continuously bound



DIFFERENT BEHAVIOUR PATTERNS

Bitumen Dispersion

University of Parma

Painting

Emulsion

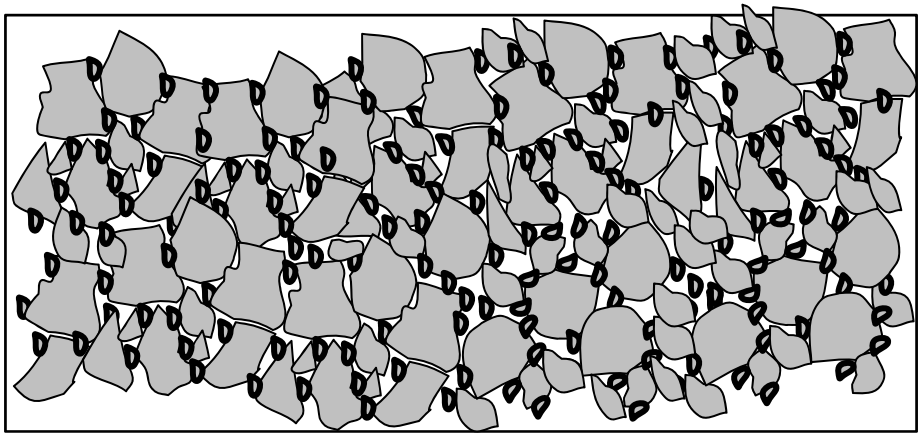
Spot-welding

Foam

Aggregate Mixing Temperature

University of Parma

Foam > 25ºC

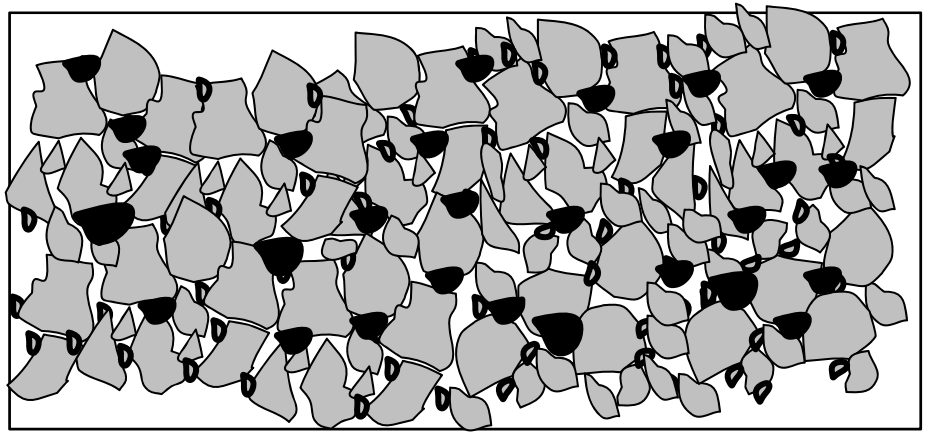


Aggregate Mixing Temperature

University of Parma

Foam >15ºC

Emulsion >10ºC

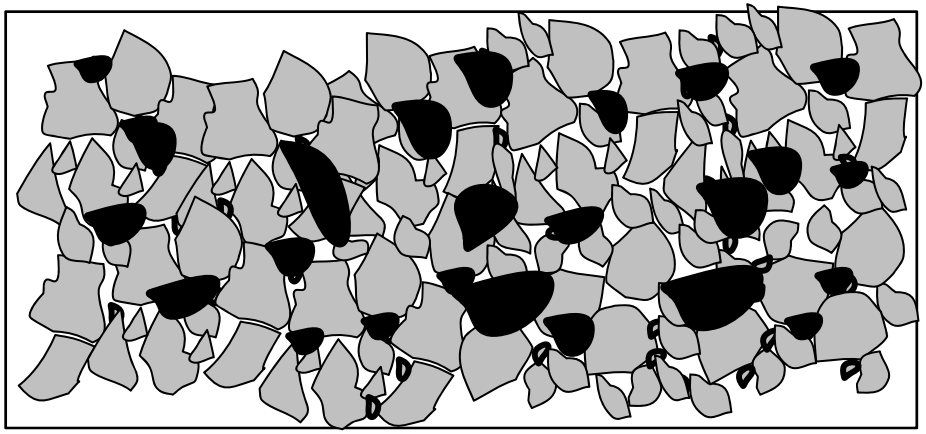


Aggregate Mixing Temperature

University of Parma

Foam <15ºC

Emulsion<10ºC



Typical Bitumen % for BSM-foam

Guidelines for estimating optimum foamed bitumen addition			
Fraction passing 0.075 mm sieve (%)	Foamed bitumen addition (% by mass of dry aggregate)		Typical type of material
	Fraction passing 4.75 mm sieve		
	< 50%	> 50%	
< 4	2.0	2.0	Recycled asphalt (RA/RAP)
4 – 7	2.2	2.4	RA/Graded crushed stone/ Natural gravel/blends
7 – 10	2.4	2.8	
> 10	2.6	3.2	Gravels/sands

Typical Bitumen % BSM-emulsion

Guidelines for estimating optimum bitumen emulsion addition (60% residual bitumen)			
Fraction passing 0.075 mm sieve (%)	Bitumen emulsion (Residual bitumen) addition (% by mass of dry aggregate)		Typical type of material
	Fraction passing 4.75 mm sieve		
	< 50%	> 50%	
< 4	3.3 (2.0)	3.3 (2.0)	Recycled asphalt (RA/RAP)
4 – 7	3.7 (2.2)	4.0 (2.4)	RA/Graded crushed stone/ Natural gravel/blends
7 – 10	4.0 (2.4)	4.7 (2.8)	
> 10	4.3 (2.6)	5.3 (3.2)	Gravels/sands

Grading requirements

University of Parma

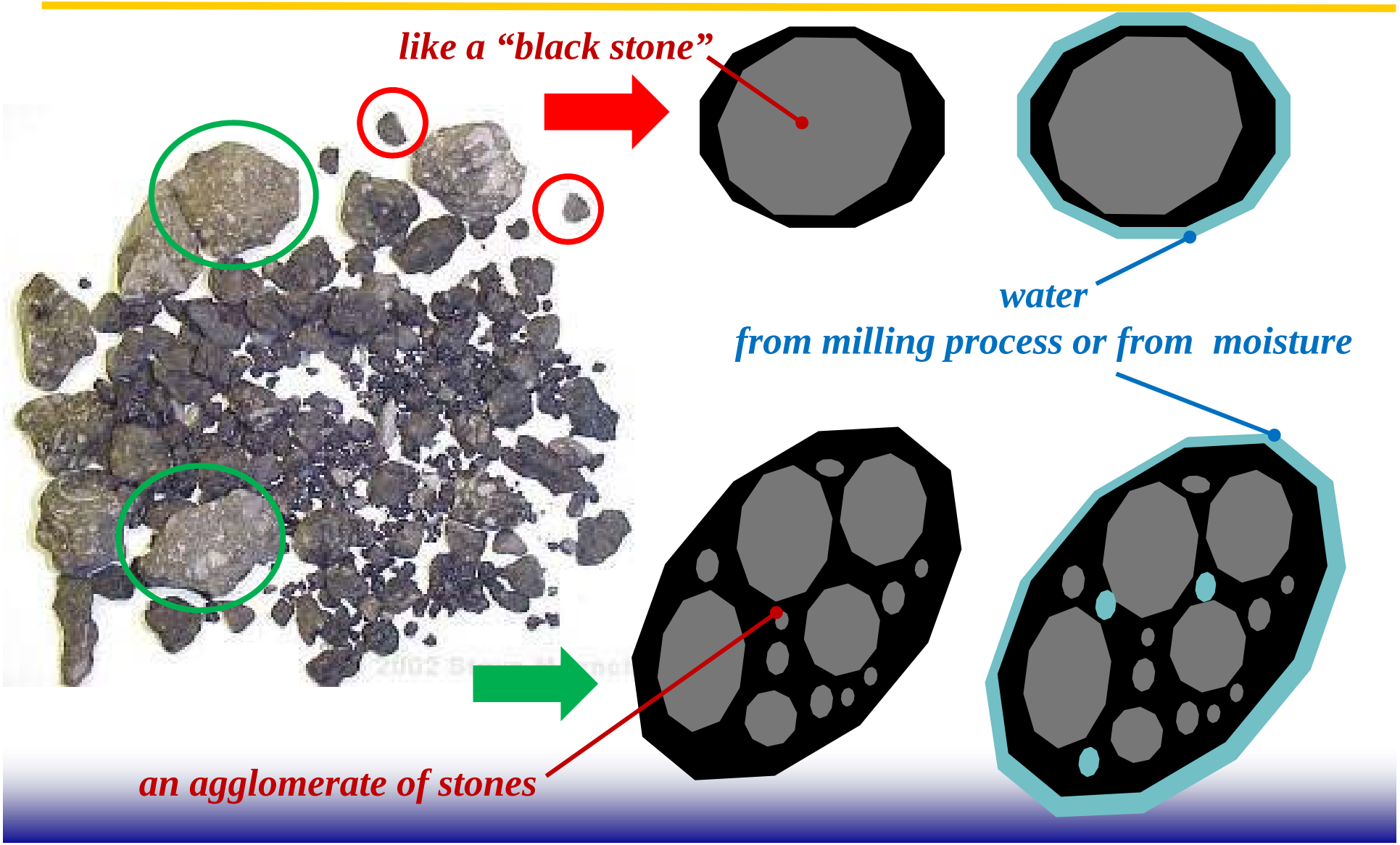
Sieve Size (mm)	Percent Passing			
	BSM-Emulsion		BSM-Foam	
	Ideal	Less suitable	Ideal	Less suitable
50	100		100	
37.5	87 – 100		87 – 100	
26.5	77 – 100	100	77 – 100	100
19.5	66 – 99	99 – 100	66 – 99	99 – 100
13.2	67 – 87	87 – 100	67 – 87	87 – 100
9.6	49 – 74	74 – 100	49 – 74	74 – 100
6.7	40 – 62	62 – 100	40 – 62	62 – 100
4.75	35 – 56	56 – 95	35 – 56	56 – 95
2.36	25 – 42	42 – 78	25 – 42	42 – 78
1.18	18 – 33	33 – 65	18 – 33	33 – 65
0.6	12 – 27	27 – 54	14 – 28	28 – 54
0.425	10 – 24	24 – 50	12 – 26	26 – 50
0.3	8 – 21	21 – 43	10 – 24	24 – 43
0.15	3 – 16	16 – 30	7 – 17	17 – 30
0.075	2 – 9	9 – 20	4 – 10	10 – 20

Grading requirements

University of Parma

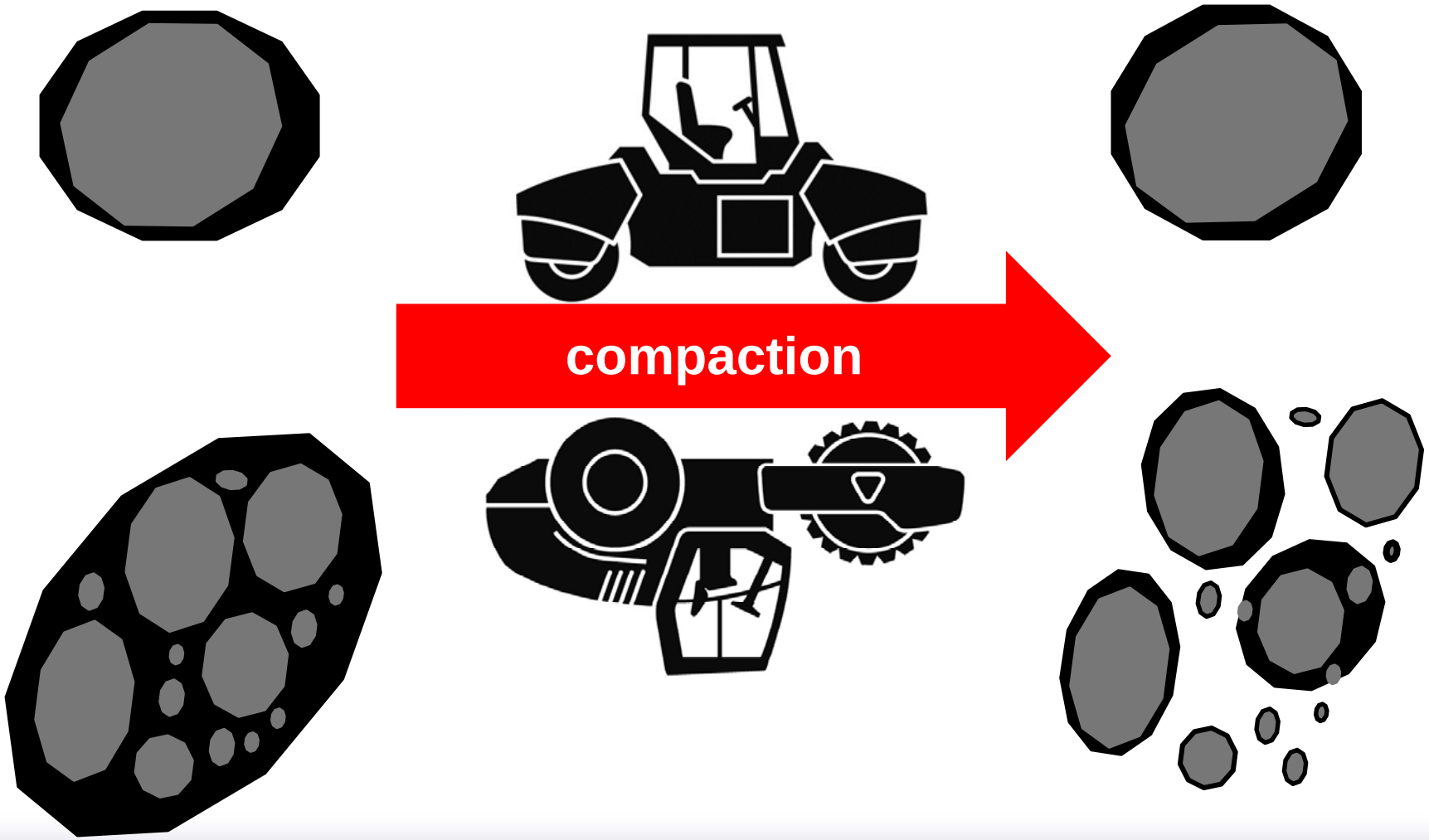
Grading requirements

University of Parma



Grading requirements

University of Parma

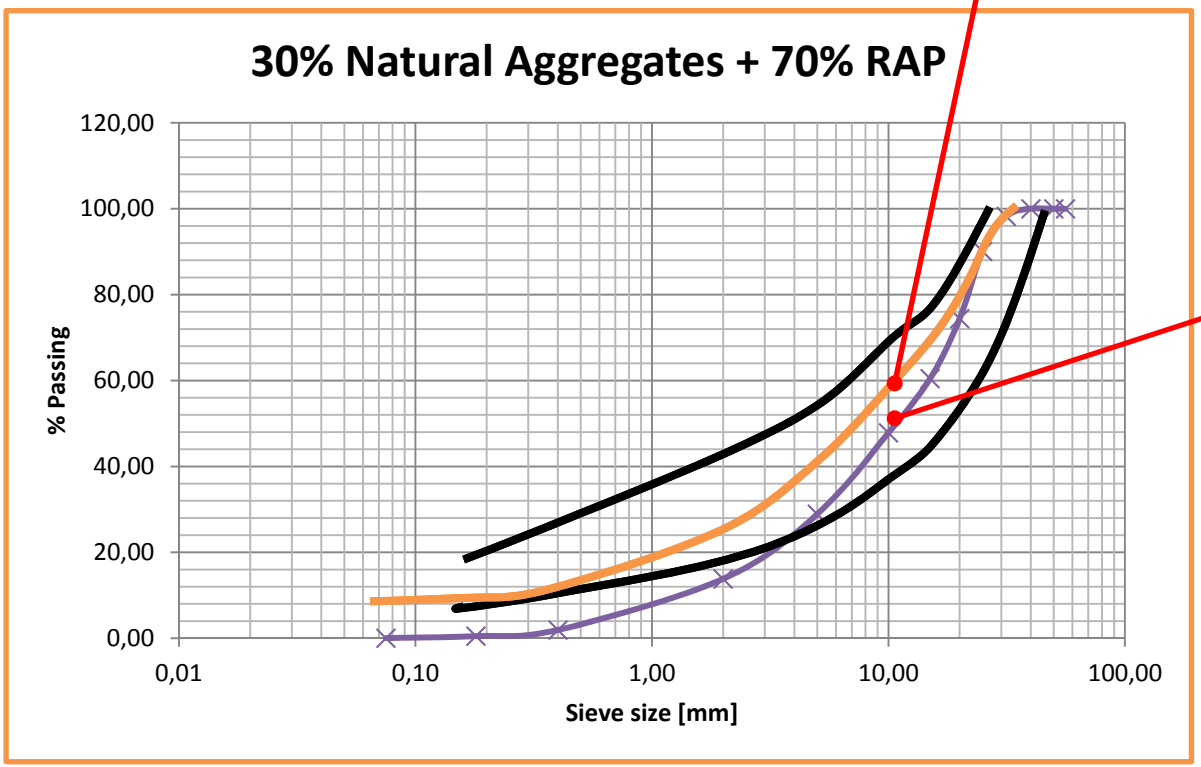


Grading requirements

University of Parma

After compaction

Before compaction

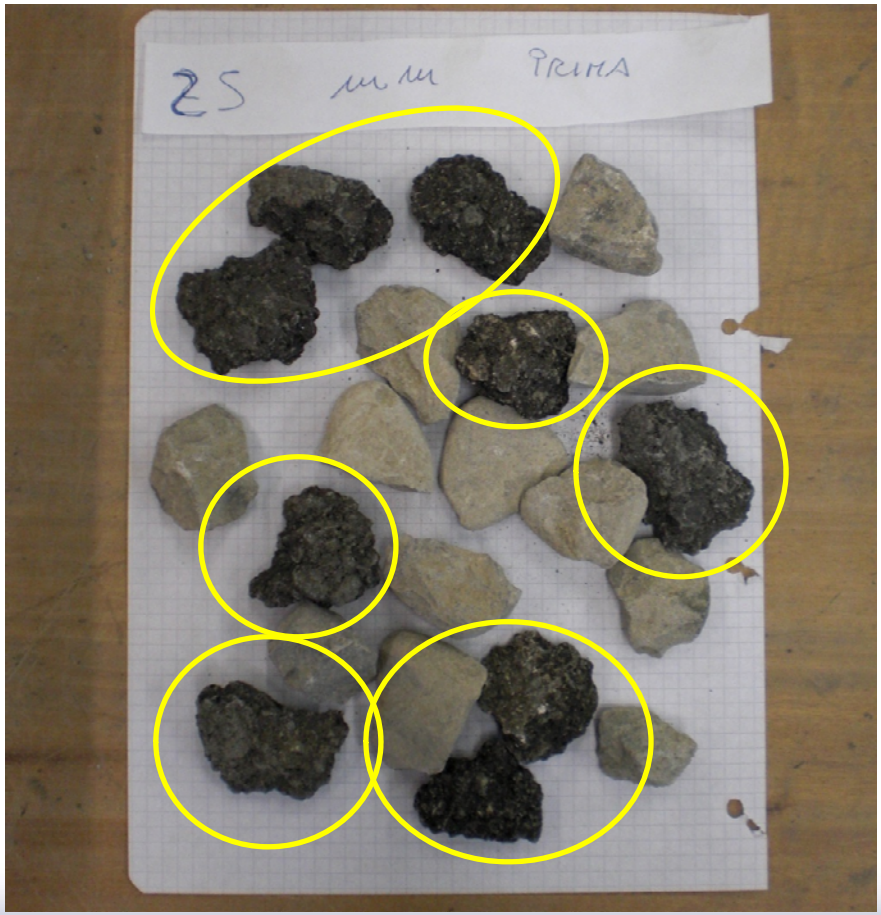


Grading requirements

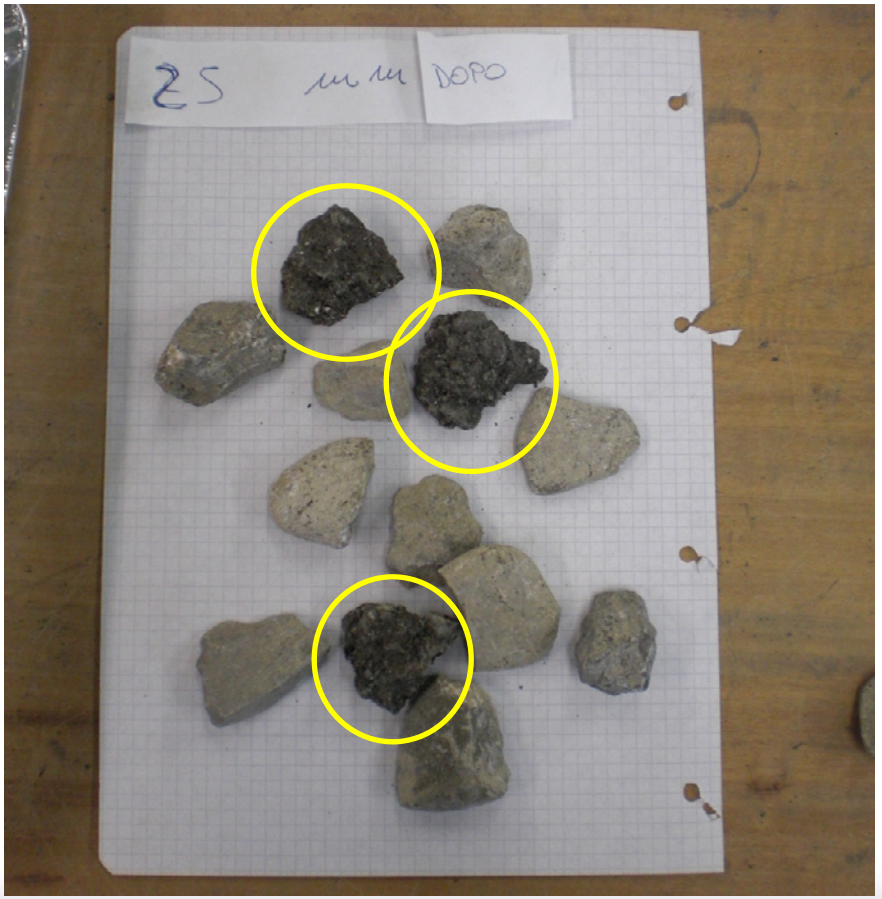
University of Parma

Retained at 25mm sieve

Before compaction



After compaction



Moisture Regime (mix & compact)

University of Parma

PURPOSE OF MOISTURE

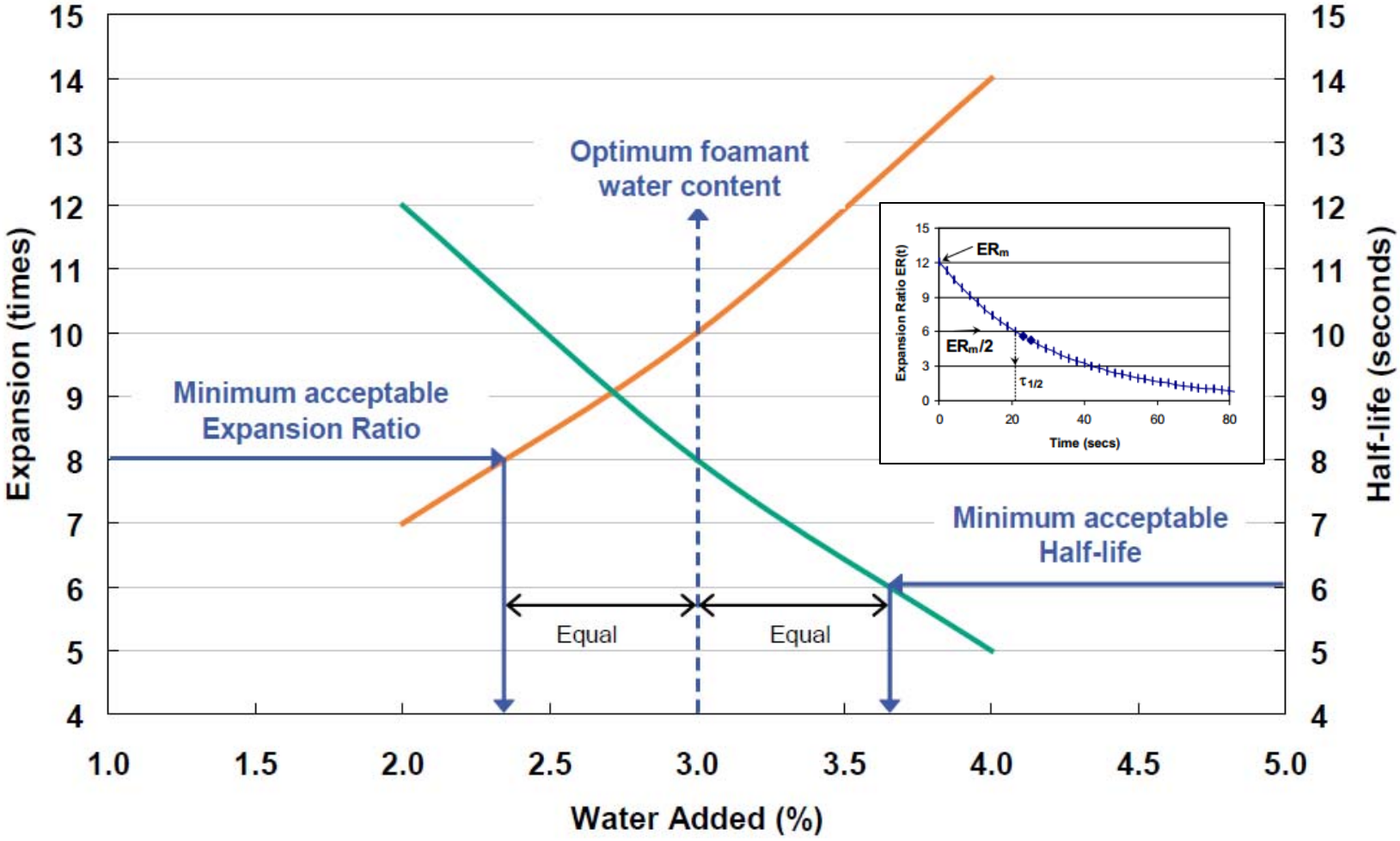
- Separation and suspension of fines
- Carrier of bitumen droplets
- Lubricant for workability
- Compaction aid

In Service:
Get water out!!

Moisture Regime (mix & compact)

University of Parma

Foam



Moisture Regime (mix & compact)

University of Parma

MIXING MOISTURE

The moisture content that will provide the best mix is termed the optimum mixing moisture content (OMMC).

Emulsion

A minimum of 1 to 2% moisture is required in the aggregate prior to adding the bitumen emulsion.

Foam

65 to 85% of the optimum moisture content (OMC) using modified AASHTO compaction should be used for the mixing moisture content when adding foamed bitumen.

Moisture Regime (mix & compact)

University of Parma

COMPACTION MOISTURE

Emulsion

Compaction have to be carried out at the optimum fluids content (OFC)

Foam

Compaction have to be carried out at the optimum moisture content (OMC)

Moisture Regime (mix & compact)

University of Parma

The water and bitumen in the bitumen emulsion act as lubricants for BSM-emulsion mixes.

The optimum moisture content (OMC) using modified AASHTO compaction should be used for the total mixing fluid content.

$$\mathbf{OFC = OMC_{MOD\text{-}U} = FMC + EWC + RBC}$$

OFC = optimum fluids content (%)
$OMC_{MOD\text{-}U}$ = optimum moisture content using Mod. AASHTO compaction on untreated material (%)
FMC = field moisture content of aggregate (%)
EWC = bitumen emulsion water content including water used for dilution as percentage of dry aggregate (%)
RBC = residual bitumen content as percentage of dry aggregate (%)

Laboratory compaction

University of Parma

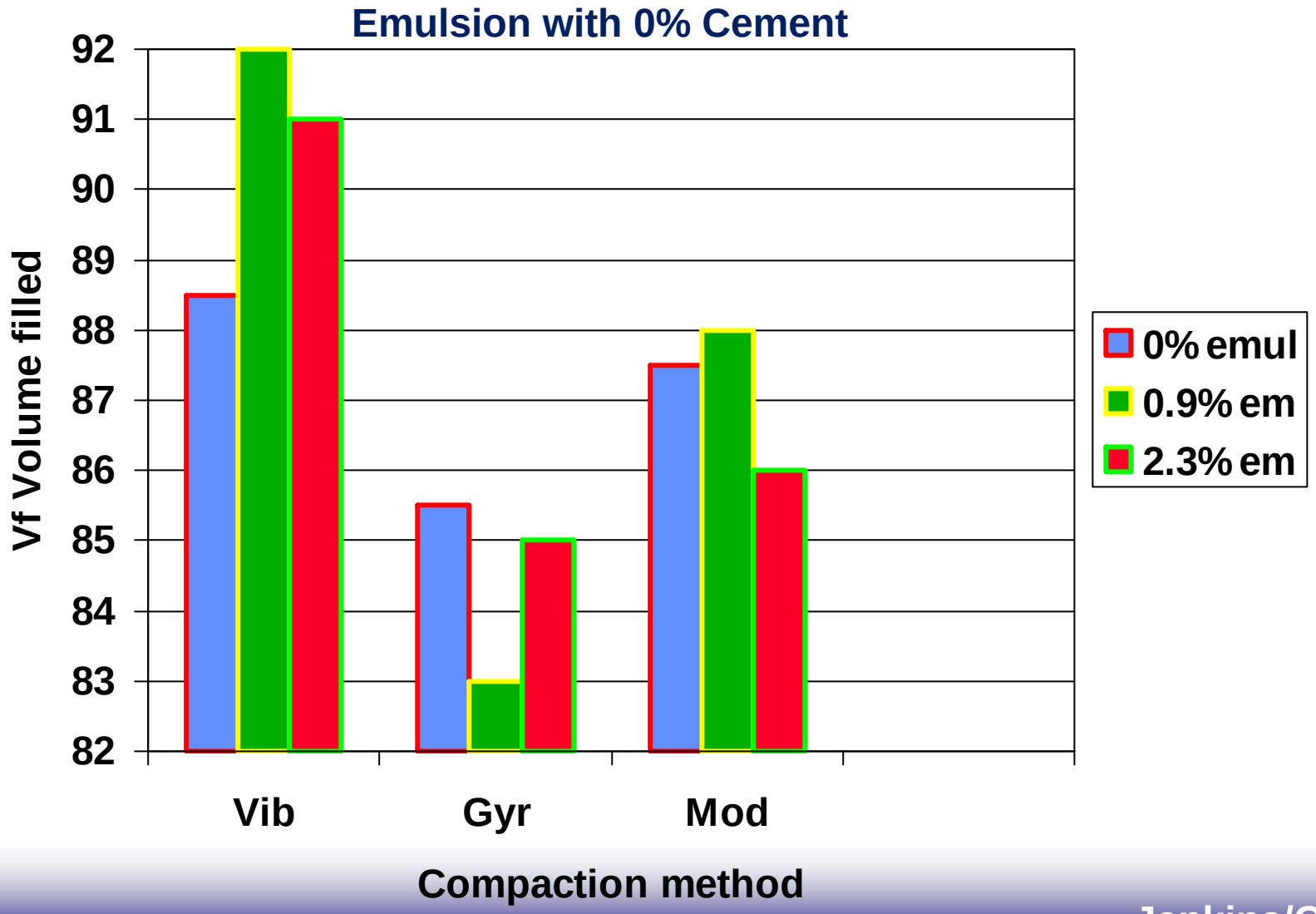
- Marshall
- Modified AASHTO
- Gyratory compactor (regula… …odified)
- Vibratory hammer
- Slab compa…

research needs: a compaction protocol

Which way to go?

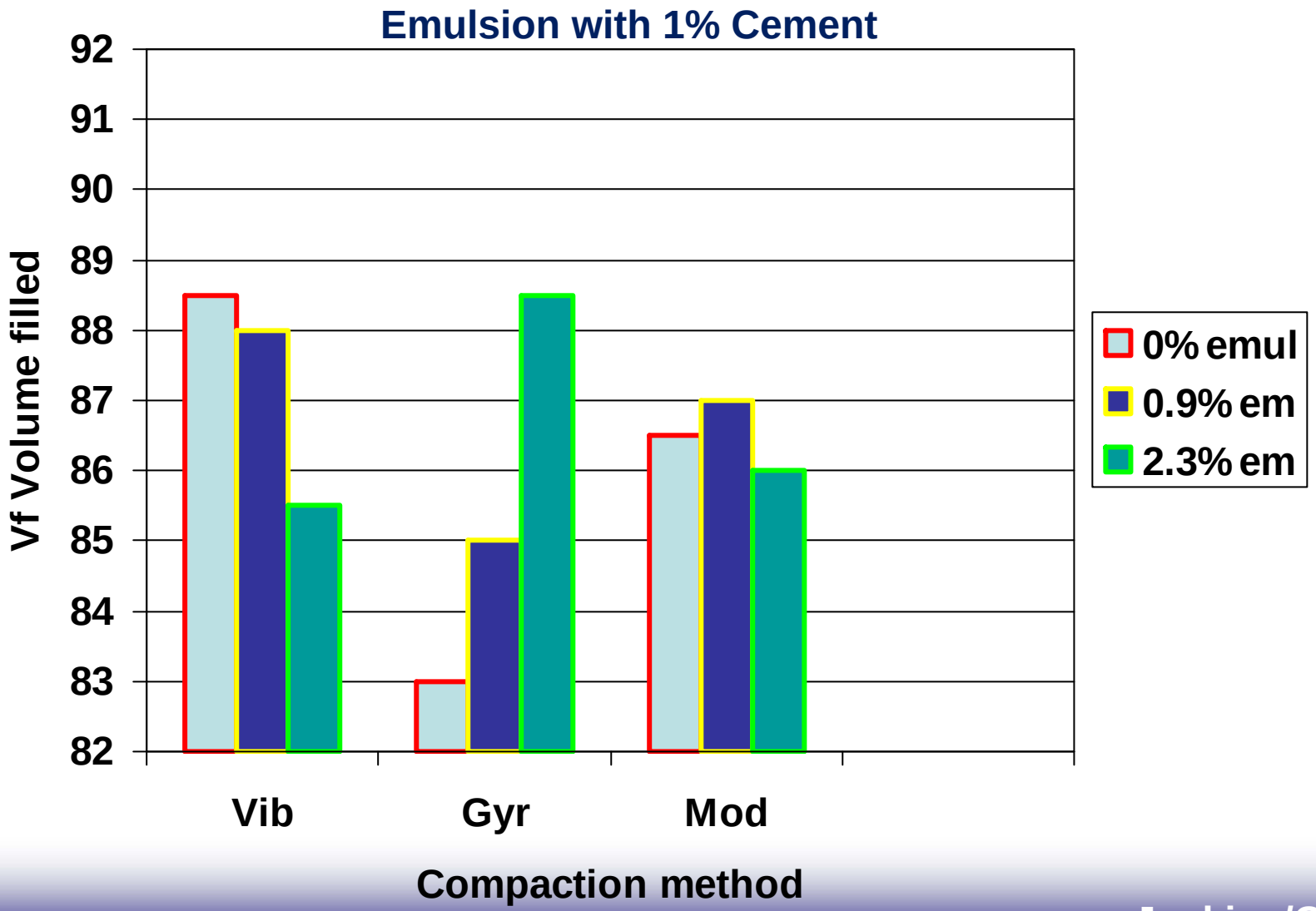
Laboratory compaction

University of Parma



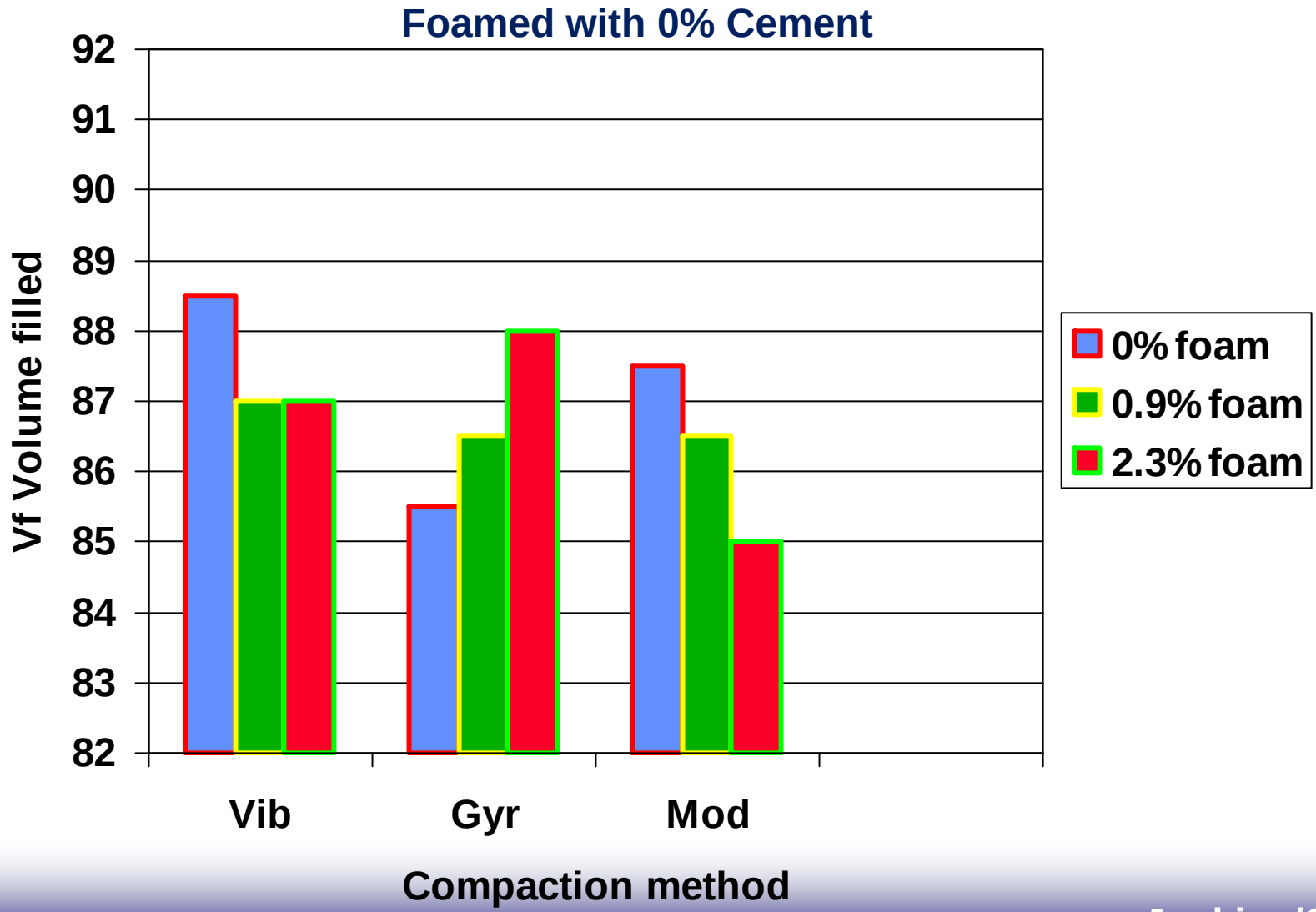
Laboratory compaction

University of Parma



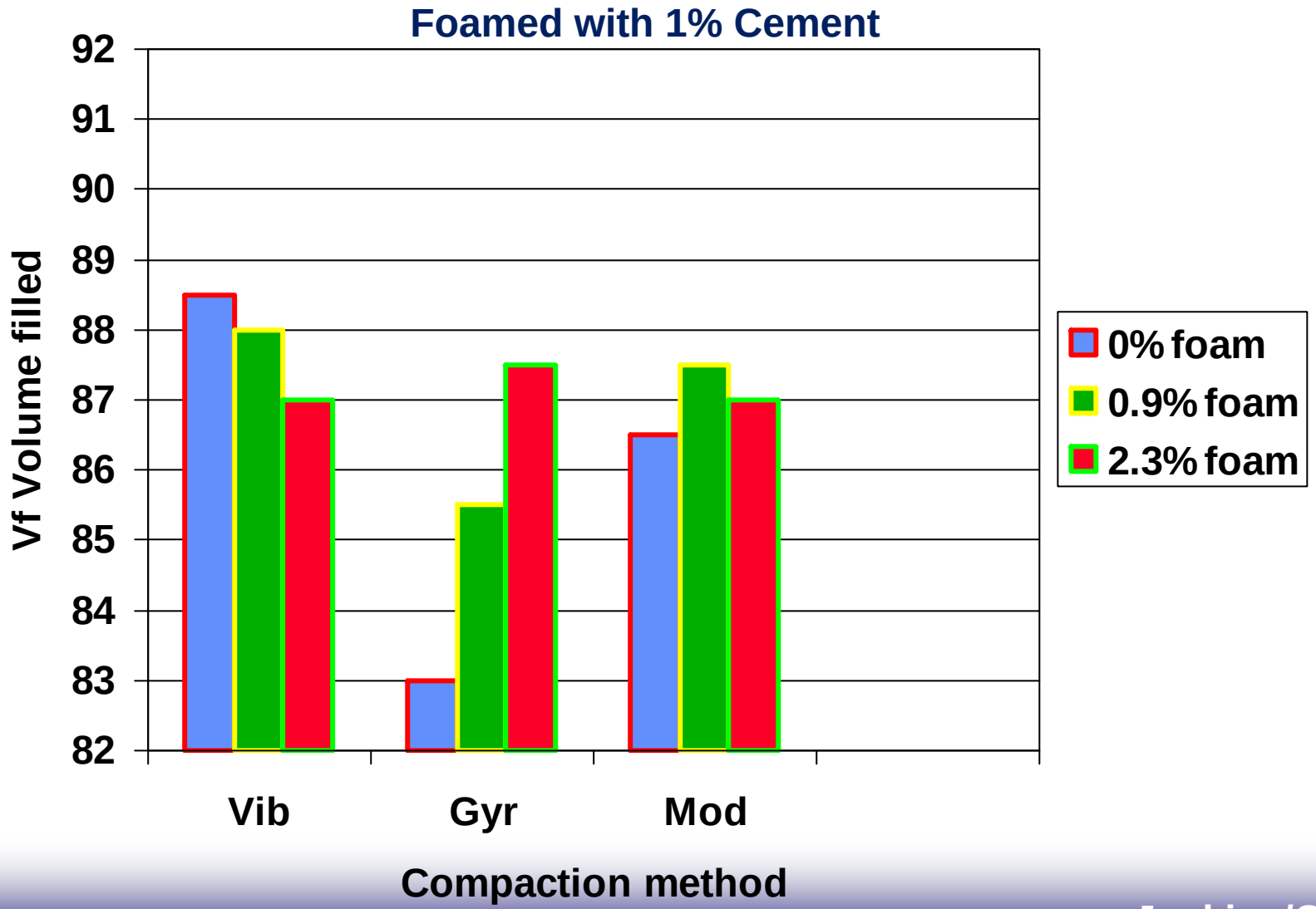
Laboratory compaction

University of Parma



Laboratory compaction

University of Parma



Active Filler

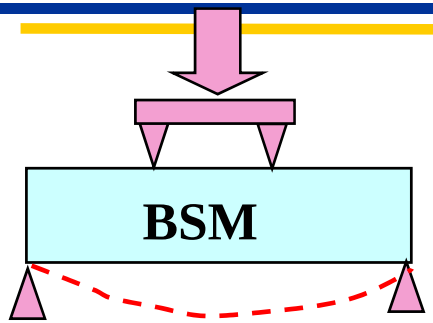
University of Parma

- **Improve adhesion** — **PRIMARY**
- **Improve dispersion** — **REASONS**
- **Modify plasticity**
- **Increase stiffness & strength**
- **Accelerate curing**

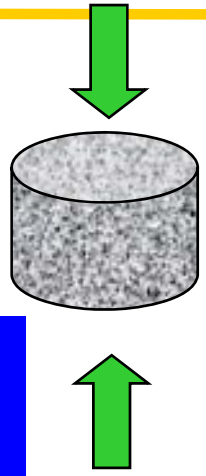
  Emulsion **Foam**
- **Breaking time** **Dispersion!**
- **Improve workability**

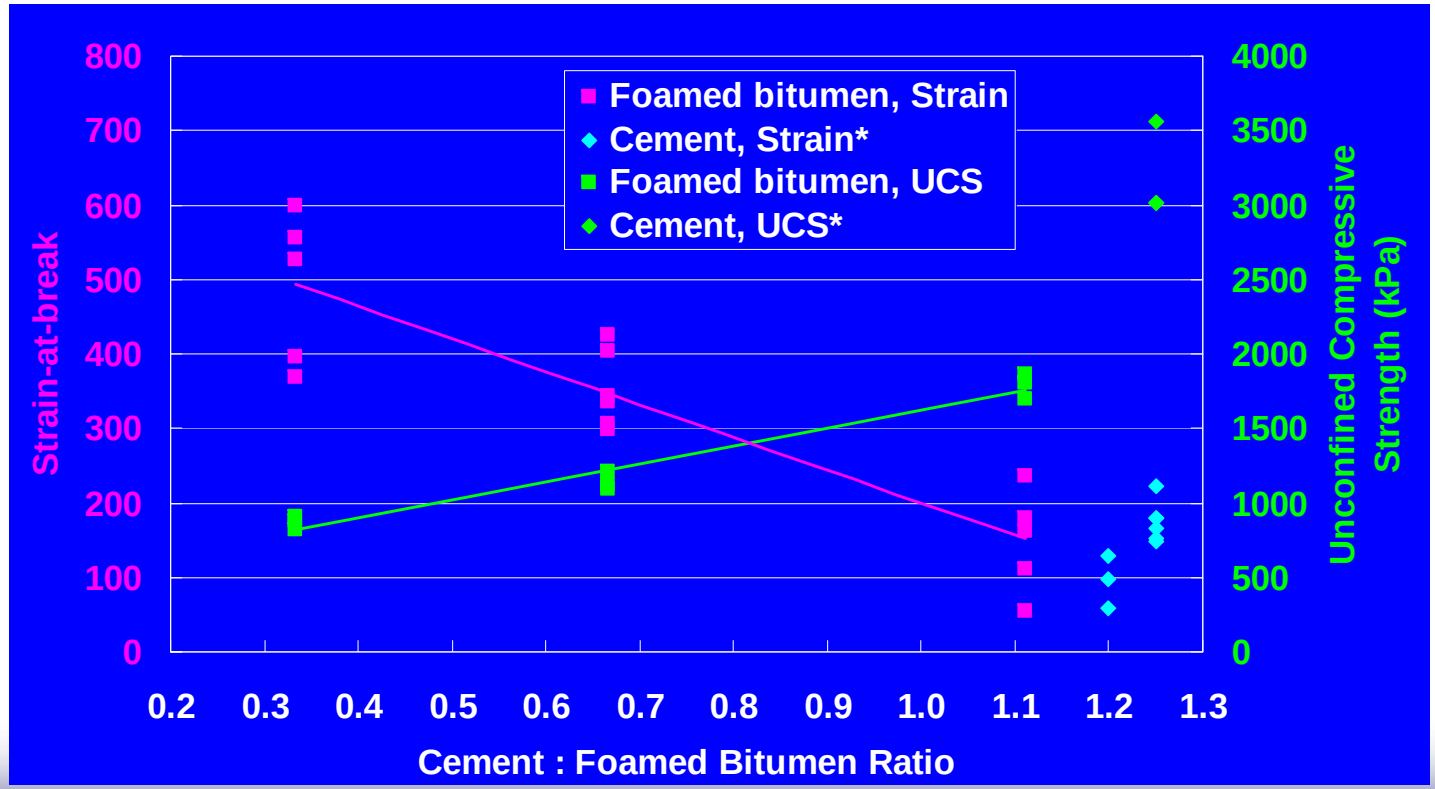
Influence of Active Filler

University of Parma



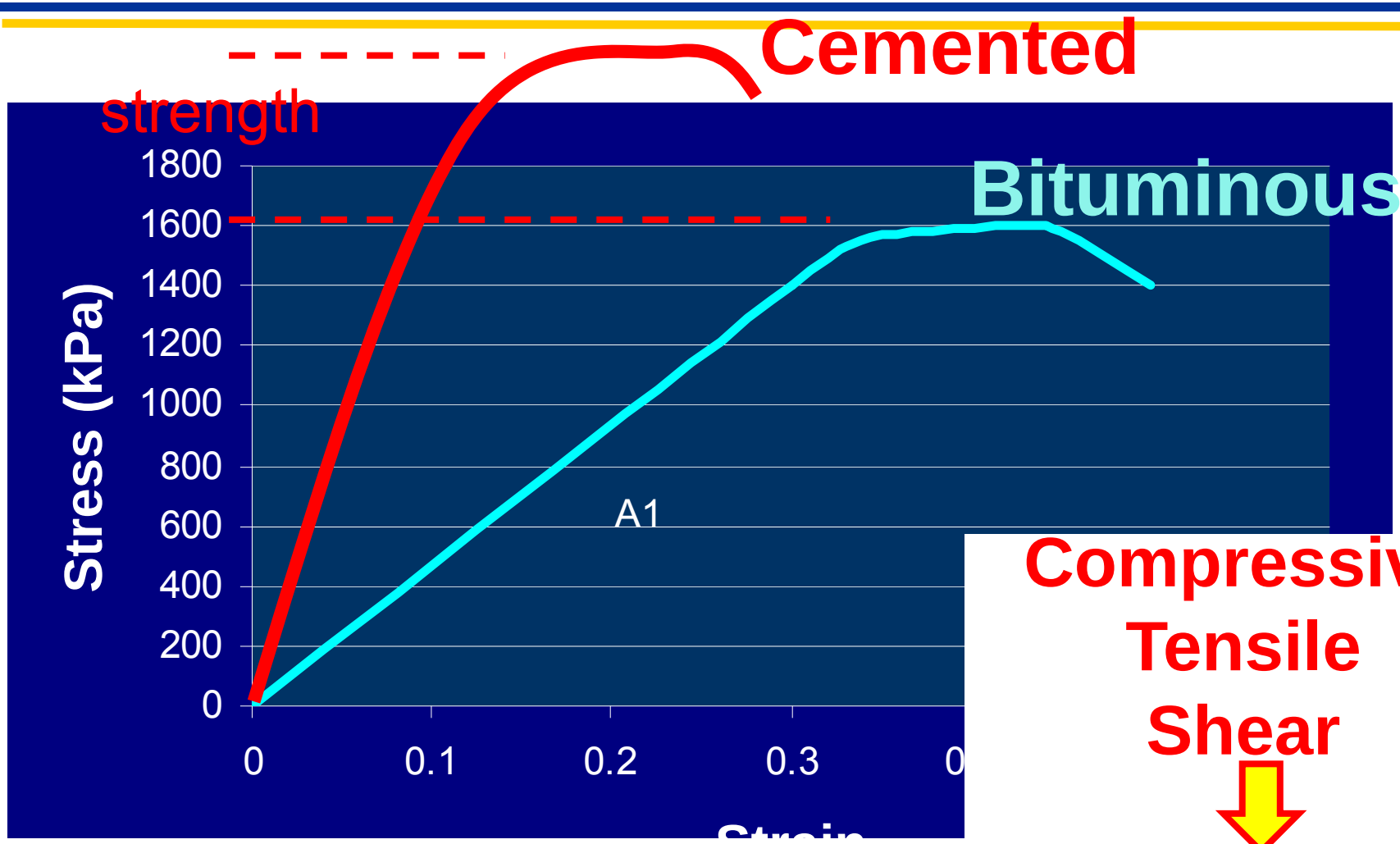
Strength and flexibility





Influence of Active Filler

University of Parma

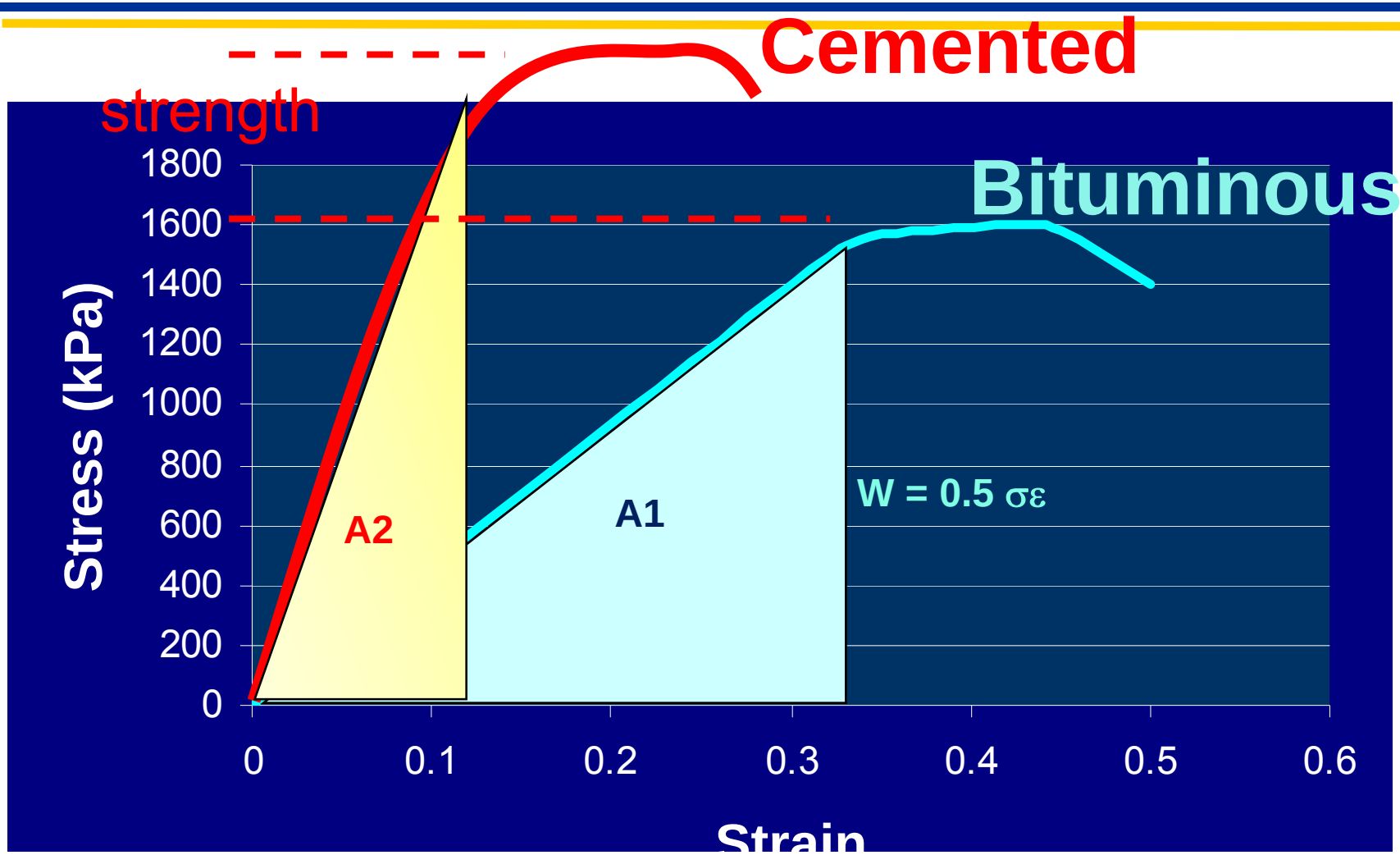


Compressive
Tensile
Shear

It's undeniable: more cement = more strength

Influence of Active Filler

University of Parma



…. but: more cement = less dissipated energy!

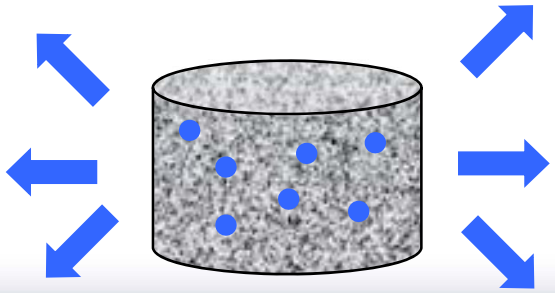
Curing

University of Parma

Discharge of water from compacted material due to:

- **Evaporation**
- **Particle charge repulsion**
- **Pore-pressure induced flow paths**

Curing is associated with strength gain



Variables for Curing

University of Parma

- Climate (temperature, rainfall, evaporation)
- Moisture conditions (subgrade, surface)
- Material type
- Layer's position in pavement
- Binder (foam versus emulsion)
- Active filler type and content

Field

- Specimen size and compaction
- Curing time (short term or long term)

Lab

Brief history of “lab-curing”

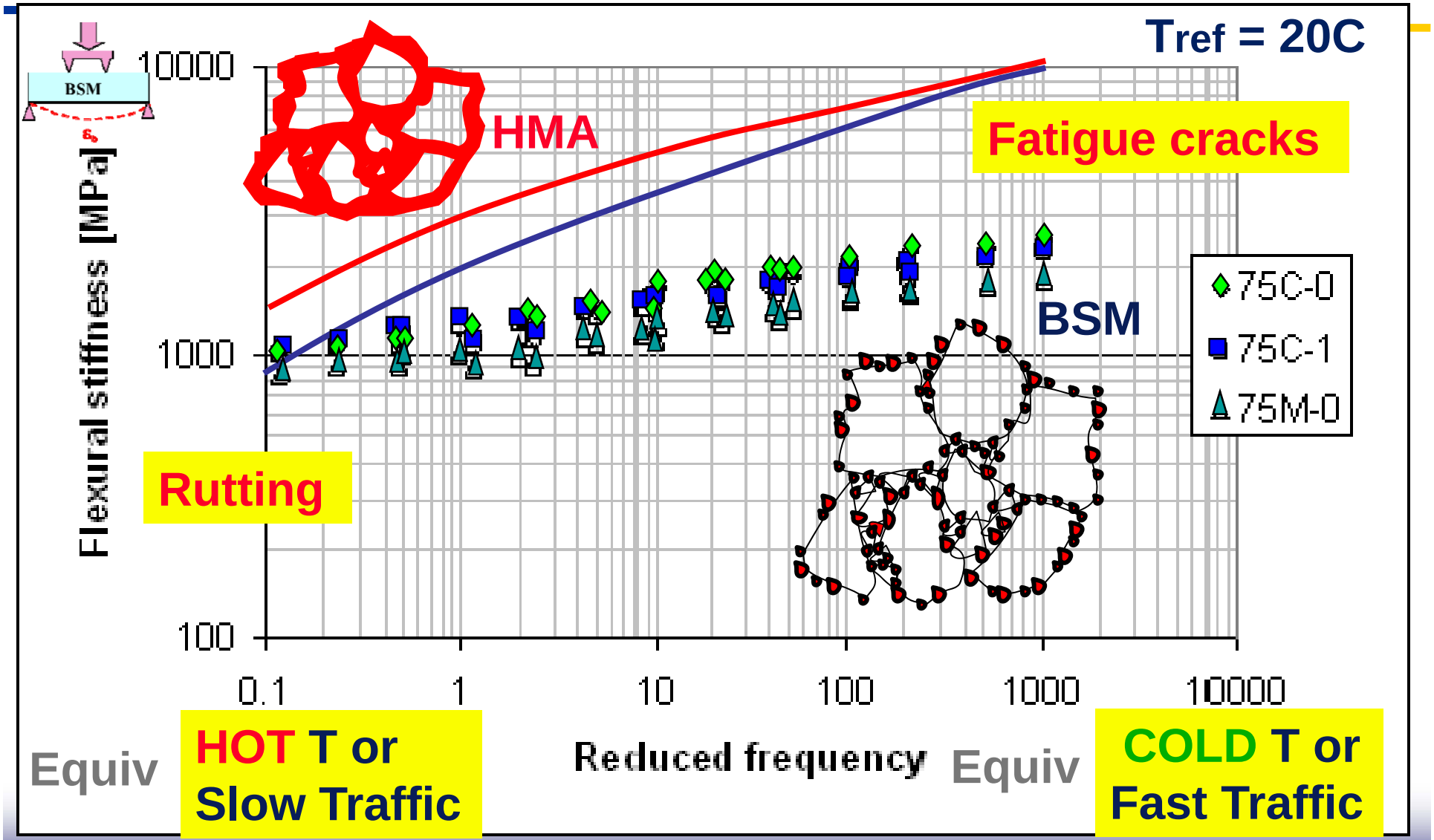
University of Parma

- 3 days at 60°C unsealed (Bowering, 1970)
- 1 day in mould [Short term] (Ruckel, 1982)
- 24 hours in mould and 72 hours at 4[illegible]ed ≡ 1 month in road (Ruckel, 19[illegible]
- Moisture more i[illegible]an temp. (Lee)
- Uns[illegible]esults in MC<1% (1972)
- [illegible]for equilibrium MC i.e. seal the specimen at desired MC (Jenkins, 1999)
- ….

research needs: a not empirical protocol

Visco-elastic properties of Mix
Beam tests on BSM-foam

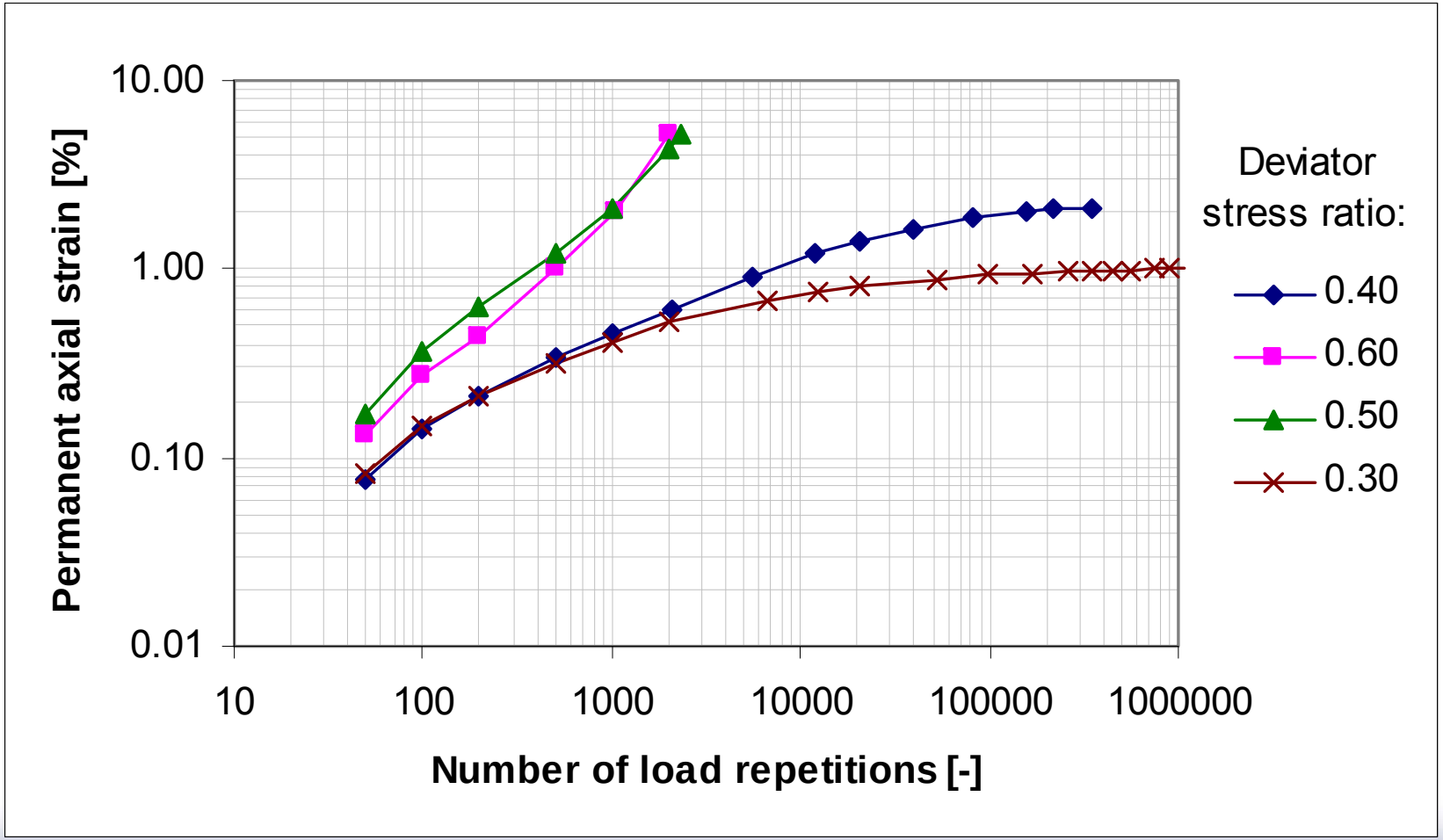
University of Parma



Permanent Deformation Triaxial (No cement)

University of Parma

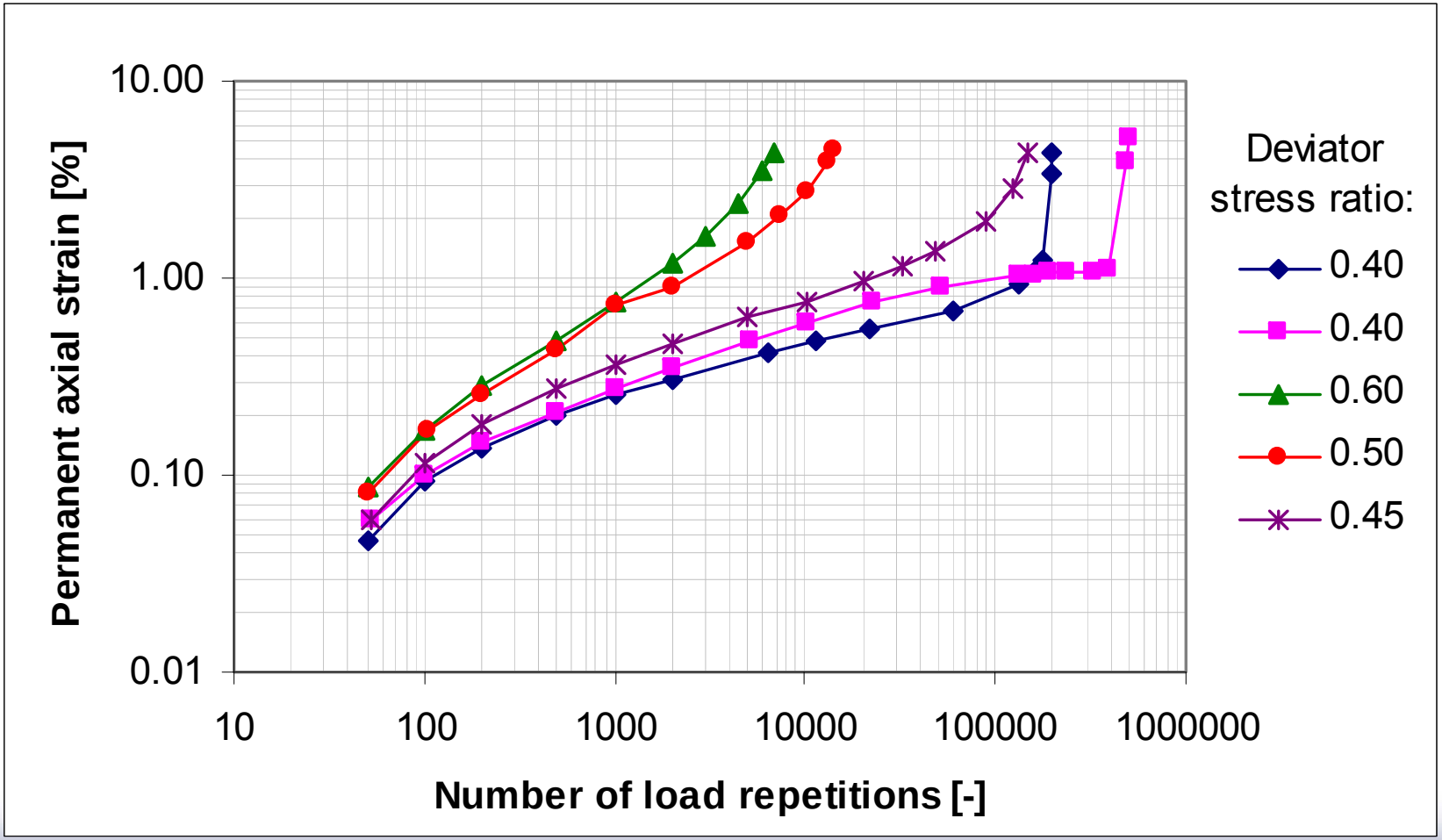
BSM-foam with 25% RAP



Permanent Deformation Triaxial (1% cement)

University of Parma

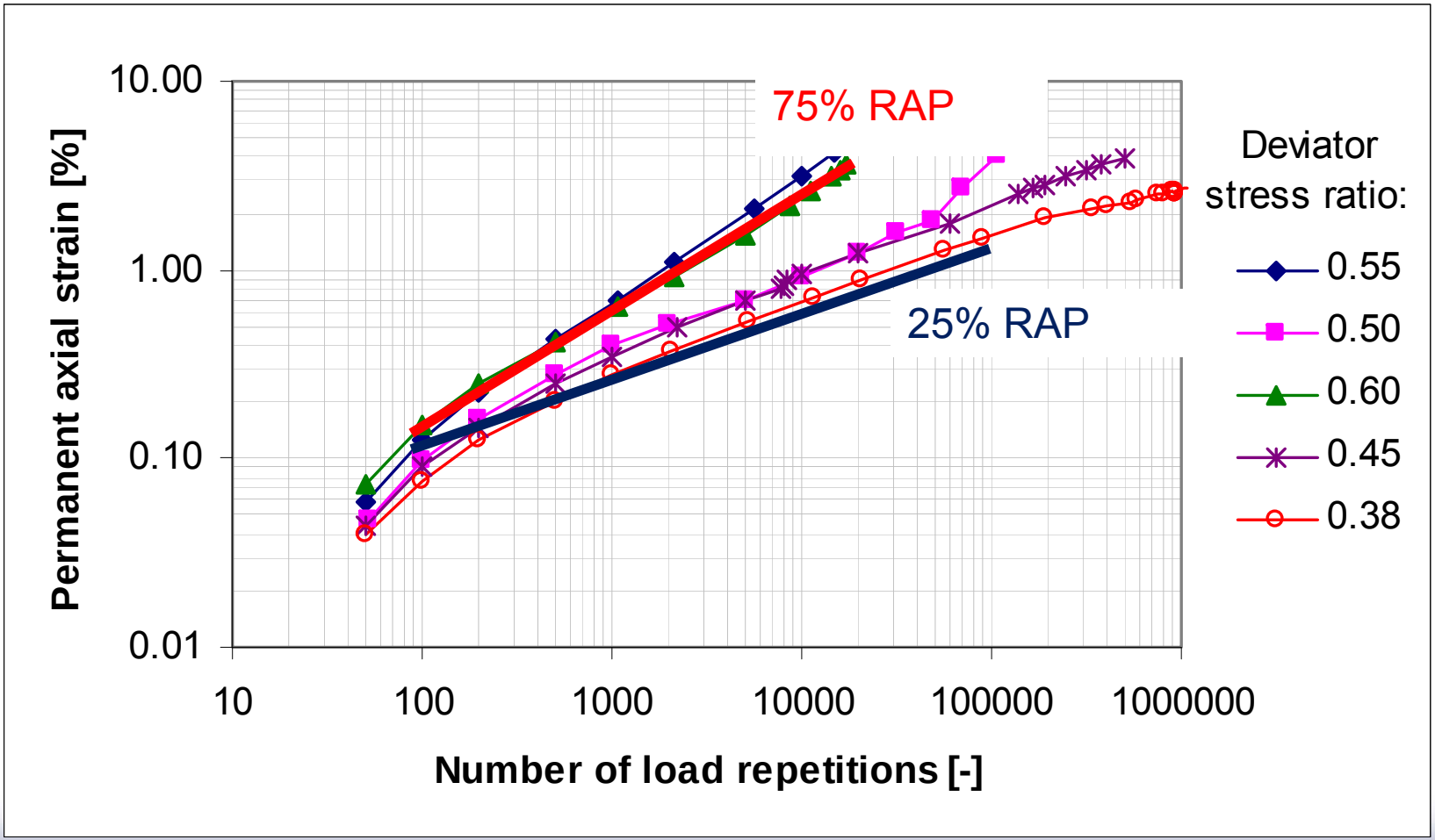
BSM-emulsion with 25% RAP



Permanent Deformation (Triaxial)

University of Parma

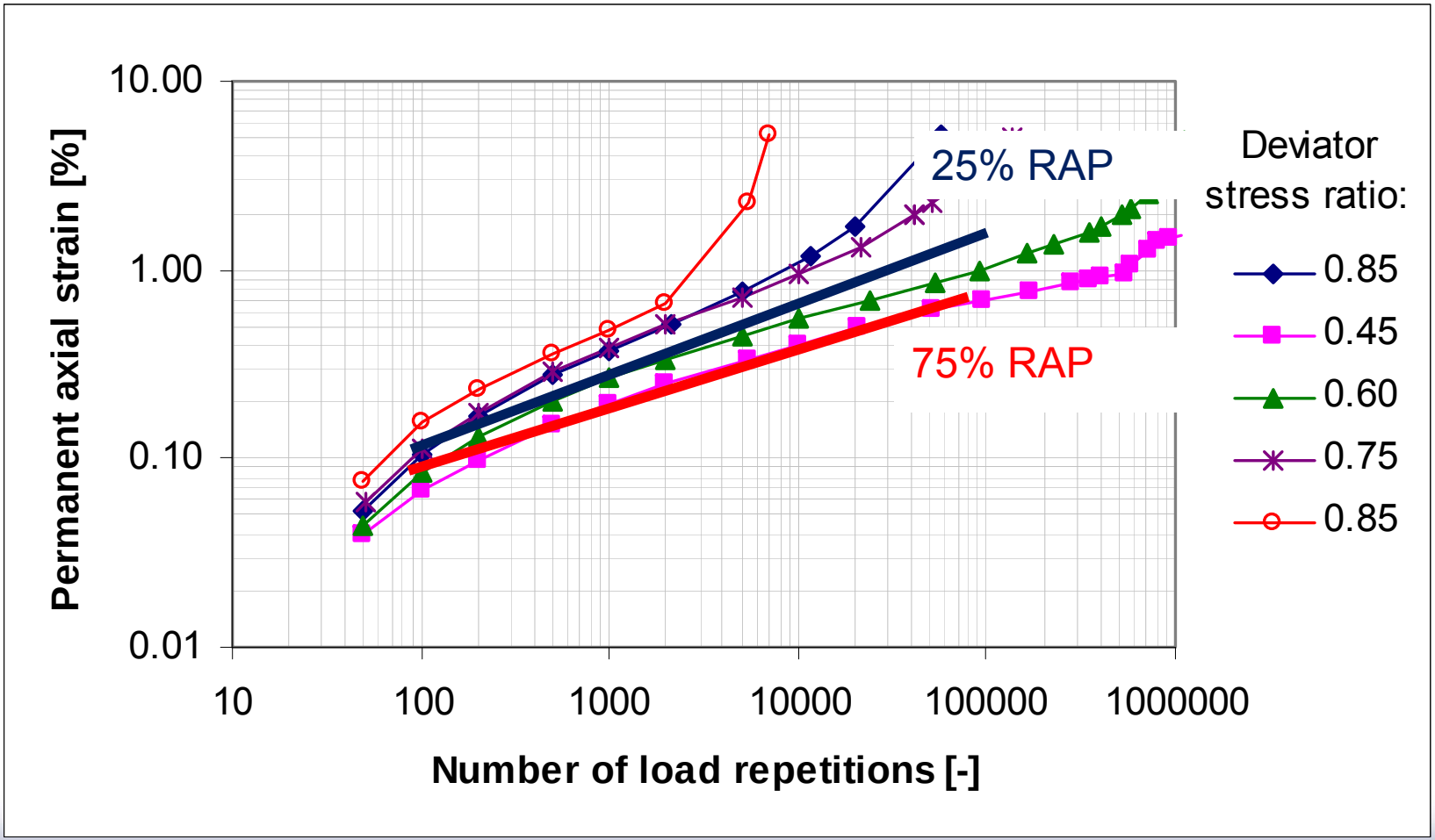
BSM-emulsion with 75% RAP



Permanent Deformation (Triaxial)

University of Parma

BSM-foam with 75% RAP



University of Parma

Rilem Technical Committee SIB

Testing and characterization of sustainable innovative bituminous materials and systems

TG6 – Cold Recycling

Thank you !