CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

CEDR Call 2012: Recycling
International workshop on Recycling
Road construction in a post-fossil fuel society
CTU in Prague • Prague, 24-25 September 2015

CoRePaSol
characterization of advanced cold recycling bitumen stabilized pavement solutions

HARMONIZED ADVANCED MIX DESIGN FOR COLD RECYCLING

Fátima Batista
LNEC LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL

CoRePaSol ● Characterization of advanced cold recycled bitumen stabilized pavement solutions

- Coordinator: Czech Technical University in Prague

- Partners: Uni Kassel Versität; University College Dublin; Laboratório Nacional de Engenharia Civil; Wirtgen Group; Wirtgen

- Main objective:

  Develop and recommend a harmonized advanced mix design procedure for cold recycled bitumen stabilized materials, for application throughout Europe

CoRePaSol ● Characterization of advanced cold recycled bitumen stabilized pavement solutions

- Cold in place recycled mix design approaches and the applied test procedures still vary considerably among European countries
- Lack of a suitable and harmonized mix design procedure
- Identified key points for further investigation
  - > Effect of different existing laboratory **compaction** methods
  - > Influence of different accelerated laboratory **curing** procedures
  - > Suitability of test procedures for **water sensitivity** and other performance related characteristics assessment
  - > Evaluation of different **mix design** approaches and requirements

► Taking into account the **availability of test procedures** in laboratories which are providing their services to road administrators and/or contractors

CoRePaSol ● Characterization of advanced cold recycled bitumen stabilized pavement solutions

WP1 ● Advanced mix design for cold recycled bitumen stabilized materials

Task 1.1	Review on specifications and international literature on mix design, comparison of mix designs applied internationally
Task 1.2	Selection and characterisation of materials
Task 1.3	Comparison of compaction and curing methods
Task 1.4	Cold-recycled mixtures characteristics and performance
Task 1.5	Harmonized advanced mix design procedure

Review on specifications and international literature on mix design, comparison of mix designs applied internationally

- Collection of world wide information about mix design procedures with emphasis in European countries
  - > Questionnaires: common practice on cold recycling, used laboratory test procedures and available standards and legislation
  - > Review of international existing literature (e.g. Wirtgen manual on “Cold Recycling Technology”, 2012) and from recent research projects on the field of cold recycling (e.g. Direct-Mat, Paramix and SCORE projects)
  - > Internal workshop on “mix design” (Munich, April 2013), with the participation of the South African expert Kim Jenkins.

Review on specifications and international literature on mix design, comparison of mix designs applied internationally

Cold-recycling techniques

Country	Type of cold recycling	What structural layers predominately	What is recycled (original structures)	Binders used		Additives used
				primary	secondary	
Czech Republic (Slovakia)	in-situ (90%) in-plant (10%)	• base courses • binder course	• binder and/or base asphalt layers • cement and/or lime stabilized base layers • macadam • granular base layers • soil stabilization	• bituminous emulsion • foamed bitumen • combination with cement	• cement • lime hydrated	Foaming agents or adhesion promoters not used in cold recycling
Finland	in-situ (much): 2-3 mil. m² per year, in-plant (less)	• base courses • binder courses	Asphalt pavements • Class I only hot recycling/remixing applies (over 5 mil. m² per year) • Class II and III	• foamed bitumen • bituminous emulsion	• cement only for increased bearing capacity • Gravel 0-32 mm • Gravel 0-55 mm Depending on fine contents to correct -> to much fines = to much water content	Sometimes fly ashes
France	Mainly in-situ , but also in-plant 2009: It has been planned that in 2012 will be 60% of RAP recycled using cold and hot technologies. *Note: The annual volume of RAP in France is about 5 millions tons.*[1]	• base courses • binder course	• Class I: unbound layers and wearing course < 4 cm • Class II and III: 5-12 cm of asphalt layers (Guide technique SETRA, 2003)	• bituminous emulsion • foamed bitumen	• cement • lime hydrated	Foaming agents sometimes used

(…)

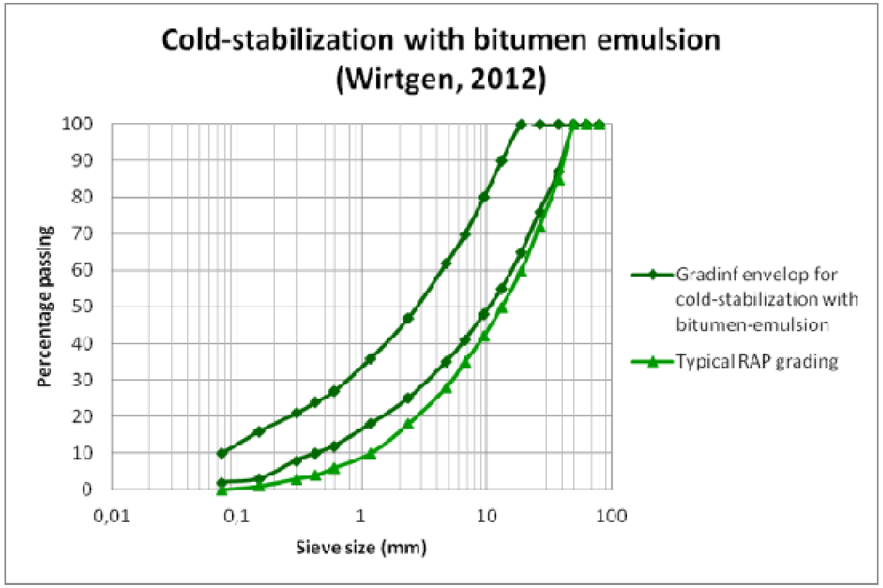
South Africa	in-situ (70 %) in-plant (30 %)	• predominantly base layers	Thin surfacing (asphalt or surface dressing) and high quality granular base	• foam bitumen	• cement • lime hydrated	Generally not used

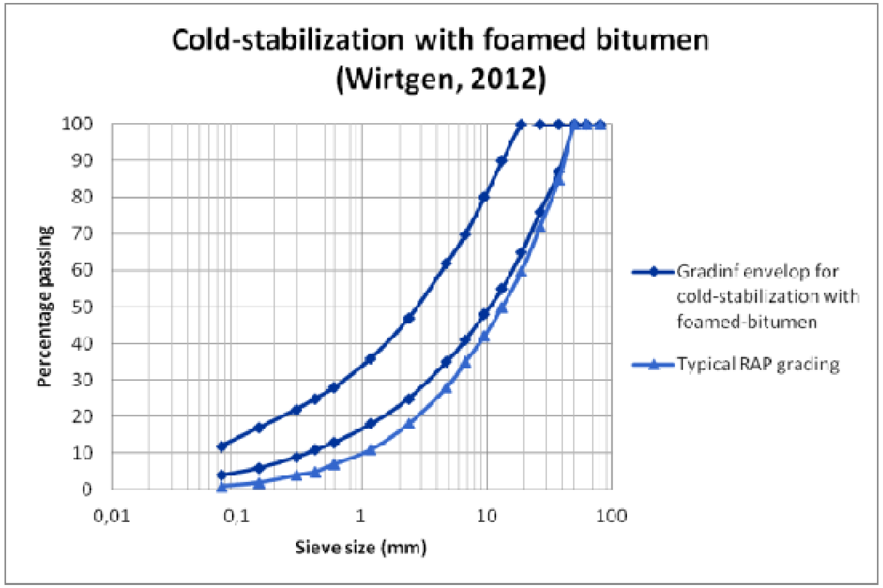
Cold-recycling techniques

- Most countries perform mainly in-situ cold recycling (more flexible, time-saving, more cost-effective)
- Cold recycling is commonly applied to a wide range of pavement layers (from sub-grade material to bituminous surface layers) ► RA can include a wide range of materials (unbound granular layers, cement/lime stabilized materials, asphalt layers)
- The large majority of cold recycled materials are applied in base or binder courses
- Bituminous binders: bituminous emulsion (not used in Finland, Norway & Sweden) and foamed bitumen (not used in Portugal & Spain)
- Secondary binders: cement and hydrated lime (not used in Finland & Sweden); other mineral binders (fly-ash, dust filler especially if containing calcium, slag)
- Corrective materials (currently to adjust the grading curve): natural aggregates (e.g. gravel, filler), other fillers (e.g. cement, lime);
- Some countries reported the use of additives such as foaming agents, adhesion promoters and/or fly ashes.

Materials used and typical compositions • RA/granular mix

- Generally there are requirements for grading of RA / final granular mix composition





- Requirements on RA quality are rather unusual and hardly possible, since this material will be always classified as heterogeneous (effect of milling different layers together, impact of local repairs during the pavement life-time, effect of possible overlays etc.).

Materials used and typical compositions ● Typical binders

- **Bituminous emulsion**: **Slow setting bitumen emulsions** (C60B5) are the most popular, but others can be used (e.g. the use of medium setting bitumen emulsions with modified binders is allowed in Norway)
- **Foamed bitumen:** A **wide range of paving grade binders** (50/70; 70/100; 100/150; 160/220) can usually be used to produce foamed bitumen. **Climatic conditions** have a major influence on the selection of the bitumen (Southern European countries using harder grades and Northern countries softer bituminous binders).
- **Cement:** Majority of countries require **Portland cement** or Portland slag cement (CEM I) to be used in cold recycling. For high cement contents, the use of low resistance cement class (with less heat of hydration) may be recommended in order to minimize the occurrence of shrinkage. As such, it is usual recommended to use 32.5 cement strength class. However, CEM I 32.5 is not marketed or even produced at the present in most countries as Portland cement, being then replaced by 42.5 resistance strength **Portland cements (CEM I 42.5)** or as an alternative **Portland-Limestone cements/Portland slag cement (CEM II 32.5)**.
- **Special hydraulic road binders:** Some countries, such as Czech Republic and Germany, have specifications **for hydraulic road binders** other than cement (e.g. lime or HRBs, with 32.5 or lower resistance class) to be used in road paving construction.

Overview on mix design approaches for cold-recycled bitumen stabilized materials

Materials used and typical compositions ● Binder contents

- Collected information shows a geographical distribution among European countries
  - Central European countries: using bituminous binders combined with **relatively high contents of hydraulic binder (≈ 3 – 5 %)**
  - Southern countries: using only bituminous emulsion or emulsion combined with **low content of hydraulic binders (< 1.5 %)**
  - Some Northern countries don't apply cement at all, since the flexible nature of the pavements with the ability to endure frost heave in winter times require flexible base courses without rigid properties introduced by hydraulic binders.

> The use of bituminous binders together with moderate/high cement contents is related to climatic conditions of ***lower temperatures*** and ***relatively high humidity***, which are favourable for the use of hydraulic binders, combined with the opportunity of using cold recycling for increasing bearing capacity of base/binder layers.

The hydraulic binders are therefore required to use the water in the mixture on their hydration process. Especially in moist regions, the base layers otherwise don't have the possibility to dry and gain their strength.

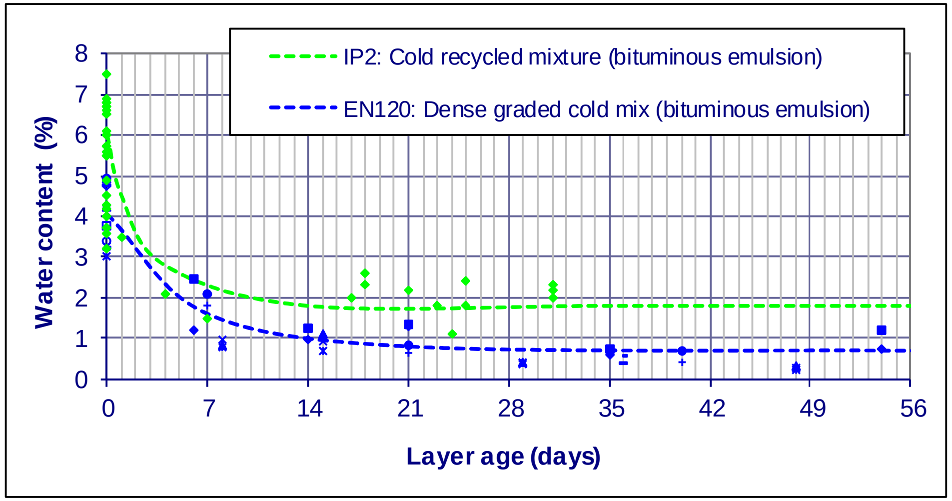
Materials used and typical compositions ● Binder contents

- In ***dryer*** and ***warmer climate*** usually the drying of the cold-recycled layer is allowed, without requiring the use of hydraulic binders

E.g. In-situ cold recycling during the Summer in the south of Portugal, i.e. with favourable weather conditions to promote mix curing

► the water content stabilized around 1-2% about two/four weeks after laying

► no layer should be placed on top during this period in order to allow water to evaporate



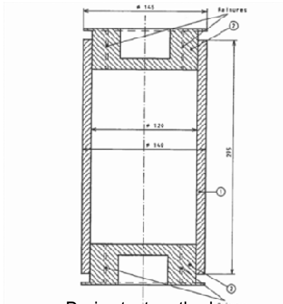
Materials used and typical compositions

- European countries have **different approaches to cold-recycling practices**
- These differences can result from:
  - important differences in **climatic conditions**: e.g. moist regions requiring the use of higher amounts of cement
  - **Geographical and historical reasons**: e.g. recycling of tar enforced the use of higher bituminous binder content in order to ensure a complete coating of the RA
- All these imply different mix design approaches, namely in terms of:
  - Compaction methods
  - Curing procedures
  - Performance evaluation tests

Compaction methods

- Most European countries apply either static or gyratory compaction, due to the important role of hydrostatic pressure
  - **Static compaction** is a relatively quick and simple method used in Czech Republic, France (together with gyratory compaction), Germany, Norway, Portugal, Spain and other European countries
  - **Gyratory compaction** is used in France, Ireland, Norway and Spain

In both type of compactions, the entire set of mould devices should allow for water to drain during load applying.


Duriez test method


Guisado *et al.*, 2011

Nevertheless, these type of compactions are performed in different ways from country to country; e.g. applied load pressure, specimens dimensions, number of revolutions, …

Curing procedures

- There are significant differences between curing procedures across countries, namely:
  - **number of days**: 3-28 days (7 days and 14 days most frequent)
  - **conditioning temperature**: 5 ºC - 50 ºC, passing through temperatures around 20 ºC
  - **conditioning relative humidity**: no requirements / 40 % - 100 % (sealed specimens). The specified curing times of 7, 14 and 28 days seem to be related with common curing times from cement based materials.

These differences are strongly related to **the type & amount of binder** used, as well as to the **climatic conditions of each region**.

Mechanical evaluation: testing conditions & quality characteristics

- The existing practice focuses mainly on:
  - **effect of water on the mixtures** (whether based on indirect tensile tests or compression tests)
  - **strength** (either indirect tensile strength or compression strength)
  - **stiffness** (repeated indirect tensile tests)

  Even though the mechanical type of testing could be the same, the obtained results can vary significantly depending on the test conditions applied (temperature, loading rate) as well as regarding the specimen preparation procedures as compaction, curing and conditioning.

Experimental studies

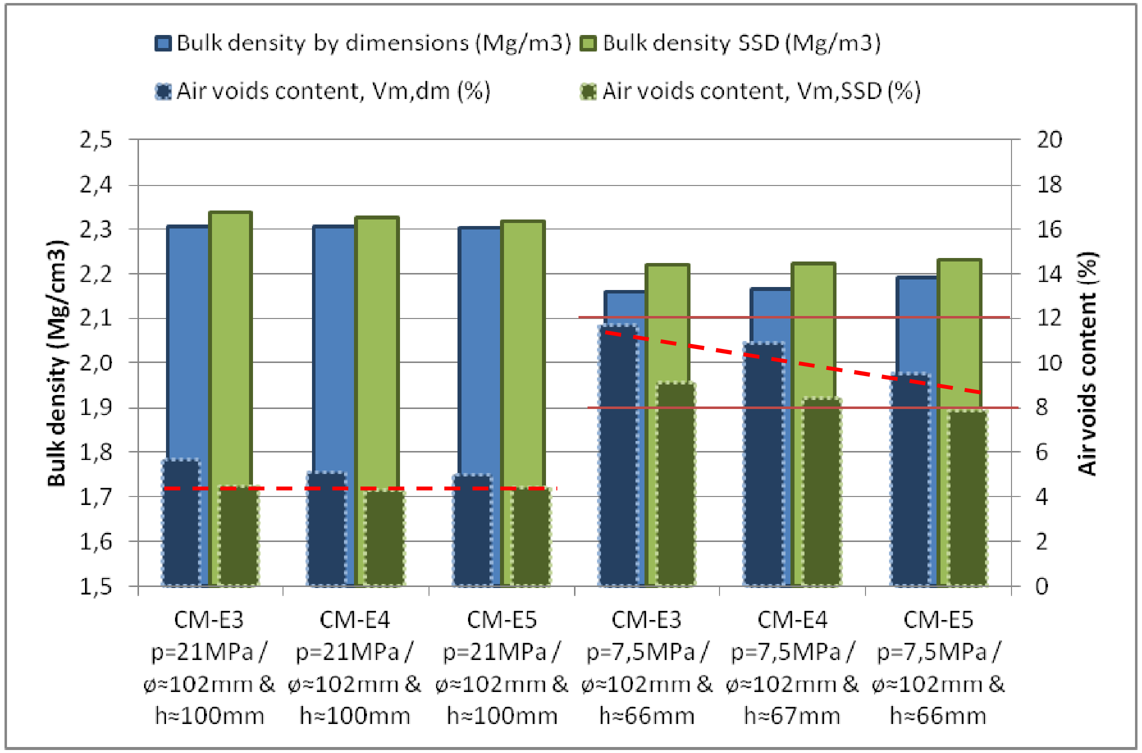
In order to evaluate the importance of the differences founds, an extended experimental program was performed, addressing the following key aspects:

- Comparison of compaction methods: Static, gyratory, impact (Marshall) and Proctor compaction
- Evaluation of curing methods, namely in terms of time, temperature and moisture:
  - on mixtures with emulsion and foamed bitumen, no cement or small amounts of cement (<1.5 %) acting as a reactive filler
  - on mixtures with bituminous binder and cement (≥1.5 %)
- Assessment of cold recycled mixture characteristics and performance

Test specimens characteristics prepared using different **compaction methods**

Experimental study A1

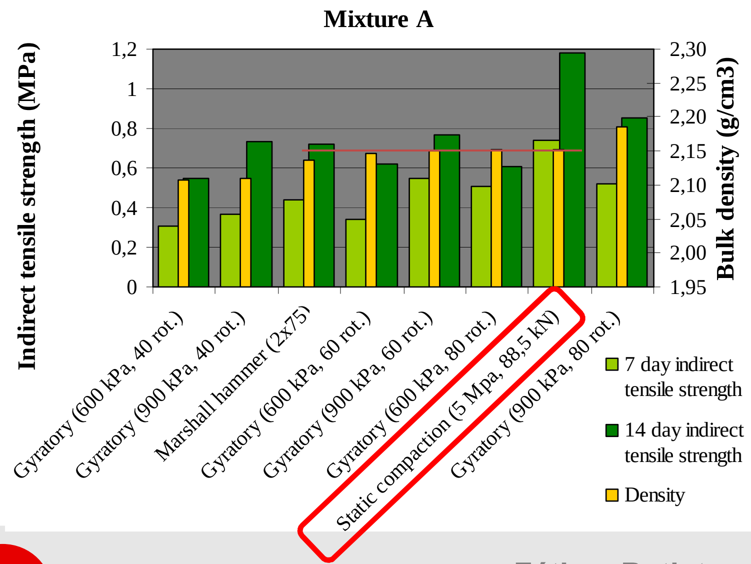
- Main objective: Evaluate the influence of applying a static compaction based on ASTM D 1074 / NLT 161 standards, using the standard (21 MPa) or reduced (7.5 MPa) load pressure
- Used binder(s): Bituminous emulsion with or without small amounts of cement

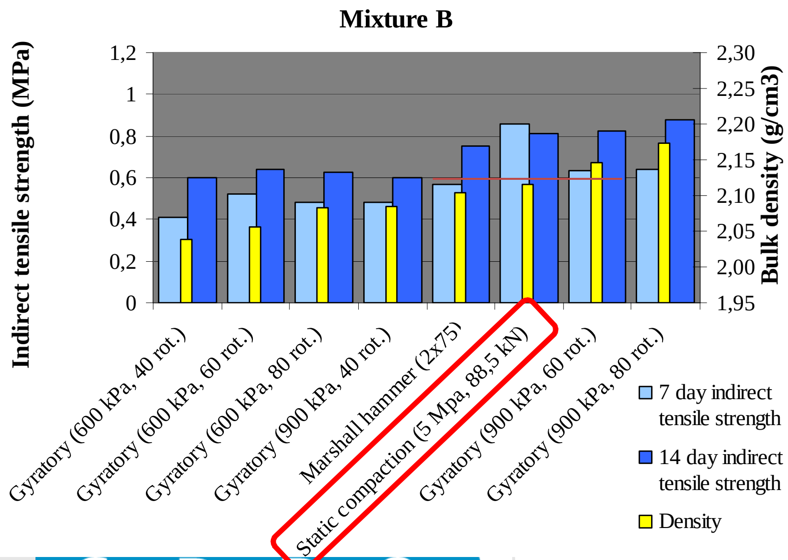


Test specimens characteristics prepared using different **compaction methods**

Experimental study A2

- Main objective: Assess characteristics of test specimens compacted by impact method (Marshall compaction) and by gyratory compactor. In this case, different vertical pressures (600 kPa and 900 kPa) combined with varying revolutions (40, 60 and 80 revolutions)
- Used binder(s): Bituminous emulsion (3.5%) or foamed bitumen (4.5%) + high amounts of cement (3%)





Test specimens characteristics prepared using different **compaction methods**

Experimental study A2

Standard deviation σ_R – Bulk density (g/cm³)			
Specimen compaction		Mix A (produced with 3.5% bituminous emulsion)	Mix B (produced with 4.5% foamed bitumen)
Marshall hammer	2 x 75 blows	**0.020**	**0.043**
Gyratory compactor 600 kPa	40 revolutions	0.015	0.021
	60 revolutions.	0.008	0.022
	80 revolutions	0.008	0.015
Gyratory compactor 900 kPa	40 revolutions	0.011	0.014
	60 revolutions	0.019	0.011
	80 revolutions	0.004	0.007
Static pressure	5 MPa	0.008	0.019
Requirements on conformity according to DIN 1996 7:1992 (for SSD)		0.008 – 0.028	

Test specimens characteristics prepared using different **compaction methods**

Experimental study A3

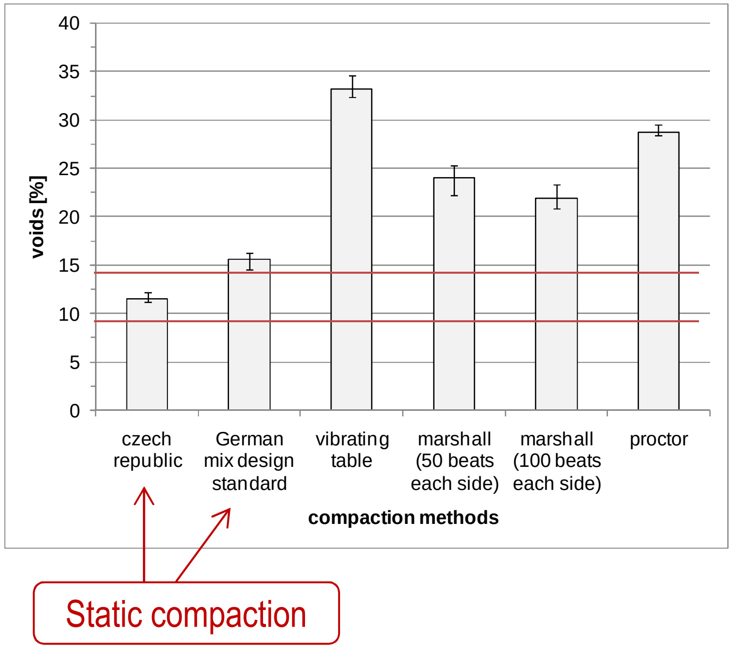
- Main objective: Evaluation of the influence of the compaction method on resulting voids content (vm) and indirect tensile strength (ITS) on specimens prepared using different compactions (Marshall compaction, Proctor compaction, static compaction and compaction using a vibrating table)
- Used binder(s): Bituminous emulsion (4%) or foamed bitumen (4%), and moderate amount of cement (2%)

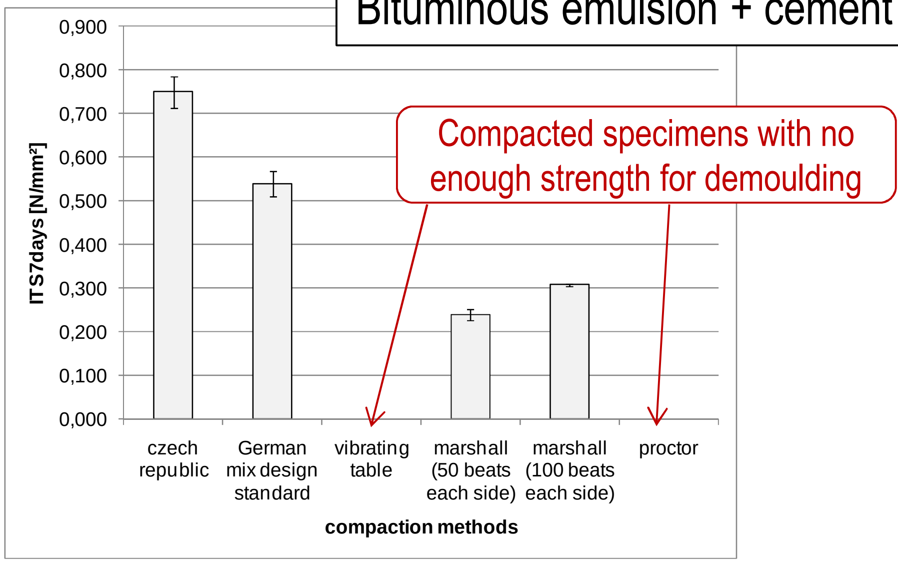
Compaction method	Standard	Characteristic	Curing methods and results
Marshall compaction	DIN EN 12697-30 (TP Asphalt-StB, part 30)	50 and 100 beats each side, dynamic, Ø = 100 mm	Room conditions 7 days, afterwards testing $ITS_{7,dry}$, void content
Vibrating table	DIN EN 13286-5	Vibration f = 50 Hz, t = 3 min each side, load on top 10.4 kg, Ø = 100 mm	
Static compaction	Czech Mix Design standard	5.0 N/mm², Ø = 100 mm	
	German Mix Design standard (M KRC)	2.8 N/mm², Ø = 100 mm	
Proctor compaction	DIN EN 13286-2	RA mixture is filled in 3 layers in forms, 22 beats each layer for compacting, Ø 150 mm	Void content in compaction form

Test specimens characteristics prepared using different **compaction methods**

Experimental study A3

Bituminous emulsion + cement mix





Cold recycled mixture characteristics and performance, considering the effect of different **curing procedures**

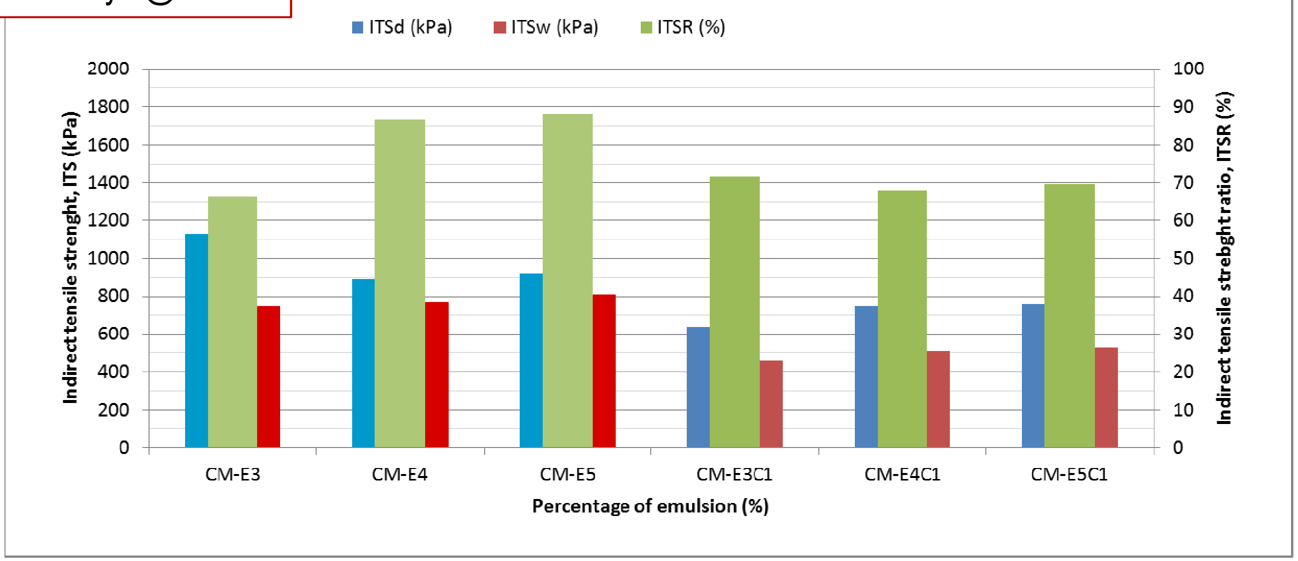
Experimental study B1 & B2

- Main objective: Assessment of water sensitivity & other performance related properties of cold recycled mixtures compacted, cured and conditioned by different procedures
- Used binder(s): Bituminous emulsion without cement or with small/moderate amounts of cement (1-2 %)

Cylindrical specimens: ø ≈ 102 mm, h ≈ 66 mm
Static compaction: p = 7,5 MPa
Curing: 1 day in the mould @ 20 ºC + 3 days @ 50 ºC

- Even 1% cement has influence on the mixture curing/strengthening
- Water sensitivity tests (EN 12697-12) are suitable for distinguishing the performance of different mixes. However, besides minimum ITSR values, also minimum ITSw values should be required

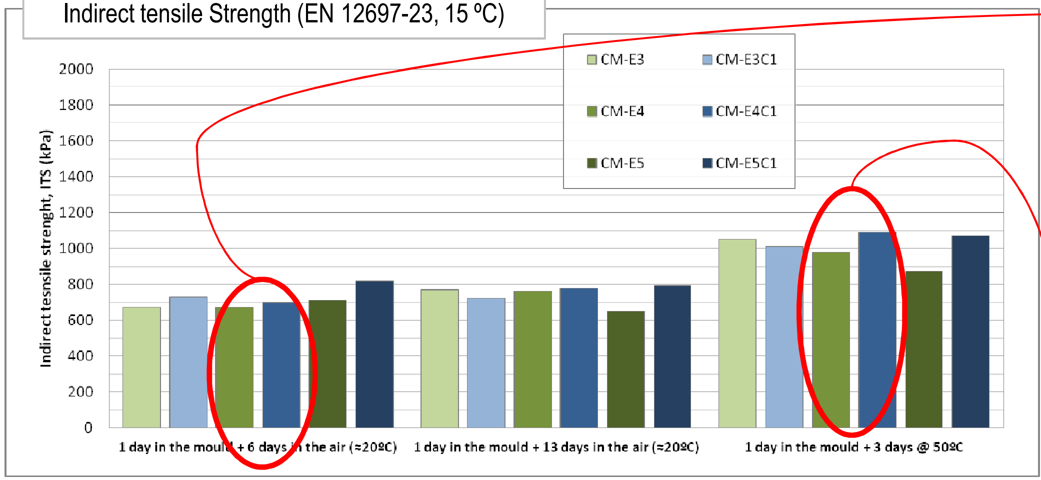
Water sensitivity (EN 12697-12, method A: ITT, 15ºC)



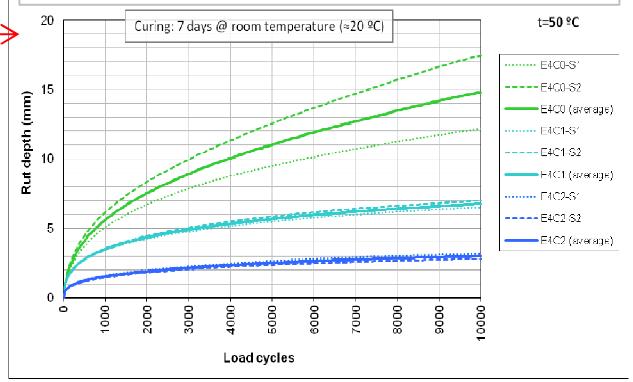
Cold recycled mixture characteristics and performance, considering the effect of different **curing procedures**

Experimental study B1 & B2

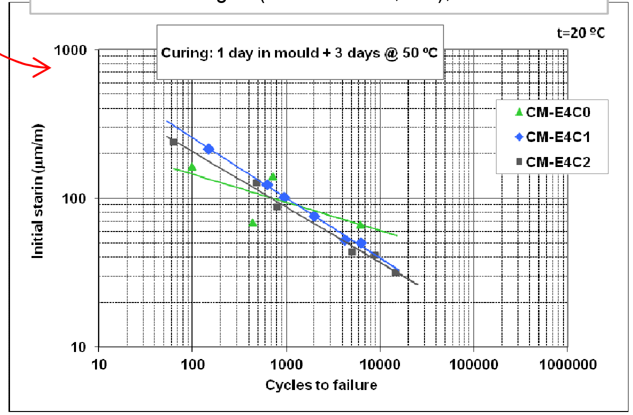
Indirect tensile Strength (EN 12697-23, 15 ºC)



Resistance to permanent deformation (EN 12697-22, WT)



Resistance to fatigue (EN 12697-24, ITT); E≈3700MPa



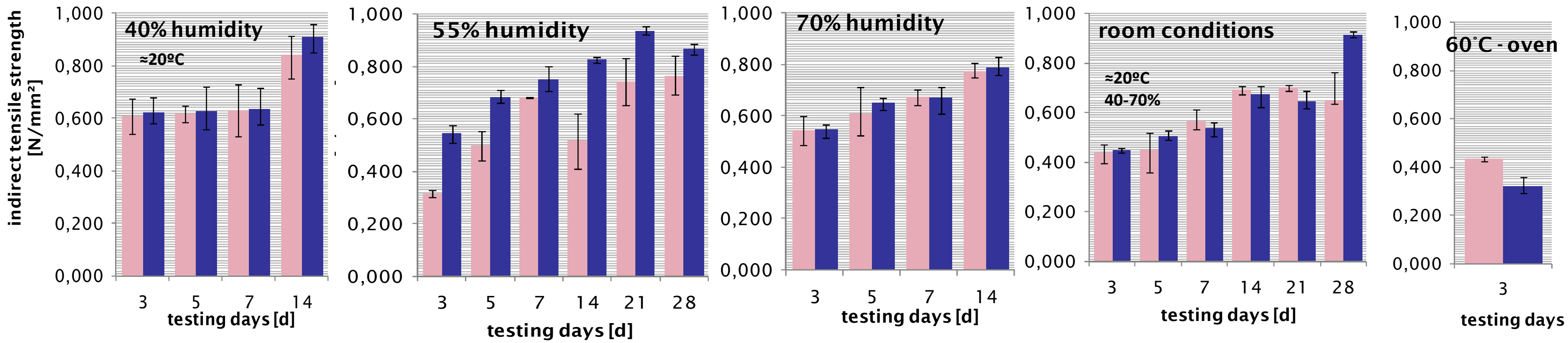
- In general, emulsion mixes increase their ITS values from earlier to later ages of curing at room temperature (7 to 14 days).
- Emulsion mixtures with 1 % of cement showed similar ITS values for 7 & 14 days of curing ▶ even small amounts of cement (which require relatively long periods of hydration in order to get strength), may change the process of curing of cold stabilized mixtures
- All mixes registered higher ITS values after accelerated curing.

Cold recycled mixture characteristics and performance, considering the effect of different **curing procedures**

Experimental study B3

- Main objective: Assessment of strength (ITS) and stiffness modulus of specimens cured at different conditions
- Used binder(s): Bituminous emulsion (3.5%) or foamed bitumen (4.5%) + high amounts of cement (3%)

foam bitumen
emulsion
+ 3% cement + added water (4%/2.5%)



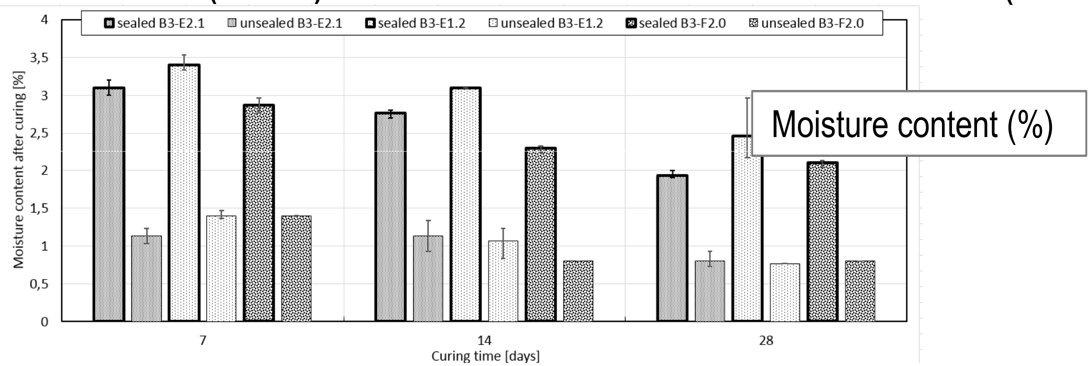
> The results show small sensitivity to the humidity conditions, probably because the water contents in the mixtures is enough for the hydration of the cement

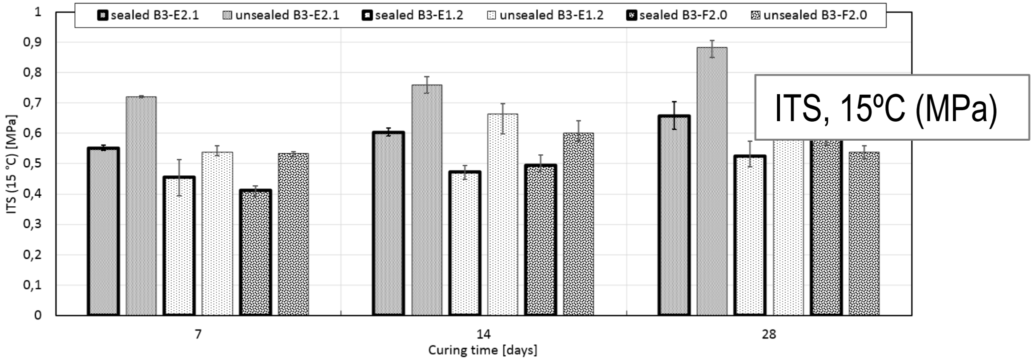
> For these materials no apparent benefits are obtained from the raise of temperature during 3 days

Cold recycled mixture characteristics and performance, considering the effect of different **curing procedures**

Experimental study B4

- Main objective: Assessment of moisture during specimen curing for cold recycling
- Used binder(s): Bituminous emulsion (2.0/3.5%), foamed bitumen (2.0%) and intermediate content of cement (1.5 %)





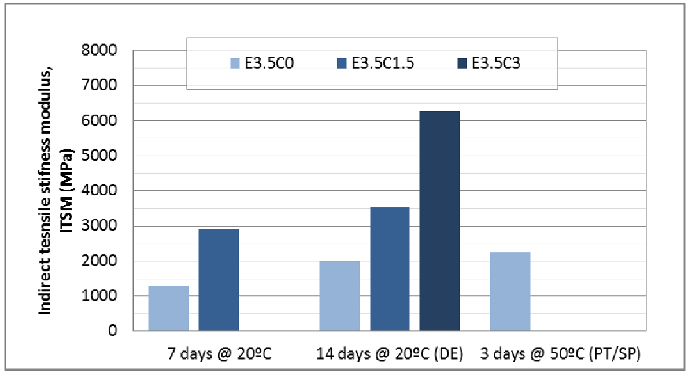
> Sealing specimens may lead to a decrease in ITS values, probably due to a longer curing of the bituminous binder ► for higher cement contents better results are expected

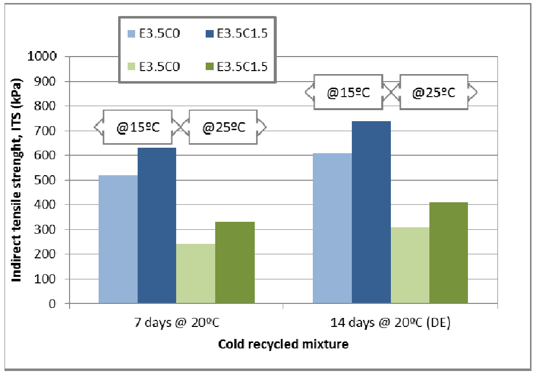
> In extreme severe moisture conditions (sealed specimens over long periods) it is necessary to add higher cement contents in order to reach similar strength levels

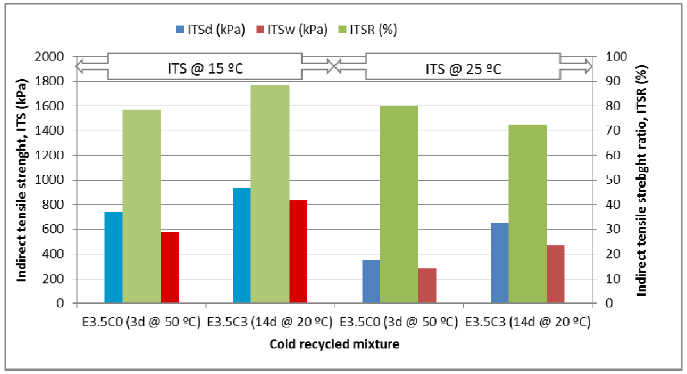
Cold recycled mixture characteristics and performance, considering the effect of different **curing procedures**

Experimental study B7

- Main objective: Investigation of relation between cement content, curing regime and test temperature on the recycled cold emulsion material mix properties
- Used binder(s): Bituminous emulsion (3.5%) with varying cement contents (0, 1.5 & 3.0%)







> The mix with 3% cement was considerably stiffer than the other materials, and the impact of this should be considered.

> Both mixtures with and without cement showed good ITSR values, at and over 80%.

> ITS results showed increase in material strength with: increase of curing period (7 – 14 days); decrease of the test temperature (25°C – 15°C); inclusion of cement in the mix.

Cold recycled mixture characteristics and performance, considering the effect of different **curing procedures**

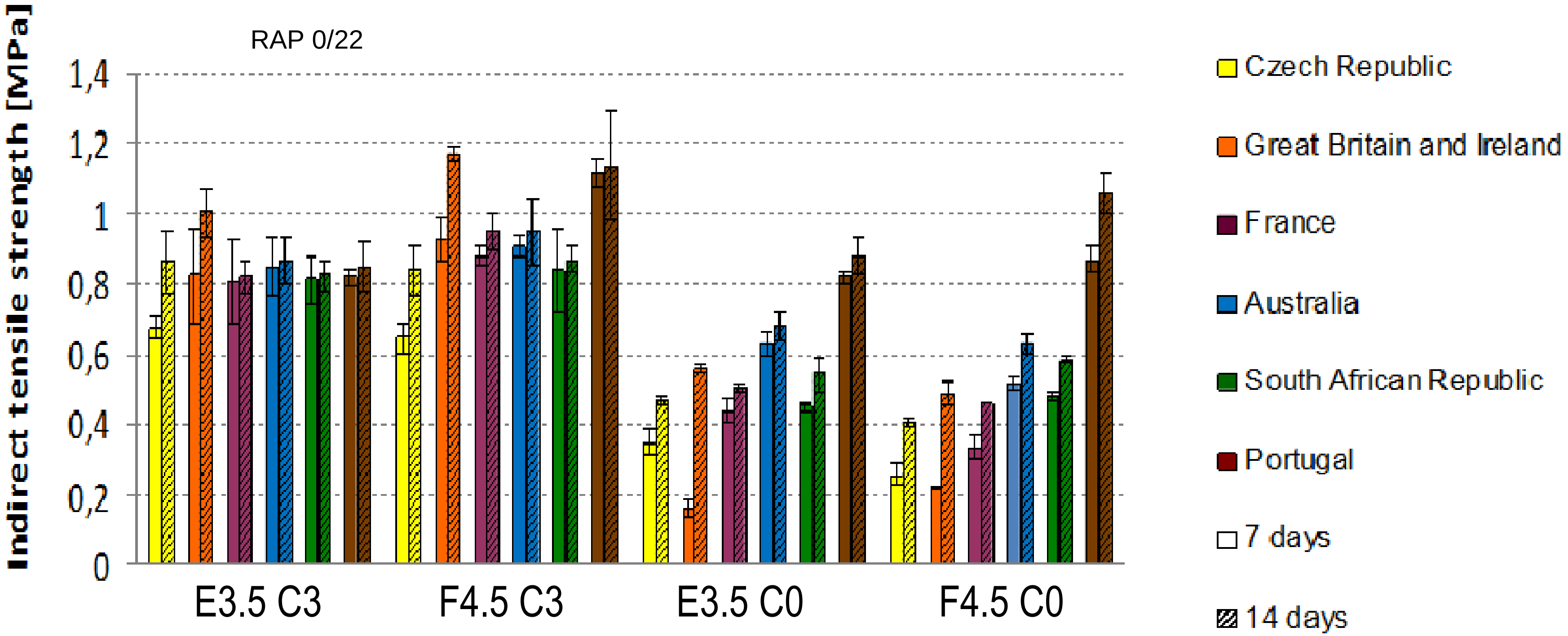
Experimental study B8

- Main objective: Evaluation of the impact of different curing procedures on strength and stiffness of cold recycled mixes using foamed bitumen, bituminous emulsion or combination with cement
- Used binder(s): Bituminous emulsion (3.5%) or foamed bitumen (4.5%), without cement or with high amount of cement (3%)

Country	BSM – Bitumen stabilized materials	BCSM - Bitumen cement stabilized materials
Czech Republic	28 days: air curing at 20°C	2 days: 90% humidity at 20°C + 26 days: 40-70% moisture at 20 °C
Finland	28 days: air curing at room conditions	28 days: 95 % humidity, 20 °C
Germany		2 days: 90% humidity at 20°C + 26 days: 40-70% moisture at 20 °C
Ireland	28 days: 20 °C	28 days: 40 °C
Norway	14 days at 95 % humidity at 5 °C	
Portugal / Spain	3 days at 50 °C	7 days at room conditions

Cold recycled mixture characteristics and performance, considering the effect of different **curing procedures**

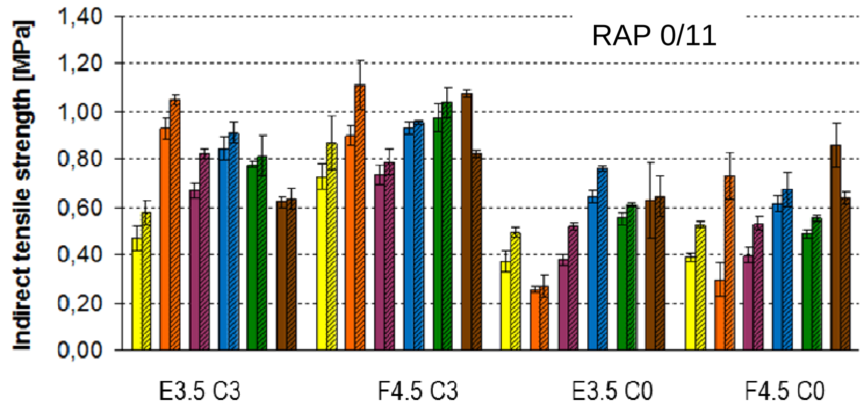
Experimental study B8



Cold recycled mixture characteristics and performance, considering the effect of different **curing procedures**

Experimental study B8

> Curing procedures in each country are strongly related with **the type of cold recycled mixtures (type & amount of binder)** commonly applied and with its **climate conditions**



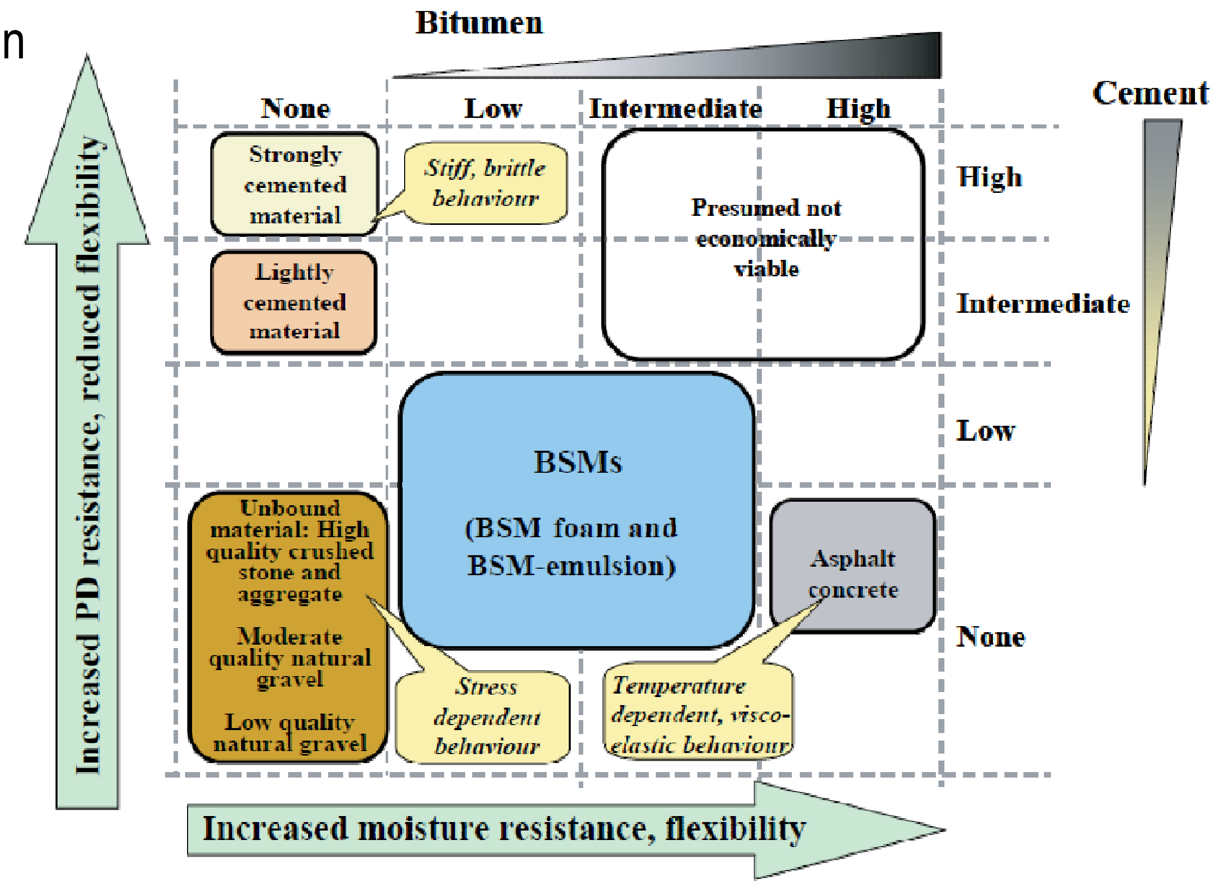
> As expected, mixtures with cement show higher values of strength for the different curing procedures, with exceptions when accelerated curing using relatively high temperature (3 days @ 50ºC) is applied.

Advanced mix design for cold recycled bitumen stabilized materials

General conclusions / Discussion

Types of cold recycling materials

- Effect of variation of bitumen and cement content on the mechanical properties



[Collings *et al.*, 2009]

Advanced mix design for cold recycled bitumen stabilized materials

General conclusions / Discussion

Types of cold recycling materials

- Types of cold recycled materials according to content of bituminous and mineral binders

Cold recycling material: Definition	acronym	Content of (residual) added bitumen	Content of mineral binder
Unbound	U	0 %	0 %
Cement stabilization	CS	0 %	1 to 6 %
Lean concrete	LC	0 %	≥ 6 %
Bitumen-stabilised material	BSM	1 to 3 %	≤ 1 %
Bitumen-cement-stabilised material	BCSM	1 to 3 %	1 to 3 %
Cold asphalt mix	CAM	≥ 3 %	0 %
Sealing cold recycled material (e.g. Sealing of tar in Germany)	SCRM	3 to 6 %	1 to 6 %

Advanced mix design for cold recycled bitumen stabilized materials

General conclusions / Discussion

Mix design principles

- Taking into account the various national specification documents for cold recycling materials, the following 6 steps for mix design are proposed:

Step 1:

> Analysis of reclaimed road materials for suitability as mix granulate: aggregate grading, bitumen content, natural water content.
>
> Regarding the grading requirements of the mix granulate following threshold values shall be applied:
>
> - content of fines (< 0.063 mm): 4 – 10 %
> - content of fine aggregates (< 2 mm): 15 % – 40 %

Advanced mix design for cold recycled bitumen stabilized materials

General conclusions / Discussion

Mix design principles

Step 2:

> Choice of binders (bitumen emulsion, mineral binder type, foamed bitumen) and optimisation of foam bitumen.

Step 3:

> Evaluation of optimum compaction water content and reference density.

The application of modified Proctor test is the most applied procedure internationally. However, some shortcomings are sometimes reported ► An alternative compaction method (e.g. Gyratory/static) might to be more feasible for conducting tests for evaluating optimum compaction water content and reference density

Advanced mix design for cold recycled bitumen stabilized materials

General conclusions / Discussion

Mix design principles

Step 4:

> Mix preparation and specimen compaction.

After mixing the cold recycled material in laboratory, specimens need to be compacted. Adequate compaction procedures identified are:

- **Gyratory compaction** according to EN 12697-31 (adapted to cold mixtures: e.g. perforated moulds, no need of heating materials)
- **Static compaction** with double-plunger and a compaction stress of **5,0 – 7,5 MPa**, depending on the type of equipment / method of applying the static load (e.g. loading rate).

In this case a **new compaction standard** needs to be drafted.

Advanced mix design for cold recycled bitumen stabilized materials

General conclusions / Discussion

Mix design principles

Step 5:

> Curing of specimens

For **simulating site-development** of the mix behaviour (strength, deformability,…), suitable laboratory curing procedures are required. From the laboratory comparisons following curing methods are recommended for specimens **demoulded 1 day after compaction**:

- for BSM (cement content < 1 %): curing of unsealed specimen at 50°C for 3 days,
- for CBSM and SCRM (cement content ≥ 1 %): curing of unsealed specimens at room conditions for 14 days

Advanced mix design for cold recycled bitumen stabilized materials

General conclusions / Discussion

Mix design principles

Step 6:

> Mechanical tests

The forward mechanical properties shall be assessed:

- **indirect tensile strength**
- **moisture susceptibility**

Depending on the type of mixtures and the specific requirements of the road (e.g. traffic level,…), other performance evaluation tests can be important (stiffness modulus, permanent deformation, …)

Advanced mix design for cold recycled bitumen stabilized materials

General conclusions / Discussion

Mix design principles

Step 6:

Furthermore following recommendations regarding the applicability of various cold recycling materials can be made:

- **Bitumen stabilized materials (cement content < 1 %):**
  - applicable with foamed bitumen for flexible pavements in cold climate,
  - applicable with bitumen emulsion in dry climate,
  - not applicable with bitumen emulsion in moist climate.
- **Bitumen-cement stabilized materials (cement content > 1 %):**
  - applicable for moist climate,
  - adequate for high early-life strength/ bearing capacity

Advanced mix design for cold recycled bitumen stabilized materials

General conclusions / Discussion

Mix design principles: Step 1 to 6

> Within these steps the variety of test methods and parameters shall be reduced in order to allow future comparisons of gained experiences

These will allow for a future harmonized specification on cold recycled mixtures!