Mix designs for cold recycled pavement materials considering local weather and traffic conditions

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ABSTRACT

Cold recycling is a road rehabilitation procedure/technique, where the reclaimed road material from rehabilitated pavements is recycled completely and used in the new structure with only small contents of new road materials. This is done preferably in-situ to save time, costs and environment. However, internationally various mix design procedures were developed since decades resulting in diverse contents of bituminous binders (emulsion or foamed bitumen) and/or mineral binders (cement or hydraulic road binder). The different material compositions result in diverse mechanical material properties and demand for different pavement designs.

Based on an international comparison of cold recycling experience, commons and differences were elaborated during European CoRePaSol project funded by the CEDR. The existing definitions of various cold recycled materials were assessed and supplemented in order to introduce clear material definitions in future European specification documents. Based on intensive test campaigns suitable assessment procedures are proposed to address these materials. At the same time based on local traffic and weather conditions as well as availability of source materials, a decision model is proposed for choosing the optimum cold recycling material for the given rehabilitation project.

Keywords: Design Mix, In-situ Recycling, Performance testing, Reclaimed asphalt pavement (RAP) Recycling

1. INTRODUCTION

The construction of new pavements as well as the maintenance and rehabilitation of existing roads consumes vast amounts of natural resources (i. e. natural aggregates, bitumen). At the same time old pavement layers are milled or demolished and have to be handled as construction waste. Asphalt pavements have a high ability for reuse and recycling. The reuse of reclaimed asphalt in new hot-mix asphalt is the recycling option with highest value, if mixing plants are equipped with the required auxiliary in order to add reclaimed asphalt to new hot mixtures. However, because of long hauling distances between construction site and a mixing plant, cold recycling of the reclaimed road materials is an environmentally and economically feasible alternative for hot recycling.

Cold recycled asphalt materials are pavement materials composed of reclaimed pavement granulates and natural aggregates, bituminous and/or mineral binder which are mixed, paved and compacted at ambient temperatures. Cold recycling is widely applied worldwide as well as within Europe, and wide practical as well as theoretical experience is available. However, these experiences are mostly focussed on selected types of cold recycled materials and are based on local application conditions, and therefore the understanding of these materials, their actual composition as well as applied mix design and construction procedures and aims vary considerably within Europe.

According to the European construction products regulation (CPR) harmonised mix design specifications are required for enabling the trade of any construction product, and is also necessary for cold recycled pavement materials which are produced in plants and transported to the construction site. For cold recycled materials, two options are available. Both plant mixing and in-situ mixing procedures are commonly used, but for the latter case there is no requirement for a harmonised European approach. However, as the mix design procedures applied are more or less the same for in-plant and in-situ cold recycled pavement materials, a harmonised approach would benefit all cold recycling techniques.

2. TYPES OF COLD RECYCLED MATERIALS

The term “cold recycled materials” defines a pavement material which is composed of high proportions of reclaimed asphalt pavement materials, as well as added binders; this is then produced, paved and compacted at ambient ‘cold’ temperature. As bituminous binders either bitumen emulsion or foamed bitumen are applied. Mineral binders, such as cement, are generally applied as ‘active filler’ for influencing the early-life properties of the cold recycled materials and/or as binding agents, resulting in more rigid mixes. In order to further classify these types of materials, the content of residual bitumen (bitumen content after breaking of bituminous emulsion) and mineral binder were used [1, 2]. As depicted in Figure 1, the resulting material properties depend on the content of bituminous and mineral binder applied and will finally be a synopsis of the extreme materials:

- without bituminous and mineral binder: unbound base layer material with stress-dependent plastic deformation behaviour; the failure mode is rutting/settling resulting in permanent deformations,
- without mineral binder and high bituminous binder content: asphalt concrete with time-temperature dependency, viscoelastic properties; the failure modes are permanent viscoplastic deformations and fatigue cracking,
- without bituminous binder and high content of mineral binder: brittle, rigid and elastic properties; failure mode is cracking (shrinkage, fatigue).

The actual material performance of the cold recycled material depends on the actual mix of bituminous and mineral binders and therefore the relevant failure mode can be unbound asphalt and/or cement-concrete-specific.

In order to evaluate which binder contents are utilised within Europe, the case study database developed in Direct-Mat project [3] was analysed. Figure 2 identifies the contents of bituminous and mineral binders of the cold recycling case studies included in the database. The wide range of bitumen and cement content clearly shows the wide variety of different materials and concepts covered by the term “cold recycled material”. Two groups of materials can be selected from the case studies:

- Emulsion bitumen-stabilised materials (BSM) with little or no cement and a residual bitumen content of 1 % to 3 % as applied in case studies in Portugal, Spain and Sweden;
- Emulsion or foamed bitumen-cement-stabilised materials (BCSM) with residual bitumen contents of 2.5 % to 3.5 % and cement contents between 1.5 % and 4.0 % as applied in France, Germany, Poland, Portugal, and Slovenia. It was later found in CoRePaSol project, that other central/eastern European countries, such as Czech Republic also use this cold-recycled material.

Reference must also be made to a single cold asphalt case study in Denmark (bitumen residue > 5 %) which was not successful.

From the case studies identified other factors besides climatic conditions seem to play an important influence on the choice of binder’s type and amount. Examples of other factors are: available recycling equipments (for instance, countries where specific devices for the production of foamed bitumen were not available for many years didn’t apply this bituminous binder in cold recycling); type of reclaimed asphalt (for instance, countries where there is a need for tar recycling, typically high amounts of bitumen emulsion are used as binder to perform this type of recycling).

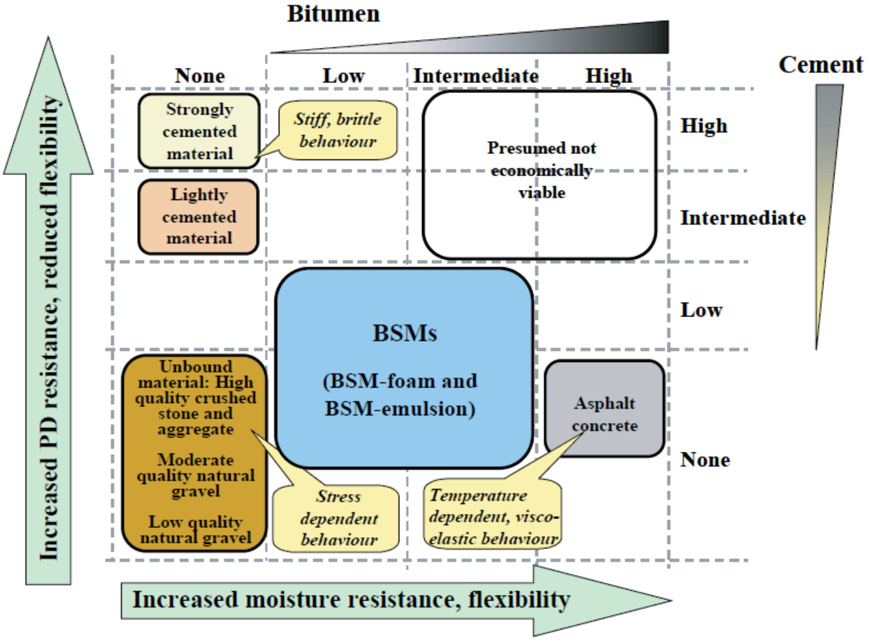

Figure 1: Conceptual behaviour of pavement materials [1]

For further evaluation of the European practices in cold recycling, the national specification documents were analysed. The ranges of binder contents as specified for various types of cold recycling materials are plotted in Figure 2. Again, some common material specifications can be found which are strongly related to different types of cold recycled material, which in turn seem to be related to geographical/historical factors in addition to the climatic conditions of each region.

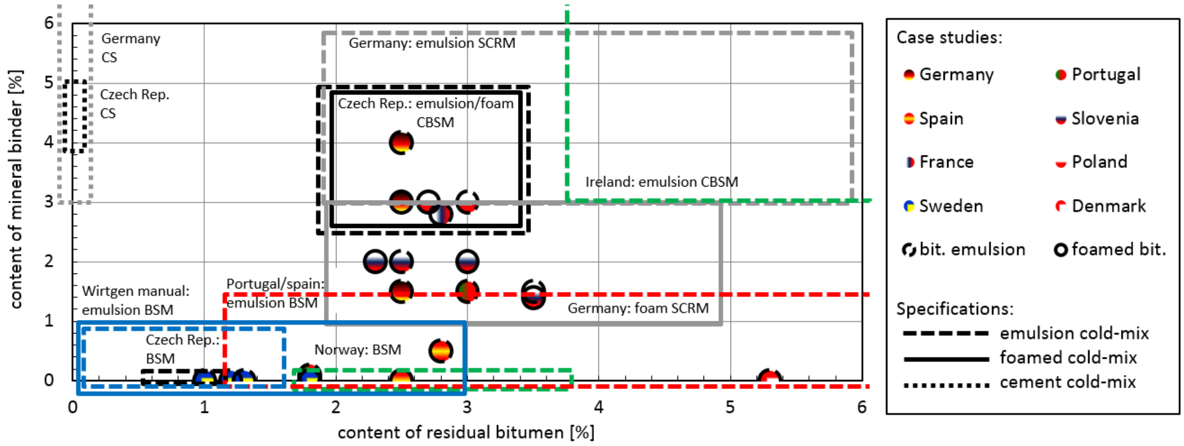

Figure 2: Binder contents of cold recycling case studies gathered during Direct-Mat project and binder content ranges of selected national cold recycling specifications

Grilli *et al*. [2] classified specific cold-recycling materials regarding the binder contents. The defined materials are further supplemented by cold recycled materials applied in Germany for the recycling of tar-contaminated road materials; these need to be sealed in the new pavement and therefore demand increased content of bituminous binders. Therefore, Table 1 summarises the different types of cold recycled materials according to their content of (residual) bitumen and mineral binder.

Table 1: 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	SCRM	3 to 6 %	1 to 6 %

3. MIX DESIGN PRINCIPLES

The various national specification documents for cold recycled materials prescribe a mix design methodology based on several steps of laboratory tests.

Step 1: Analysis of reclaimed road materials for suitability as mix granulate: aggregate grading, bitumen content, natural water content;
Step 2: Choice of binders (bitumen emulsion/foamed bitumen, mineral binder type) and optimisation of foam bitumen, if required;
Step 3: Evaluation of optimum compaction water content and reference density;
Step 4: Mix preparation and specimen compaction;
Step 5: Curing of specimens;
Step 6: Mechanical tests.

Whereas the general mix design outline is similar between the national specification documents, it was observed that differences in the applied test methods and conditions can occur.

3.1 Mix-design-step 1: Analysis of reclaimed road materials

The new cold recycled mix usually contains more than 90 % of the recovered material from the existing road. Therefore, the evaluation of the characteristics of the reclaimed material is a fundamental issue for the whole mix design process. Firstly it is important to recover a suitable sample representing the actual properties of the reclaimed road material during the recycling project. For in-plant recycling suitable samples from a stockpile may be feasible for conducting the mix design, if a stockpile management for reclaimed asphalt materials guarantees homogeneous properties of the stockpile. However, more usual for cold recycling project is the application of single-source reclaimed material which is milled just before the cold recycling process from the actual construction site. This is true for in-situ recycling but also for plant recycling where a mobile cold mixing plant is erected at the construction site. In these cases of single-source reclaimed road material, the sample for conducting the mix design should be milled from the actual site in advance representing the real material conditions during recycling.

From the reclaimed road material sample, the bitumen content as well the grading is evaluated. The binder content is needed for checking the added residual bitumen content after construction. However, the content of reclaimed asphalt in the recycling material also has a significant effect on the mechanical properties of BSM and BCSM [4].

Regarding the grading of the reclaimed road material, all national specifications demand a minimum fines content (< 0.063 mm) and specific range proportions of fine aggregates (≤ 2 mm) as summarised in Table 2. Usually pure milled reclaimed asphalt shows a shortage of fine grain particles and sometimes filler. In order to achieve the required grading, additional crushed aggregates can be added to the mix granulate material during the recycling process. The grading has a significant effect on the resulting void content of the cold recycled material. Minimum content of fines is required to improve aggregate coating with foamed bitumen as well as improve the breaking process of the emulsion. Last but not least, excessive content of fines will reduce the water susceptibility of the resulting pavement material.

Table 2: Specifications for particle grading of mix granulate [5]

Country	emulsion cold mix		foamed bitumen cold mix	
	Fines (< 0,063 mm)	Fine aggregates (< 2 mm)	Fines (< 0,063 mm)	Fine aggregates (< 2 mm)
Czech Rep.	≤ 6 %	-	≤ 6 %	-
Finland	4 % - 8 %	-	4 % - 8 %	-
Germany	2 % – 10 %	≥ 20 %	3 % – 12 %	≥ 25 %
Portugal, Spain(1)	≤ 3 %	15 % - 40 % (h>10 cm) or 19 % - 42 % (h≈6-10cm)	-	-
South Africa	4 % - 10 %	25 % - 40 %	2 % - 9 %	25 % - 40 %

(1) Both Portugal and Spain have specifications for the grading of the reclaimed asphalt material, which must fit one of the required grading envelops: one for applications in layer thicknesses higher than 10 cm and other for layer thicknesses between 6 cm and 10 cm.

3.2 Mix-design-step 2: Choice of binders (bitumen emulsion / foamed bitumen, mineral binder type) and optimisation of foamed bitumen

For the various cold recycling mixtures it was observed that similar types of binders are applied in the various countries:

- Bituminous emulsion: Slow setting bitumen emulsions produced with at least 60 % of paving grade bitumen (e.g. C60B5) are the most popular ones. In some countries, such as Norway, the use of medium setting bitumen emulsions with modified binders (e.g. C60BP4 and C65BP4) is also allowed. In Czech Republic, bitumen emulsions produced with polymer modified bitumen (e.g. C60BP5 and C65BP5) are also used for partial recycling (in-plant recycling).

- Foamed bitumen: A wide range of paving grade binders according to EN 12591 (e.g. 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. In practice, Southern European countries generally use harder grades and Northern countries softer bituminous binders.
  Bitumen for hot-mix asphalt application is not always suitable for preparing foamed bitumen. Therefore, the foaming application should be raised during the binder purchase, because foaming properties are not yet part in the specification system. For some binders it is necessary to apply foaming agents to reach the required bitumen foam characteristics.
  The bitumen foam properties are defined by expansion ratio (initial foam volume / pure bitumen volume) and half-time (duration until the foam degenerates to half of its initial volume). The foaming water content, foaming temperature and air pressure shall be optimised to reach an expansion ratio ≥ 10 as well as a half-time ≥ 10 s.
- 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, the use of Class 32.5 cement is usually recommended. However, Class 32.5 CEM I is not marketed or even produced at present in most countries, and has largely been replaced by Class 42.5 CEM I or alternative Portland-limestone cements/Portland slag cement (CEM II/A-L or CEM II/A-S).
- 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) to be used in road paving construction.

The specified upper and lower limits of the residual bitumen and cement content vary considerably between the specifications in each country, as represented in Figure 2. The reason for this is that different types of cold recycled materials are applied. In addition, the selection of binder type and content is also made taking into account the pavement climate conditions, namely in terms of temperature, moisture as well as winter conditions (freeze/thaw cycles).

3.3 Mix design step 3: Evaluation of optimum compaction water content and reference density

During construction cold recycled materials more or less have similar properties as unbound road materials. Because of ambient paving and compaction temperature, the friction between the grains is not reduced by low-viscosity bitumen; thus water is required for improving the compactibility. Therefore, the optimum water content is usually evaluated by the modified Proctor method according to EN 13286-2. However, other compaction procedures (e.g. gyratory or static compaction) are also applied for identifying the optimum water content.

The added water content is dependent on the natural moisture of the recycled asphalt material (RAP) as well as the water content of the bitumen emulsion (if used).

3.4 Mix design step 4: Mix preparation and specimen compaction

For mix preparation it is recommended to use a laboratory mixer which is capable of thoroughly mixing the cold recycled mix in short time. After mixing, the specimens for mechanical tests need to be compacted. The synthesis of national mix design specifications showed a wide variety of applied compaction procedures as summarised in Table 3. High variety of applied specimen size, compaction methodology and compaction parameters were identified.

Table 3: Laboratory compaction procedures for specimen preparation of cold recycling mixtures

Country	Specimen diameter (Ø)	Static compaction: vertical pressure	Gyratory (no. of rotations)
Czech Republic	150 mm	5 MPa	-
France	80 mm (D < 14 mm) 120 mm (D ≥ 14 mm)	≈11 MPa (60 kN & Ø=80mm/ 120 kN & Ø=120mm), Duriez test (NF P 98-251-4) ≈4 MPa (20 kN & Ø=80mm/ 40 kN & Ø=120mm), Duriez test (as recommended by research studies)	100
Germany	150 mm	2,8 MPa	-
Ireland	150 mm	to refusal density by impact, gyratory or vibratory compaction	
Norway	100 mm	10 MPa	96 % of 200 gyr.
Portugal / Spain	101.6 mm (or other proving that Ø≥4.D)	21 MPa (NLT 161/ASTM D1074) 7-8 MPa (recommend from research studies)	-

Comparison tests conducted during CoRePaSol project clearly identified a significant effect of the applied compaction procedure on the resulting void content and mechanical strength [5] as identified in Figure 3. Especially the impact compaction procedures according to Marshall and Proctor are not feasible for adequate compaction of cold recycled materials.

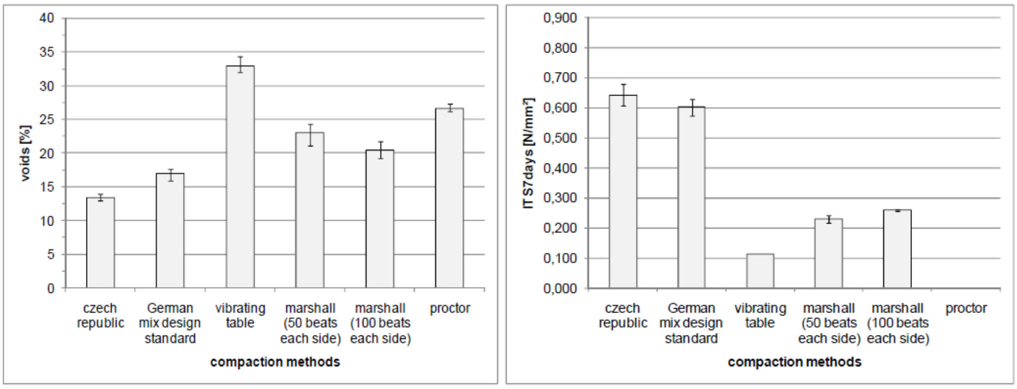

Figure 3: Effect of applied compaction procedure on voids content and ITS (5 °C) for a foamed bitumen BCSM [5]

A second study conducted during CoRePaSol project concentrated on the effect of varied compaction pressure (21 MPa vs. 7.5 MPa) in static compaction procedure [6]. The high compaction stress produces void contents similar to hot-mix asphalt concrete; however the smaller stress results in void contents of 10-12 % which well corresponds to the compaction reached in real site conditions. Furthermore, in this case, it was possible to distinguish the compacted mixtures (which were produced with different emulsion contents) in terms of their voids content.

When comparing compaction parameters in gyratory, static and Marshall compaction (see Figure 4) it can be observed that similar bulk densities can be reached with static compaction (5,0 MPa) and specific gyratory compaction parameters [6]. However at similar average bulk densities, static compaction results in higher indirect tensile strength compared to gyratory or Marshall compaction. In addition, the highest standard deviation values of the bulk density were observed for the specimens compacted by the Marshall method (e.g. σ_R=0.020 or 0.043 g/cm^3 for Mix A and Mix B, respectively).

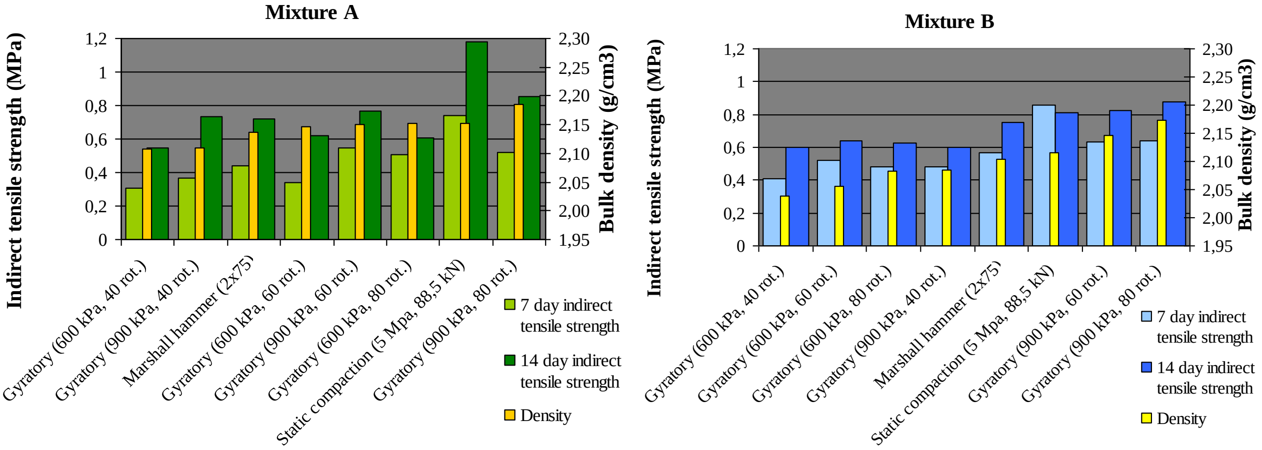

Figure 4: Bulk density and ITS of specimens after various compaction procedures.
Mix A: Emulsion BCSM, Mix B: Foamed bitumen BCSM [6]

In summary, the comparison studies resulted in two favourite compaction procedures, which are candidates for inclusion in a European harmonised mix design procedure. Besides gyratory compaction according to EN 12697-31, static compaction using a double-plunger system and a compaction force of 5,0 MPa to 7,5 MPa, depending on the used test procedure (i.e. loading rate), was found suitable for specimen preparation. In both cases, perforated moulds or loading plates are required allowing the drainage of excessive water during the compaction process. It should be noted that other possible compaction methods used outside Europe, such as the dynamic compaction used specifically for cold recycled mixes in South Africa (Kango-hammer compaction), were not included in these comparisons.

3.5 Mix design step 5: Curing of specimens

Cold recycling materials show a significant time-dependent strength development after laying and compaction. For materials with bitumen emulsion, the bitumen particles start to coalesce after breaking of the emulsion, which usually occurs during compaction. This curing process can last several months until the strength of the pavement material is fully developed. The free emulsion water has to drain or evaporate from the mix. The addition of mineral binder (cement, lime or HRB) can accelerate the curing process (by providing a reduction on the water content, which is used on their hydration) and will increase the early-life bearing capacity. However this will increase the rigid bonds in the material and introduce brittleness into the cold recycled materials.

For foamed bitumen mixtures, curing also is required for added water evaporation and drainage.

In the case of BCSM, the cement hydration process results in a time-dependent increase of strength in the cold recycled mix.

Table 4: Laboratory curing procedures

Country	BSM	CBSM / SCRM
Czech Republic	28 days: air curing at 20 °C	2 days: 90% humidity at 20 °C + 26 days: 40-70% humidity 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% humidity 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

As identified in Table 4, the curing procedures applied in laboratory according to the national mix design specifications show a wide variety of curing parameters (duration, temperature, moisture). However, this variety can be explained by specific differences in climate and site curing conditions as well as the preference for specific types of cold recycled materials.

In order to evaluate reasons for the wide variation of curing procedures, an extensive laboratory assessment was conducted on various cold recycled materials within the CoRePaSol project [6] and already discussed elsewhere [7]. Within these studies various curing parameters were assessed (temperature, duration, moisture – by controlled climate chamber as well as by “simplified” control via unsealed and sealed specimen). The following conclusions could be drawn from these experiments:

- After compaction the specimen shall be stored in the mould (sealed in a plastic bag) for one day at room condition for allowing a demoulding without deteriorating the specimen.
- Curing at elevated temperature (40 °C or 50 °C) at unsealed condition:
    - Suitable only for cold recycled materials with a mineral binder content ≤ 1 %. The fast drying of the specimen won’t allow hydraulic reactions of cement occurring in field under moist conditions.
    - Curing duration of 3 days is adequate.
    - Medium-term strength development by consolidation effects in reclaimed asphalt can also be simulated.
- Curing of unsealed specimen at room conditions as defined by temperatures around 20 °C and moisture between 40 % and 70 %:
    - Procedure is feasible for unsealed specimen with an adequate content of cement > 1 %.
    - Moisture between 40 % and 70 % won’t affect the specimen properties.
    - The assessed strength development identifies a curing duration of 14 days as recommended while 28 days is not required.
- Curing of sealed specimens at room conditions:
    - Emulsion BSM with a cement content ≤ 1 % identified a slow strength increase. Therefore sealed curing is not feasible for these types of cold recycled materials.

The laboratory-applied curing tries to simulate and accelerates the curing conditions in filed. There of course are strongly affected by climate and paving conditions. Therefore, the curing experiments allow further conclusions on the applicability of specific cold recycled materials regarding the climate conditions:

- Emulsion BSM (cement content ≤ 1 %) need drying for strength development and therefore are not applicable in moist regions.
- Foamed bitumen BSM show adequate strength development also at moist curing conditions.
- However, in dry, warm climate, the addition of cement as in BCSM may not be required or useful for reaching adequate stiffness and strength properties.

3.6 Mix design step 6: Mechanical tests

For mix design usually mechanical tests are applied on cured specimen. The main properties checked in more-or-less all national specifications are:

- void content, which specification values depend on the conducted compaction regime,
- indirect tensile strength, where various test parameters are applied (alternatively values for ITS of dry specimens and wet specimens can be evaluated),
- water sensitivity tests by comparing the strength of dry-cured and water-conditioned specimens,
- stiffness tests.

A selection of test conditions applied are summarised in Table 5. As can be observed, the requirements are similar between the analysed national recommendations. For BSM with < 1% of cement, the voids content is an important mix design parameter controlling the stiffness and strength of the material.

Table 5: Mechanical test methods applied for mix design and test parameters

Country		Void content	ITS test temperature	ITS	Water conditioning	ITSR
Czech Rep.	BSM	6 – 14 %	15 °C	≥ 0,3 MPa	7 days @ 20 °C	≥ 60 %
	BCSM	-		0,3 – 0,7 MPa		≥ 85 %
Finland	BSM	-	10 °C	≥ 0,5 MPa	frost-thaw	≥ 40 %
Germany	SCRM	8 – 15 %	5 °C	0,75 – 1,2 MPa	14 days @ 20 °C	≥ 70 %
	BSM	5 – 15 %		0,7 -1,0 MPa		
Portugal/Spain	Specification based on unconfined compressive strength (IRS ≥ 70% or 75% respectively for low and high traffic volume)					

When evaluating the threshold values for indirect tensile strength, the varied test temperature has to be considered. Because of the added bitumen but also of the RA bitumen, cold recycled materials have a temperature-dependent strength. As identified in BSM with < 1 % of cement viscoelastic properties dominate the material performance and therefore only a bottom limit of indirect tensile strength is required. However, with increased content of cement, the material becomes increasingly brittle. Therefore, BCSM and SCRM also need an upper limit of indirect tensile strength in order to avoid shrinkage cracking in the pavement.

All cold-recycled materials are sensitive regarding moisture. Therefore, the assessment of moisture susceptibility is an essential part of the mix design process. Again, various moisture conditioning regimes and threshold values are applied within Europe so far. For these reasons an experimental comparative study was conducted during CoRePaSol-project, [8]. Emulsion BSM and CBSM were prepared and specimens were compacted with varied procedures. After commonly applied curing procedures (3 days @ 50 °C for BSM & 11 days @ room conditions for CBSM), one set of specimens were commonly moisture conditioned (stored saturated in water at 40 °C for 3 days). The results are summarised in Table 6.

As can be seen by the results, the addition of cement will improve moisture susceptibility of the cold recycling materials, if the cement is allowed to hydrate. This is especially true for cement contents ≥ 3 %. Furthermore increasing bitumen emulsion content will also benefit he moisture resistance of the cold recycled materials. When comparing the results obtained at similar mixtures after static compaction it can further be observed, that improved compaction (and therefore reduced void content) will strongly affect the water sensitivity.

Table 6: Synthesis of water susceptibility study results

Study	Sample name	RA content	Bitumen emulsion content	Cement content	Compaction	Curing	ITSdry	ITSwet	ITSR [%]
CZ	A	100	3,5	3,0	Static (5 MPa)	11d20	0,75	0,78	104
	C	100	3,5	0,0		3d50	0,65	0,3	46
	W	100	2,5	1,0		3d50	0,75	0,6	80
IR	a	33	3,5	0	Gyratory	28d40	0,74	0,58	78
	c	33	3,5	3,0		28d40	0,93	0,83	89
GER	I	95	2,0	0	Static (2,8 MPa)	3d50	0,39	0,14	36
	II	95	3,5	0		3d50	0,76	0,31	41
	III	95	3,5	1,5		11d20	0,83	0,63	76
PT	CME3C0	100	2,8	0	Static (7,5 MPa)	3d50	1,13	0,75	66
	CME3C1	100	2,8	1,0		3d50	0,64	0,46	72
	CME4C0	100	3,8	0		3d50	0,89	0,77	87
	CME4C1	100	3,8	1,0		3d50	0,76	0,51	67
	CME5C0	100	4,7	0		3d50	0,92	0,81	88
	CME5C1	100	4,7	1,0		3d50	0,76	0,53	70

4. CONCLUSIONS

Based on relevant findings of CoRePaSol project, the following recommendations can be drawn for drafting a harmonised mix design approach for cold recycled materials.

The mix design shall be conducted by following six steps. Within these steps the variety of test methods and parameters shall be reduced in order to allow future comparisons of gained experience:

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 %

Step 2: Choice of binders (bitumen emulsion / foamed bitumen, mineral binder type) 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, shortcomings from an impact compaction procedure are reported (mainly when relatively high amounts of binder are applied). Therefore, an alternative compaction method might be more feasible for conducting tests for evaluating optimum compaction water content and reference density. Some additional experiments are necessary to define a suitable compaction procedure based on controlled compaction energy.

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 (which needs however to be adapted to cold mixtures: e.g. perforated moulds/plates, no need for 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.

Step 5: Curing of specimens.
For simulating site-development of strength, suitable laboratory curing procedures are required. From the laboratory comparisons following curing methods are recommended for specimens, which are 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,

Step 6: Mechanical tests
In order to assess the mechanical properties, the indirect tense strength as well as moisture/water sensitivity shall be assessed.
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, …)

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

- Bitumen stabilised 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 stabilised materials (cement content > 1 %):
  - applicable for moist climate,
  - adequate for high early-life strength/ bearing capacity.

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