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# Report on Durability of cold-recycled mixes: Test procedures for simulating long-term ageing

Final report

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# CEDR Call2012: Recycling: Road construction in a post-fossil fuel society

# CoRePaSol
# Characterization of Advanced Cold-Recycled Bitumen Stabilized Pavement Solutions

# Report on Durability of cold-recycled mixes: Test procedures for simulating long-term ageing

Final report

## Deliverable D2.1 – part ageing

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# Executive summary


The durability of pavement materials highly depends on the construction material long-term mechanical properties. Therefore, laboratory assessment procedures are applied during mix design in order to optimise the pavement performance. However, often these assessed material properties only represent the short-term properties of the material. During traffic loading the material is subjected to several distresses that affect its mechanical properties:

- Traffic loading results in fatigue crack initiation
- Initiated cracks will propagate
- Moisture as precipitation (rainfall, dew) or subsoil saturation
- Temperature effects (frost/thaw)
- Chemical effects in the pavement material (e. g. long-term ageing).

This report contains experiments for evaluating the long-term aging properties of cold recycled materials.

In order to evaluate if there is an effect of ageing in road layers composed of cold recycled materials which has to be taken into account in the mix design procedure, an ageing procedure according to De la Roche et al. (2009) is applied on laboratory produced bitumen stabilised material. The evaluation of the results is intended to consider ageing effects during mix design and to assess the performance during service lifetime.

After evaluating the collected data from laboratory tests and from literature following conclusions can be drawn:

- The applied ageing procedure shows significant ageing effects in cold recycled mix specimens and can be applied for mix design.

- The ageing effects of compacted cold recycled materials are affected by the specimens void content.

- The bituminous emulsion mixtures as tested in this study are less sensitive to ageing effects compared to the analysed foamed bitumen mixtures despite of higher voids contents, which confirms observations of Jenkins et al (2008).

- The softening point ring and ball as representative of the recovered bitumen properties are not feasible to identify differences in ageing effects between cold recycling mixtures. Therefore, mechanical tests on mix specimens are necessary to identify the ageing susceptibility of these materials.

- The applied ageing procedure is feasible to evaluate the recyclability of cold recycled materials.

# 1 Introduction

The durability of pavement materials highly depend on the construction material long-term mechanical properties. Therefore, laboratory assessment procedures are applied during mix design in order to optimise the pavement performance. However, often these assessed material properties only represent the short-term properties of the material. During traffic loading the material is subjected to several distresses that affect its mechanical properties:

- Traffic loading results in fatigue crack initiation
- Initiated cracks will propagate
- Moisture as precipitation (rainfall, dew) or subsoil saturation
- Temperature effects (frost/thaw)
- Chemical effects in the pavement material (e. g. long-term ageing).

In order to assure feasible long-term performance of the pavement material, the relevant long-term performance has to be assessed already during mix design in order to avoid pavement failure due to improper long-term performance.

This report contains experiments for evaluating the long-term aging properties of cold recycled materials.

Asphalt pavement layers are exposed to traffic and environmental influence which are limiting the service lifetime. Due to long term ageing influenced by oxygen, UV radiation and high temperature the viscosity of bituminous binder increases and the flexible character of the asphalt pavement is reduced. The layers ageing depends on the accessibility of oxygen and therefore on the layer position in the pavement and its voids content. Ageing potential of an asphalt layer depends further on its kind of bituminous binder and aggregates. Knowledge of the effect of ageing in different asphalt layers is important when introducing durability considerations into mix design for asphalt materials.

In contrast to hot mix asphalt (HMA) cold recycling technique is a rehabilitation method to produce a new road layer by milling an existing asphalt layer and mixing the resulting granulate with bituminous binder (bituminous emulsion or foamed bitumen) at ambient temperature. Whereas, for hot recycling technology it is assumed that the added binder mixes thoroughly with the heated aged binder during mixing, this is not the case in cold recycling, where the new binder coats the reclaimed asphalt granulates.

In order to evaluate if there is an effect of ageing in road layers composed of cold recycled materials which has to be taken into account in the mix design procedure, an ageing procedure according to De la Roche et al. (2009) is applied on laboratory produced bitumen stabilised material. The evaluation of the results is intended to consider ageing effects during mix design and to assess the performance during service lifetime.

The objectives in this study for WP2 are:

- evaluation if ageing is a relevant issue for the long-term performance of cold recycled mixtures,
- identification of differences in the long-term ageing behaviour of foamed bitumen and bituminous emulsion,
- assessment of the applicability of laboratory ageing procedure in order to prepare simulated reclaimed asphalt of cold recycled material with known composition.

# 2 State of the Art

Ageing of hot-mix asphalt is distinguished into short-term ageing and long-term ageing.

Short-term ageing is addressed during mixing in the mixing plant, transportation and paving at hot temperatures up to 150 °C. Short-term ageing is linked to oxidation effects and distillation loss of volatile compounds of bituminous binders.

After paving and compaction long-term ageing occurs at temperatures between -30 °C and 70 °C during service lifetime. Long-term ageing results in oxidation of bitumen compounds resulting in the enlargement of C-H-molecules which will increase the binders viscosity. Ageing methods to simulate long term ageing and short term ageing were developed to simulate ageing behaviour and to predict end of service lifetime for bitumens as well for hot-mix asphalt materials.

In the literature it is pointed out that the development of the binder properties depends on type of the used binder and that properties of asphalt mixture are influence by climate and road characteristics (Strickland 1998, Renken 2007).

Bituminous binders in bitumen stabilised material are foamed bitumen or bituminous emulsion.

Foamed bitumen is produced by spraying cold water into hot bitumen in an expansion chamber with air pressure. This results in bitumen foamed by air- and water vapour filled bitumen bubbles (Wirtgen 2012). In contact with aggregates the bubbles burst which results in a good bitumen coverage of the aggregate surface.

Bituminous emulsion is bitumen dispersed in fine particles in water stabilised by emulsifying agents. There are cationic and anionic emulsion types, whereas cationic bituminous emulsions are the most popular used types in Europe (compare Deliverable 1.1). Adhesion between binder and aggregate particles is created by water evaporation remaining a thin film of bitumen (Shell 2003), whereas the stabilising agents in the emulsion can increase the adhesion of the bitumen and the aggregate.

The main differences between HMA, foamed and emulsion mixes were summarized by Jenkins (2000) in Table 1.

**Table 1: Comparison between HMA and BSM procedure (Jenkins 2000 and Jenkins 2008)**

| Parameters | Bitumen emulsion | Foamed bitumen | Hot mix asphalt |
|---|---|---|---|
| Bitumen temperature during mixing | 50°C – 70°C | 170°C -180°C | 140°C -180°C |
| Aggregates temp | Ambient 25°C | Ambient (25°C) Half warm (40°C-99°C) | Hot (140°C – 200°C) |
| Moisture content during mixing | 60%-70% OMC | 70% - 85% OMC | Dry |
| Type of coating of aggregates | Thin coating coarse particle and cohesion of mix with fines mortal | Partial coating of large particle with spot welding of mix with fines mortar | Coating of larger particle with controlled film thickness |
| Construction and compaction temp | Ambient (25°C) or Half warm (40°C-95°C) | Ambient or Half warm (40°C-95°C) | 140°C–160°C |

In general ageing in BSM depends on voids content in the layer or compacted and increase with higher voids content and consequently higher oxygen content (Jenkins 2008, Petersen 2009). Jenkins et al. (2008) pointed out that “the high surface area of bitumen in BSM-foam and uneven distribution of the bitumen over the different granular fractions might be the factors resulting in premature ageing”. Bitumen stabilized materials are non-continuously bound materials. Figure 1 shows the different binder characteristic of continuously bound HMA / emulsion mix and non-continuously bound foamed bitumen mix Wirtgen (2012). The higher the surface of the spotwelds the higher is the possibility for ageing (Jenkins et al. 2008).

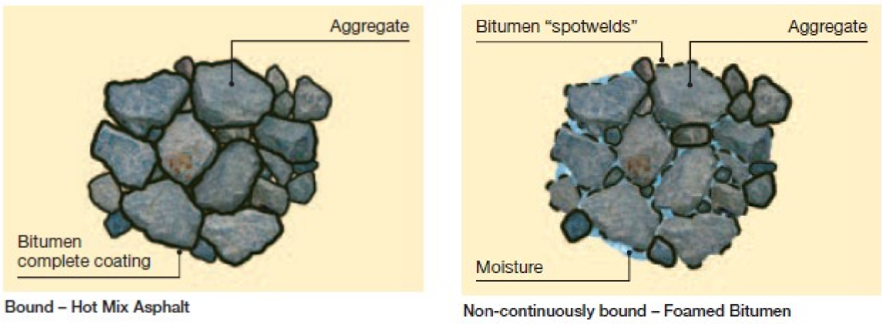


**Figure 1. Difference between Hot Mix Asphalt and non-continuously-bound foamed bitumen (Wirtgen 2012)**

Jenkins et al. (2008) evaluated ageing effects during the production of foamed bitumen mixes. During bitumen circulation in the laboratory foaming unit and the foam generation no ageing occurs. This was confirmed by a master thesis at university of Kassel (Bachmann 2014). Jenkins et al. (2008) concluded that short term ageing of the bituminous binder is not an issue for BSM.

However, long-term ageing affects the road materials during several years of traffic loading on site. In general there are two different ageing methods used for asphalt mixtures. On the one hand there are methods used for produced specimens from asphalt mixtures and on the other hand methods for loose materials. Ageing of loose material results in homogenous ageing property in the mix whereas the ageing of compacted specimens will result in high ageing at the specimens surface, whereas the ageing effects inside the specimens are less severe and highly depended of the specimens voids content (Mollenhauer et al. 2011, Jenkins et al. 2008). Though, for the assessment of mechanical asphalt properties on the aged loose mixture it is necessary to compact specimens. The changed bitumen viscosity will affect the mixes compactibility and therefore the resulting specimen properties might not represent long-term aged material on site.

However, for simulating reclaimed road materials with known properties in order to evaluate the recyclability of these materials, the ageing procedure on loos mix is suitable. After the applied ageing new binder is added and the aged road granulate is handled as freshly-milled road material. Therefore, the long-term ageing procedure according to De la Roche et al. (2009) as developed for hot-mix asphalt was applied in this study on loose cold recycled mixtures. The loose asphalt mix is spread on a tray and stored for  9 days in an ventilated oven at a temperature of 85 °C. This procedure is further included in the newly proposed EN 12697-52.

# 3 Experimental program and laboratory tests

## *3.1 Design of test program*

In order to assess the long-term ageing properties of cold recycled asphalt mixtures as well as the applicability of the laboratory ageing procedure proposed by RILEM on cold recycled asphalt materials, two materials were assessed. Cold recycled mixtures were prepared with bitumen emulsion (A1) as well as foamed bitumen (A2). In order to distinguish the ageing potential in the added bituminous binder from the additional ageing of the binder of the reclaimed asphalt, three additional samples were prepared. Two additional cold mixtures were prepared with the same added binder content compared with mixtures A1 and A2 but with pure aggregates as mix granulate. These reference mixtures were labelled B1 and B2. Finally the granulated reclaimed asphalt was also subjected to the ageing conditioning in order to assess the remaining ageing potential.

For the cold (recycling) mixtures, (A) and (B), specimens were compacted by impact compaction according to EN 12697-30 (Marshall Compaction). In WP1 of CoRePaSol project a study of different compaction methods showed that impact compaction leads to higher voids contents compared to static compaction. Higher voids contents result in increased ageing effects of the compacted material.

The indirect tensile strength was evaluated in order to assess the stiffness and strength properties of specimens after specimen compaction as well as after the ageing conditioning. Furthermore, the bitumen was extracted from the cold asphalt mixtures in order to identify the ageing effects directly on the bitumen properties.

The set-up of the study is shown in Figure 2. After mixing, the specimens were compacted and dry-cured for 28 days at room conditions. Afterwards the indirect tensile strength (ITS) of one set of specimens were assessed. From the tested specimen, the bitumen was recovered and softening point by ring and ball ($T_{R\&B}$) of the recovered bitumen were conducted. This stage of test results are labelled “day 0 after curing”, representing unaged conditions.

As mentioned before, the ageing procedure used and recommend in Re-Road and RILEM project was applied in this study. In order to assess the ageing progress in this method specimens were aged in a ventilated oven at 85 °C for 1, 3, 6, 9, 14 and 21 days. After each period, a set of specimen was taken out of the oven and temperature conditioned for the indirect tensile strength tests. Afterwards the bitumen was extracted from the tested specimens and recovered for testing softening point ring and ball.

Additionally, uncompacted pure asphalt granulate without any fresh bituminous binder was aged in a bucket for 9 days at 85 °C as reference. Bitumen was recovered at 0, 3, 6 and 9 days during the ageing procedure after curing and the softening point ring and ball was determined.

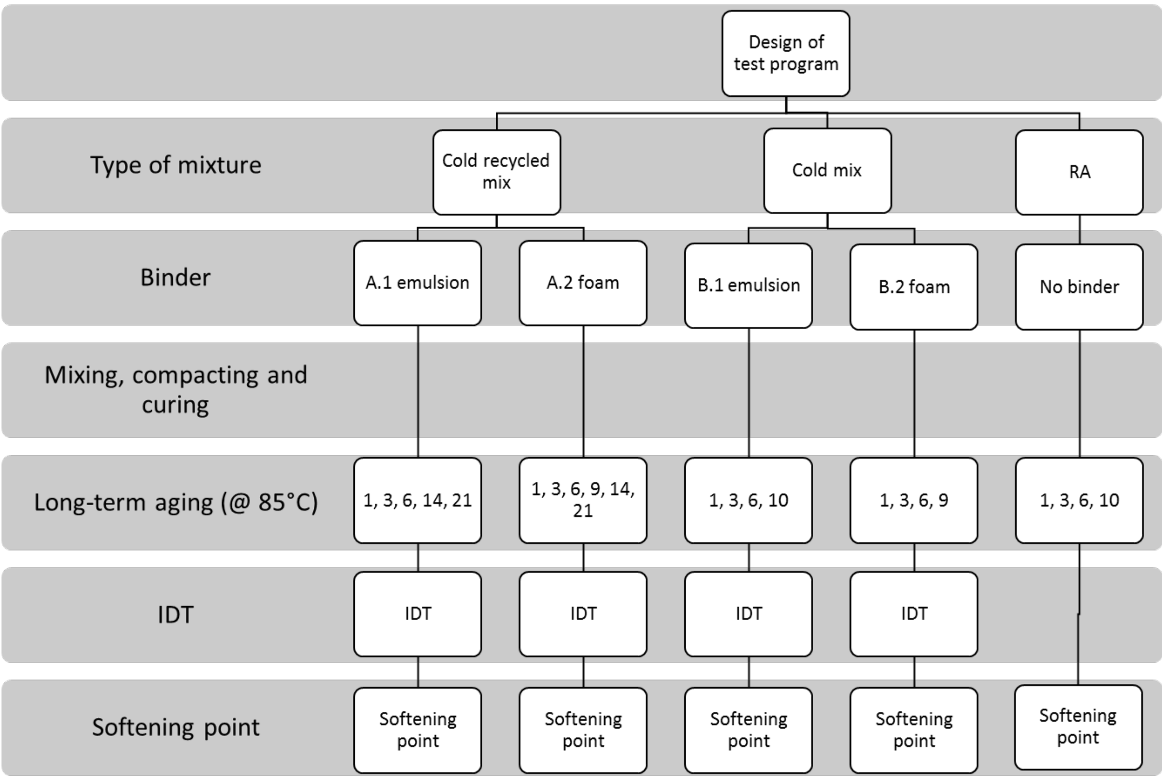


**Figure 2. Experimental work for cold recycling mixture**

## *3.2 Materials*

### *3.2.1 Source materials*

The reclaimed asphalt material was obtained from the Hermann Wegener GmbH & Co. KG stockpile in Rhünda (Germany). Figure 3 shows the grading of the reclaimed asphalt granulate.

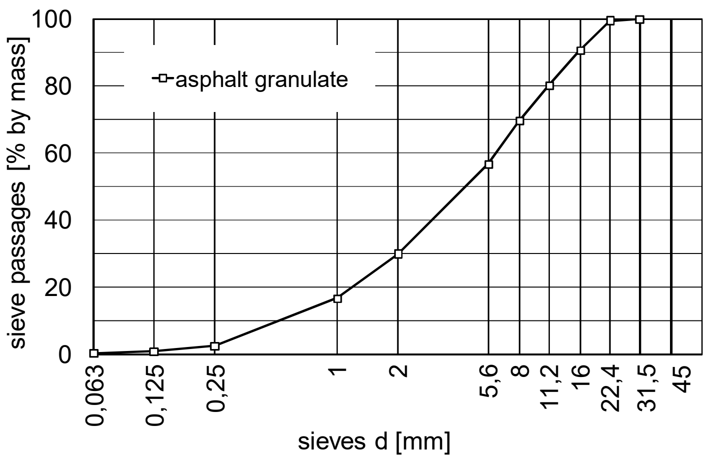


**Figure 3. Grading of particle size for reclaimed asphalt.**

As cationic bituminous emulsion C60B1-BEM provided by Esha Straße GmbH, Gotha, was applied. This type of emulsion is especially produced for mixtures bound by bituminous emulsion (BEM) in Germany (FGSV, 2007) with following characteristics (Table 2):

**Table 2: Characteristic for bituminous emulsion**

| | | |
|---|---|---|
| Bituminous emulsion | C | Cationic emulsion |
| | 60 | Bitumen content 60% by mass |
| | B | Unmodified bitumen |
| | 1 | Class of breaking value |
| Recovered bitumen | Penetration grade @ 25° [1/10mm] | < 100 |
| | Softening point R&B [°C] | ≥ 43 |

Bitumen with penetration grade 50/70 (provided by Shell) was used for production of foamed bitumen. The bitumen characteristics penetration grade and softening ring and ball are given in Table 3. The foaming process was conducted by applying a water content of 4,5 %, a temperature of 180 °C and a air pressure of 5,5 bar.

**Table 3: Binder properties of the bitumen used for foaming and the bitumen recovered from the bituminous emulsion**

| | Foamed bitumen 50/70 (before foaming) | Recovered bitumen in bituminous emulsion |
|---|---|---|
| Penetration grade [1/10mm] | 65,7 | 78 |
| Softening point R&B [°C] | 49,5 | 46 |

### *3.2.2 Mix design*

Table 4 summarises the mix composition of the four mixtures prepared in this study. The mix design of the two mixtures analysed in this study correspond to mixtures assessed in Deliverable D4.1 (Mix I and Mix III).

**Table 4: Mixture composition**

| Type of mixture | A.1 | A.2 | B.1 | B.2 |
|---|---|---|---|---|
| **RA content** | 96,4 % | | - | - |
| **Basalt** | - | - | 100% | |
| **Limestone filler** | 3,6 % | | - | |
| **Bituminous emulsion content** | 6,4 % (4 % residual binder) | - | 6,4 % (4 % residual binder) | - |
| **Foamed bitumen content** | - | 4 % | - | 4 % |
| **Cement content** | 2 % | | | |

The assessed mixtures represent cold recycling mixtures according to German standard FGSV 2005. The composition indicates a cold-recycling mix aiming at high bearing capacity and encapsulating dangerous substances.

For all mixtures the same grading of mix granulate was applied. In order to reach the minimum requirements of fines content as specified in the mix design guide (FGSV, 2005), 3,6 % of inactive limestone filler was added to the granulated reclaimed asphalt. The resulting grading as plotted in Figure 4 was also aimed with the pure- basaltic aggregate mix composition.

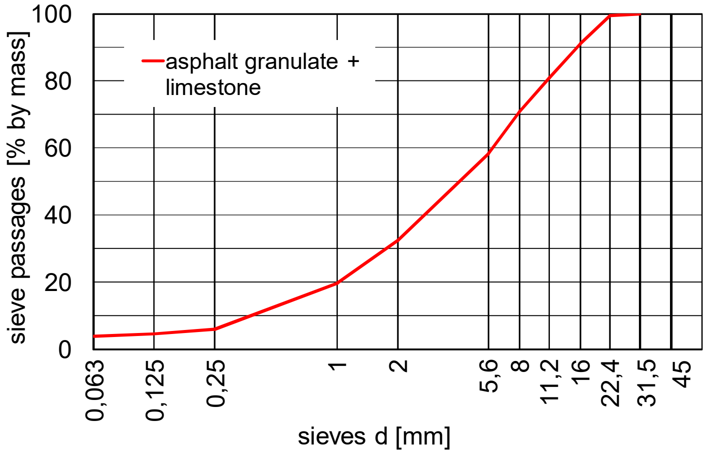


**Figure 4. Particle size distribution of reclaimed asphalt**

Table 5 gives an overview about the detailed mix composition, resulting in the same grading as for mix A. Due to included fines in the basalt aggregates no limestone filler had to be added to reach the grading requirement.

**Table 5: Detailed mix composition of the used mixtures**

| Type of mixture | | Content of … | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Asphalt granulate | Virgin aggregate | | | | | | |
| | | | 16/22 | 11/16 | 8/11 | 5/8 | 2/5 | 0/2 | Limestone filler |
| **Asphalt granulate** | **A** | 96,4 | - | - | - | - | - | - | 3,6 |
| **Basalt aggregate** | **B** | - | 13,3 | 2,2 | 12,6 | 6,7 | 29,9 | 35,3 | - |

The foamed bitumen was produced with Wirtgen WLB 10 S Laboratory plant (Wirtgen Cold recycling manual 2nd).

### *3.2.3 Sample preparation, specimen curing and ageing procedure*

The four mixtures were produced using a Wirtgen compulsory pugmill mixer WLM 30. After pre-mixing of aggregates and cement for 1 minutes, water was added to the mixture and mixed again for 1 minute. After adding the binder emulsion or spraying the foamed bitumen into the mix, the mixing was proceeded for 1 minute until the aggregates and binder were distributed homogenously and the aggregates were fully covered. From the freshly-produced mix, cylindrical specimens (Ø 101,6 +/-0,1 mm, 63,5 +/- 2,5 mm height) were compacted according to Marshall compaction method (EN 12697-30) using 2x75 blows.

After compaction, the specimens were covered in their moulds and stored for 24 hours at room conditions. Afterwards the specimens were demoulded and cured for 28 days under room conditions (Figure 5). This procedure corresponds to German mix design standard (FGSV 2005) for conditioning specimens for ITS testing after 28 days.

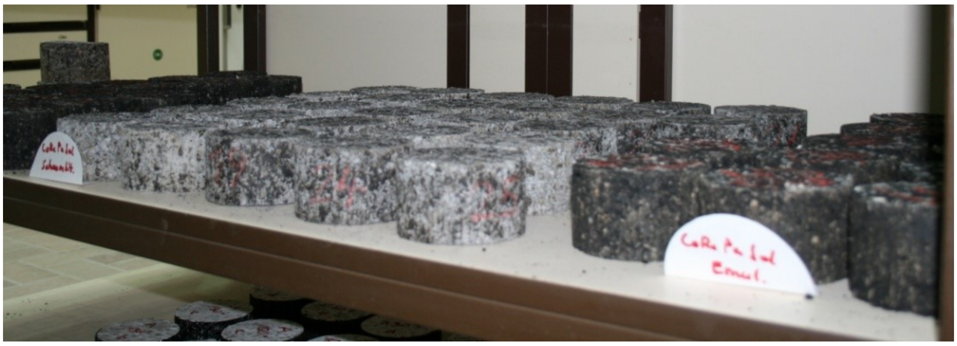


**Figure 5. Curing procedure under room conditions**

## *3.3 Laboratory tests*

### *3.3.1 Bulk density and void content*

At the end of the dry curing procedure, the specimen mass and dimensions (diameter, height) were measured. From these values the moist bulk density of conditioned specimens were calculated.

### *3.3.2 Indirect tensile strength test (IDT)*

The indirect tensile strength test (IDT) was applied to determine deformation behaviour and strength of a mixture during tension loading. Each specimen was temperature conditioned for 4 h at 15°C. Afterwards it was placed directly between an upper and lower loading strip. The upper loading strip was driven with a rate of 50 mm/min until failure. In this study the test frame according to EN 12697-23 were applied (compare Figure 6).

The indirect tensile strength (ITS) is determined from the maximum force $F_{max}$ measured during the test:

$$ITS = \frac{2 \cdot F_{max}}{\pi \cdot d \cdot h}$$

$F_{max}$ Maximum vertical force [N]

d Diameter of specimen [mm]

h Height of specimen [mm]

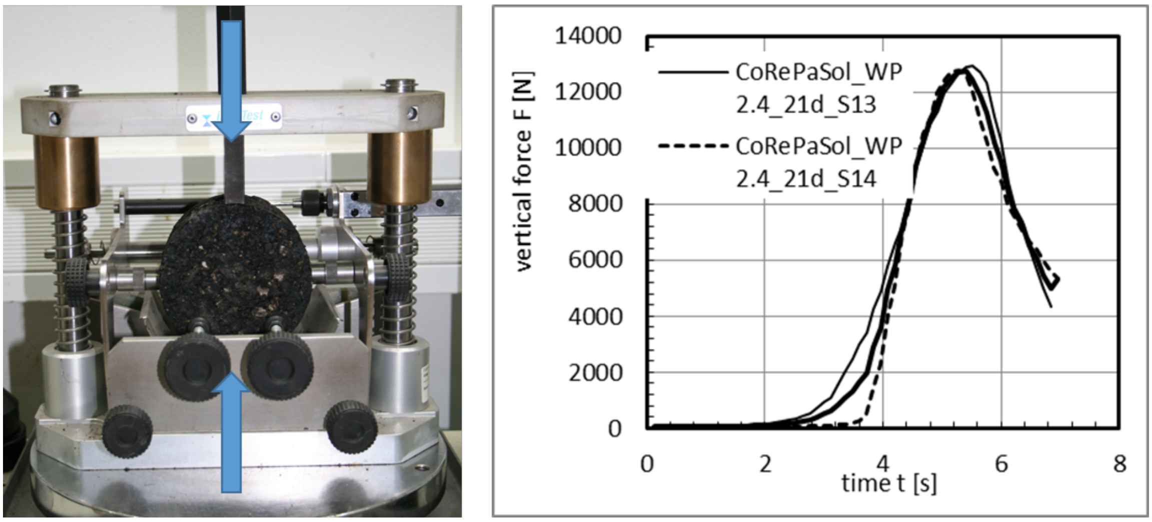


**Figure 6. Test frame for indirect tensile strength**

### *3.3.3 Softening point ring and ball ($T_{R\&B}$)*

After testing the indirect tensile strength the bitumen was extracted from the specimen and/or the reclaimed asphalt (sample C) and recovered according to EN 12697-1 and 12697-3 using hot extraction with toluene as a solvent. Afterwards softening point ring and ball was determined for the recovered bitumen according to EN 1427.

# 4 Results and discussion

The results of the laboratory tests are summarised in Table 6:

- the voids content of the prepared specimens after varied aging times,
- their indirect tensile strength values obtained
- softening point ring an ball values measured on binders recovered from the cold mix and the reclaimed asphalt after the applied ageing stages.

The results are summarized for the materials tested:

- A1: Cold recycled mix with bitumen emulsion,
- A2: Cold recycled mix with foamed bitumen
- B1: Cold mix with basaltic aggregates and bitumen emulsion
- B2: Cold mix with basaltic aggregates and foamed bitumen
- RA: reclaimed asphalt as applied in mixes A1 and A2.

## *4.1 Voids content*

In order to check the comparability of the cold recycled mixtures analysed in this study, the voids content of the indirect tensile test specimens was evaluated from the maximum density and the bulk density after ageing conditioning. The moisture content could be neglected for this evaluation because of the long duration of ageing conditioning of the specimens at elevated temperature.

As can be observed in Figure 7, the specimens with reclaimed asphalt and bituminous emulsion reach higher void content (20.8-22 %) compared to the mix with foamed bitumen (18-21 %). Furthermore, the mixtures containing pure basalt aggregates reach lower voids contents compared to mixtures composed of reclaimed asphalt.

Generally, there is no systematic difference in the voids contents of the specimens compacted from one cold mix. Though, for the mixtures prepared with foamed bitumen A2 and B2, there can be differences observed. For the specimens compacted from mixture A2 and tested in ITS after 6 days of ageing conditioning, the voids content is higher compared to the specimens, which were tested after prolonged ageing time. For mix B2, the specimens used for 6 and 10 days ageing time have lower voids contents compared to shorter ageing time. These differences shall be considered when interpreting the results of indirect tensile strength and softening point because increased voids content will decrease the specimen's resistance against ageing.

## *4.2 Indirect tensile strength*

The results of indirect tensile stress tests are summarised in Table 6 and plotted in Figure 8. The indirect tensile strength measured on the emulsion mix A1, composed of reclaimed asphalt, indicate no effect of ageing conditioning time. The indirect tensile strength measured on the unaged specimen of approximately 0.8 MPa can be observed with only minor differences in all ageing stages.

The same observation can be made for the emulsion mix with basaltic aggregates. The slightly higher indirect tensile strength of this mixture also doesn't show a significant change during ageing conditioning.

**Table 6: Voids contents, indirect tensile strength results and softening points of the test samples analysed**

| Sample Mixture | Ageing time | Void content [%] | | | | Indirect tensile strength [MPa] | | | | Softening point $T_{R\&B}$[°C] |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Single values | | | **Mean** | Single values | | | **Mean** | |
| A1 | 1 | 21.4 | - | | **21.4** | 0.693 | - | | **0.693** | **62.5** |
| | 3 | 22.0 | 21.9 | | **22.0** | 0.794 | 0.893 | | **0.844** | **64.5** |
| | 6 | 21.4 | 21.2 | | **21.3** | 0.755 | 0.720 | | **0.737** | **67.5** |
| | 14 | 20.9 | 20.7 | | **20.8** | 0.849 | 0.887 | | **0.868** | **71.0** |
| | 21 | 21.5 | 20.9 | | **21.2** | 0.723 | 0.705 | | **0.714** | **74.0** |
| A2 | 0 | 18.3 | 20.0 | | **19.1** | 0.603 | 0.547 | | **0.575** | **62.5** |
| | 1 | 19.3 | 18.9 | | **19.1** | 0.913 | 0.801 | | **0.857** | **61.5** |
| | 3 | 19.3 | 20.1 | | **19.7** | 1.139 | 0.957 | | **1.048** | **64.0** |
| | 6 | 21.1 | 20.1 | | **20.6** | 0.915 | 0.944 | | **0.929** | **67.0** |
| | 9 | 19.5 | 18.3 | | **18.9** | 1.097 | 1.375 | | **1.236** | **68.5** |
| | 14 | 18.6 | 18.3 | | **18.5** | 1.283 | 1.466 | | **1.374** | **70.5** |
| | 21 | 20.7 | 18.6 | | **19.6** | 1.330 | 1.340 | | **1.335** | **74.5** |
| B1 | 1 | 19.3 | 19.2 | 18.0 | **18.9** | 1.011 | 0.915 | 0.842 | **0,923** | **60.0** |
| | 3 | 17.4 | 18.7 | 19.3 | **18.5** | 0.879 | 0.898 | 0.748 | **0,842** | **60.5** |
| | 6 | 19.9 | 18.8 | 18.5 | **19.0** | 0.873 | 0.883 | 0.841 | **0,866** | **60.5** |
| | 10 | 18.2 | 20.2 | 19.0 | **19.1** | 0.782 | 0.755 | 0.836 | **0,791** | **63.0** |
| B2 | 1 | 16.3 | 19.2 | 18.6 | **18.0** | 0.829 | 0.637 | 0.575 | **0,680** | **55.0** |
| | 3 | 17.2 | 17.1 | 18.6 | **17.7** | 1.022 | 1.204 | 0.801 | **1,009** | **63.5** |
| | 6 | 17.1 | 16.8 | 15.9 | **16.6** | 1.094 | 0.943 | 1.157 | **1,065** | **66.5** |
| | 10 | 17.6 | 15.8 | 16.5 | **16.6** | 1.124 | 1.087 | 1.092 | **1,101** | **64.5** |
| RA | 1 | | | | | | | | | **66.5** |
| | 3 | | | | | | | | | **69.5** |
| | 6 | | | | | | | | | **73.0** |
| | 10 | | | | | | | | | **75.0** |

On the other hand, the foamed bitumen mixtures indicate a clear ageing effect on the indirect tensile strangth values. The prolonged ageing time will result in an increase in indirect tensile strength. The partly decrease of ITS in sample A2 at an ageing time of 6 days can be explained by the increased void content of these specimens.

The increased strength can be explaiend with a increase in materials stiffness due to ageing of the bituminous binder. In the deflection-controlled test, the stiffness increase results in an increase of the stress in the specimens and therefore in an increase of the strength value.

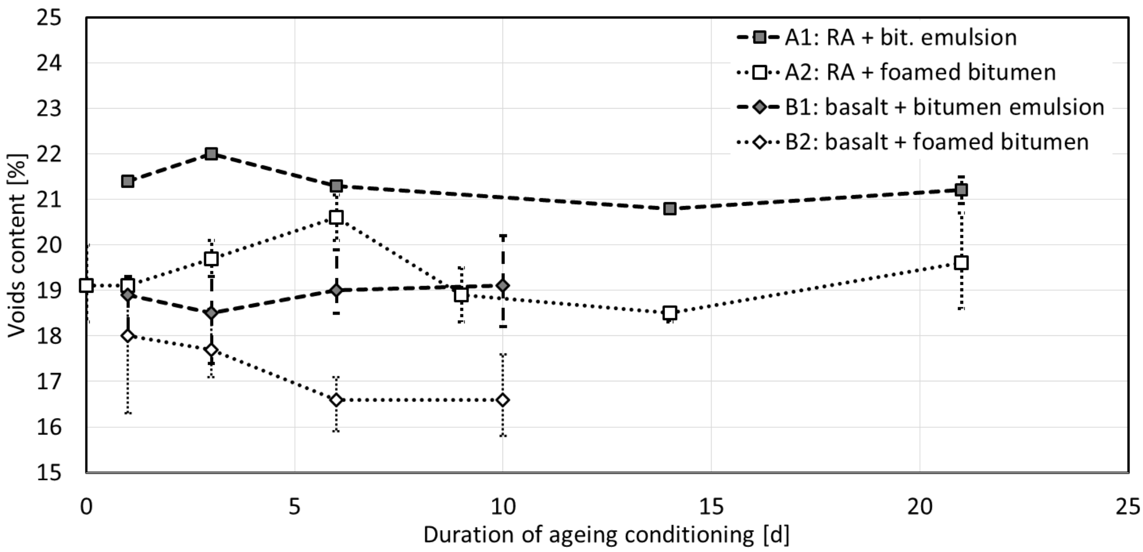


**Figure 7. Void contents of specimens compacted from cold mixtures**

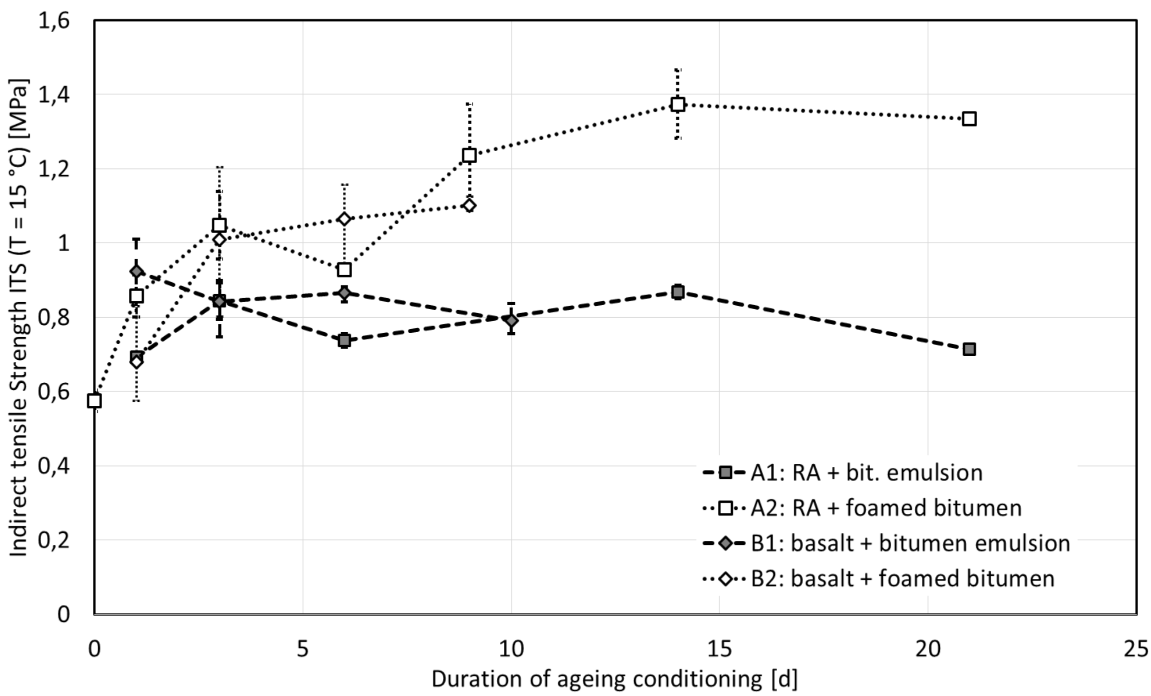


**Figure 8. Effect of ageing conditioning time on the indirect tensile strength ITS (T = 15 °C)**

## *4.3 Softening point ring and ball*

In Figure 9 the results of softening points ring and ball ($T_{R\&B}$) evaluated from the bitumen recovered from the specimens and the reclaimed asphalt after conducting the ageing conditioning.

The bitumen recovered from the cold recycling mixtures A1 and A2 indicate a very similar increase during the ageing conditioning. Starting at an initial softening point ring and ball of 62.5 °C, both mixtures indicate a parallel increase of the bitumen viscosity. After nine days of ageing, the softening point increased for 6 °C up to 68.5 °C (for sample B1). After 21 days of ageing a softening point of 74 °C is reached.

The bitumen which is recovered from the cold recycling mix specimens (samples A1 and A2) is a mixture of the bitumen of the reclaimed asphalt and the added bitumen (bitumen emulsion or foamed bitumen). In order to evaluate the source of the ageing, the mixtures with pure basaltic aggregates as well as the reclaimed asphalt (RA) was evaluated similarly.

In contrast to the cold recycling samples A1 and B1, the softening point increase of the mixtures containing pure basaltic aggregates inhibit a reduced effect of ageing. Especially the samples of the emulsion mix (B1) only indicate an increase of the softening point of about 3 °C during ten days of ageing. For the foamed bitumen mix a strong increase of the softening point at the beginning of the ageing conditioning can be observed. Though, the softening point indicate an decrease of the values between 6 and 10 days of conditioning. This divergence cannot be explained clearly, as only one mix sample was analysed by softening point ring and ball.

For the reclaimed asphalt it can be observed, that the softening point increases during the ageing conditioning from 66 °C up to 75 °C after 10 days.

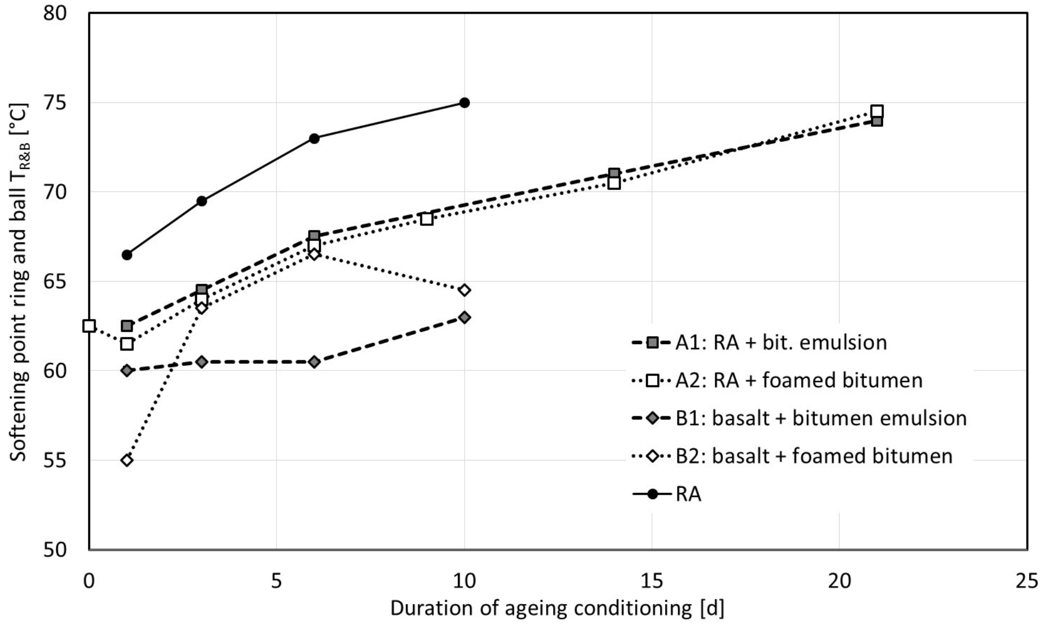


**Figure 9. T $_{R\&B}$ for recovered bitumen of cold recycling mixture**

## *4.4 Discussion*

For the indirect tensile strength, there is a clear difference between the ageing effect in emulsion mixtures (A1 and B1) and in foamed bitumen mixtures (B1 and B2). Whereas the emulsion mixtures don't show an significant effect of ageing on the indirect tensile strength, a clear strength increase can be observed in the foamed bitumen mixtures. Even the lower voids content in the foamed bitumen mixtures won't prevent the faster ageing effects. Therefore, this study confirms observations of Jenkins et al. (2008), who analysed field long term aged bitumen stabilised materials and also found increase ageing in foamed bitumen bound materials.

Interestingly, the ageing effects observed in the softening points of recovered binders doesn't comply with the indirect tensile strength test results. Here no clear difference in the ageing susceptibility could be identified between emulsion and foamed bitumen mixtures. Especially the mixtures where reclaimed asphalt was used as mix granulate (A1 and A2) show the same development of softening point ring and ball. Here, the bitumen as recovered from the cold mix is actually a mix of the fresh added binder and the RA bitumen. Obviously, the indirect tensile strength as representative of the specimens mechanical properties, are not predominantly affected by the overall bitumen viscosity. The binding character predominates the strength properties.

In the foamed bitumen mixture specimen the new binder is not evenly distributed in the mixture but concentrated on single spots between granulate particles. During ageing, these spots of fresh binder are affected by ageing and show a stiffening effect which results in an increase of indirect tensile strength values obtained.

In mixtures composed of mix granulate and bituminous emulsion, the bitumen will cover all the granulate particles evenly resulting in a good coating quality. The ageing effect which can be observed in the bitumen recovered from these specimens won't significantly affect the indirect tensile strength.

The divergence between the results of softening points of the bitumen recovered from the mixtures and the actual properties of the specimens indicate that the bitumen properties alone can't be applied for identifying the ageing susceptibility of cold recycled materials.

# 5 Conclusions

After evaluating the collected data from laboratory tests and from literature following conclusions can be drawn:

- The applied ageing procedure shows significant ageing effects in cold recycled mix specimens and can be applied for mix design.
- The ageing effects of compacted cold recycled materials are affected by the specimens void content.
- The bituminous emulsion mixtures as tested in this study are less sensitive to ageing effects compared to the analysed foamed bitumen mixtures despite of higher voids contents, which confirms observations of Jenkins et al (2008).
- The softening point ring and ball as representative of the recovered bitumen properties are not feasible to identify differences in ageing effects between cold recycling mixtures. Therefore, mechanical tests on mix specimens are necessary to identify the ageing susceptibility of these materials.
- The applied ageing procedure is feasible to evaluate the recyclability of cold recycled materials.

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