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VERSITÄT

RA activity, ageing of cold recycled mixes and multiple recycling

Sachgebiet Bau und Erhaltung von Verkehrswegen

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Background and Scope

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- **Reuse or recyclability is one of the basic requirements defined in EU construction product regulation No. 305/2011.**
- **Concurrent paving procedures (hot recycling) claim for 100 % recyclability and even long-term storage of bitumen for post-oil era**
- **Questions are raised:**
  - What is the role of RA in cold recycled material?
  - Can ageing and recycling process be simulated in laboratory?
  - What procedures are available for recycling of layers composed of cold recycled material
    - > *(Multiple) cold recycling*
    - > *Hot recycling*

Question 1: What is the role of RA in cold recycled material?

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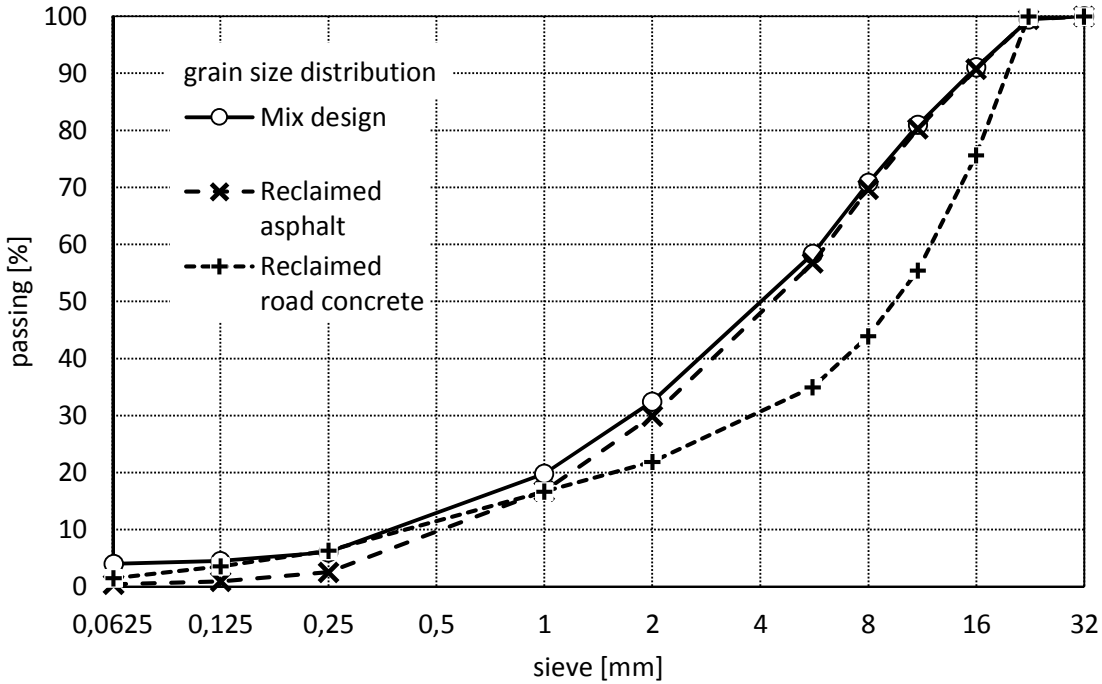
Laboratory study on the effects of various mix granulates in cold recycled material

- **3 mix granulates:**
  - Reclaimed asphalt (RA)
  - Reclaimed concrete
  - Natural aggregates (e. g. from unbound base layers)
- **Same grading**
- **Residual bitumen content: 4 %**
  - Bitumen emulsion (cationic, 60 % bitumen, 50/70)
  - Foamed bitumen 50/70; Foaming @ 180 °C, 5.5 bar, 4,5 % water
- **Active filler: 2 % Portland cement**
- **Mixing water content (total): 7.8 %**



Sample mixtures (same grading)

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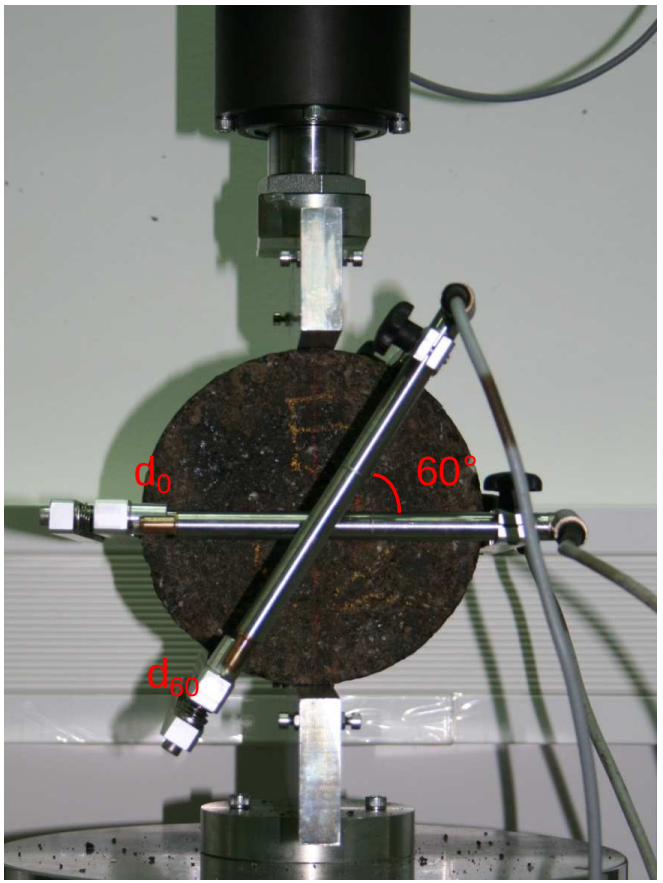
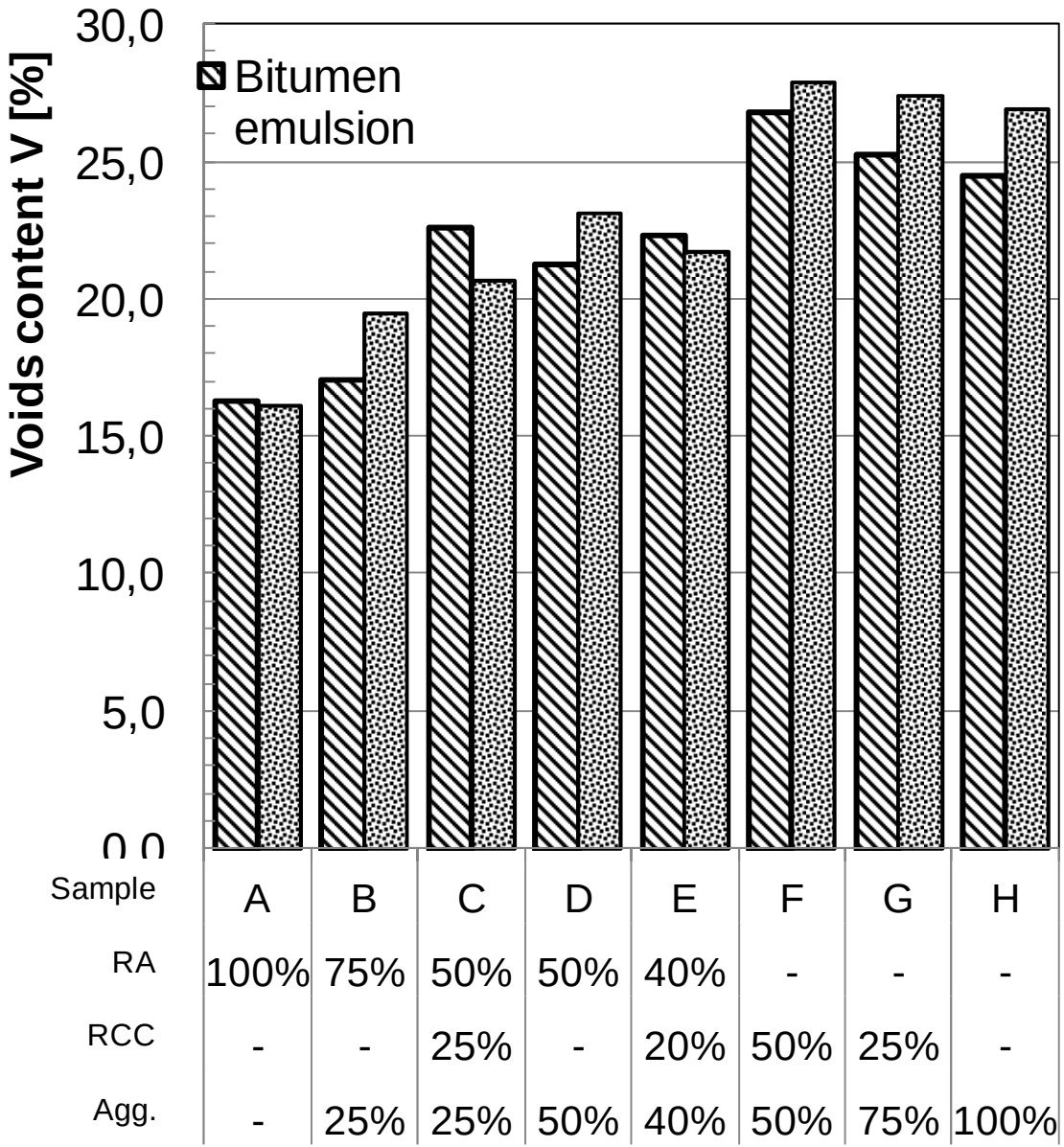
Mix variations		Reclaimed asphalt (RA)	Reclaimed road concrete (RRC)	Crushed natural aggregates (agg.)
A	100/0/0	100%	-	-
B	75/0/25	75%	-	25%
C	50/25/25	50%	25%	25%
D	50/0/50	50%	-	50%
E	40/20/40	40%	20%	40%
F	0/50/50	-	50%	50 %
G	0/25/75	-	25%	75%
H	0/0/100	-	-	100%

Laboratory tests

- **Static compaction (30 s à 45.9 kN)**
- **Specimen curing:**
  - 1 day in mould
  - 2 days demoulded @ 20 °C, 80 % humidity
  - 25 days at room conditions
- **Tests**
  - Bulk density & void content
  - Indirect tensile strength (5 °C)
  - 7 day, 28 days, 14 days in water
  - CBR dry

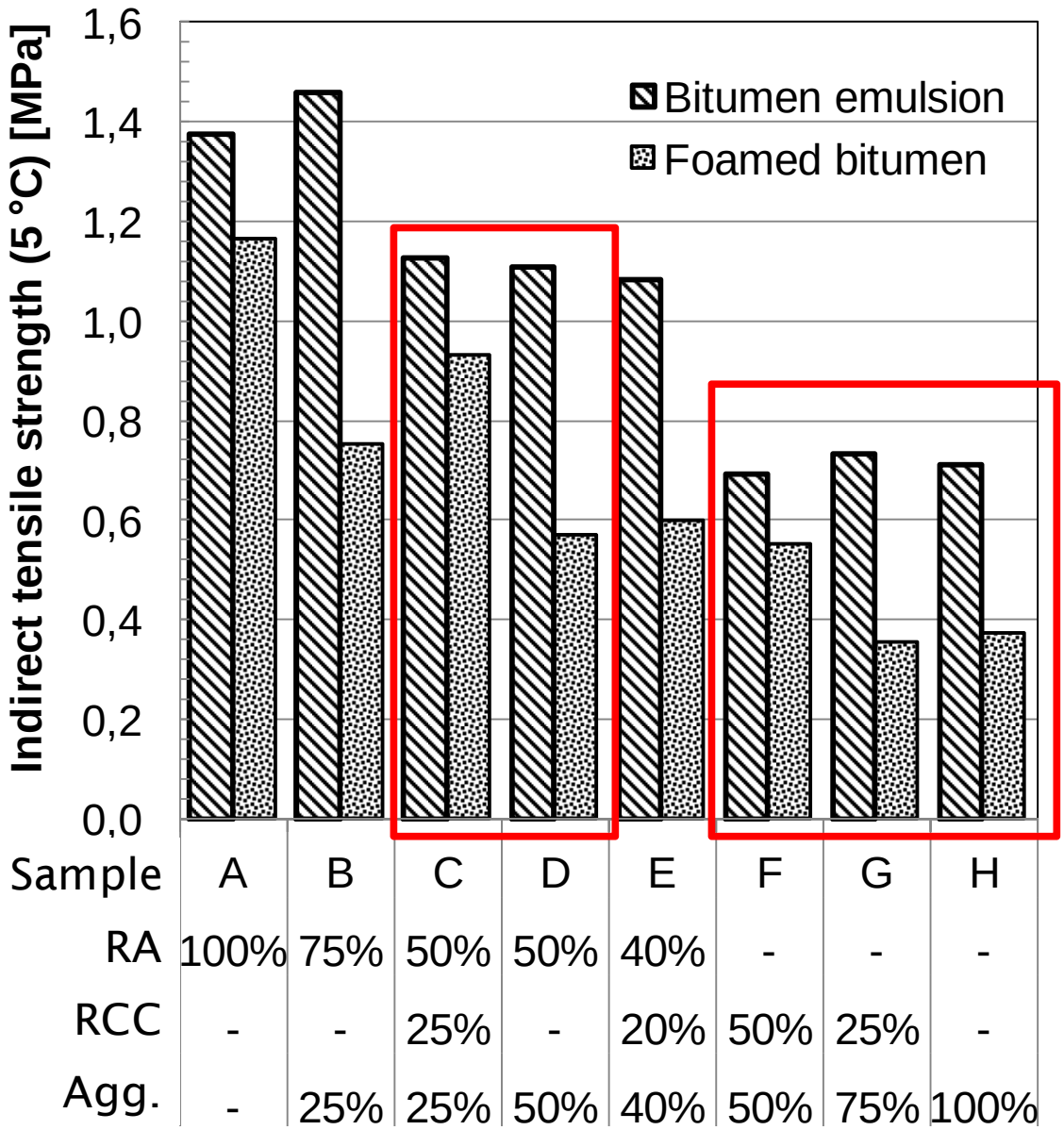


Voids content



- **Insufficient compaction (German requirement: < 15 %)**
  - Reasons:
  - Coarse mix, low fines
  - Low compaction energy
- **The higher RA content in mix granulate, the lower the void content**
  - At same grading, RA allows for better compaction
  - Similar results for emulsion and foamed bitumen mix

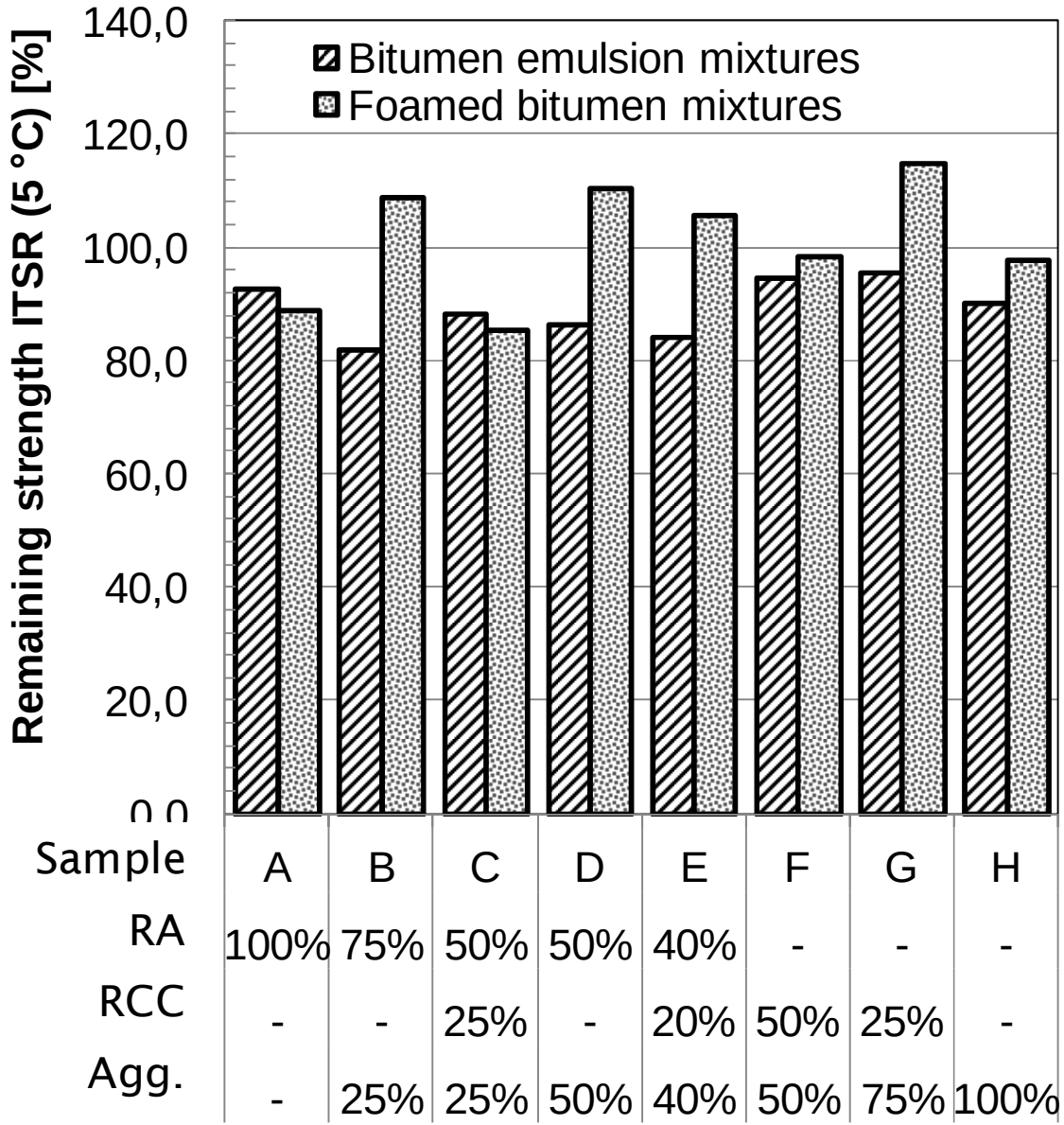
Indirect tensile strength (after 28 days of curing)



Sample	A	B	C	D	E	F	G	H
RA	100%	75%	50%	50%	40%	-	-	-
RCC	-	-	25%	-	20%	50%	25%	-
Agg.	-	25%	25%	50%	40%	50%	75%	100%

- **The higher RA content, the higher the ITS obtained**
  - Reduced voids content
  - Increased flexibility
- **RA content has stronger effect on foamed bitumen mixtures compared to bitumen emulsion mixtures**
- **Difference between crushed concrete and crushed natural aggregates at same RA content:**
  - No effect for emulsion mixtures
  - Higher RCC content results in higher ITS for foamed bitumen mixtures
- **Bitumen emulsion mixtures have higher strength compared to foamed bitumen mixtures**

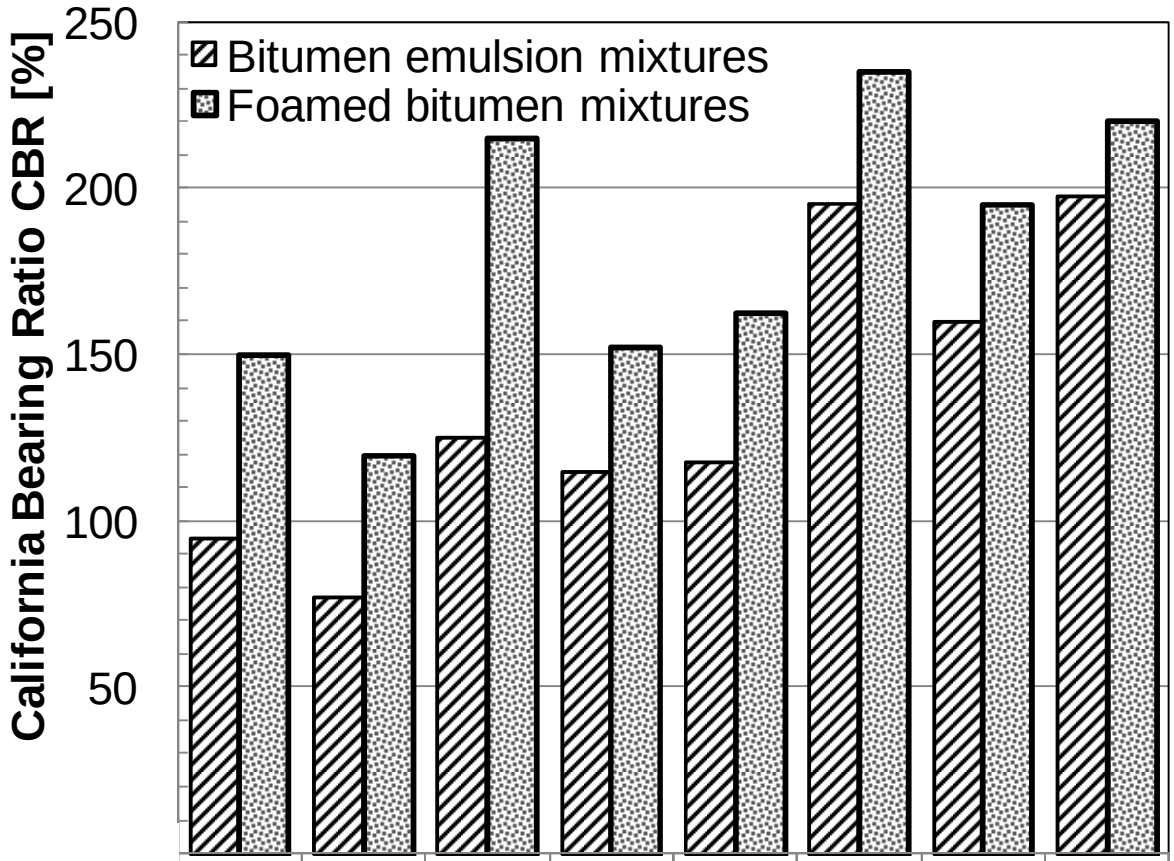
Water susceptibility (14 days @ 40 °C)



Sample	A	B	C	D	E	F	G	H
RA	100%	75%	50%	50%	40%	-	-	-
RCC	-	-	25%	-	20%	50%	25%	-
Agg.	-	25%	25%	50%	40%	50%	75%	100%

- **Applied mix design results in feasible ITSR for all samples**
- **Emulsion mixtures: Strength loss**
- **Foamed bitumen mixtures: Often strength increase observed (hydration of active binder)**

CBR as parameter for bearing capacity and resistance against permanent deformation



Sample	A	B	C	D	E	F	G	H
RA	100%	75%	50%	50%	40%	-	-	-
RCC	-	-	25%	-	20%	50%	25%	-
Agg.	-	25%	25%	50%	40%	50%	75%	100%

- **Increase of RA content will reduce CBR**
  - Increased flexibility
  - Increased viscoplasic properties
- **Foamed bitumen mixtures reach higher CBR**
  - Higher friction between granulate by discontinuous bitumen bonds

Conclusions (1) on RA activity study

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- **The content of RA controls the relevant parameters of CBSM. AN increase of RA content at same mix composition results in:**
  - Improved compactibility & decreased void content
  - Higher indirect tensile strength
  - Reduced bearing capacity and reduced resistance against permanent deformations

  Foamed bitumen mixtures are more sensitive to RA content (factor 3) compared to emulsion mixtures (factor 2)
- **Binder in RA shows active (benefitial) role in the properties of cold recycled materials**

Recyclability of layers composed of cold recycled mixtures

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The end of life characteristics of pavement materials plays an important role in life-cycle-based decisions and are therefore a basic requirement for construction works.

Two options represent recycle strategies of highest value:

- **Recycling in cold recycled mixtures**
- **Recycling in hot mix asphalt**

For the assessment of recyclability during mix design and for research, a accelerated ageing procedure is required.

Applicability of laboratory ageing procedures on cold recycled materials

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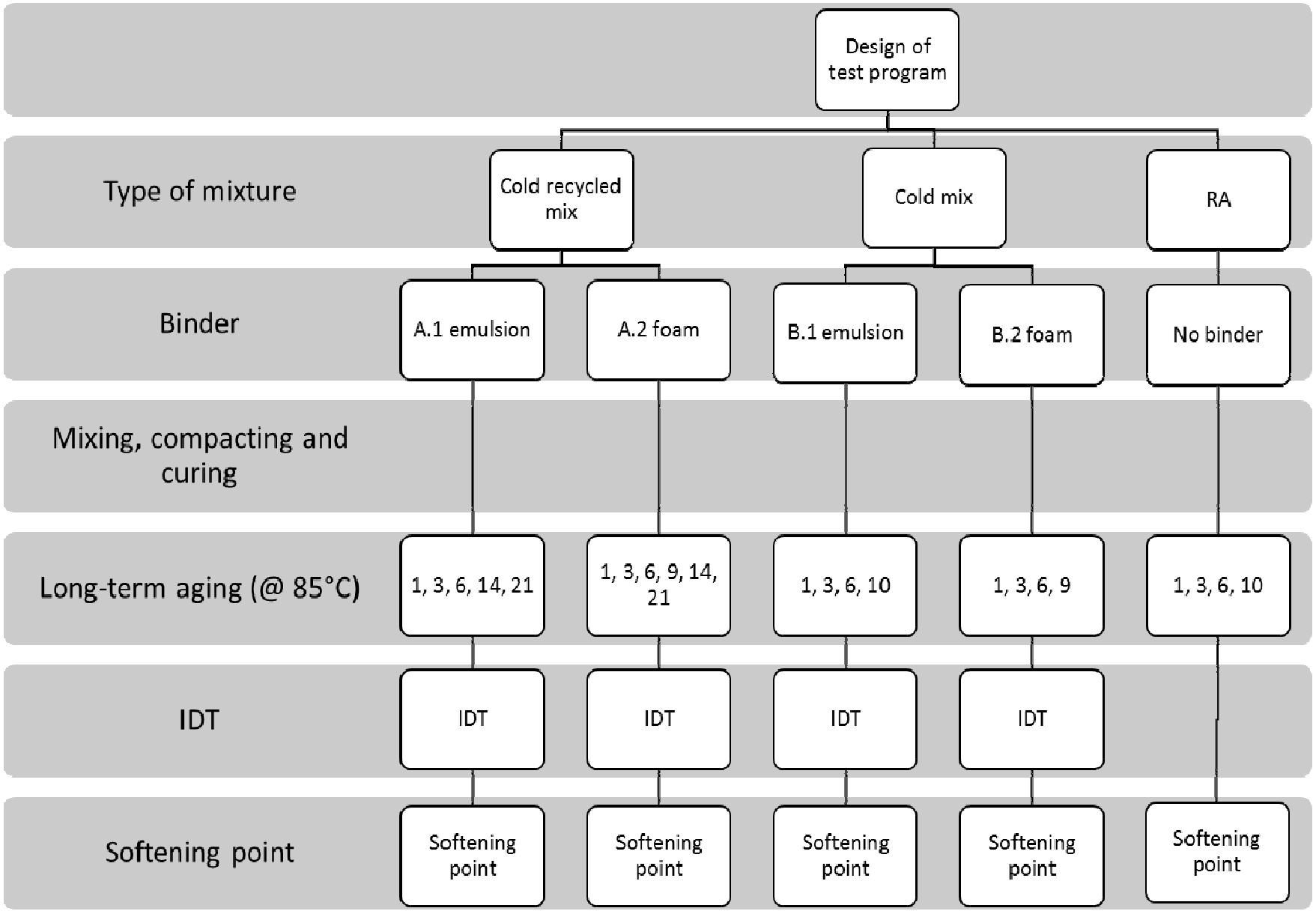
Adoption of hot-mix asphalt ageing procedure (applied during Re-Road project) and specified in TS EN 12697-54

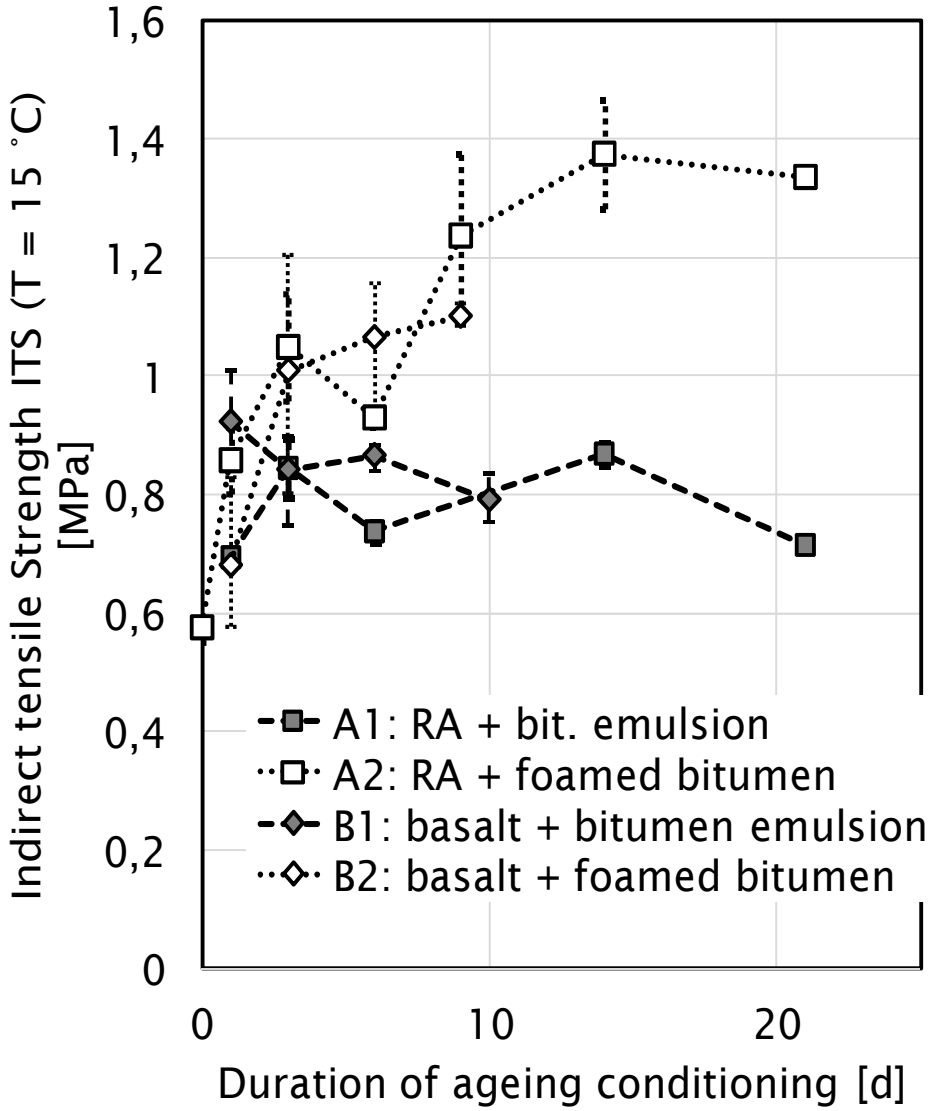
- **Oven ageing of compacted specimens at 85 °C**
- **Assessment of ageing effects by**
  - Analyses on extracted bitumen (here $T_{R\&B}$)
  - Mechanical tests on aged specimens (here: ITS)

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 %			
Voids content of specimens	21,3±0,6	19,4±1,3	18,9±1,4	17,2±1,7

Design of ageing experiment



Ageing effects on ITS



- **Mixtures with foamed bitumen (A2 and B2) show a strong increase of ITS during ageing.**
- **Ageing doesn't affect the ITS results obtained on bitumen emulsion mixtures (A1 and B1)**
- **No difference in ITS effects can be observed for RA or pure aggregates mixtures**

Conclusions (2) on laboratory ageing procedure

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- **Aging procedure according to TS EN 12697-54 is applicable for cold recycling mixtures**
- **Bituminous emulsion mixtures are less sensitive to aging effects compared to foamed bitumen mixtures.**
- **This effect is confirmed by Jenkins et al. (2008) where recovered bitumen was tested from field investigation on long term aged BSM. No clear statements to aging behavior could be given but that foamed bitumen mixes seemed to be more susceptible to aging.**

End-of-life properties of cold recycled materials

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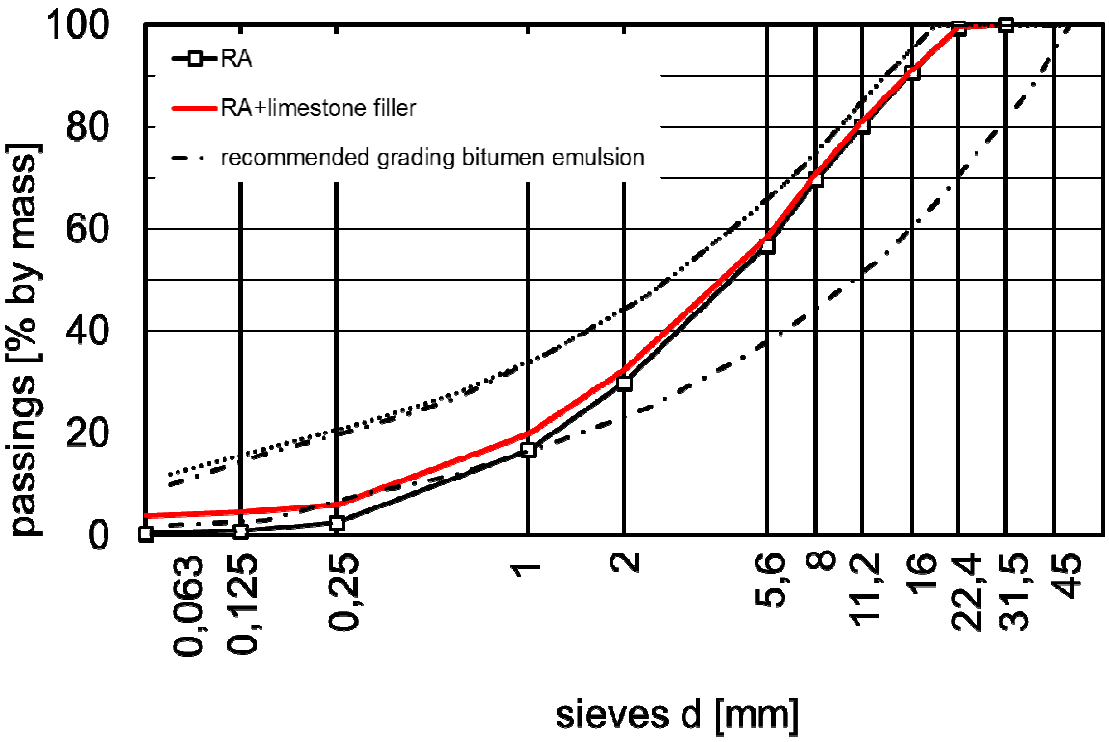
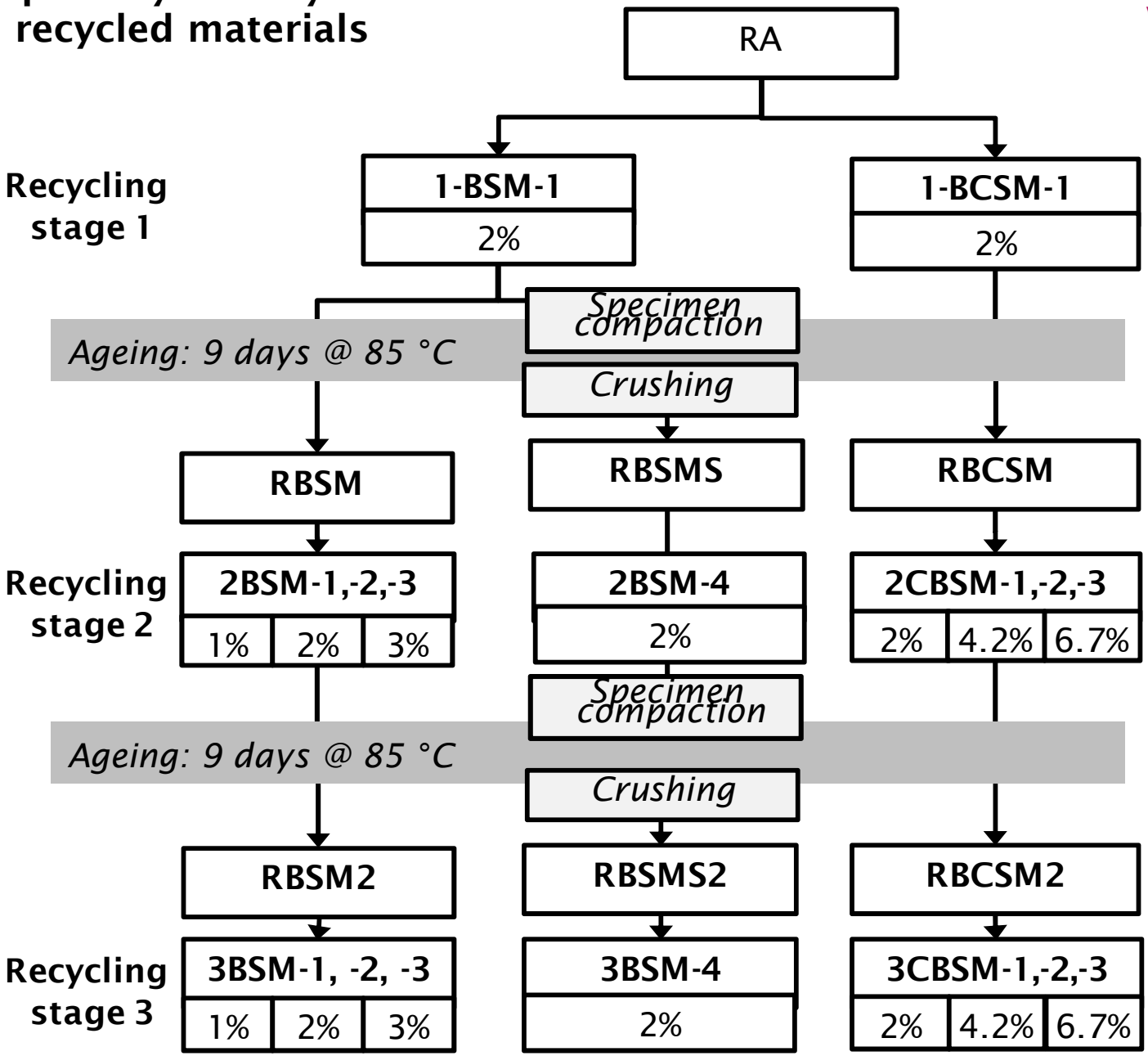
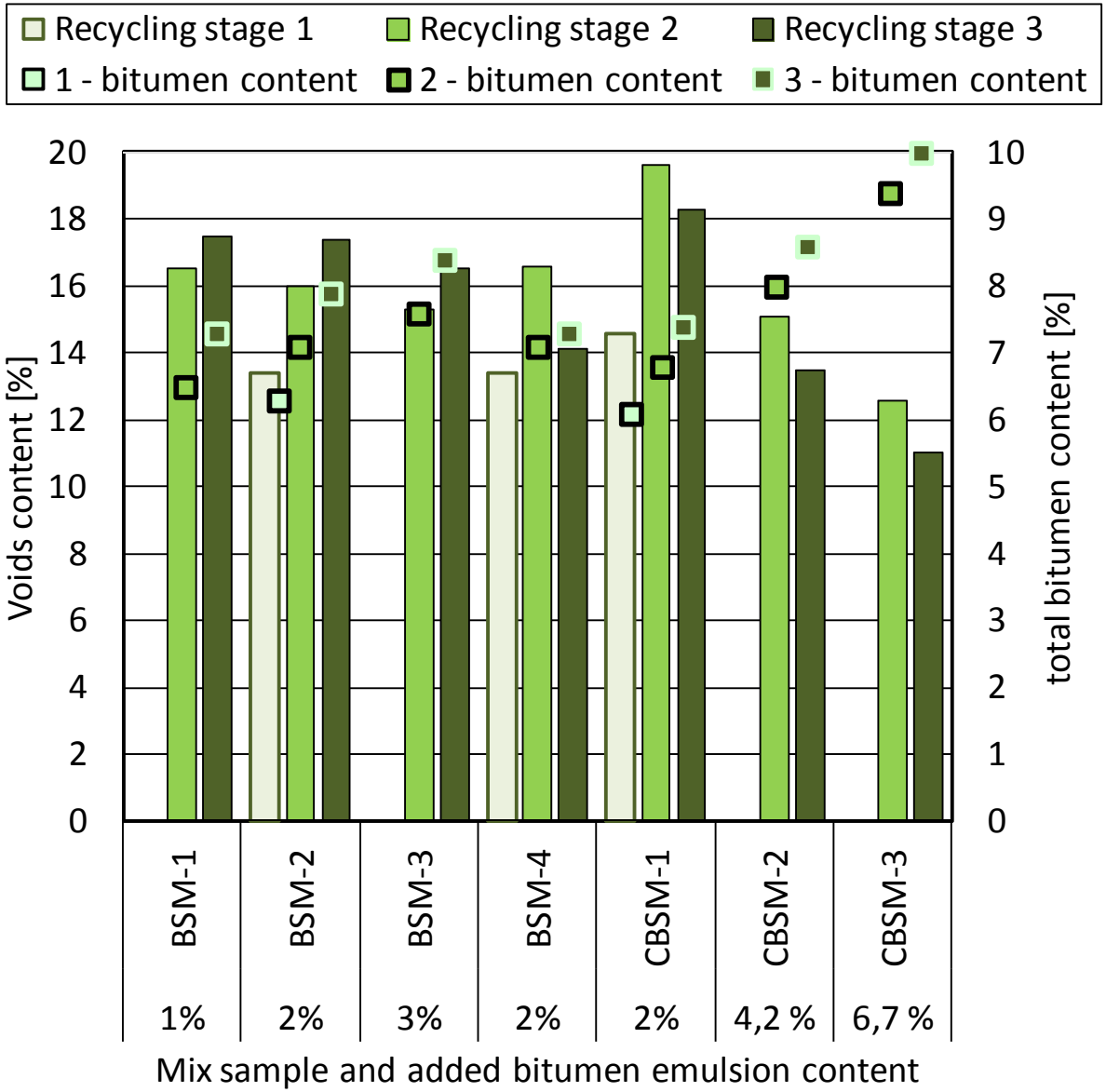
- **Multiple recycling study:**
  - Bitumen stabilised material BSM (low bitumen content; no cement)
  - Bitumen-cement stabilised material BCSM (medium bitumen content; 3 % cement)
  - Use of emulsion mixtures only
  - Simulation of 3 recycling cycles



Multiple recyclability of cold recycled materials

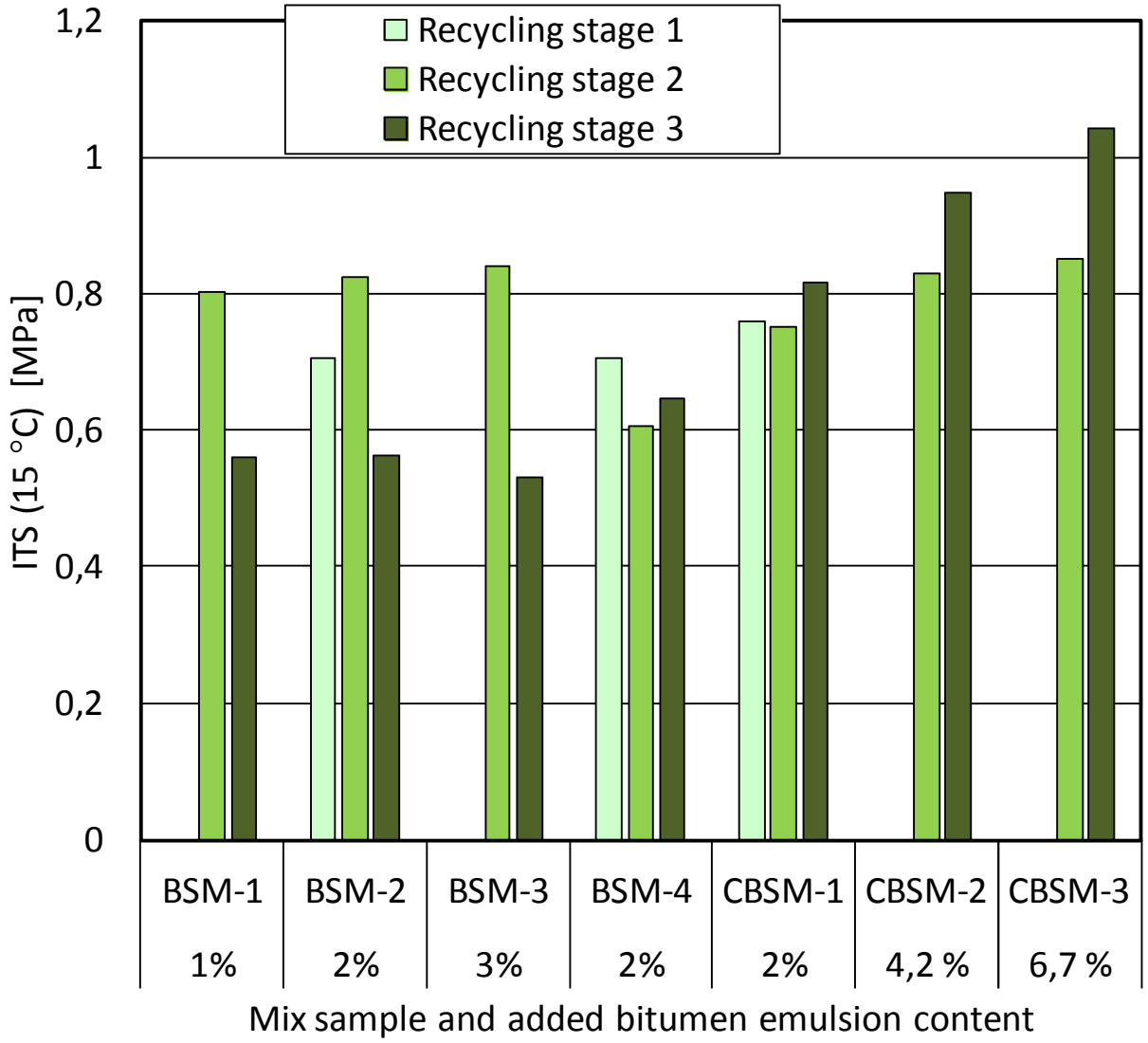


Multiple recyclability of cold recycled materials



- **Increase of bitumen emulsion content:**
  - improved compactibility
  - Reduced void content
- **Effect of multiple recycling:**
  - BSM: increasing voids content
  - CBSM:
    - > *decreasing void content*
    - > *Excessive increase of total binder content*

Multiple recyclability of cold recycled materials



- **Increase of bitumen emulsion content on ITS:**
  - BSM: no significant effect
  - CBSM: significant increase of strength
- **Effect of multiple recycling:**
  - BSM: strength increase in 2nd but decrease in 3rd recycling stage
  - CBSM: increasing strength during multiple recycling

Recyclability in hot-mix asphalt

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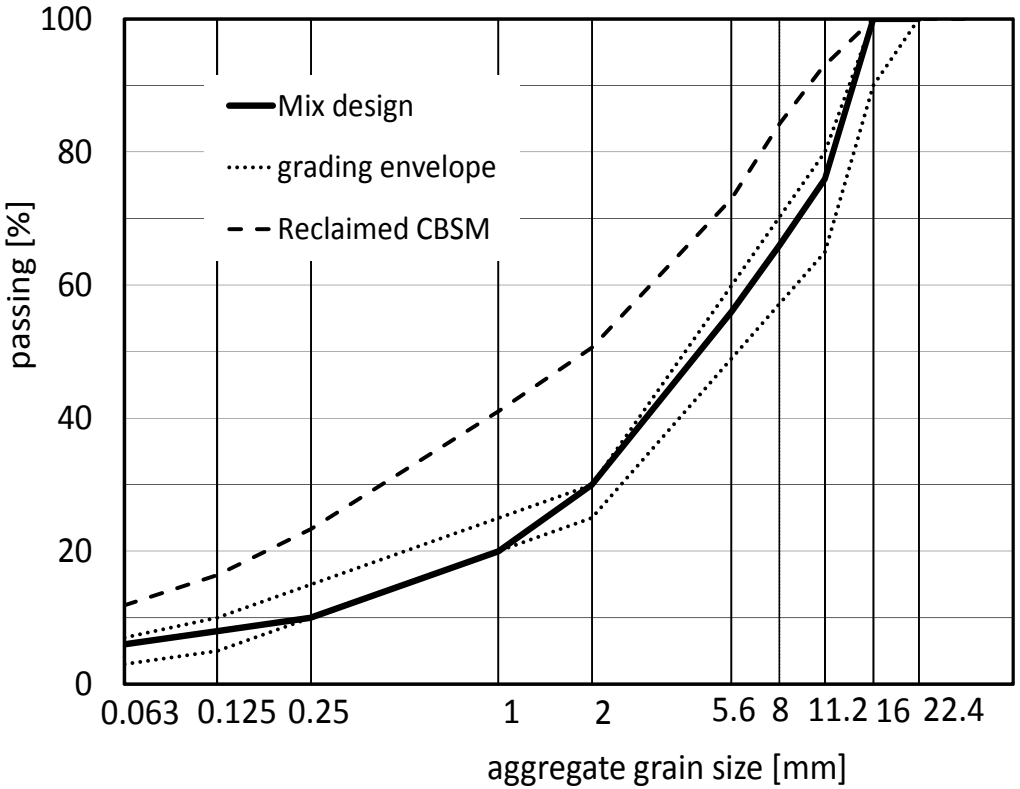
Hot-mix asphalt material: AC 16

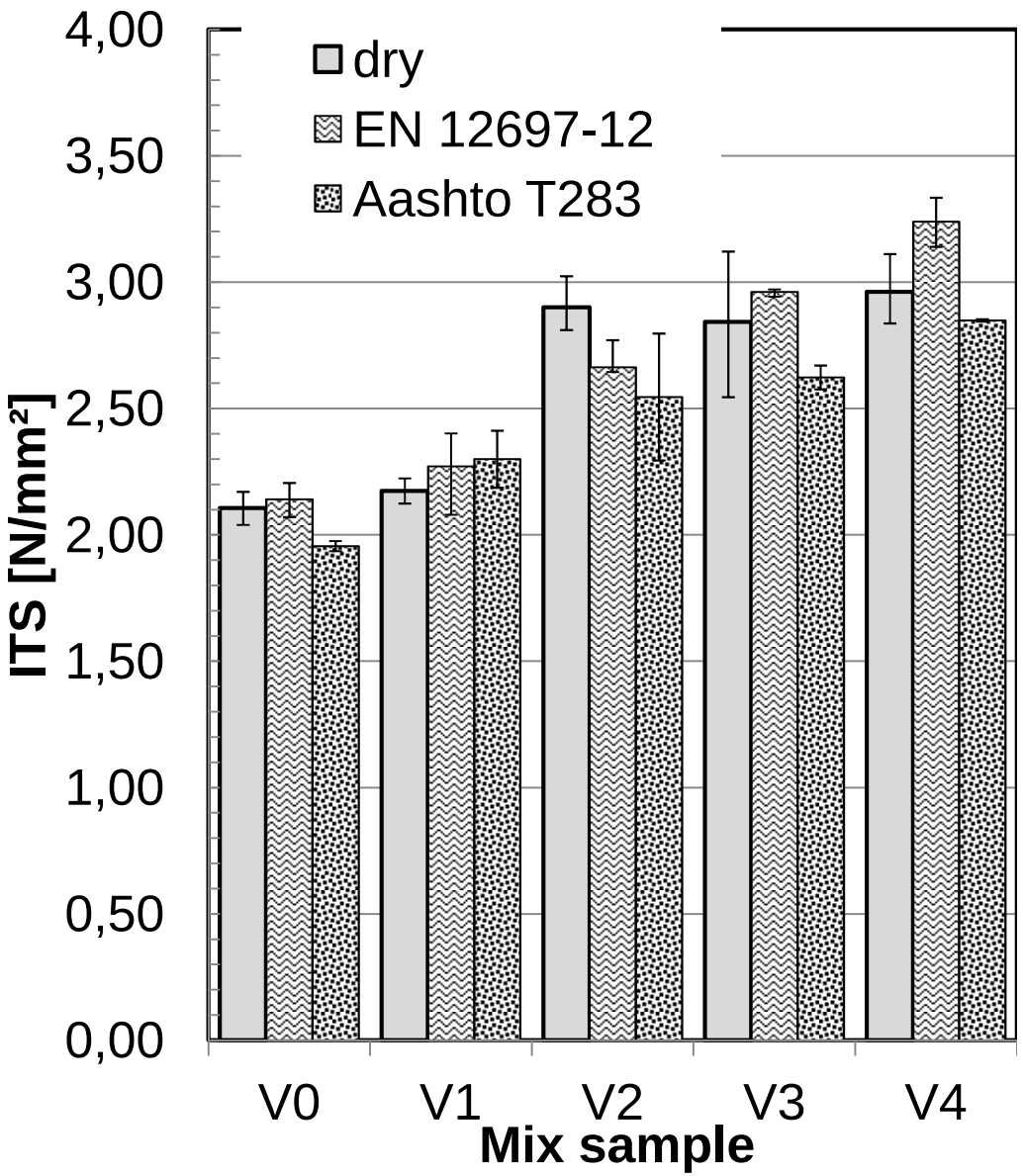
- Design bitumen content: 4.6 %
- Addition of 0 %, 15 % and 30 % of artificially aged CBSM
  - 95 % RA sampled from stockpile, 5 % fines
  - 2 % bit. emulsion, 3 % cement
  - Marshall compaction
  - Ageing 10 days @ 85 °C
  - Manually crushing of aged specimens
- Evaluation of CBSM binder activity vs. black rock theory



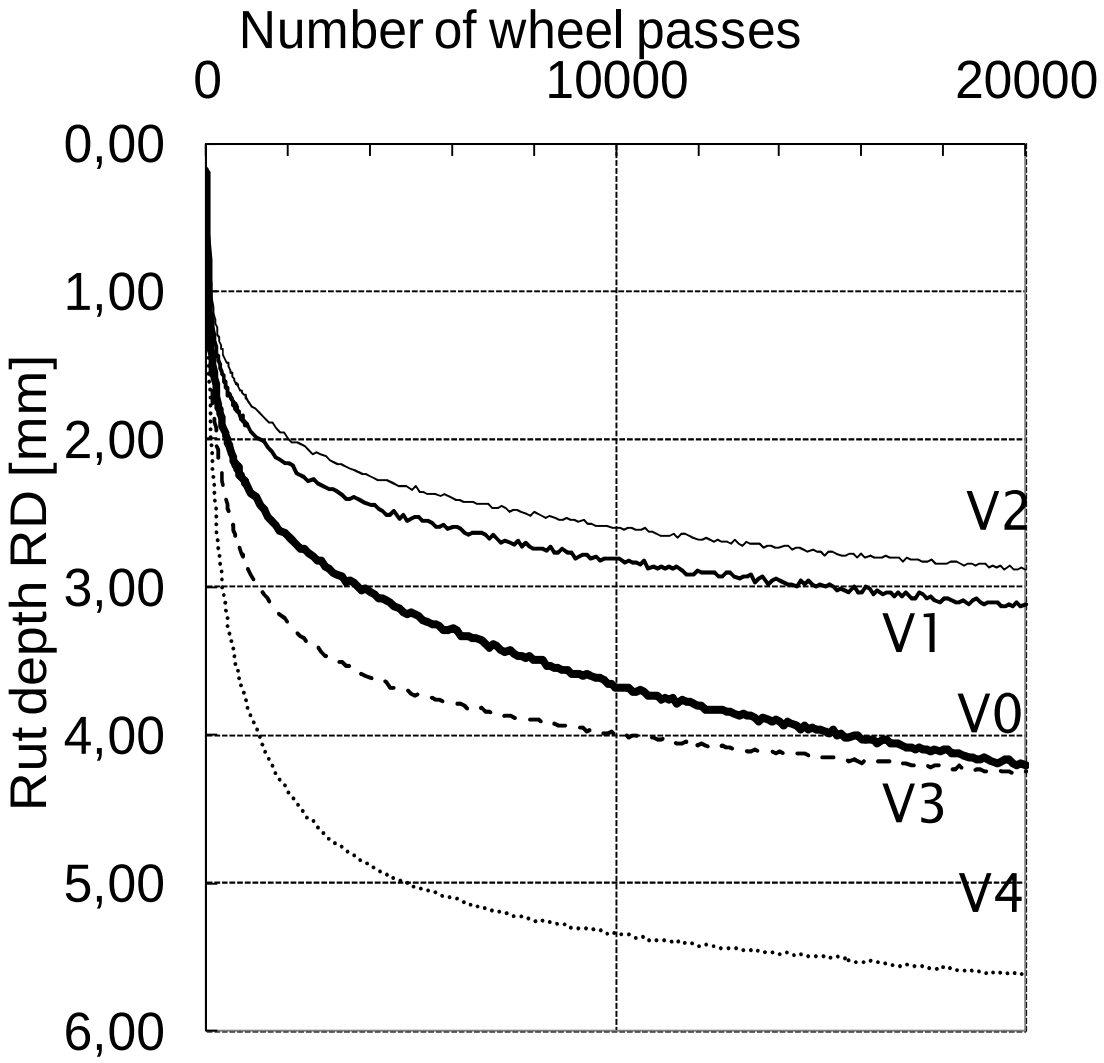
Sample Mix	RCBSM content	Content of added bitumen (50/70)	Content of RCBSM bitumen	Total bitumen content
V0	0%	4.6 %	0 %	4.6 %
V1	15%	3.8 %	0.8 %	4.6 %
V2	30%	3.0 %	1.6 %	4.6 %
V3	30%	3.8 %	1.6 %	5.4 %
V4	30%	4.6 %	1.6 %	6.2 %

Hot recyclability: ITS (15 °C)

- **Marshall-compacted specimens**
- **Water sensitivity – conditioning methods:**
  - Dry,
  - water saturated (40 °C, 72 h),
  - Aashto T283 - Frost-Thaw cycle: (-16 °C; +60 °C)
- **Results:**
  - Increasing ITSdry with increasing RA content
  - No significant effect of specimen conditioning (durability)

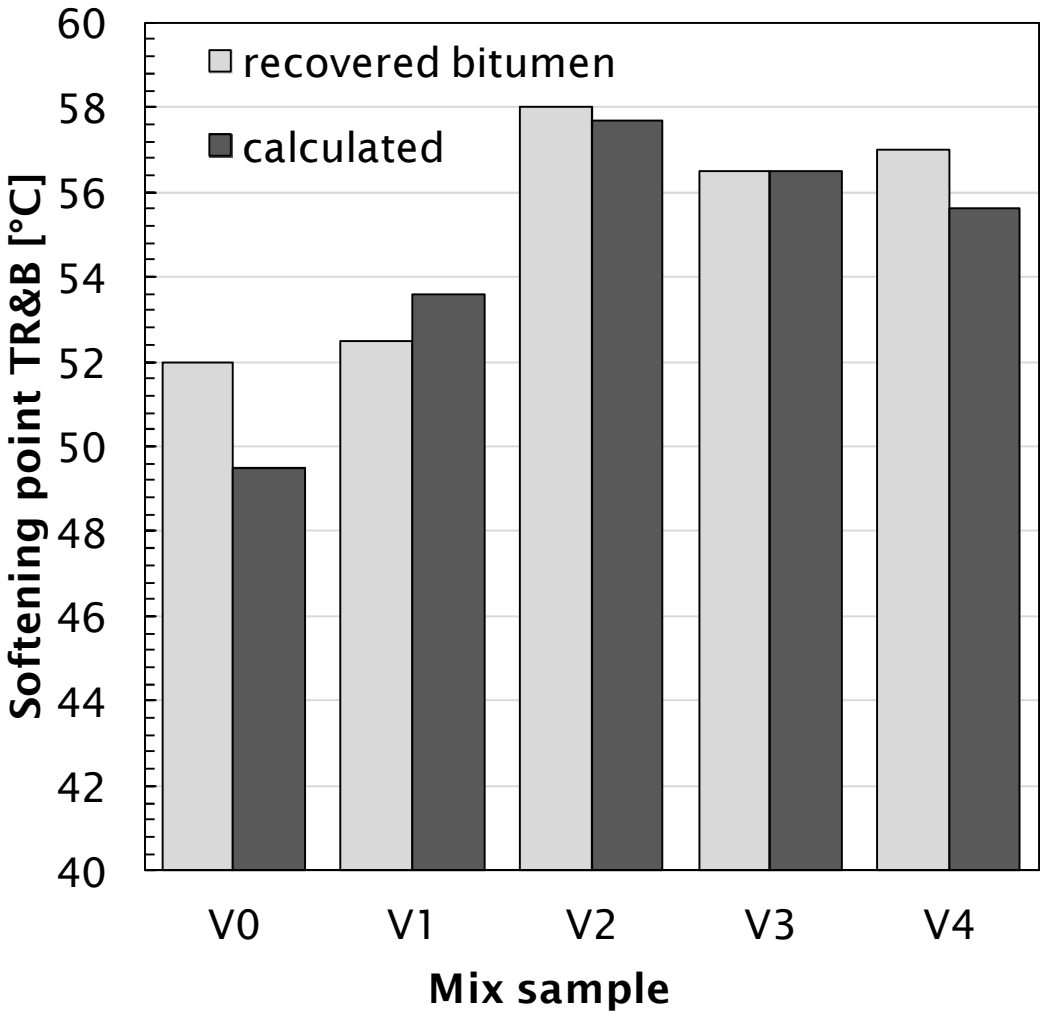


Rutting resistance: Wheel tracking tests



- **Addition of 15 % RA (V1) and 30 % RA (V2) will reduce rutting susceptibility, when less added binder is used**
- **Addition of 30 % and increase of added bitumen (V 3 and V4) will result in increased rutting**
- **Bitumen in reclaimed CBSM can be reactivated during hot recycling**

Softening point $T_{R\&B}$ of recovered bitumen



- **Viscosity mixing law acc. EN 13108-8:**
  the resulting viscosity can be calculated from the viscosity of added binder and the viscosity of the binder in RA:

$$T_{R\&B\ mix} = a \times T_{R\&B\ 1} + b \times T_{R\&B\ 2}$$

- **Comparison between calculated and recovered TR&B shows applicability of mixing law**
- **Reclaimed BCSM can be considered as uaul „RA“ in HMA mix design**

Conclusion (3) on recyclability of cold recycled materials

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- **Layers of cold recycled materials can be recycled both by cold recycling as well as hot recycling**
- **For cold recycling:**
  - the resistance against permanent deformation shall be evaluated in order to avoid mixtures with excess of total bitumen content.
  - For BSM, at least 2 recycling cycles can be reached
- **For hot recycling:**
  - Sample mix design procedures applicable as for RA originating from hot mix asphalt
    - *Reactivation of RA binder*
    - *application of mixing formula for resulting binder viscosity*
  - Cement included in the cold recycling mixture doesn't interfere with the recyclability of the bitumen.
  - Providing suitable aging properties, the bitumen "stored" in cold recycled mixtures can be recovered and reactivated again during hot recycling process.
- **For warm recycling:**
  - Applicability of warm recycling with 2 additives was shown in a lab study

Thank you very much for your attention!

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