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Hrvatsko asfaltersko društvo

Croatian asphalt association

Simuliranje višestrukog recikliranja asfalta proizvedenog po vrućem postupku

Simulating repeated recycling of hot mix asphalt

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International seminar ASPHALT PAVEMENTS 2018

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OUTLINE

- History of asphalt pavement recycling
- Simulation of repeated recycling
- Change of aggregate properties
- Change of binder properties
- Change of hot mix properties
- Conclusions

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HISTORY OF ROAD RECYCLING

Phase 1 : poor road network

new roads >> reconstructions

(Switzerland 1950, developing countries 2017)

Phase 2 : good road network

new roads ≤ reconstructions

(Switzerland 1980, eastern Europe 2017)

Phase 3 : road network "complete"

new roads << reconstructions

(Switzerland, Japan 2017)

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ROAD RECYCLING TODAY

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Switzerland

>50% of reconstruction takes place in the surface layer

0 .. 30% of RAP is allowed in new surface courses

⇨ ca. 80% excess RAP from surface courses every year

- in base layers up to 60% RAP is allowed

EXCESS RAP

How to reduce the RAP stockpiles

- increase the RAP-amount in all pavement layers
- use as unbound material (restricted in Switzerland)
- separate the binder from the stones and use the cleaned aggregates

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SIMULATION IN THE FIELD

How to simulate repeated recycling?

2024	2030	2036
1. Reconstruction	2. Reconstruction	3. Recon
pavement	pavement	
1. Cycle	2. Cycle	3. Cycle

pavement

Not applicable:

Time, change of material, traffic, climate

SIMULATION IN THE LABORATORY

Is the simulation possible in the laboratory?

- mineral aggregates: damage by milling/crushing difficult to simulate in the laboratory

- binder aging
  - in the field aging takes too much time
  - ⇨ simulated aging from new asphalt mix to produce artificial RAP in the laboratory

⇨ ⇨ Simplified approach for multiple recycling by separating

⇨ the effects of mineral aggregates and binder

SIMPLIFIED APPROACH

1. Simulation of aggregate damage in the field

   only one recycling cycle possible because of practical reasons

2. Simulation of binder damage in the laboratory

   production of RAP hot mix asphalt (HMA) with “identical” properties

At which recycling content does the repeated recycling becomes relevant?

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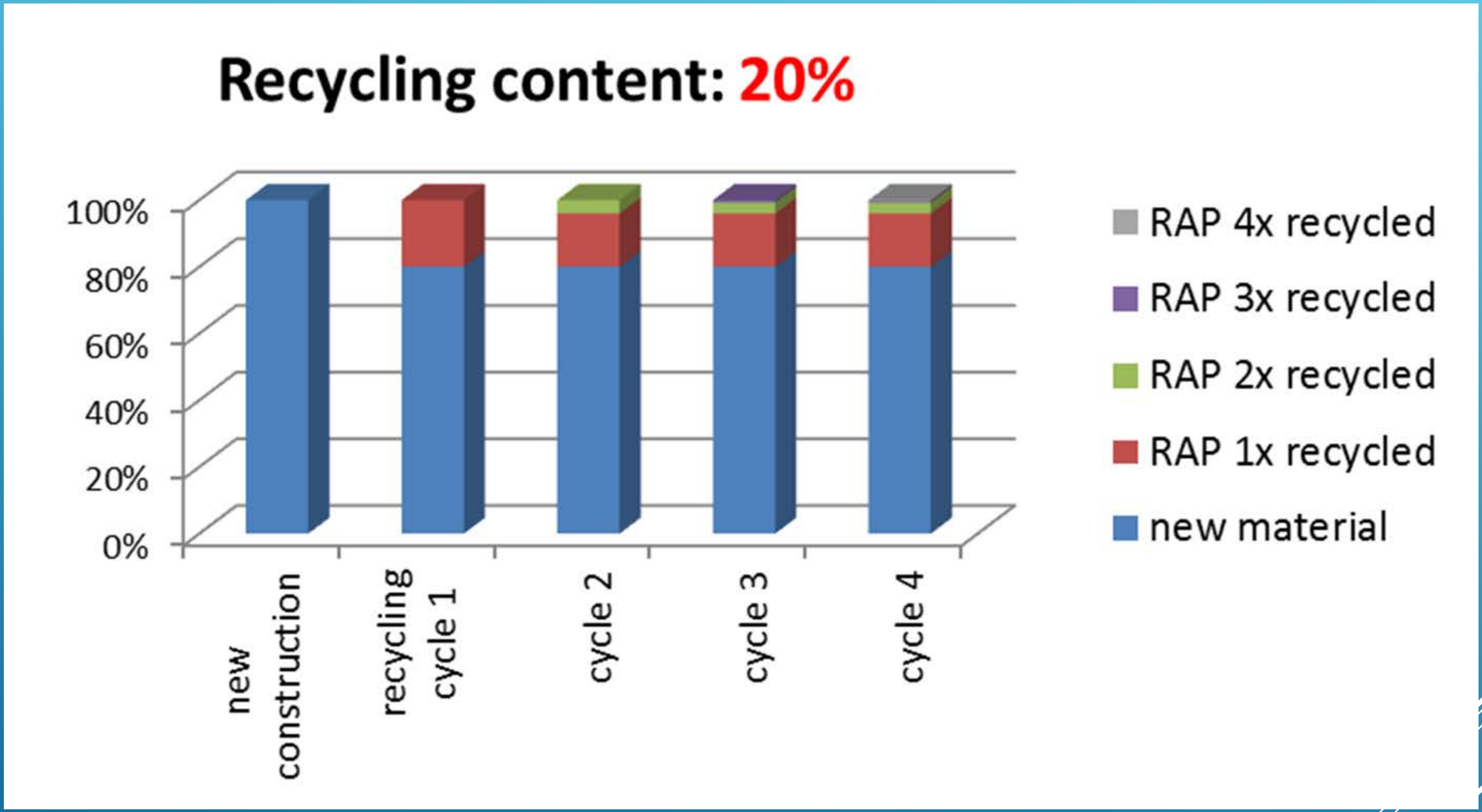
IMPACT OF REPEATED RECYCLING

Influence of RAP at **20%** recycling content



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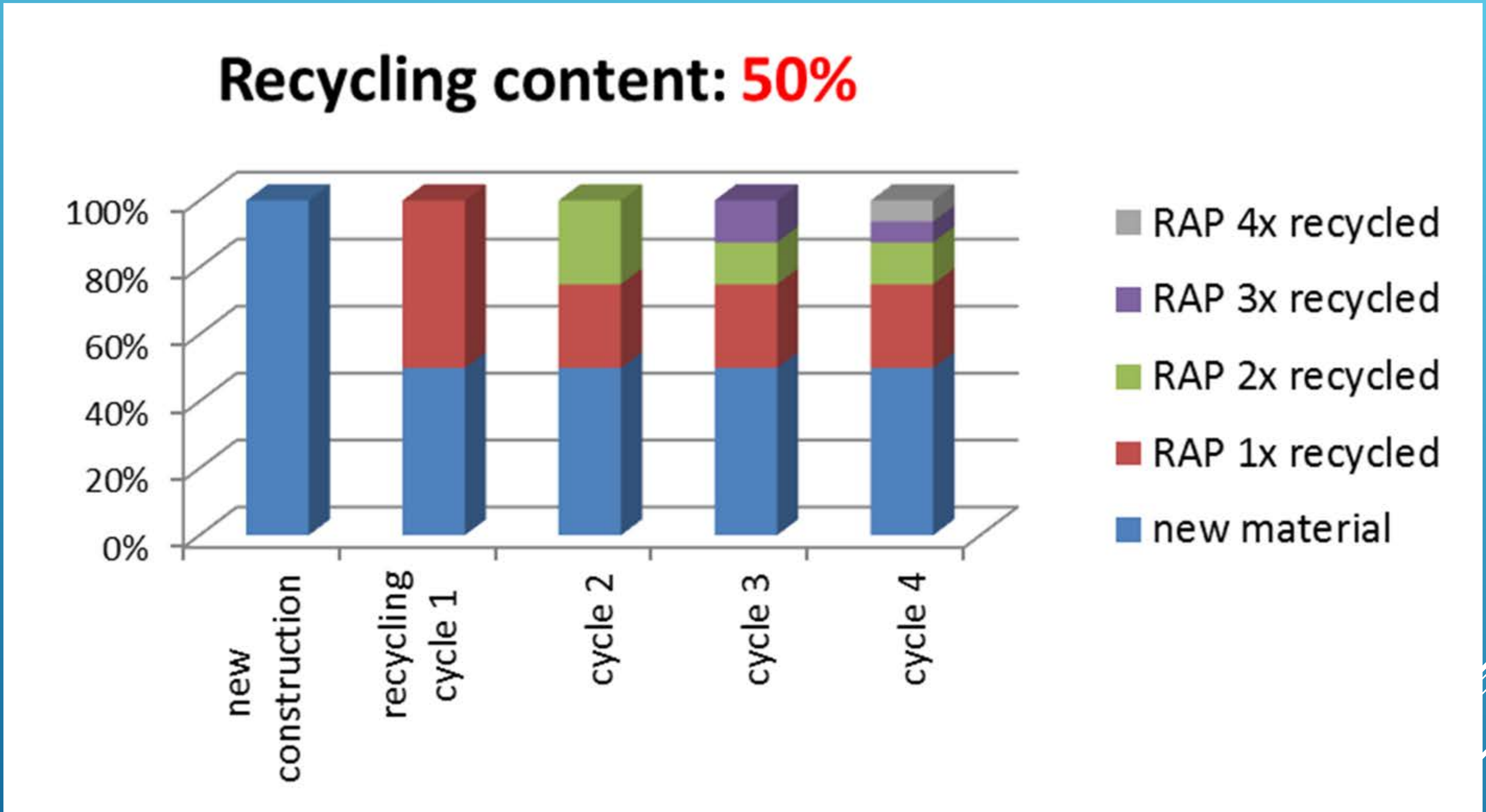
IMPACT OF REPEATED RECYCLING

Influence of RAP at **50%** recycling content



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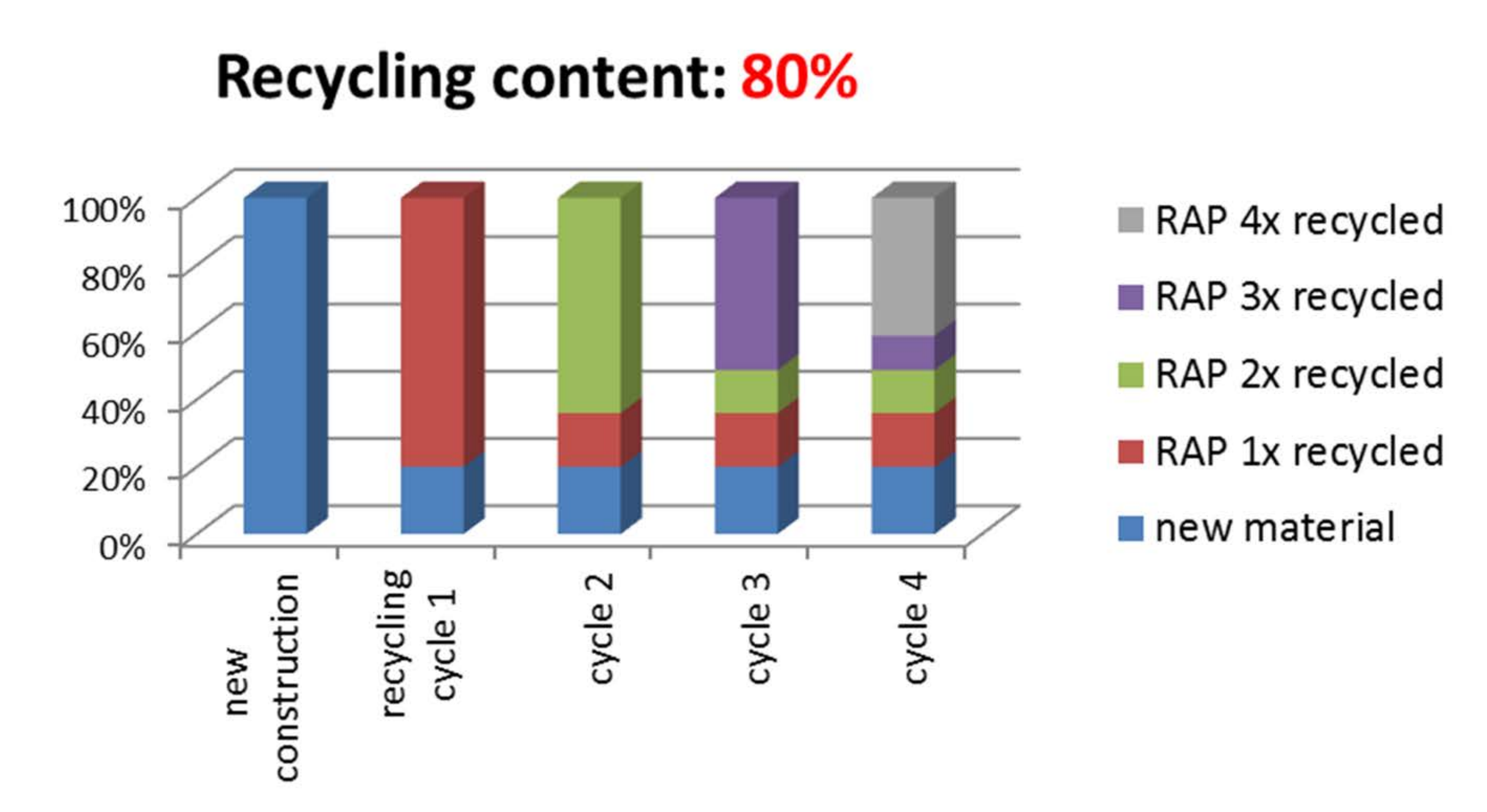
IMPACT OF REPEATED RECYCLING

Influence of RAP at **80%** recycling content



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CHANGE OF AGGREGATES

Test field with a 2-layer pavement

- 35 mm surface course AC 11 N
- 65 mm base layer AC T 22 N
- Milling in 3 layers
- in base layers up to 60% RAP is allowed

RAP base layer

RAP surface layer

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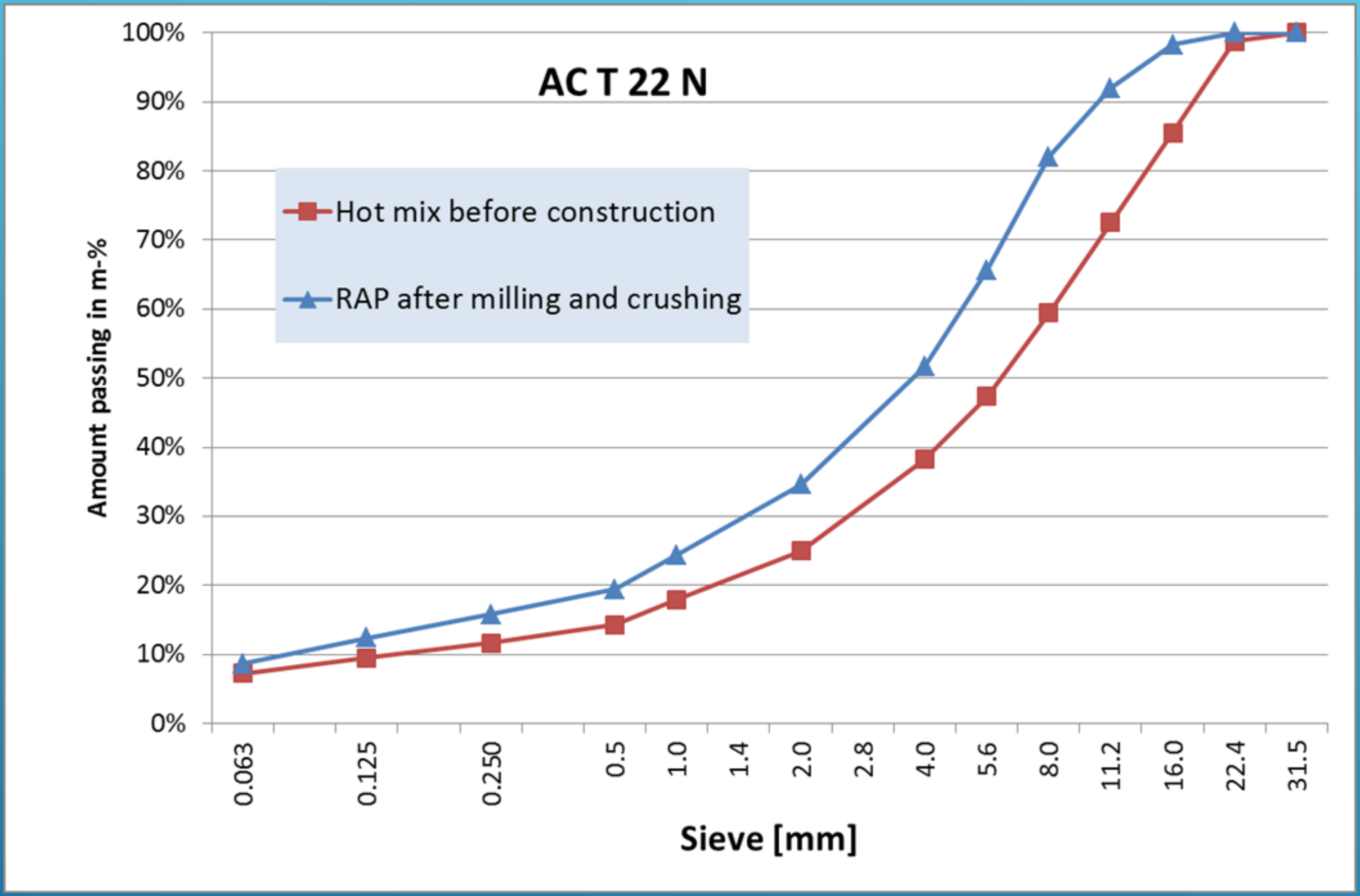
CHANGE OF AGGREGATE SIZE

Base layer AC T 22 S



- 0/22 mm changes into 0/16 mm after milling/crushing
- formation of fine particles < 0.5 mm is small

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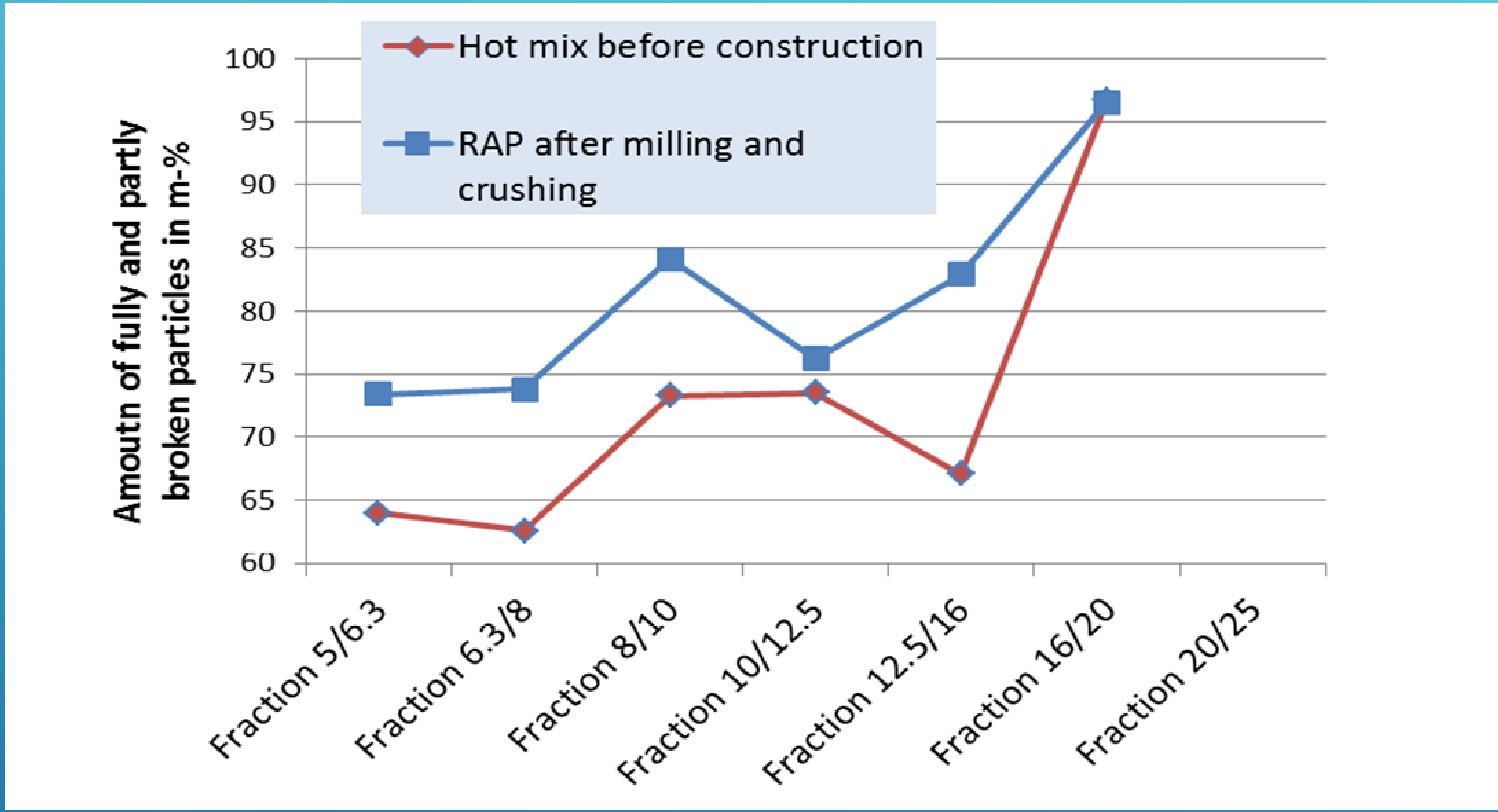
CHANGE OF PARTICLE FORM

Broken versus round aggregates



1. Percentage of broken particles increased
   - damage of particles (cracks, brittleness) was not investigated

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CHANGE OF MIX PROPERTIES

Reconstruction of the original hot mix:

- 60% of RAP
- 40% of natural aggregates (different source) to construct the same aggregate size distribution
  ⇨ mainly addition of coarse aggregates
- binder of the RAP didn’t age significantly due to the short time (1 year) in the field (Pen 40 0.1 mm)

What are the differencies?

- less percentage of round aggregates
- binder composition is less homogeneous

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REPEATED RECYCLING

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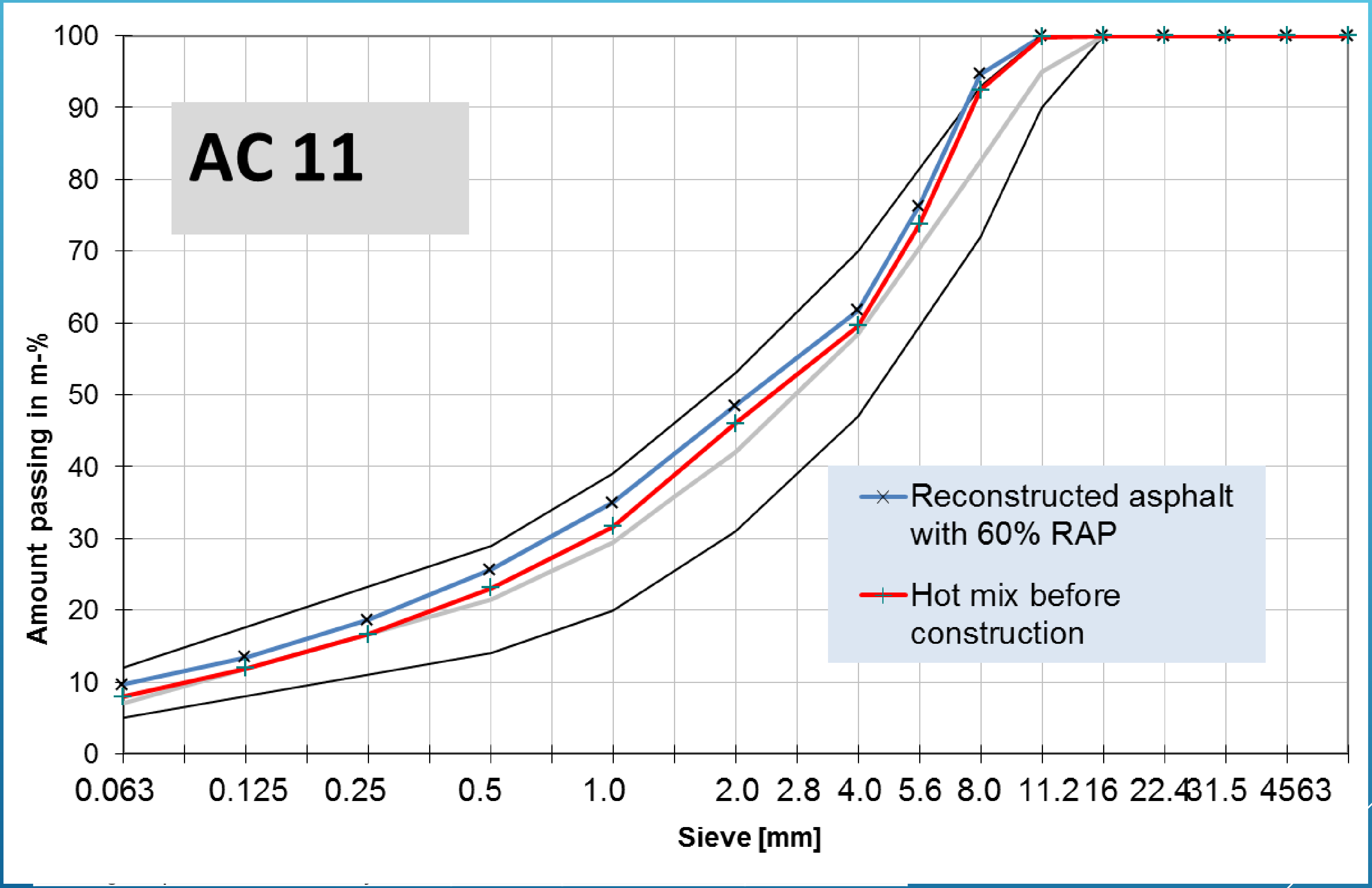
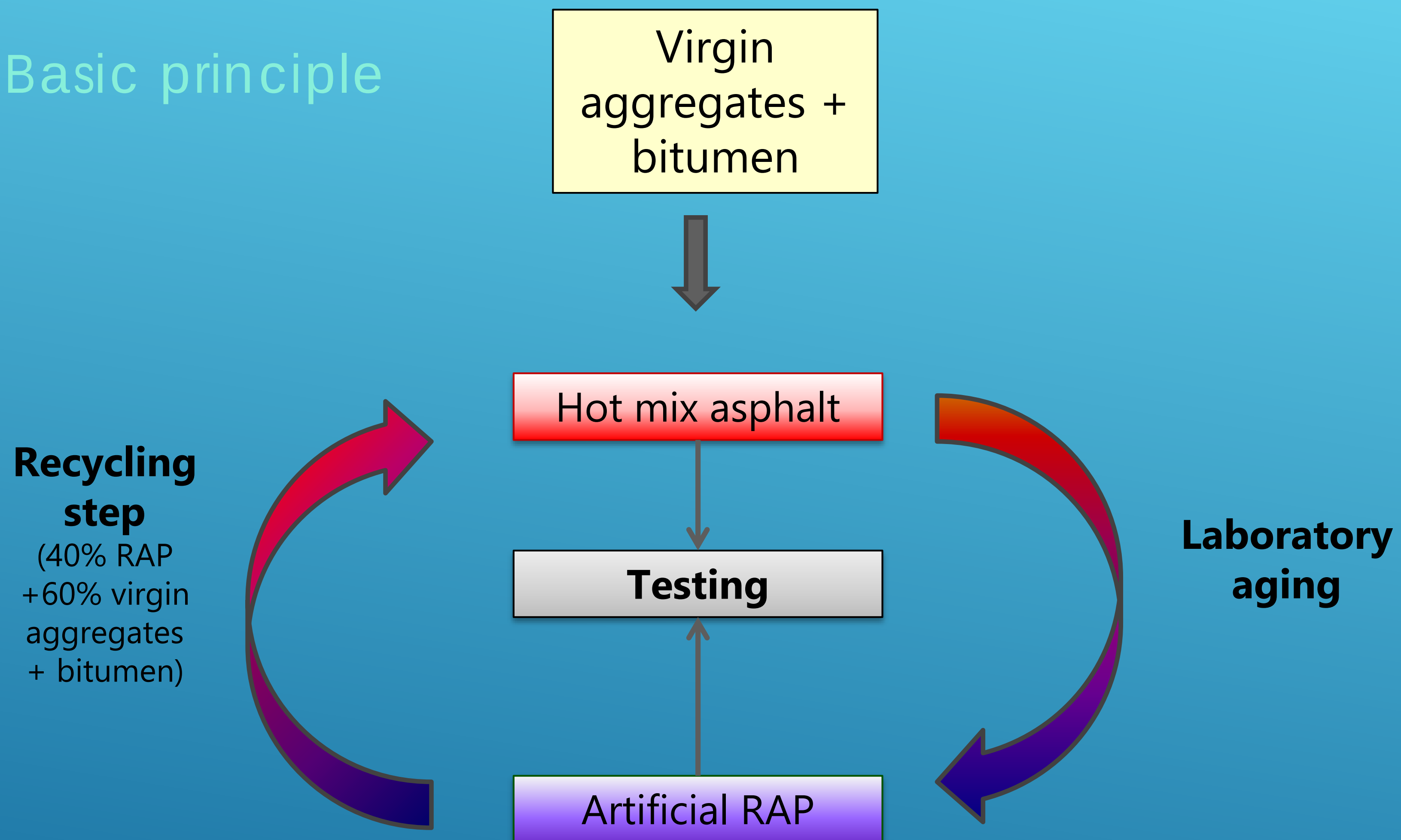
Reconstructed hot mix AC 11 with 60%-RAP



CHANGE OF BINDER PROPERTIES

Basic principle



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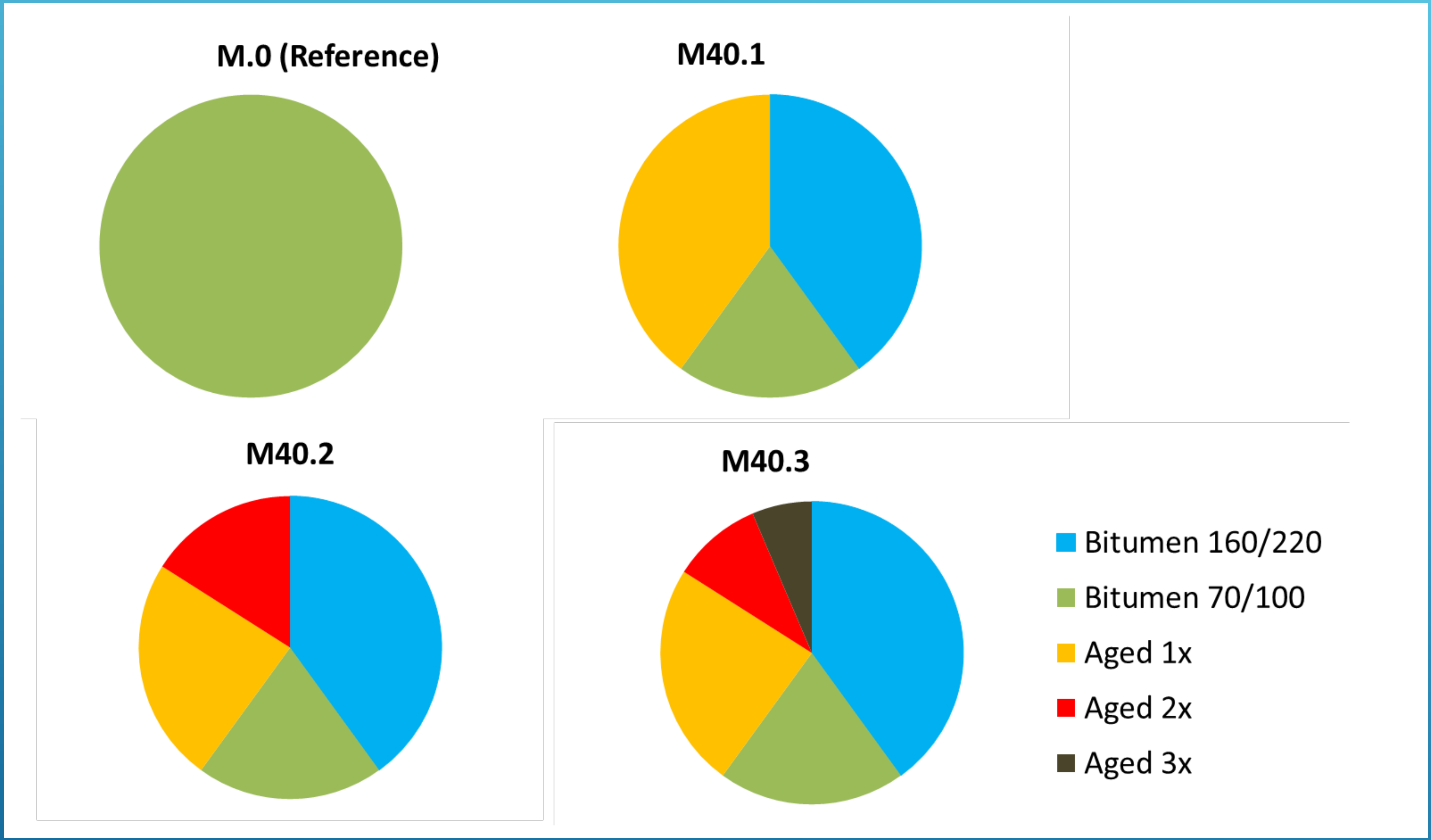
CHANGE OF BINDER COMPOSITION

1. Simulation with 40% RAP



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RECOVERED BINDER

Binder properties

Test method	Penetration [0.1 mm]	Softening point R+B [°C]
Reference mix M.0 (0% RAP)	42	55.7
Artificial RAP R.0	30	60.2
Recycling mix M40.1 (40% RAP R.0)	50	53.2
Artificial RAP R40.1	33	61
Recycling mix M40.2 (40% RAP R40.1)	n.d.	n.d
Artificial RAP R40.2	33	60
Recycling mix M40.3 (40% RAP R40.2)	50	53

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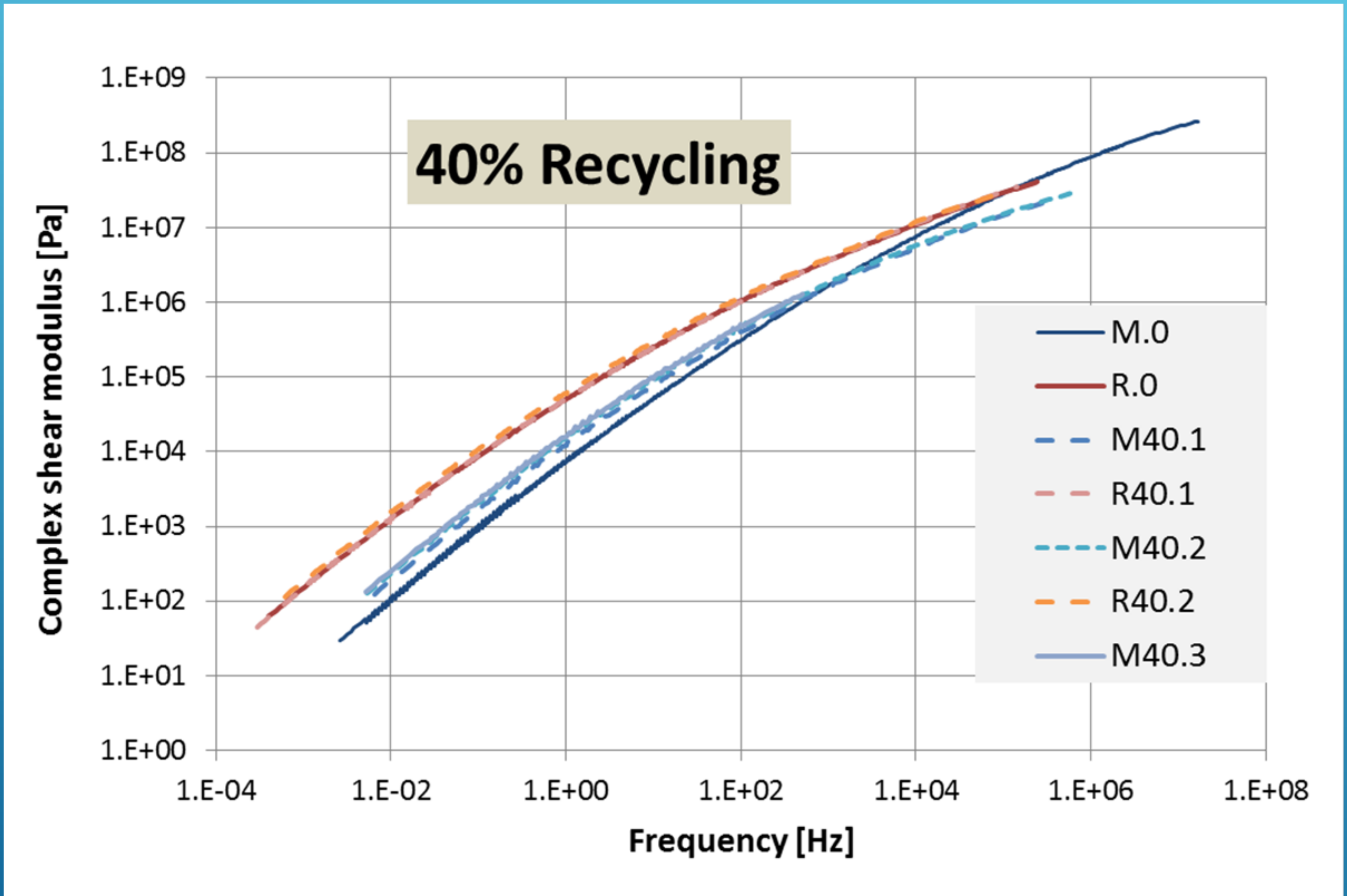
RECOVERED BINDER

DSR master curves



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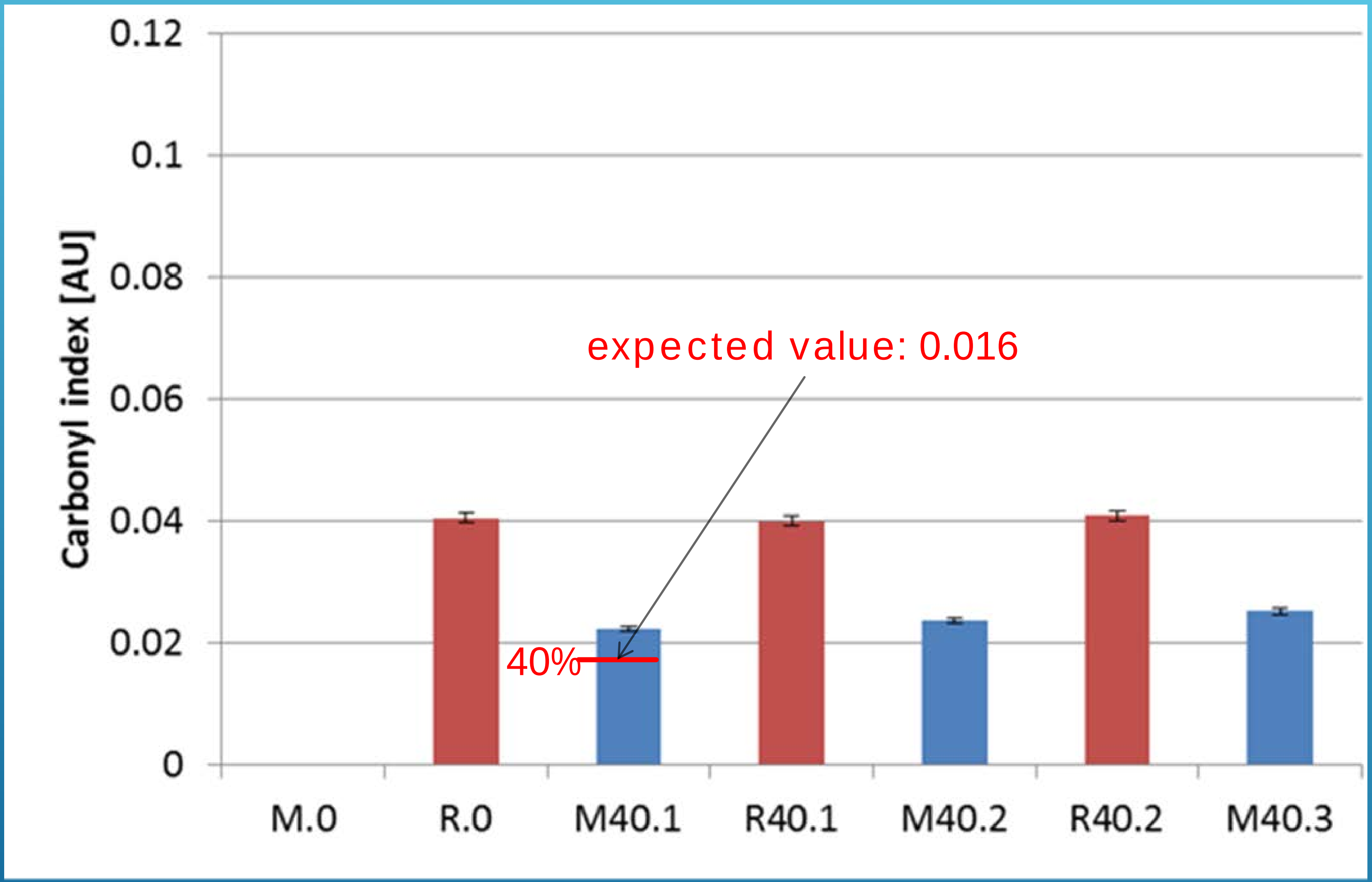
RECOVERED BINDER

FTIR Carbonyl index (Infrared spectroscopy)



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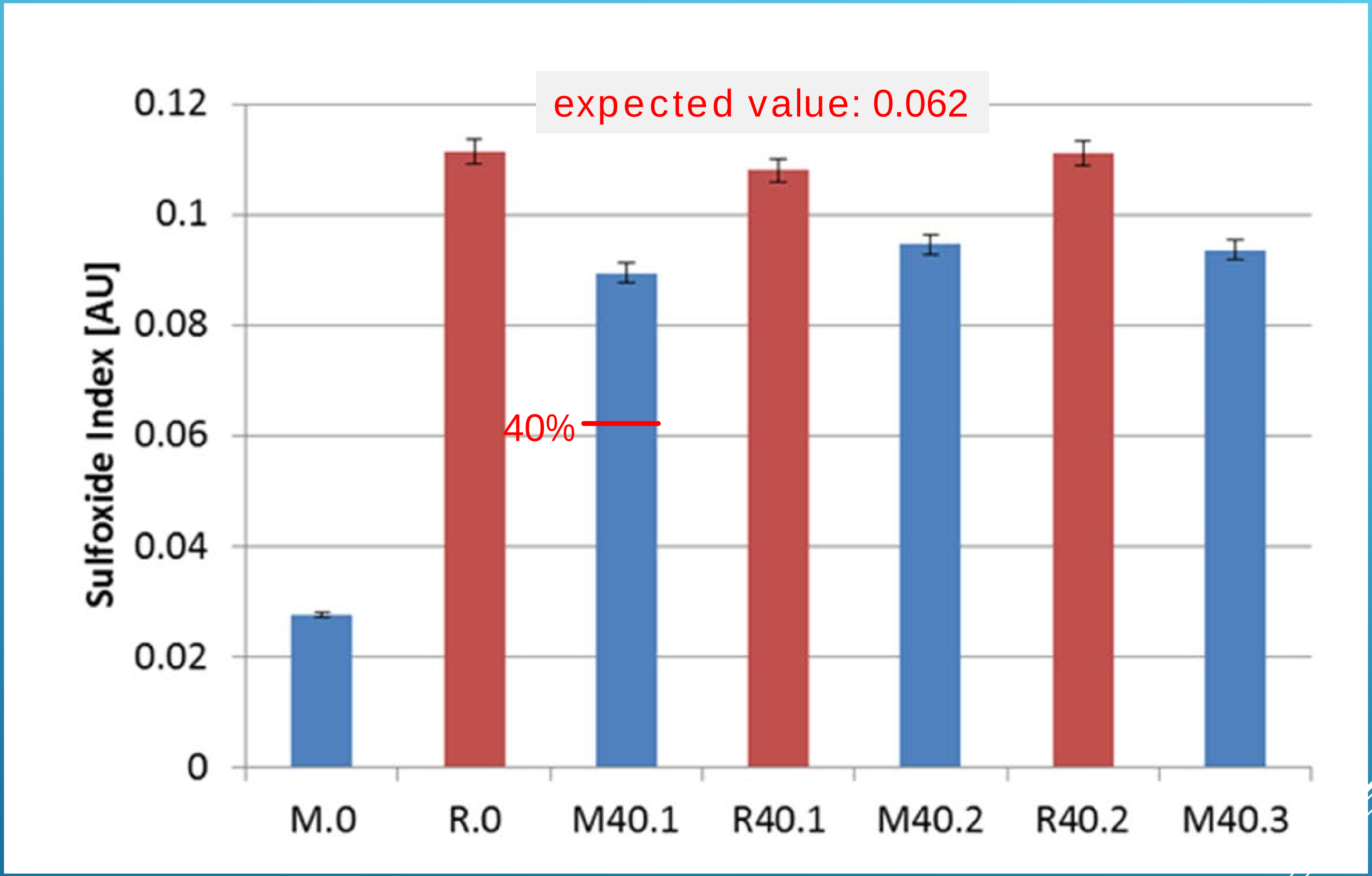
RECOVERED BINDER

FTIR Sulfoxide index (Infrared spectroscopy)



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RECYCLING MIXES

Mix properties

40% Recycling mixtures		M.0	M40.1	M40.2	M40.3
Binder content	M-%	5.8	5.4	5.9	6
Void content	%	2.6	4.5	2.5	2.2
Marshall stability	kN	11.2	10.1	10.6	10
Marshall flow	mm	3.3	2.5	3.2	3.5
Water sensitivity ITS dry	kN	1383	1017	824	923
ITSR	%	85	87	75	71
Stiffness modulus 10 °C	MPa	10800	10200	9000	7900
20 °C	MPa	4800	4900	4100	3600
30 °C	MPa	2100	2000	1600	1400
Permanent deformation cycles @ inflection point	0.1	1650	1430	1010	1520
creep rate	µstrain	14.6	14.0	13.9	14.5
Fatigue performance ε_6 (strain at 10^6 cycles)	[‰]	0.031	0.027	0.025	0.029
Low temperature test ITS @ -10 °C	kN	5.3	4.6	4.8	4.7

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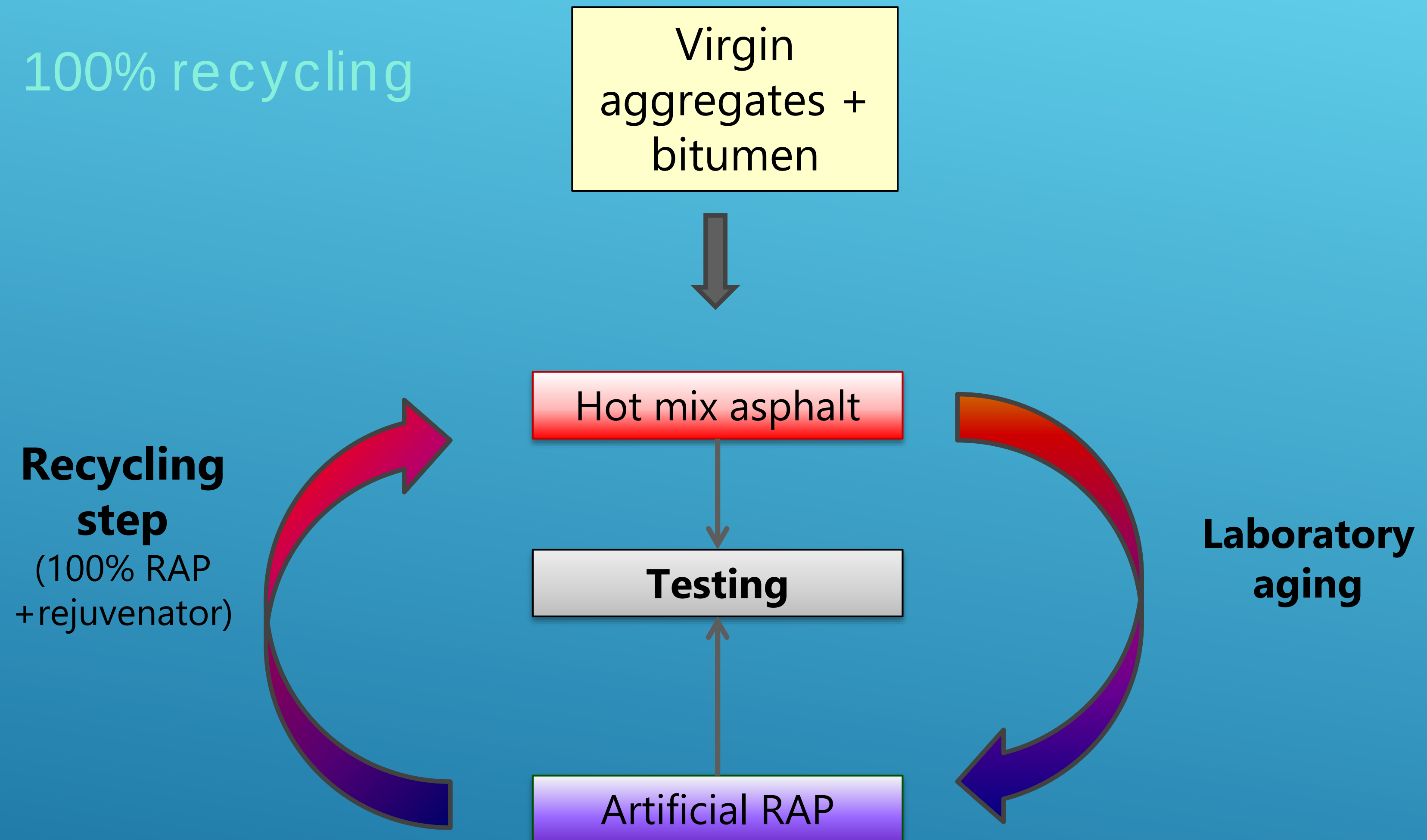
SIMULATION OF BINDER DAMAGE

100% recycling



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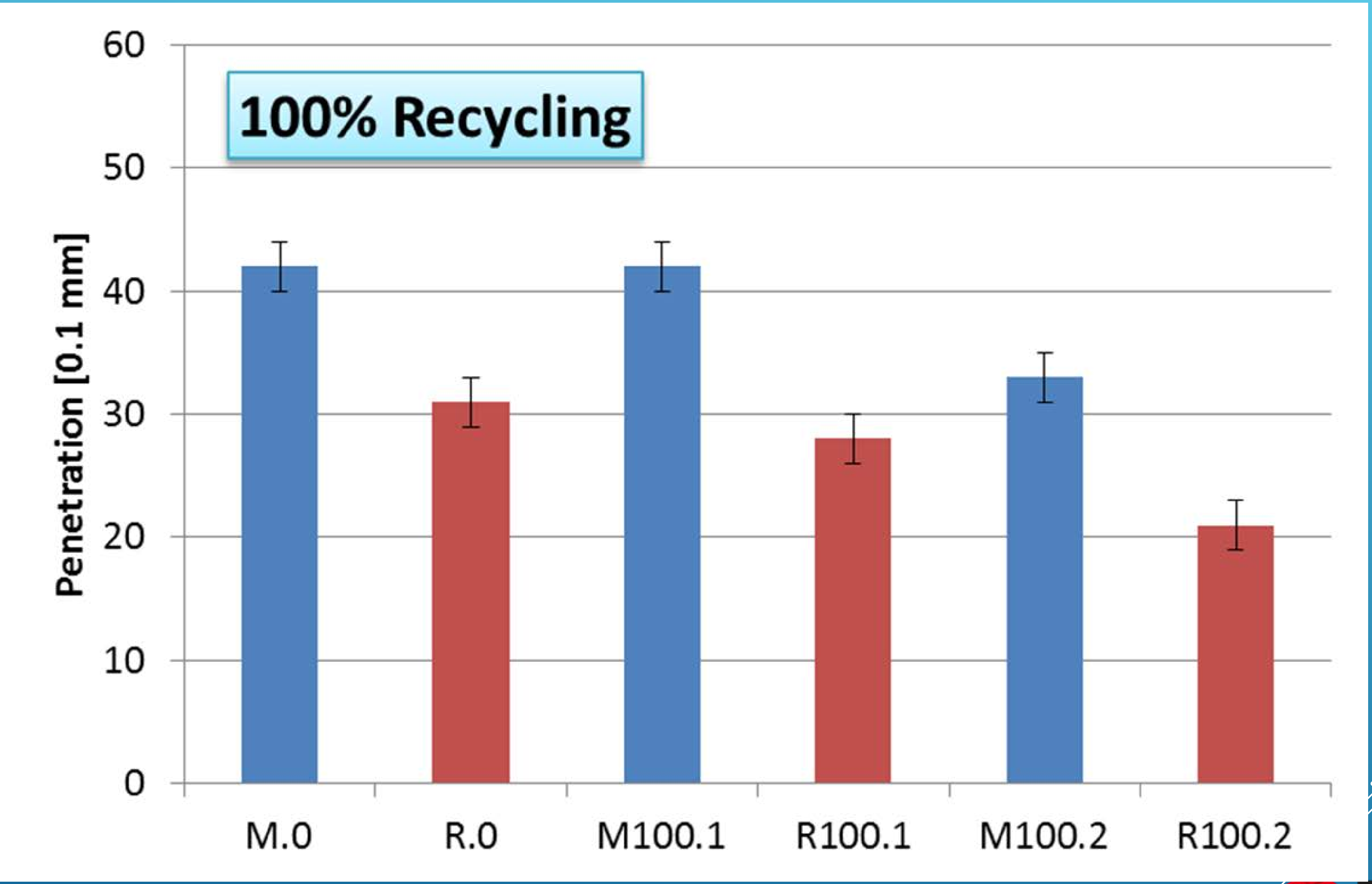
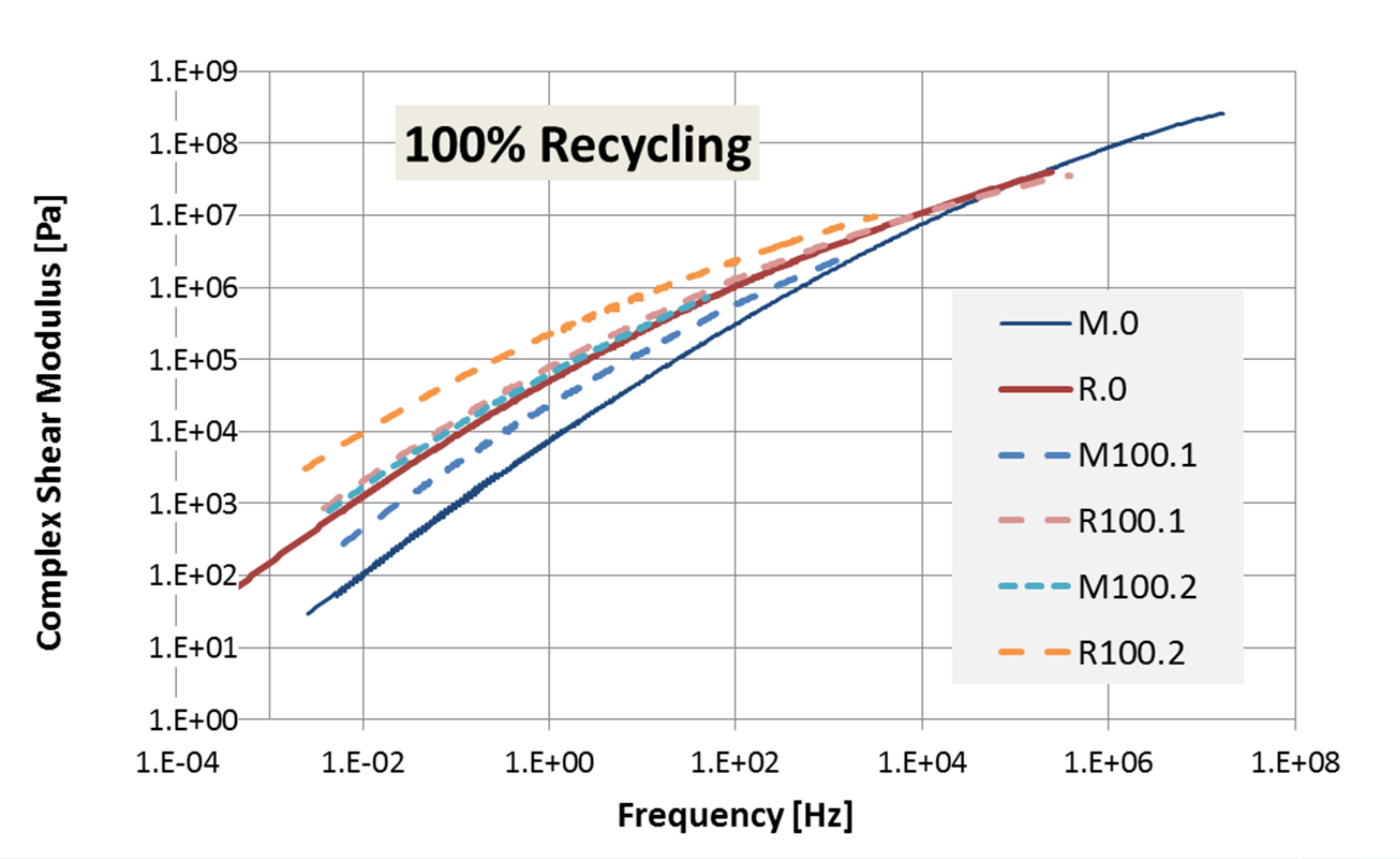
RECOVERED BINDER (100%-STUDY)

Needle penetration



RECOVERED BINDER (100%-STUDY)

DSR master curves



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RECYCLING MIXES

Mix properties

100% Recycling mixtures		M.0	M100.1	M100.2
Binder content	M-%	5.8	nd	**6.1**
Void content	%	2.6	nd	**2.6**
Marshall stability	kN	11.2	nd	**14.6**
Marshall flow	mm	3.3	nd	**4.0**
Water sensitivity ITS dry ITSR	kN %	1383 85	nd	**1658** **84**
Stiffness modulus 10 °C 20 °C 30 °C	MPa MPa MPa	10800 4800 2100	nd	**13600** **7900** **4000**
Permanent deformation cycles @ inflection point creep rate	 0.1 µstrain	 1650 14.6	nd	 **10000*** **0.7***
Fatigue performance ε_6 (strain at 10^6 cycles)	 [‰]	 0.031	nd	 **0.037**
Low temperature test ITS @ -10 °C	kN	5.3	nd	**4.8**

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CONCLUSIONS

- Influence of multiple recycled RAP becomes the dominating part above 60% recycling content
- Milling and crushing result in finer aggregates
- With 40% repeated recycling as expected most properties don't change significantly except for the water sensitivity
- Recycling mixes containing rejuvenating agents are aging in a more complicating way.
- FTIR is not a suitable method to determine the aging degree, as at a certain point most of the possible functional groups are oxidized, but hardening of the binder is still proceeding.
- All results are based on laboratory experiments and should be validated in the field, as some processes in the plant are difficult to simulate in the laboratory.

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