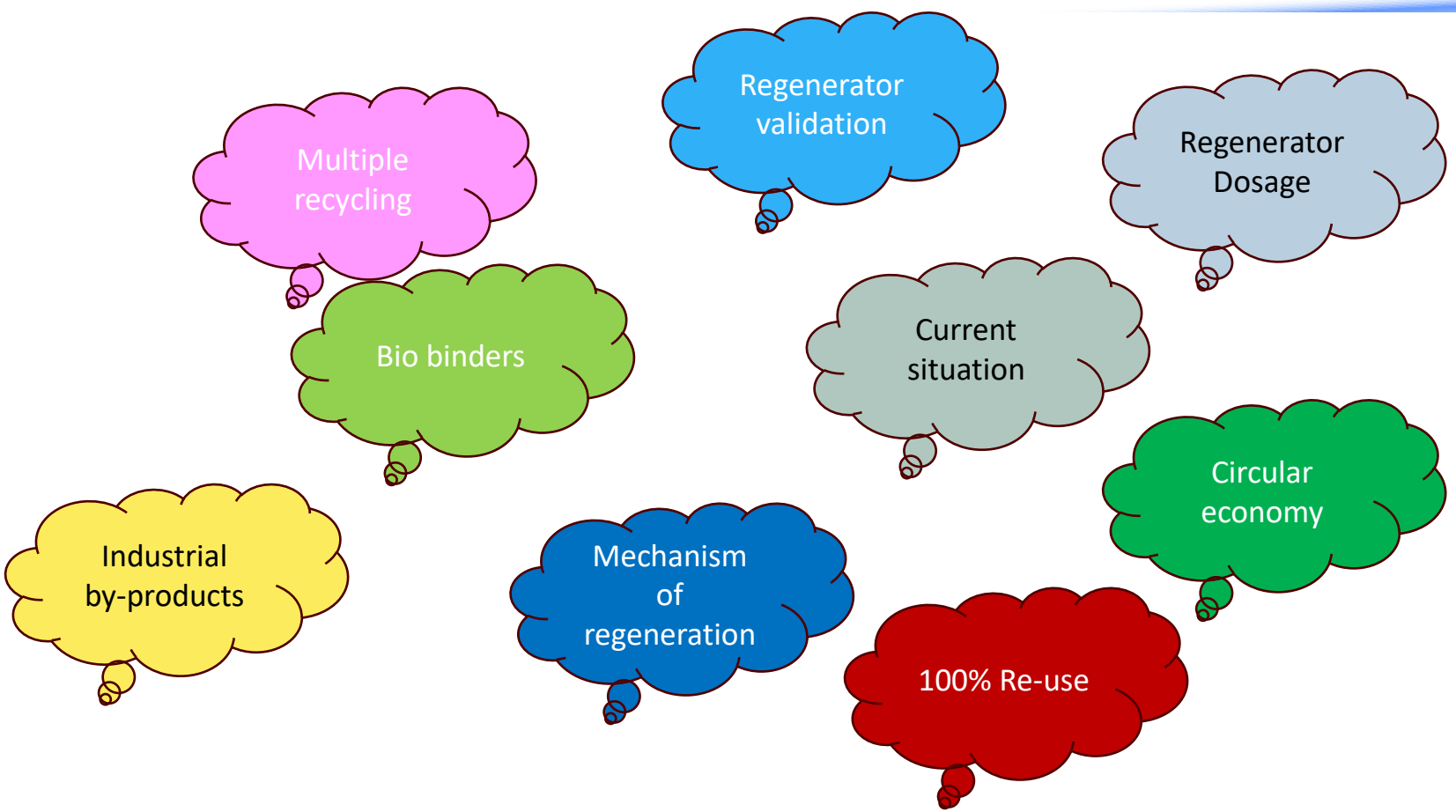
Empa
Materials Science and Technology

Keynote lecture

Challenges in hot and warm asphalt recycling

8. 9. 2025 Dr. Martin Hugener

Outline


Regenerator validation
Regenerator Dosage
Multiple recycling
Bio binders
Current situation
Circular economy
Industrial by-products
Mechanism of regeneration
100% Re-use

Definitions

Europe

- **RA** = reclaimed asphalt, directly removed from pavements or processed and tested
- **Regenerator** (former Rejuvenator)

US

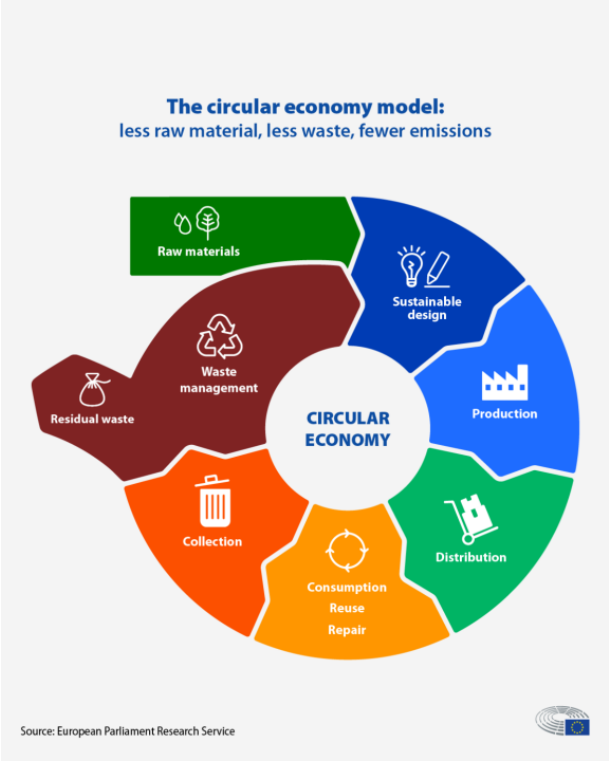
- **RA**, **ARA** = (asphalt) recycling agent
- **RAP** = reclaimed asphalt pavement

- **Re-use**: material used for the «same» purpose
- **Recycling**: material used for a different purpose, e.g. unbound (Downcycling)

European green deal

- Replacing fossil fuels with energy from renewable sources
- 40% renewable energy by 2030
- Green house gas reduction of 55% until 2030
- Climate neutrality by 2050 (zero net greenhouse emissions)
- Circular Economy Action Plan (CEAP)

⇨ **Huge challenge for the construction industry**



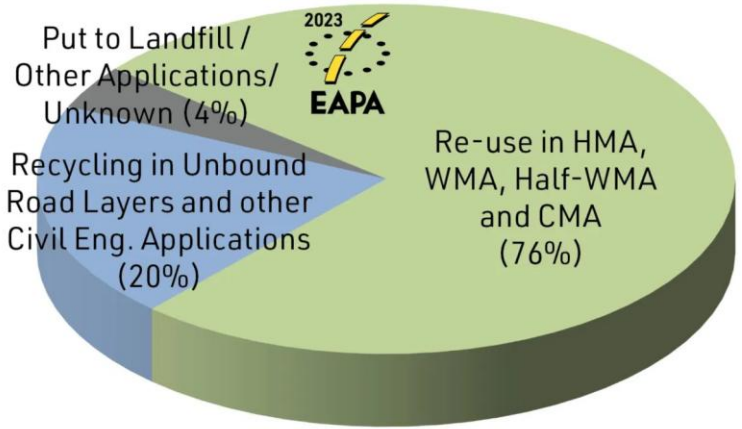
Circular economy in road construction

Asphalt Re-use and Recycling – Current situation

Europe

- 2023 270 Mt asphalt produced
- 60 Mt RA in Europe
- Recycling: 96% of asphalt pavement is re-used/recycled
- Big gap between new asphalt produced and asphalt pavementremoved ??

EAPA asphalt in figures 2023



Current situation in Switzerland

Switzerland (EAPA)

- 4.7 Mt asphalt produced (2023)
- 1.65 Mt (35%) site-won RA (2023 estimated) **?**
- Swiss road network yearly increases < 0.1%
  ⇨ removed pavement material should be equal new pavement material
- 89% of RA re-used??

According to industry:

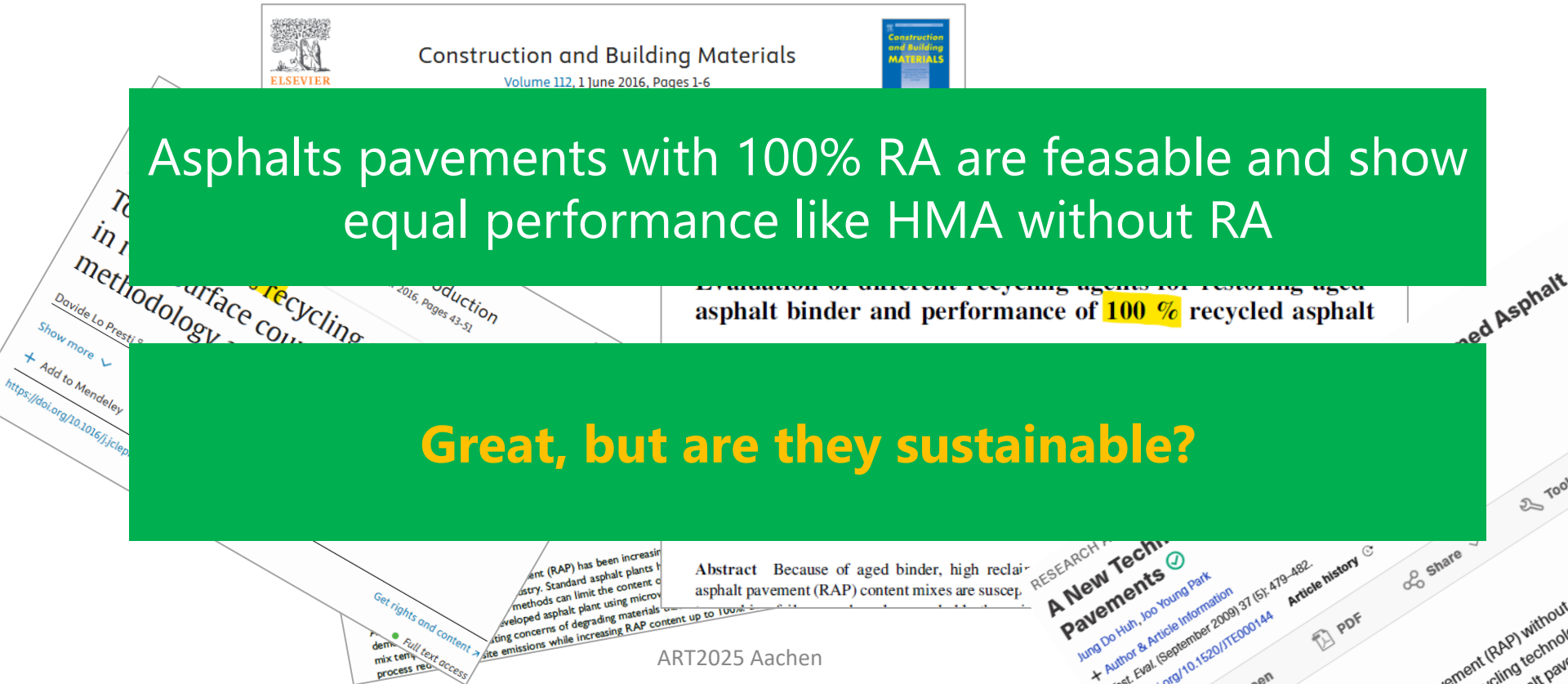
- RA re-use is only 30-35% depending on the plant technology
- The rest is used unbound, goes in landfills or exported

Obstacles to higher RA use in Switzerland

- Tenders often don't specify minimum recycling rates
- There are no ecological selection criteria ⇨ only the prize counts
- Virgin aggregates (especially from outside of Switzerland) are too cheap
- Requirements for RA quality increase, which result in more testing and making re-use of RA less competitive
- In surface layers the RA content is still low (requirements, gap graded mixtures, polymer binders)
- A large amount of RA origins from surface layers, as they are more frequently rebuilt. This RA is rich in binder and consists of fine aggregate fractions (8mm), which limits the recycling rate in coarse mixes.

- Because of insufficient performance, the Swiss Highway Agency reduced the maximum RA content in bound base courses of highways to 60% (Swiss standard allows 80-100%)

Research


Construction and Building Materials
Volume 112, 1 June 2016, Pages 1-6
Asphalts pavements with 100% RA are feasable and show equal performance like HMA without RA
asphalt binder and performance of 100 % recycled asphalt
Great, but are they sustainable?
Abstract Because of aged binder, high reclai
asphalt pavement (RAP) content mixes are suscep
Pavements
Jung Do Huh, Joo Young Park
Author & Article Information
Article history
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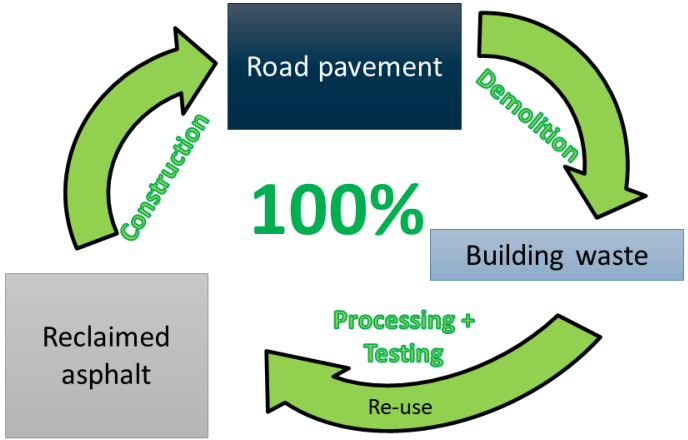
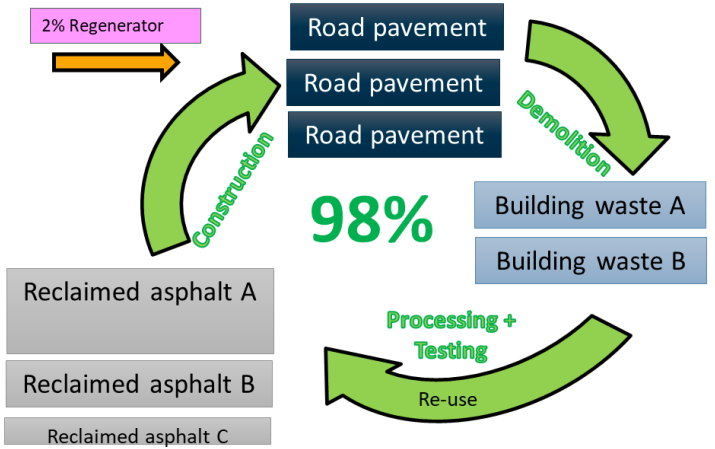
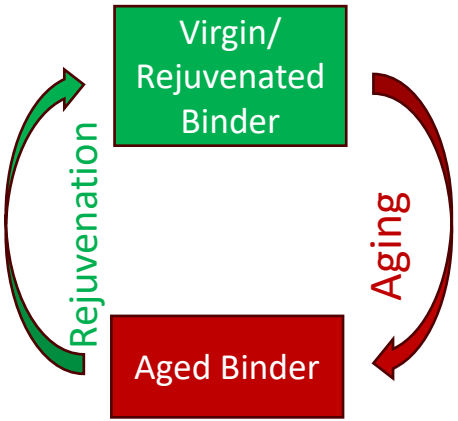
Is 100% re-use feasible in practice?



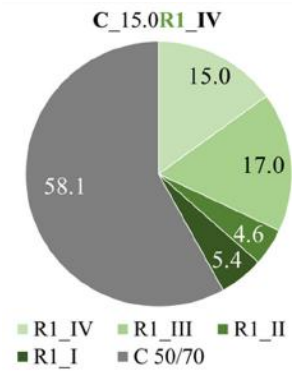


- Milling and crushing leads to finer mixtures, without adding coarse aggregates we will end with very fine asphalt pavements
- Binder regeneration becomes very challenging, as only small amounts can be added (use of regenerators)
- Because of material quality and composition, the amount of "100%"-recycling pavements is limited
- High quality asphalt with PmB are not possible, as the polymers in modified RA are degraded and need to be complemented

Repeated 100% recycling



(Binder level)



Aged rejuvenated binder after 4 cycles

- With each cycle, the asphaltene content increases
- The oxidized molecules don't disappear

Reuse with pure rejuvenators, without the addition of virgin binder, only allows a limited number of reuse cycles.

Schwettmann et. al.,
Construction and Building Materials 2025

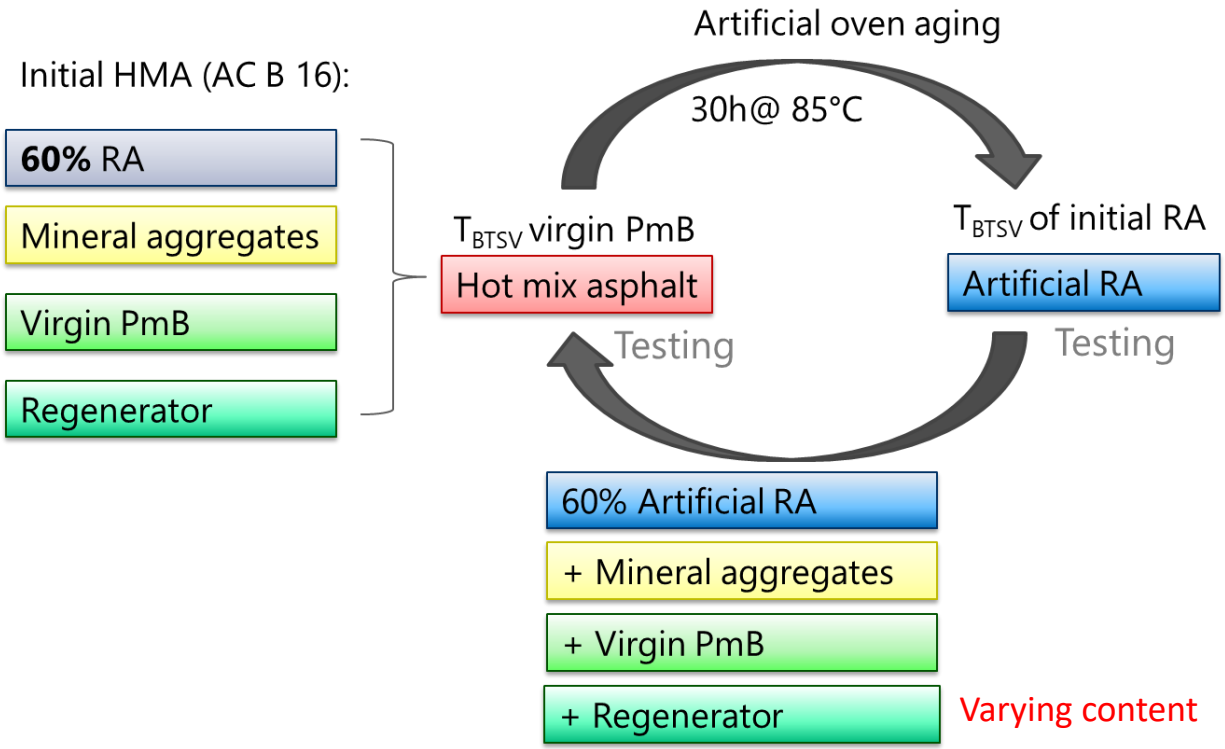
Multiple recycling on the mixture level

Technische Universität Braunschweig | Empa Materials Science and Technology | TU WIEN | RUHR UNIVERSITÄT BOCHUM RUB

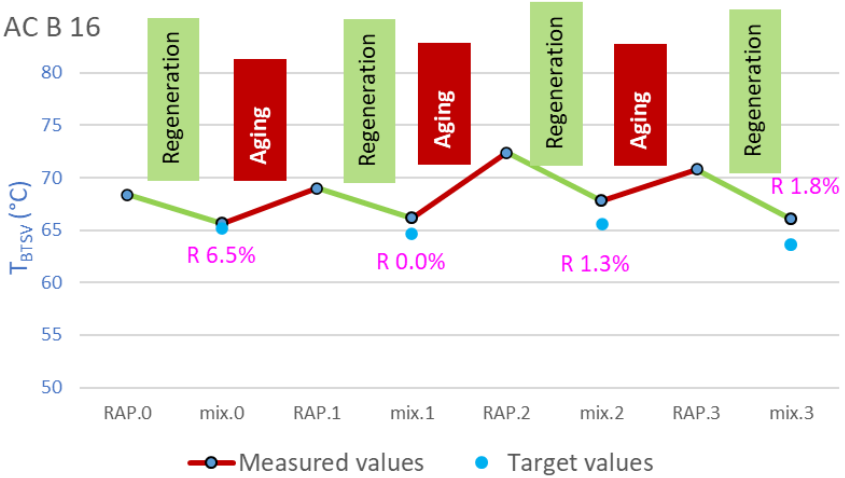
D-A-CH-Forschungsprojekt

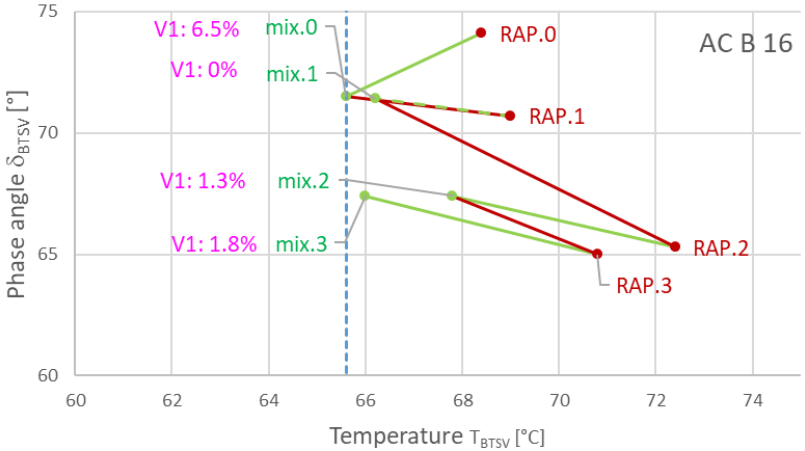
MEHRFACHRECYCLING IM STRASSENBAU

www.mobilityplatform.ch/de/catalogsearch/result/?q=mehrfachrecycling



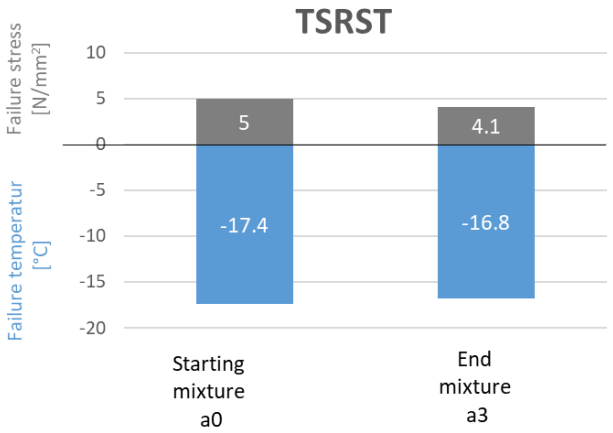
Multiple recycling 60% on the mixture level

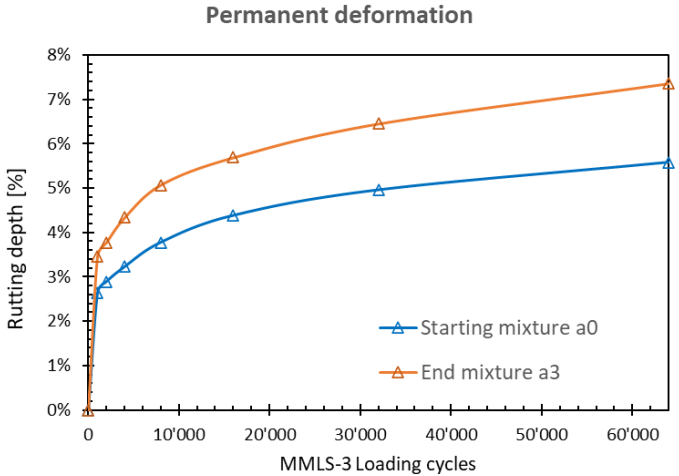




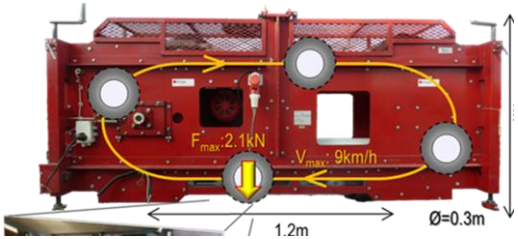
- It is possible to adjust the shear modulus (T_{BTSV}), but not the phase angle when a regenerator is added
- The addition of bitumen is beneficial for the regeneration of the old binder
- It was not possible to predict the effect of aging -> the regenerator dosage needs to be calculated before each cycle

Multiple 60% recycling - mixture results



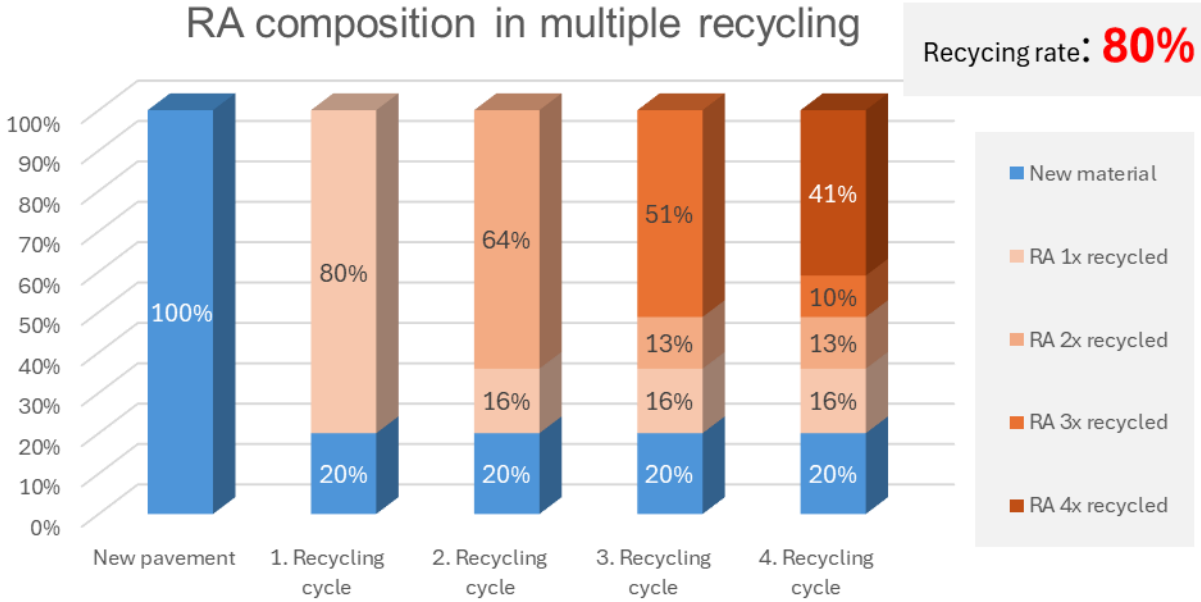


- Low temperature characteristics were comparable
- End mixture, which was recycled multiple times, showed higher permanent deformation
- Binder testing alone is not sufficient
- For mixtures with a high RA content, the balanced mix design has been proven useful



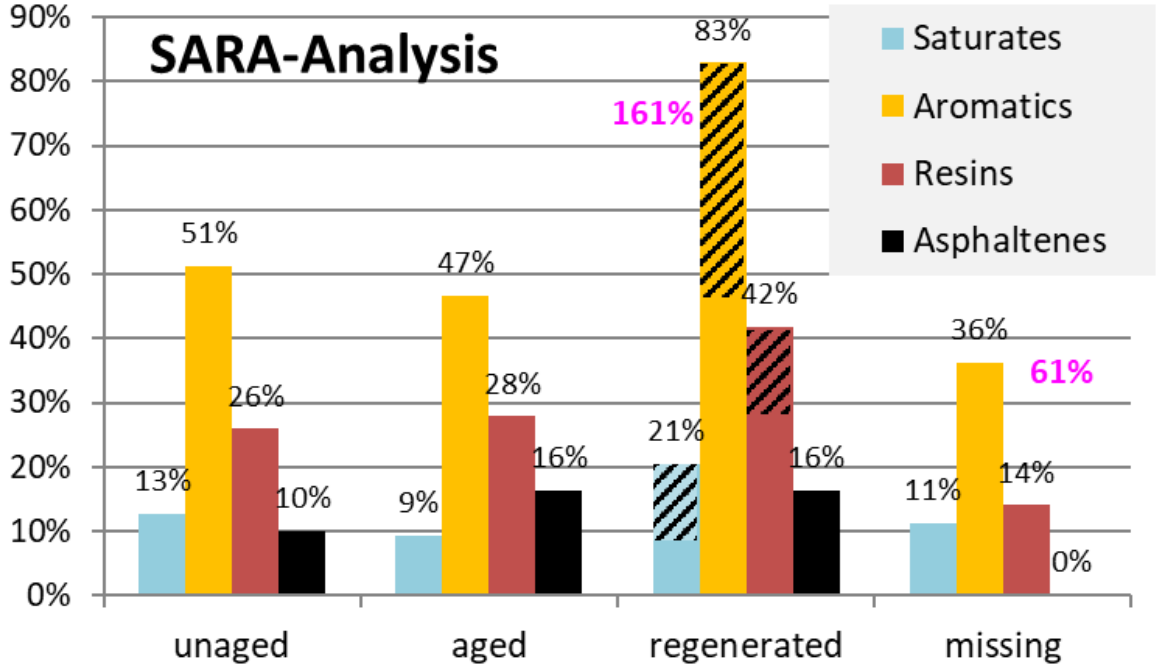
Model mobile load simulator MMLS-3

Repeated recycling on the mixture level



Now 64% are recycled multiple times

Regeneration with soft bitumen



Regeneration with regenerators

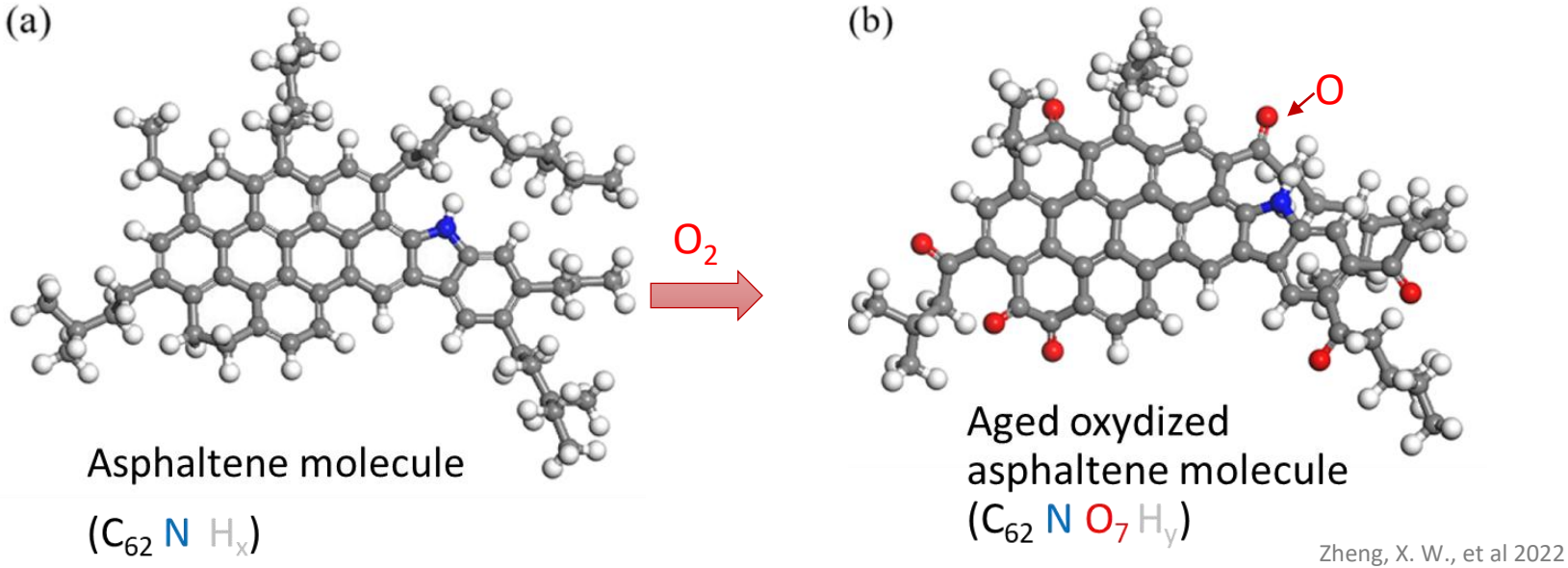
- When the amount of added binder is small (high recycling rate), compensation of missing SARA fractions is no more possible
- Very soft binders are not always straight run bitumen, but often normal grade bitumen, softened with a regenerator

⇨**Regenerators are needed**

How do regenerators work?

- Regenerators cannot reverse aging (oxidation)
- Already small quantities of regenerators are effective
- Chemical composition of regenerators are very different from bitumen and among each other

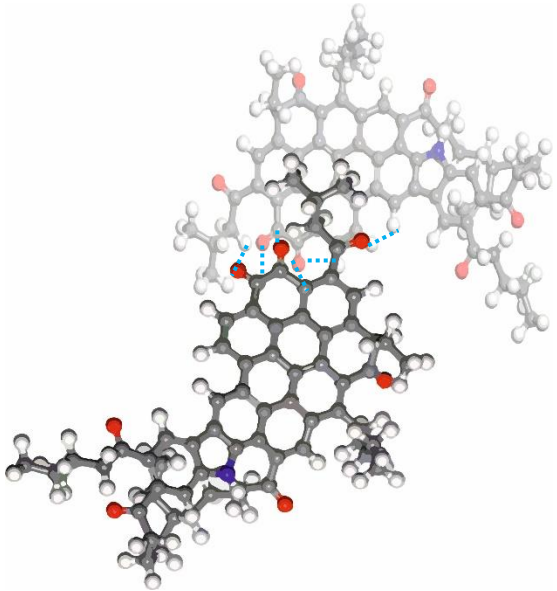
Oxidation of asphaltenes (Molecular modelling)



Zheng, X. W., et al 2022

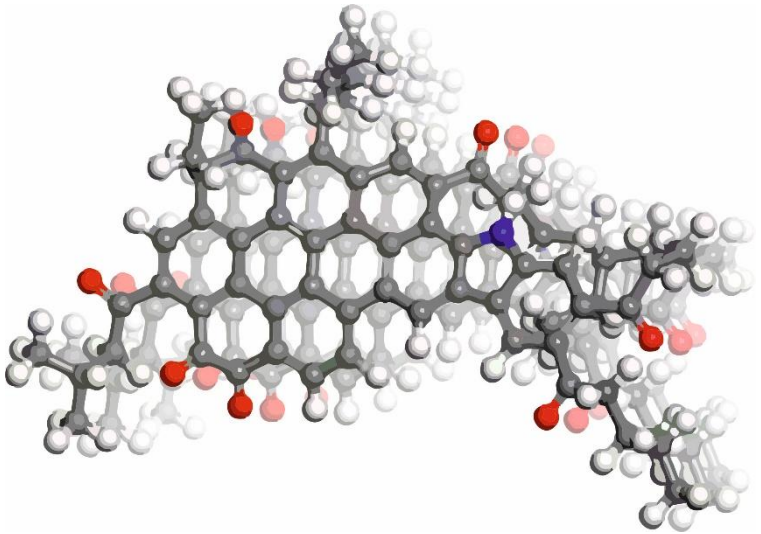
Through the incorporation of oxygen, the aged asphaltene molecule becomes more polar
⇨ stronger electrostatic attraction

Agglomerations of asphaltenes (Molecular modelling)



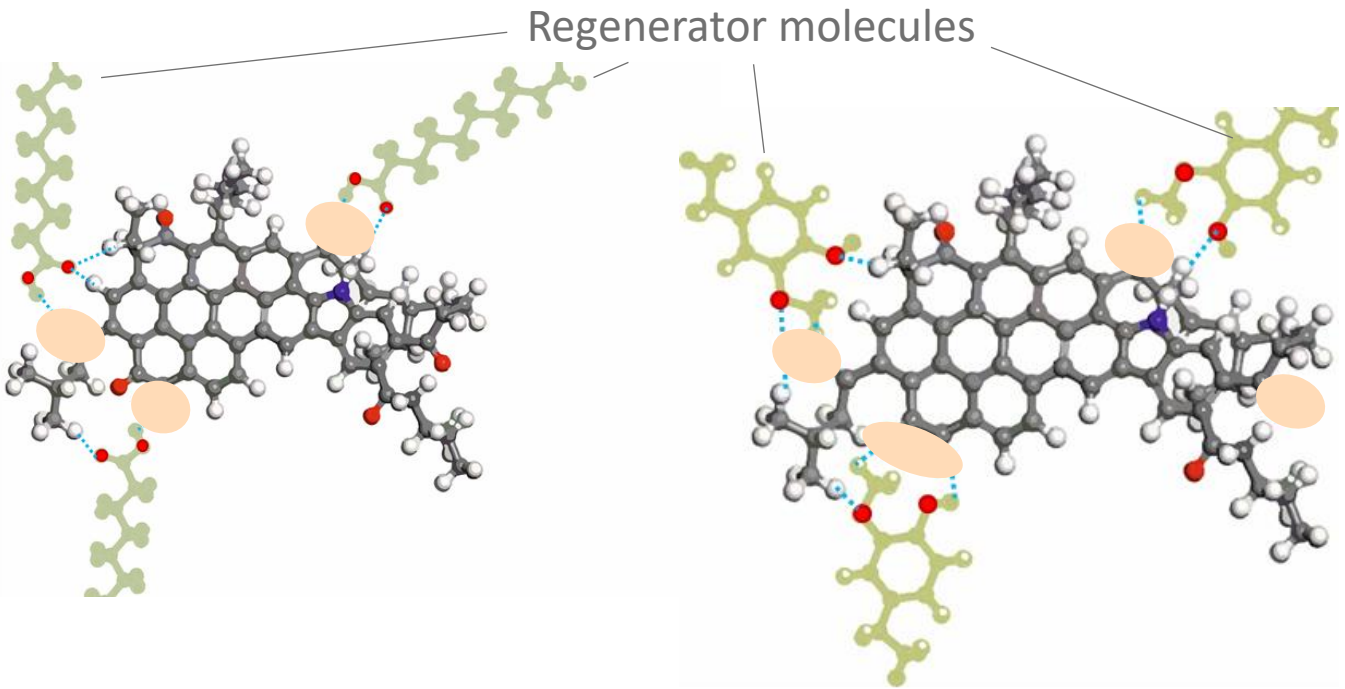
The polar groups of asphaltenes attract each other ⇨ agglomerations are formed movements are restricted -> higher viscosity

Stacked asphaltenes



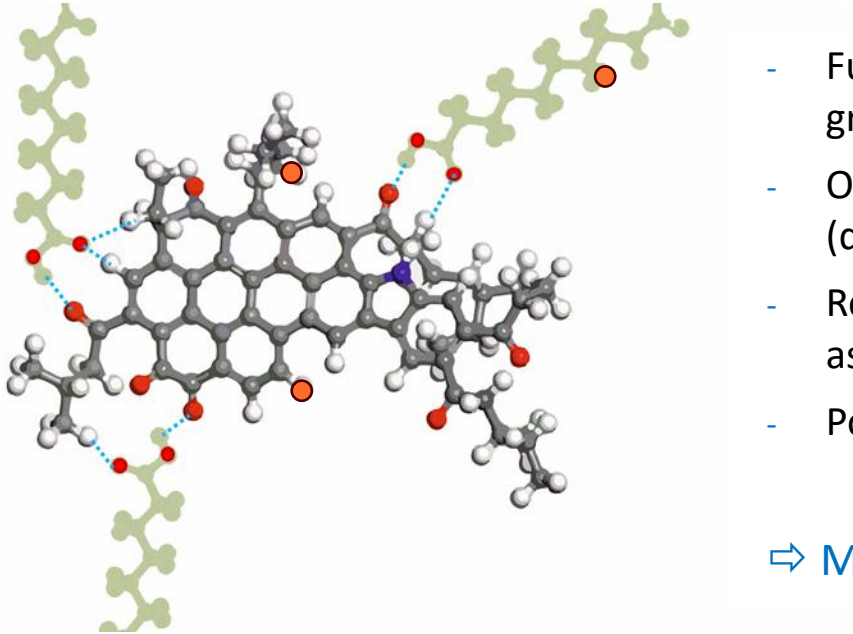
Asphaltenes in agglomerations are not chemically bonded (reversible!)

De-Agglomeration = Regeneration



Small polar regenerator molecules block the polar groups of the asphaltene and break up the agglomerations

Aging of regenerated asphaltene



- Further oxidation of asphaltenes -> new polar groups are formed that are not blocked
- Oxidation of the regenerator molecule itself (double bonds of fatty acid regenerators
- Reaction of the regenerator molecule with the asphaltene increasing its size
- Polar group of the regenerator is destroyed

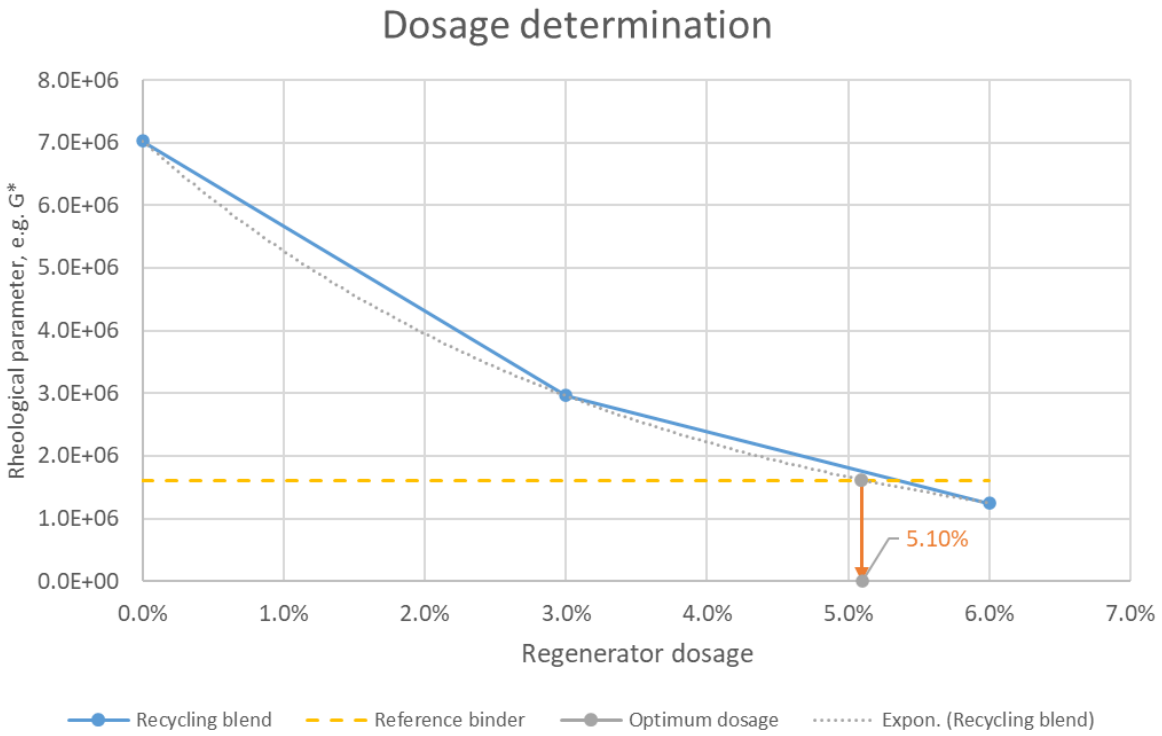
⇨ More regenerator is needed

Regenerator dosage determination

Parameters

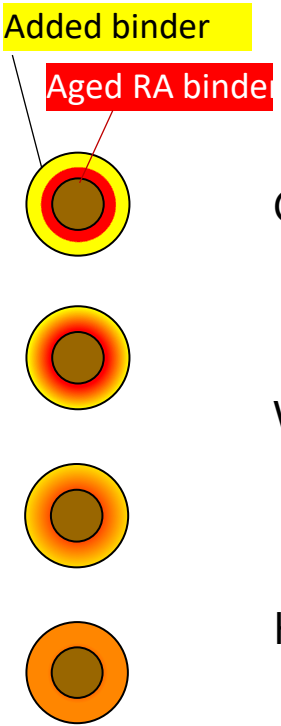
- RA (binder content + viscosity)
- Recycling rate
- Recycling mixture (binder content + viscosity)

⇨**Recycling binder blend**
(composition in the recycling mixture)
= RA binder
+ virgin binder +Regenerator



Binder availability ?

Binder availabilty



No blending (black rock)

Partial blending

Full blending

Cold recycling

Warm recycling

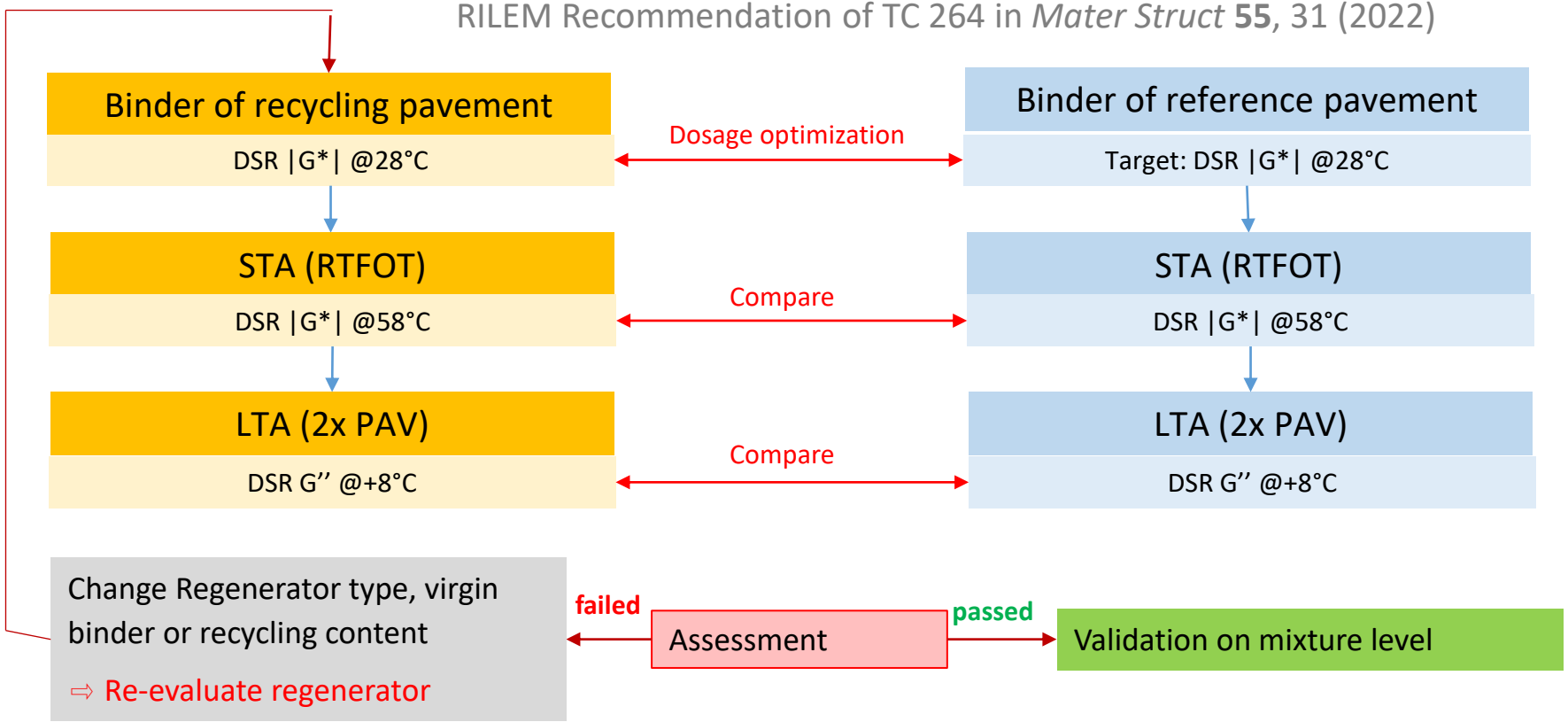
Hot recycling

Influencing factors

- Mixing temperature
- Mixing energy
- Mixing time
- Viscosity of old/new binder
- Binder film thickness
- Agglomerations

Regenerator validation

RILEM Recommendation of TC 264 in *Mater Struct* **55**, 31 (2022)



Challenge renewable bio binders

- Decarbonization of the asphalt industry requires that fossil binders will be replaced by bio binders from biomass resources.
- The current bio-additives and extenders are not full binders. In most cases they are used together with RA and don't work alone with mineral aggregates (lower adhesion and cohesion properties), low viscosity.
- However, pure bio binders are possible and are promoted more and more

Recyclability of bio binders

- Tested only for one recycling cycle, what happens in multiple recycling?
- Mixing with other RA types could lead to incompatibilities
- Compatibility with other bio-binders?

Industrial by-products

- There is a long tradition of “improving” asphalt pavements with industrial by-products, some call it linear landfill instead.
- Asphalt pavements are attractive for getting rid of industrial by-products and waste (e.g. plastic waste, rubber tires) due to its enormous capacity. Theoretically, based on the annual asphalt production in Europe, the addition of one percentage allows to incorporate 2 Mt of a by-product/waste.
- However, in circular economy it is vital that road material can be re-used as often as possible. The more different additives and by-products are added, the more difficult and unpredictable becomes recycling in medium terms.
- Apart from that, re-using high contents of RA, the reclaimed asphalt becomes the main component of the asphalt mixture. Hence, it is compulsory that RA of high quality is used.

Summary

- Asphalt it is a precious construction material that can be re-used/recycled to 100%
- Asphalt is one of the most recycled materials worldwide, but we have do more to reach the goals of the European green deal
- We have to be careful not to jeopardize the recyclability of asphalt by pushing recycling to the limits
- Overall, sustainability (pavement life time, repeated recycling) is more important than ultra high recycling rates.
- Improve the quality of RA, not only the quantity.
- Let's not lose sight of the big picture by optimizing individual aspects.
- Ironically, certain environmental goals like the reduction of green house gas and the focus on renewable materials are challenging the recycling of asphalt.

Thank you for your attention