Empa
Materials Science and Technology

HighRAP

Highly Recycled Asphalt Pavement

PROJECT SUMMARY

Full report

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Introduction

Switzerland is not fully using the potential to re-use asphalt for production of new asphalt mixtures. Federal Office for the Environment (BAFU) estimates that in Switzerland around 2.5 million tons of asphalt are removed every year, resulting in around 750,000 tons (30% from 2.5 million tons) that are not re-used.

A significant reason for the large amount of Reclaimed Asphalt Pavement (RAP) leftovers is that very few new roads are being built in Switzerland. This means the milled asphalt needs to be re-used in asphalt production at a high content in order to avoid accumulation of stockpiles. The research project VSS 2005/454 EP3 (1) estimates that to avoid RAP accumulation, wearing courses on average should contain 50% RAP and base courses – 70% RAP.

The restrictions toward limiting the maximum RAP content have good basis. The caution is mostly driven by the fact that RAP binder has aged and is too stiff. As a consequence high RAP mixtures may be prone to cracking (2–4) and part of the RAP binder is likely not blending with the introduced virgin materials leading to the “black rock” effect (5–7). Unfortunately, the traditional mix design and quality control approaches are not always suitable for the evaluation of these effects. The various materials that are added, including binders with different viscosities, rejuvenators, and RAP, create complex impacts that cannot always be characterized with the traditional parameters.

Another problem is the often insufficient homogeneity of RAP which does not allow to have confidence in continuity of the developed mixture design (8–10). Finally, the production process is a hindrance since heating of RAP needs a technologically advanced asphalt plant and the process generates emissions.

HighRAP project overview

The objective of the *HighRAP* project is to develop recommendations that would allow increasing the average reclaimed asphalt content in asphalt production without compromising the pavement performance.

The project, summarized in Fig. 21, addressed three main research topics: 1) RAP Materials, 2) Mix design, 3) Performance. Within these topics, individual studies addressed characterization of RAP, improvement of RAP crushing and screening, aging and rejuvenator selection, performance-based mixture design, and construction of two test sites with high RAP content: one in a high traffic road and one at high altitude (1,900 m above sea level).

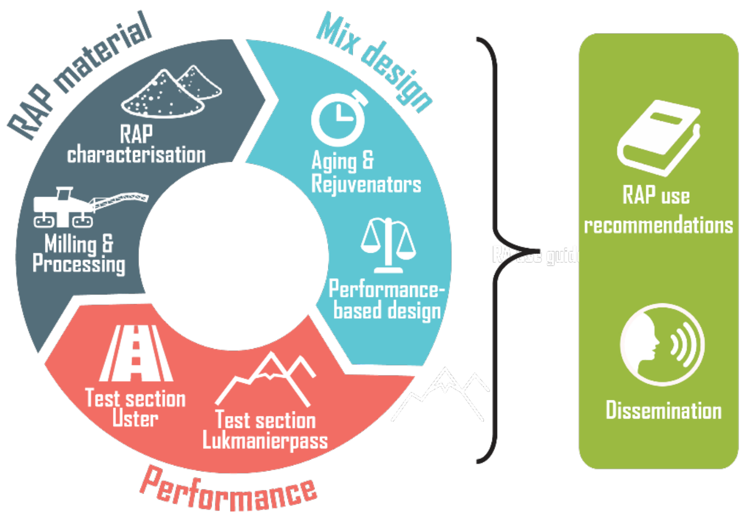

***Fig. 1** Overview of the HighRAP project*

The HighRAP project tasks and activities for each of the three research directions are shortly summarized in Tab. 3.

Tab. 1 *Summary of HighRAP project activities*

Study	Tasks	Activities during HighRAP project
 RAP milling & processing	Develop RAP processing procedures that allow maximizing the RAP use in production.	• A full-scale experiment to evaluate the effect of milling. • A full-scale experiment to develop a method for quantitative assessment of RAP crushing and screening procedure.
 RAP characterization	Develop simplified test methods for rapid RAP characterization without extracting binder.	• A full-scale experiment to evaluate the suitability of two methods for characterization of RAP without extraction of binder.
 Aging & Rejuvenators	Develop an aging protocol for mixture design to assess durability of rejuvenated RAP.	• Laboratory-aging of asphalt to compare with plant produced mixes and road cores. • Development of a procedure for evaluation of rejuvenator aging resistance.
 Performance-based mix design	Develop of a procedure that would allow designing high RAP mixtures with similar performance and life cycle to the conventional asphalt.	• Use a performance-based mixture to design the mixtures for test sections. • Develop acceptance criteria for semi-circular bend and cyclic compression tests.
 Test section in Uster	Evaluate full-scale production and paving of high RAP mixtures for high traffic roads.	• Construction of a test section in Uster to validate the performance of polymer-modified mixtures with high RAP content.
 Test section in Lukmanierpass	Evaluate full-scale production and paving of high RAP mixtures for high altitude roads.	• Construction of a test section in Lukmanierpass to validate the performance of foundation and base course mixtures with high RAP content.

The findings from each study and the recommendations that arouse from the HighRAP project are described below.

RAP material

Inhomogeneity of RAP is caused by variability of the milled pavement, blending together RAP from various sources, various pavement aging states, various damage states, milling of multiple layers, etc. Furthermore, RAP often has high filler content. This is partially due to the milling and subsequent crushing operations, where filler (dust) is generated as a result of mechanical impact. A high filler content often limits the maximum RAP content in mixture, because it does not allow to fulfil the gradation requirements of asphalt mixtures. A high filler content also reduces the void content of the mixture to unacceptably low levels.

In each of the two test sections that were paved during the project, one of the HighRAP mixtures was produced using RAP that had either different binder content or different binder properties compared to the mixture design. In both cases, this led to unexpected mixture properties and highlights the importance of ensuring high RAP homogeneity using reliable methods, especially when very high RAP content is used.

For these reasons, development of methods to produce, and test RAP are a part of the HighRAP research project.

Processing

Three indexes that allow evaluating crushing and screening of RAP were developed:

- *Chunk Index* demonstrates the size of RAP agglomerations.
- *Breakdown Index* demonstrates the reduction of RAP aggregate particle size during processing.
- *Filler Increase Index* reflects the amount of generated filler content during RAP processing.

The indexes can be determined using gradation analysis of RAP before and after binder extraction. The concept behind the indexes and an example result expression are illustrated in Fig. 22. A spreadsheet-based calculator for determining the three indexes can be accessed here (11): https://doi.org/10.5281/zenodo.5500154.

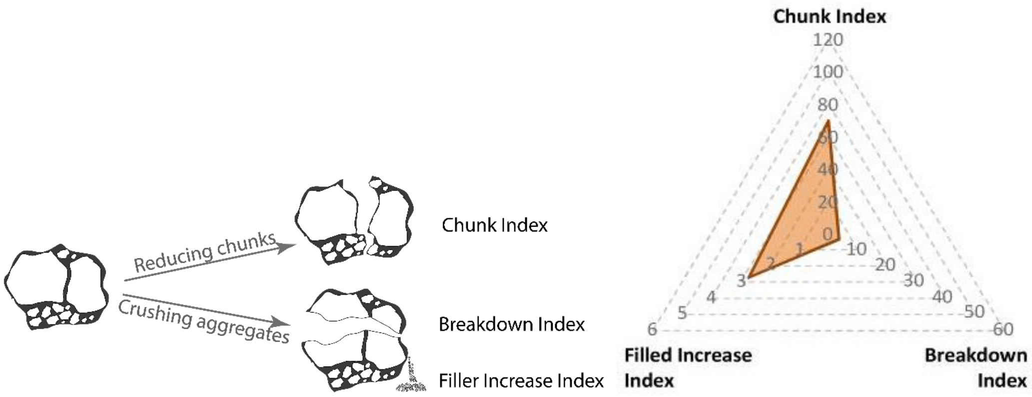

***Fig. 2** Principle of Chunk Index, Breakdown Index, and Filler Increase Index (left) and a result for one processed material (right)*

In order to validate the indexes, a case study was performed using four different crushers: GIPO, Ammann, Benninghoven, and SBM. These machines crushed five different sources of RAP to produce a total of seven different materials.

The results showed that the three indexes are a useful quantitative means to characterize RAP. As such, they allow optimizing the crushing and screening process, they permit comparing different RAP crushers, and they can help to select RAP management techniques to maximize recycling of RAP.

Milling

The milling experiment was performed by varying the milling parameters in four full-scale jobsites. The results shown in Fig. 23 demonstrate that the properties of milled RAP can be affected by the milling parameters, most notably - milling machine moving speed. Optimizing the milling process to minimize aggregate breakdown and filler generation is possible but further research is needed before recommendations for any changes in milling practice can be suggested. The *Chunk Index, Breakdown Index, and Filler Increase Index* proved well suited for the evaluation of the milling process. A spreadsheet-based calculator for determining the three indexes can be accessed here: http://doi.org/10.5281/zenodo.4450091 (12).

It was found that the milling process, despite the milling teeth reaching up to 1000 °C, did not age the RAP binder and that the angularity of aggregates did not change during milling at the tested location regardless of the milling parameters used.

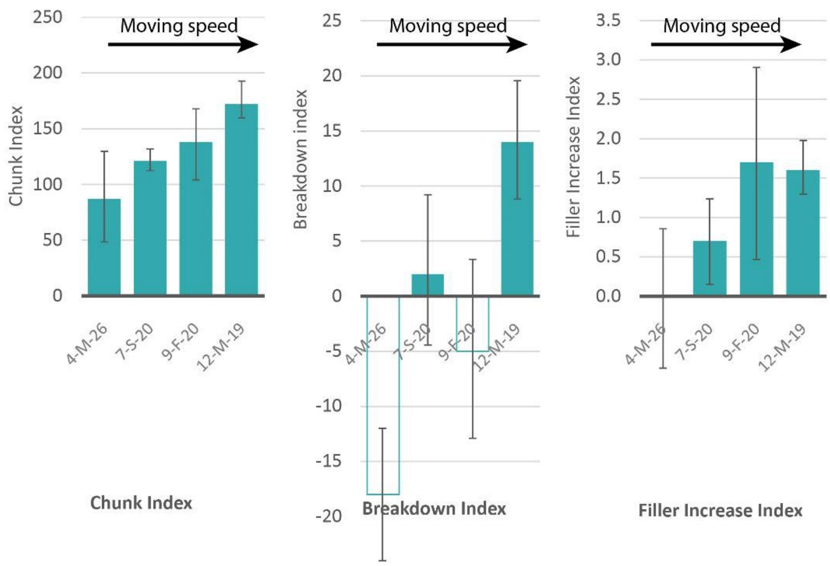

Fig. 3 *Milling machine moving speed affects the Chunk Index, Breakdown Index, and Filler Increase Index*

RAP characterization

An important practical factor that prohibits ensuring homogeneity of RAP stockpiles is the large effort and time needed to test the properties of RAP. Extraction of aggregates and recovery of RAP binder are time consuming and require working with hazardous solvents. Separating the RAP into constituent materials might not even be the best approach for testing since the material that is used in production is RAP rather than the constituent materials of RAP. For this reason, new test methods need to be developed for rapid RAP characterization.

To attempt developing practical and rapid characterization methods for RAP testing, the Cohesion and Fragmentation tests were explored (13) (see Fig. 24). For both tests, the procedures were simplified and the parameters that impact the results were investigated.

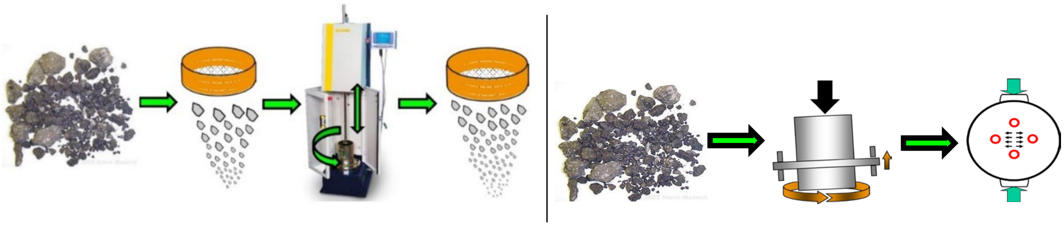

Fig. 4 *Fragmentation test (left) and cohesion test (right)* (13)

The Fragmentation test was intended for characterization of RAP agglomeration and RAP aggregate toughness. The test results had a high repeatability and they show a potential to characterize the RAP depending on the processing method that was used for preparing the RAP. However, the relationship between the fragmentation test result and RAP aggregate toughness and RAP agglomerations could not be clearly assessed. The interactions are complex and depend also on the dampening effect of the RAP mortar and likely other parameters, including RAP binder viscosity.

The Cohesion test was intended for characterization of RAP binder content and binder properties. The test results were found sensitive to binder softening point and binder aging but not to binder content.

Neither the Cohesion nor the Fragmentation test are ready for implementation into practice at this time. Further research is necessary to establish if the fragmentation and cohesion tests can be useful for quick characterization of RAP or other methods should be developed.

Recommendations regarding RAP material

- Continue testing the RAP properties using the traditional tests: binder content, binder properties, and aggregate gradation. Permit the use of high RAP content in asphalt production only if homogeneity of RAP is ensured. The control of consistency of binder content and binder properties is especially important since the gradation can be more easily controlled through crushing and sieving.
- Determine the limits for acceptable variability in RAP binder content and binder penetration, depending on the design RAP content. An example methodology for calculation of permitted RAP variability is presented in the report. A spreadsheet with a calculator can be downloaded at: https://doi.org/10.5281/zenodo.7441805 (14).
- Follow the best RAP management practices and rigorously test the RAP binder content and binder properties to ensure high RAP homogeneity. The specific procedures put into place for RAP management (milling, sieving, crushing, source separation) depend on the local circumstances.
- Use the developed Chunk, Breakdown and Filler Increase indexes to optimize RAP processing operations. This can allow the production RAP for reaching maximum recycling.
- Consider separation of RAP based on the source of milling or mixture types.

Design of mixtures with high RAP content

The traditional mix design procedures consider volumetric proportions (bitumen, content, gradation, porosity, etc.) and sometimes includes testing of mechanical characteristics of mixtures (Marshall test, wheel tracking test). The traditional mixture design methods were developed for characterizing mixtures comprised of virgin materials and do not allow to capture the challenges related to designing high RAP mixtures:

- Use of high RAP content increases cracking potential because of the presence of aged binder. Implementation of mix design and quality control procedures are necessary to allow routine cracking resistance characterization of high RAP mixtures.
- Stiffness of the RAP binder must be reduced through the use of rejuvenators or soft binders. A method for determination of their optimum dosage is required and longevity of the produced asphalt must be ensured.
- Diffusion of the recycling agents and incomplete RAP binder activation is not considered in asphalt design.

Use of performance-based test methods can allow to capture the above-mentioned effects and thus with a higher degree of confidence permit application of high-RAP mixtures. A key part of the HighRAP project was therefore evaluation of the potential to use performance-based mixture tests for design of high RAP mixtures.

Aging and rejuvenator selection (Binder tests)

Ideally, the performance-based test methods should allow for determining the properties of the final mixture without needing to extract RAP binder. However, at this time, the available test methods do not allow to do it with full confidence. For this reason, it is important to test the binder performance as well.

The rejuvenator dosage for the test sections was selected by testing samples at three rejuvenator contents and interpolating to the dosage that provides the desired binder penetration grade as shown in Fig. 25. This proved to be a successful approach since the binder properties of the produced mixtures mostly fulfilled the target grade requirements, including the softening point values. A similar approach can be applied if a soft binder grade is used.

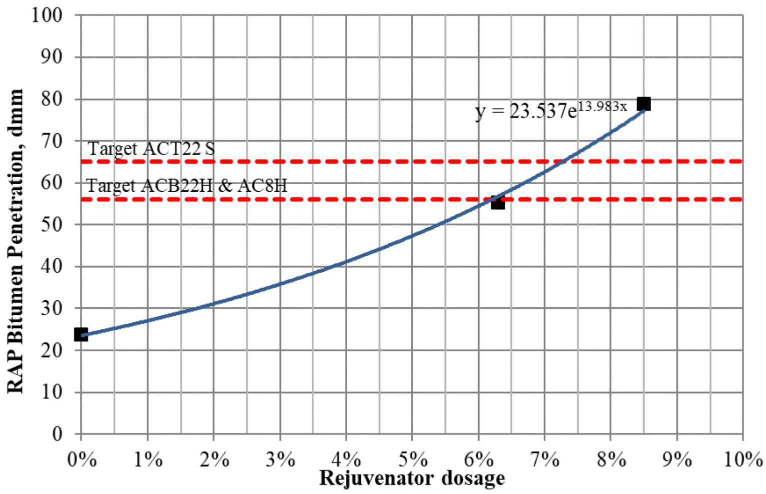

Fig. 5 *Determination of rejuvenator dosage using penetration tests, for the three target mixtures used in the Uster test section*

The binder, rejuvenated with an additive based on crude tall oil, was tested for aging resistance. The results showed that the rejuvenator used in this research is not expected to exhibit accelerated aging compared to the binders without rejuvenators. However, different rejuvenators and soft binder grades can have various aging resistance. For this reason, it is important to determine the aging resistance for the combination of the particular materials used in asphalt production.

Recommendations regarding aging and rejuvenator selection:

- Ensure conformity to the conventional binder test requirements also for the mixtures with high RAP content.
- Before permitting the use of a new rejuvenator or soft binder grade, determine the aging resistance of a binder blend containing all the binders used in mixture design. The recommended aging method includes one RTFO cycle (short-term aging) followed by two PAV cycles (long-term aging). This method was shown to provide binder properties similar to the RAP binder and thus can be considered to realistically simulate field aging.
- As a minimum, it is recommended to test penetration before and after aging as well as mass loss during RTFOT. Other test methods can be added based on local circumstances.
- Select the rejuvenator dosage based on penetration test results to ensure conformity to the target binder grade. A spreadsheet for estimating the optimum rejuvenator dosage is available here: https://doi.org/10.5281/zenodo.7441761 (15).
- Evaluate the use of MSCRT use as a routine binder test method, especially for binders containing polymers. This test can be performed quicker than the conventional tests and it enabled evaluating elasticity and resistance to rutting.

Performance-based Mix Design

The mixtures for test sections were designed using the performance-based mix design method. Using this procedure allowed the design of mixtures with high RAP content. The following steps were implemented:

1. Optimize the rejuvenator content for the mixtures based on target penetration results.
2. Use a cracking test and a plastic deformation test to balance the design binder content and other design parameters.

3. As needed, perform additional binder and mixture tests before approving the final designs.

The selection of test methods for steps 2 and 3 depend on the local circumstances. As an example, in Uster test section the binder optimization was performed using Semi-Circular Bend (SCB) characterizing cracking and cyclic compression tests characterizing plastic deformation. The balanced design visualization for deciding between two binder grades for a mixture is demonstrated in Fig. 26.

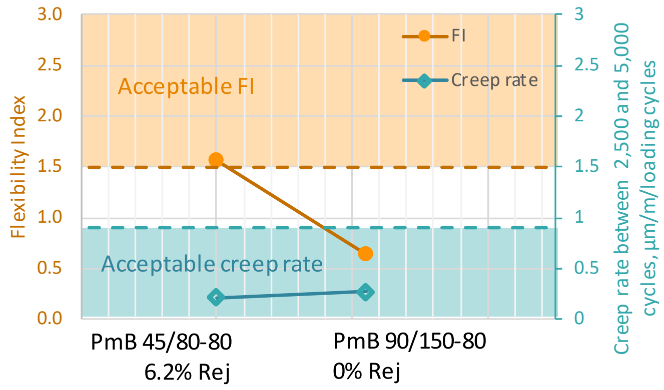

Fig. 6 *Optimization of bitumen type and rejuvenator content for AC B 22 H mixture*

SCB Flexibility Index was found to be a useful method for mixture design and quality control. During the research, the test was found to be sensitive to binder content and binder properties (including binder aging) and therefore it can be used in the balanced mixture design. In one instance, however, the test result failed to show that a mixture contained a hard binder. For this reason, to avoid false positive results, it is important to test the extracted binder properties as well.

The acceptance requirements for the SCB flexibility index were established for the design of HighRAP mixtures. For the base, binder, and foundation courses, the minimum SCB Flexibility Index (FI) requirement was set to 1.5 while for the AC 8 mixture it was 4.5.

Due to the simpler test procedure compared to the French Rut Tester, the cyclic compression test was used for the design and/or testing of mixtures paved in Uster and Lukmanierpass test section. The test result expression in some instances was found difficult since a different metric had to be used depending on the failure type. In some instances, the test also had a high variability.

The maximum permitted creep rate between 2,500 and 5,000 cycles was established for the design of HighRAP mixtures as follows: 0.3 µm/m/loading cycle for AC 8 H, 0.5 µm/m/loading cycle for AC B 22 H, and 0.9 µm/m/loading cycle for AC 22 S and AC F 22 mixtures. These thresholds were established based on a small sample set and should not be applied in other designs without verification.

The Marshall test was used for the balanced mixture design procedure for Lukmanierpass mixtures. The test was found useful but in some instances, it delivered results that should not be expected given the changes in the design.

Based on an aging experiment, it was decided not to age the mixtures during the mixture design phase since the results of unaged samples were reasonably close to the results of plant-produced asphalt and road cores. Aging would also limit the ability to distinguish between various mixture designs.

The SCB, stiffness, and fatigue tests could not distinguish between mixtures that contained PmB and those that did not. The use of MSCRT test on the recovered binder is recommended for this purpose.

Recommendations regarding performance-based mixture design:

- Add performance-based mixture test methods to the mixture design requirements. The testing of cracking resistance is especially important for mixtures containing high RAP content.
- Aging of mixtures before testing with the methods used in this research is not recommended. Instead, aging resistance should be determined for binder blends as explained before.
- It is recommended to use the performance-based mixture design method to optimize the mixture performance. However, at this time it is not recommended to use the tests to replace the conventional requirements for testing recovered binder properties and mixture binder content.
- To avoid aging, the time between mixture production and sample compaction and testing should be kept as short as possible. Long delays cause aging of the samples and compromise the findings. Road-cores permit longer storage time compared to loose mixtures since their air void content is lower in comparison.

Performance of highly recycled mixtures

The production process of mixtures with high RAP content is more complex due to the necessity to blend more materials, heat the RAP, manage emissions, all while ensuring the necessary production quantity and quality. The construction of demonstrators with high RAP content gives a chance to evaluate the production and paving processes, and allows identify any challenges. Such challenges can then be addressed through management decisions, by developing an engineering solution or addressing in a research study.

A successful placement of paving test section serves as an example of the technological possibilities, allows monitoring of long-term performance, and can serve to increase the trust in production in mixtures with high RAP content.

Due to these considerations, the construction of test sections was an important part of the HighRAP project.

RAP use in high traffic volume roads

Four HighRAP mixtures, including two polymer-modified mixtures, with high RAP content were paved in Aathalstrasse, Uster, Three reference mixtures were also placed. A video from the test section construction is available here: https://youtu.be/MvyCwyrMNOs.

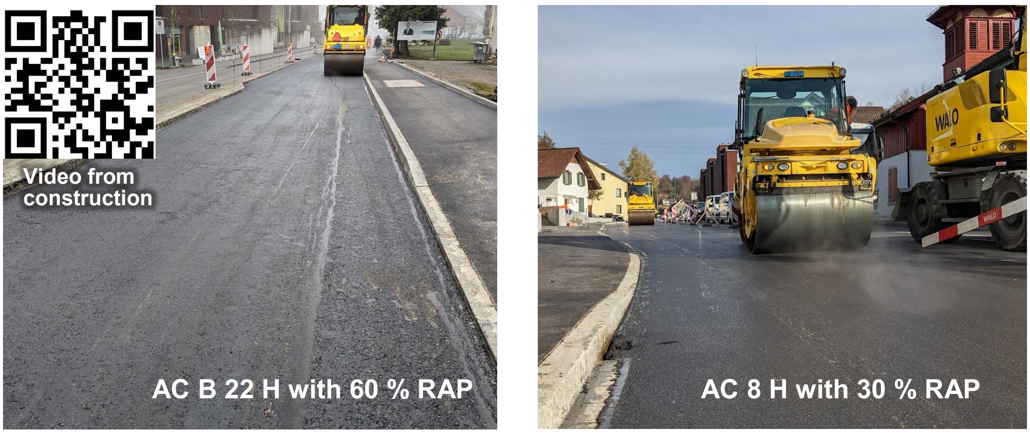

Fig. 7 *Construction of HighRAP test section in Uster*

The Uster test section results demonstrated that by following a performance-based mix design procedure it is possible to produce mixtures (including a wearing course mixture) with at least 30% RAP content, without sacrificing mixture performance. At 30 % RAP content, it is considered possible to achieve the requirements of 45/80-80 binder grade. The skid resistance of this mixture was not determined.

For the RAP used in the study at 60 % RAP content, it was not possible to achieve to 45/80-80 binder grade but achieving a 45/80-65 grade was possible. The HighRAP mixture fulfilled the requirements towards cracking and rutting resistance but as a consequence of the lower softening point, the properties of this mixture in most tests were slightly worse than those of the AC B 22 H reference mixture. The performance in traffic load simulator MMLS3 was significantly worse compared to the reference likely due to lower polymer content.

The production of AC T 22 S mixture with 80 % RAP content was possible in the laboratory but due to the particular properties of the available RAP at the time of production, it was only possible to produce a mixture with 65 % RAP that was similar to the reference mixture. The production of 75 % RAP mixture resulted in inferior performance, likely due to the different RAP binder properties in the RAP that was available at the time of production.

It has to be mentioned that for the AC T 22 S and AC B 22 H, up to 15 % more reclaimed material was used in the mixtures in the form of a "secondary aggregates". This material is produced by stripping RAP from most binder (remaining binder content <1 %) and it is used as a replacement of virgin aggregates.

Fig. 28 compares the most informative performance-based tests results of the HighRAP mixtures with the reference mixtures paved in the Uster test section.

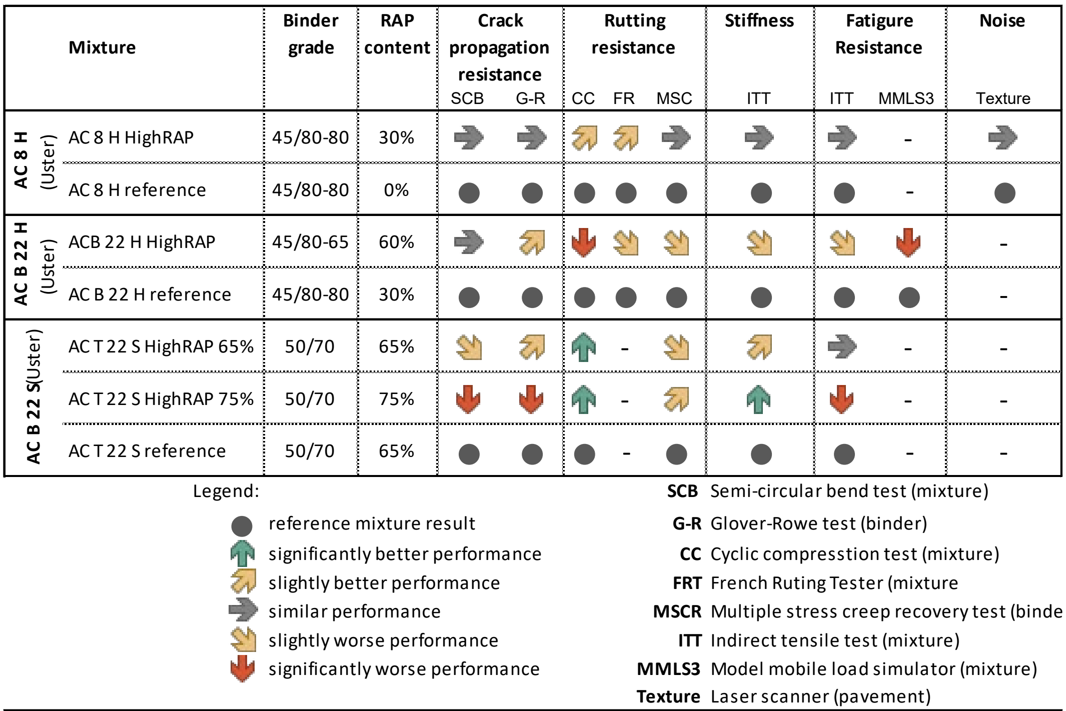

Fig. 8 *Summary of the performance of the Uster test section mixtures*

Recommendations regarding the use of RAP for high-traffic roads:

- If the RAP properties permit, allow the use of up to 30 % RAP in polymer-modified mixtures with a target grade of 45/80-80, including wearing course mixtures. The requirements for conventional binder properties have to be ensured.
- Production of up to 40 or 50 % RAP mixtures with a polymer-modified binder target grade of 45/80-65 is possible. The correspondence to conventional binder properties has to be ensured.

- The use of a performance-based mixture design procedure is recommended to provide a higher degree of certainty in the expected mixture performance. Until more data is gathered, this procedure should be used as an addition to conventional tests.
- To ensure a reliable use of more than 30 % RAP use in PmB mixtures, the use of highly polymer-modified virgin binder should be considered. Such a binder might allow to compensate for the lack of polymers in the RAP binder and increase the RAP content.
- The use of high-content of RAP in pavements intended for high-traffic intensity roads should only be permitted if high homogeneity of RAP can be ensured.

RAP use in pavements at high altitude

Five HighRAP mixtures having high RAP content were paved in Lukmanierpass at an altitude of above 1,900 m along with the respective reference mixtures as shown in Fig. 29. At this altitude currently high content of RAP is not permitted and AC F type mixtures are not used.

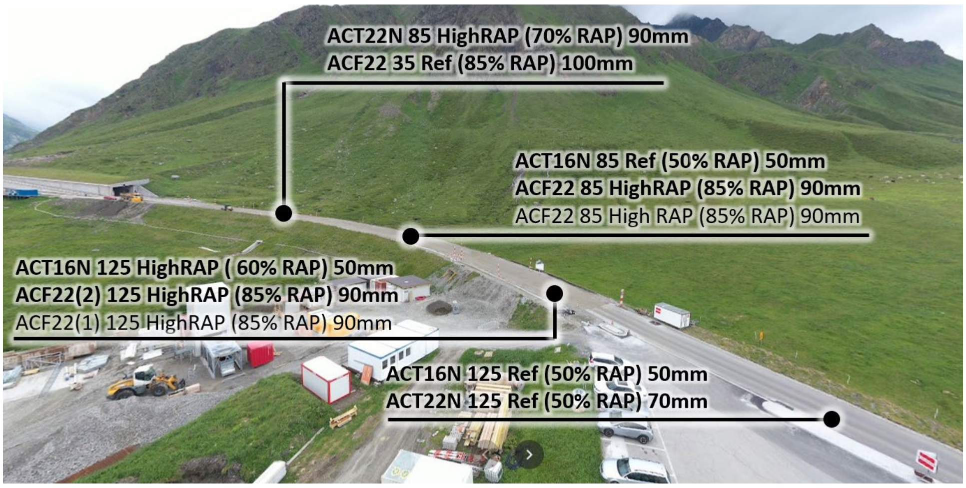

Fig. 9 *The location of Lukmanierpass test section mixtures. The HighRAP abbreviations indicates the mix was designed as part of the project.*

From the results of the Lukmanierpass test section, it can be concluded that by following a performance-based mixture design, it is possible to produce AC F 22 mixtures having 85% RAP content with similar properties compared to the mixtures conventionally paved at altitudes above 1,200 m. The resistance to plastic deformations of the AC F 22 HighRAP mixtures, due to the use of less angular aggregates is worse than that of the AC T 22 N reference mixture and due to the softer binder it is worse than the reference AC F 22 mixture with 20/50 binder. However, at high altitudes, considering that AC F 22 is a foundation-course mixture, the risk of plastic deformations is smaller.

The AC T 16 N and AC T 22 N mixtures could be produced with a 10 % to 20 % higher RAP content compared to the reference mixtures while still ensuring properties that are similar to the respective reference mixtures.

Fig. 30 compares the most informative performance-based tests results of the HighRAP mixtures with the reference mixtures paved in the Lukmanierpass test section.

	Mixture	Binder grade	RAP content	Crack propagation resistance SCB	Crack propagation resistance G-R	Rutting resistance CC	Rutting resistance BTSV	Thermal Cracking resistance TSRST	Stiffness ITT	Fatigue Resistance ITT	Fatigue Resistance MMLS
AC T 16 N (Lukmanierpass)	ACT16N 125 HighRAP	100/150	60%	→	→	→	→	→	↗	↗	-
	ACT16N 125 Reference	100/150	50%	●	●	●	●	●	●	●	-
	ACT16N 85 Reference	70/100	50%	↗	→	↘	→	→	↗	↗	-
AC T 22 N (Lukm)	ACT22N 85 HighRAP	70/100	70%	→	→	→	→	→	↑	↗	-
	ACT22N 125 Reference	100/150	50%	●	●	●	●	●	●	●	-
AC F 22 (Lukmanierpass)	ACF22 85 HighRAP	70/100	85%	↗	↗	↑	↘	↑	↗	↘	↗
	ACF22(2) 125 HighRAP	100/150	85%	↗	↗	→	↓	↑	→	→	→
	ACF22(1) 125 HighRAP	100/150	85%	↑	↗	→	↓	-	-	-	-
	ACF22 35 Reference	20/50	85%	●	●	●	●	●	●	●	●

Legend:

- ● reference mixture result
- ↑ significantly better performance
- ↗ slightly better performance
- → similar performance
- ↘ slightly worse performance
- ↓ significantly worse performance

SCB Semi-circular bend test (mixture)
G-R Glover-Rowe test (binder)
CC Cyclic compresstion test (mixture)
BTSV BTSV temperature (bitumen)
TSRST Thermal stress restrained specimen test (mixture)
ITT Indirect tensile test (mixture)
MMLS3 Model mobile load simulator (mixture)

Fig. 10 *Summary of the performance of Lukmanierpass test section mixtures*

Recommendations regarding the use of RAP at high altitude

- Permit the use of AC F mixtures at high altitudes if the correspondence to the current binder and mixture requirements is ensured and it is demonstrated that the design binder is not prone to accelerated aging.
- The use of a performance-based mixture design procedure is recommended to provide a higher degree of certainty in the expected mixture performance. This procedure should be used as an addition to conventional tests.
- If performance-properties are verified, permit the use of AC T type mixtures with at least 70 % RAP. For AC F 22 type mixture, 85 % RAP use is possible.
- The use of high content of RAP at high altitudes should only be permitted if high homogeneity of RAP can be ensured.

A note regarding the proposed recommendations

The provided recommendations are the opinion of the first author based on the results of this research. Situations can be different and therefore sound expert judgment should be used before deciding to apply these recommendations. Many of the recommendations are intended to be a holistic solution. For example, permitting higher RAP content should only be considered along with adapting procedures for ensuring high RAP homogeneity.

Full report

Download the full report, presentation, and developed tools from: https://www.empa.ch/web/s308/highrap

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HighRAP Project Results

"Highly Recycled Asphalt Pavements" full report: https://www.empa.ch/web/s308/highrap
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Objective: Develop recommendations for high asphalt pavement recycling

FULL-SCALE RAP CRUSHING AND SCREENING EXPERIMENT

- Max Reclaimed Asphalt Pavement (RAP) content can be limited by too much fines in RAP
- Chunk, Breakdown, and Filler increase (CBF) indexes allowed to quantitatively characterize RAP processing using sieve analysis. Calculator developed and available

FULL-SCALE MILLING EXPERIMENT

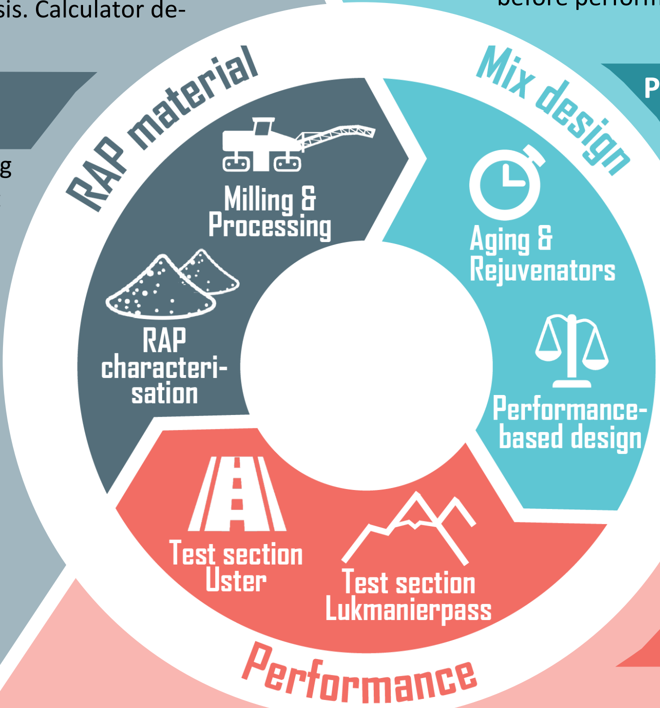
- RAP did not age during milling
- Aggregate angularity did not change during milling
- RAP agglomerations increase with increasing speed and less filler is generated

RAP CHARACTERIZATION

- The current RAP test methods are inefficient
- In some cases RAP was not homogeneous
- Fragmentation and Cohesion tests evaluated but further research is necessary to develop rapid RAP characterization tests

REJUVENATOR SELECTION & MIX AGING RESISTANCE

- Dosage based on penetration. Calculator developed & available
- RTFO+2xPAV aging simulated RAP binder properties
- Rejuvenated binder blends—not prone to accelerated aging
- No aging for lab mixes required to replicate plant-production before performance tests



PERFORMANCE-BASED MIX DESIGN

- Cracking test (SCB) and plastic deformation test (CC or Marshall) used to optimize binder content
- Conventional mix design requirements mostly fulfilled
- Additional binder and mixture used to confirm the final designs (e.g. low-temperature cracking test, FRT, BTSV, Glover-Rowe test, MSCR)

TEST SECTION AT >1900M

- 85 % RAP was used in foundation course mixtures with good performance
- 60-70 % RAP was used in base course with good performance
- Good thermal cracking resistance for all mixtures

TEST SECTION ON HIGH TRAFFIC (T3) STREET

- 30 % RAP used in wearing course with good performance in PmB 45/80-80 grade; with 60% RAP not possible to reach this grade
- 40-50 % RAP likely allows to reach PmB 45/80-65 grade
- 65% RAP used in unmodified binder course—with good performance

RECOMMENDATIONS

- Use RAP ≤30 % in PmB wearing course (PmB 45/80-80) and ≤50 % in PmB base/binder course (PmB 45/80-65)
- Use RAP in high altitude ≤ 70 % in base/binder course and ≤85 % in foundation course
- (Higher RAP contents can be considered with proof of performance)
- Permit high RAP use only if high RAP homogeneity of RAP is ensured (especially binder content & properties)
- Use performance-based mix design for type testing (testing of cracking resistance is especially important)
- Select rejuvenator dosage based on target penetration
- Approve rejuvenator/soft binder by testing aging resistance (RTFO+2xPAV): test mass loss & penetration
- Ensure correspondence to conventional extracted binder & mixture test requirements
- Consider MSCR binder test for RAP use in PmB mixtures
- Use CBF indexes to optimize RAP crushing and screening
- Consider using high-PmB to reach the target PmB grade
- Implement these recommendations after local validation

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