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INNOVATIVE PAVEMENT MAINTENANCE AND REPAIR STRATEGIES

A PIARC CASE STUDIES COLLECTION

TECHNICAL COMMITTEE 4.1 *PAVEMENTS*

PIARC

STATEMENTS

The World Road Association (PIARC) is a nonprofit organisation established in 1909 to improve international co-operation and to foster progress in the field of roads and road transport.

The study that is the subject of this report was defined in the PIARC Strategic Plan 2020– 2023 and approved by the Council of the World Road Association, whose members are representatives of the member national governments. The members of the Technical Committee responsible for this report were nominated by the member national governments for their special competences.

Any opinions, findings, conclusions and recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of their parent organisations or agencies.

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A PIARC COLLECTION OF CASE STUDIES

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EXECUTIVE SUMMARY

2022R28EN

INNOVATIVE PAVEMENT MAINTENANCE AND REPAIR STRATEGIES

A PIARC CASE STUDIES COLLECTION

This report contains the collection of case studies related to innovative pavement maintenance and repair strategies of road pavements.

This report addresses different pavement types i.e. flexible and (semi-)rigid pavements - as well as different road types. It considers both functional and structural aspects.

The report covers innovation aspects on a technical level, such as the use of special or innovative materials, or the use of specific maintenance techniques, as well as innovative and strategic organizational aspects of pavement maintenance.

The document does not aim to provide any conclusions or recommendations on innovative pavement maintenance and repair strategies of road pavements but rather summarizes the most important findings based on each specific case study.

CONTENTS

1. INTRODUCTION

This collection of seventeen case studies presents a set of examples on innovative pavement maintenance and repair strategies of road pavements.

To structure this document, the pavement type and/or sort of measure of each case study was taken into consideration.

1.1. STRUCTURE OF THE DOCUMENT

The collection of case studies includes innovative maintenance aspects for two major types of road pavements: asphalt and concrete.

Some case studies present technical aspects of innovative maintenance, concerning new materials and/or techniques.

Regarding the technical aspects, this collection of case studies approaches several types of structural and functional solutions for pavement maintenance, with each serving different purposes.

The present report also presents innovative organizational and strategic aspects of pavement maintenance.

To structure this document a division of the case studies were conducted. The case studies were grouped into 5 subchapters:

- Innovative surface technical maintenance and repair strategies on asphalt pavements - materials and/or techniques;
- Innovative structural technical maintenance and repair strategies on asphalt pavements - materials and/or techniques;
- Innovative structural technical maintenance and repair strategies for widening rural roads and edge strengthening;
- Innovative surface technical maintenance and repair strategies on concrete pavements - materials and/or techniques;
- Innovative organizational and strategic aspects on pavement maintenance.

1.2. READING GUIDE

Chapters 2 and 3 focus on innovative technical maintenance and repair strategies on asphalt pavements.

Chapter 4 focuses on innovative structural technical maintenance and repair strategies for widening rural roads and edge strengthening.

Chapter 5 considers innovative surface technical maintenance and repair strategies on concrete pavements.

Finally, chapter 6 presents innovative organizational and strategic aspects on pavement maintenance.

1.3. METHODOLOGY

These case studies were collected directly from the members and the countries represented in TC 4.1 Pavements.

The case studies cover mostly Europe, America, and Asia. Although the Technical Committee has not received case studies from Low- and Medium-Income countries, some of the case studies addressed in this report may be useful for these countries.

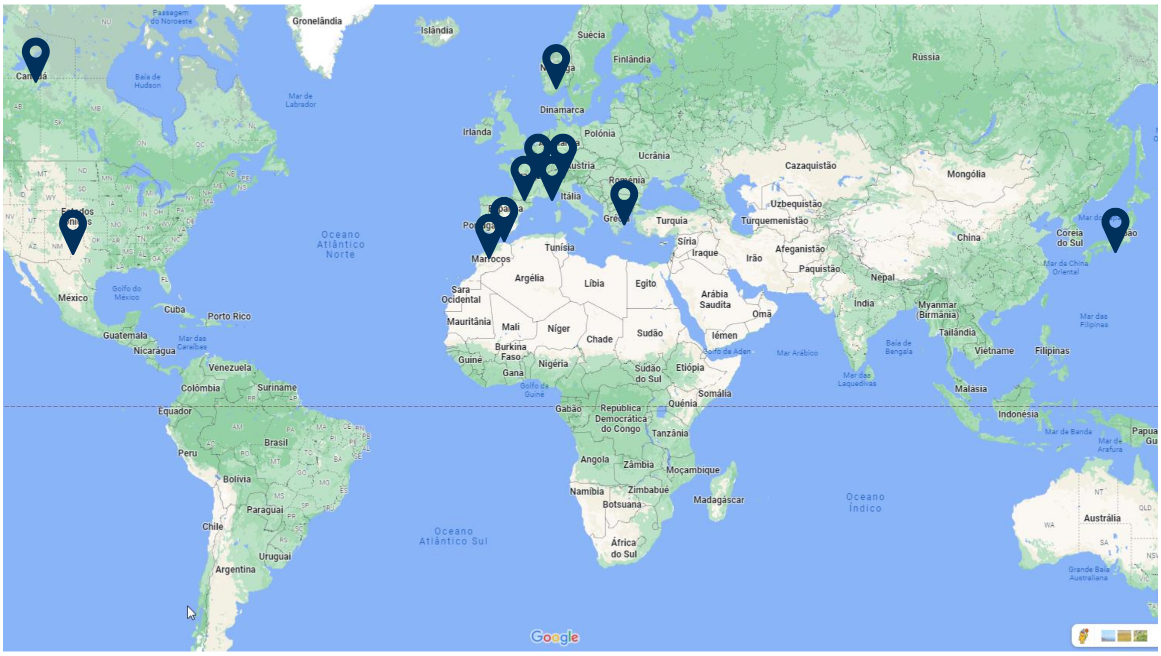

Figure 1: Map of World with case studies (map layout © Google Maps)

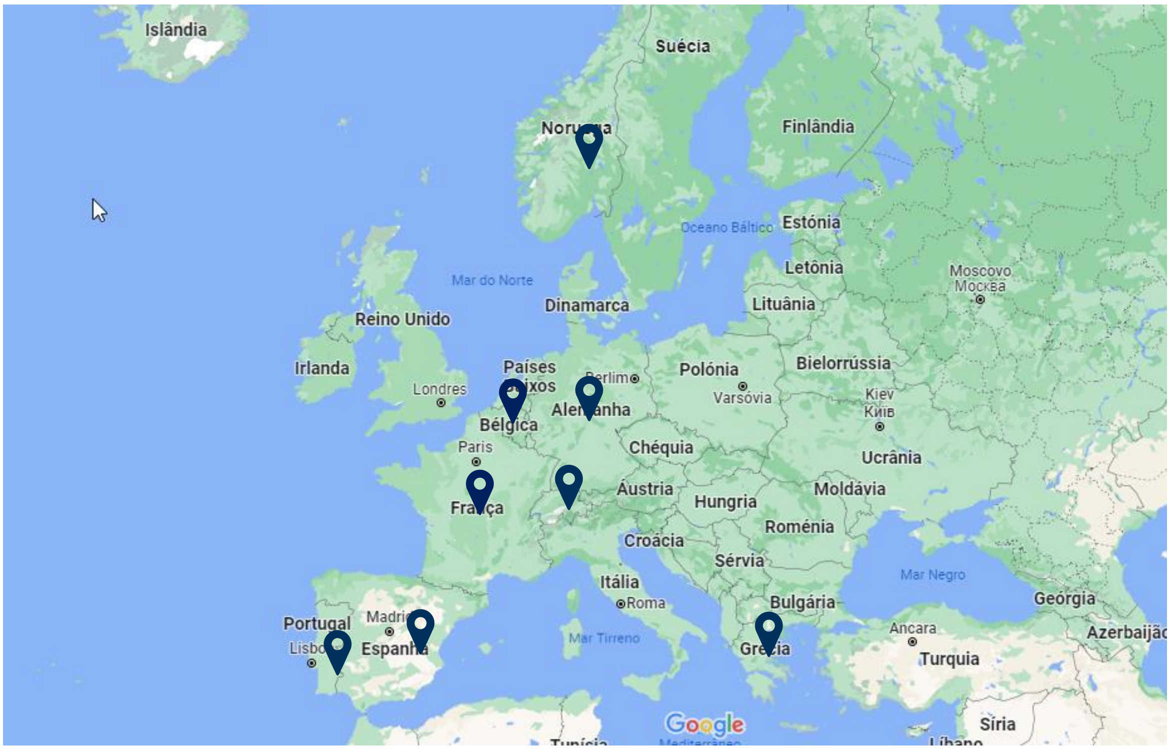

Figure 2: Map of Europe with case studies (map layout © Google Maps)

2. REFERENCES

The references for each case study are given in each subchapter.

3. INNOVATIVE SURFACE TECHNICAL MAINTENANCE AND REPAIR STRATEGIES ON ASPHALT PAVEMENTS - MATERIALS AND/OR TECHNIQUES.

This chapter presents a set of case studies that aim to show different maintenance and repair strategies, involving new materials and/or techniques to improve the surface characteristics of a road pavement.

3.1. How 3D milling can improve the quality of asphalt pavement resurfacing: A Belgian demonstration project

3.1.1. Introduction

Good longitudinal evenness is crucial for the safety and comfort of the road user. When reconstructing asphalt roads, it is therefore important to control the evenness of the constructed pavement. Traditional milling, wherethe present surface is most often used as a reference plane, copies the current profile of the road; However, ordinarily, the profile of the road should be changed to improve the evenness. Nonetheless, when modifying the existing profile, other important parameters must not be compromised, for example:

- compliance with layer thicknesses during construction;
- connections of the adjacent parts of the road.

This is not always an easy task, which is why the thorough and precise measurement of the existing situation, and the design of a good execution plan are of great importance. A traditional survey is very intensive and time-consuming. New and innovative 3D technology can be used to make the survey easier and to guide the milling work accurately.

The Belgian Road Research Centre (BRRC), together with the Flemish Road authorities (AWV), Colas Belgium (contractor), Topcon (technology supplier) and Topoff (milling company), organized a test case, on the N725 in Lummen, to demonstrate and evaluate recently developed 3D technology. During the project, various techniques for measuring and milling were demonstrated. An overview is given in

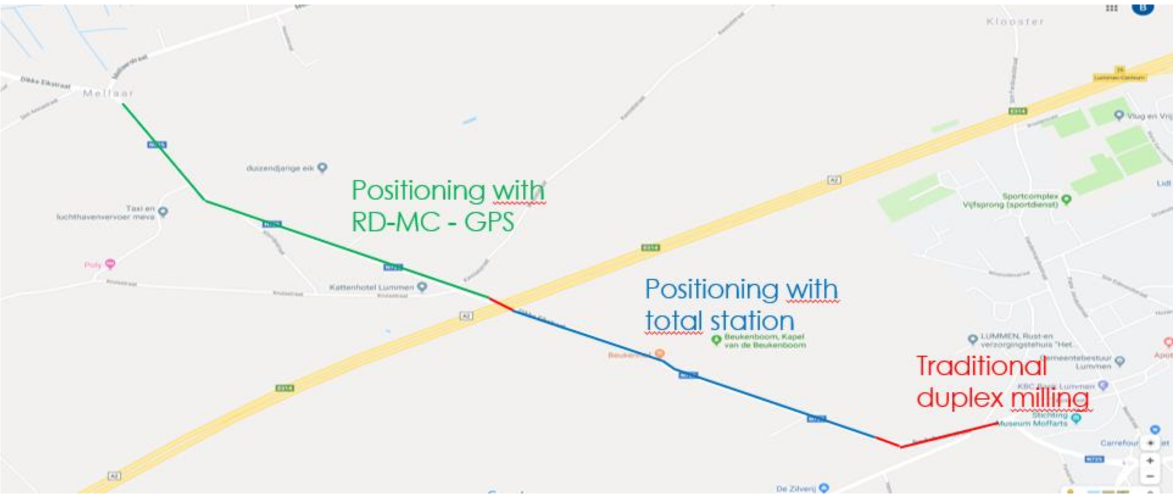

Figure 3 . One part of the road is in an open area; hence it is suitable for the use of GPS guidance techniques. Another part is covered by overhanging trees and dense foliage that can obstruct the GPS signal. This is where the static devices were demonstrated. In a first section of the job site and

on the bridge over the motorway, some of the milling work was carried out in the traditional way (duplex milling).

In order to monitor the improvement of the longitudinal evenness, measurements were performed by BRRC and AWV before and after the construction.

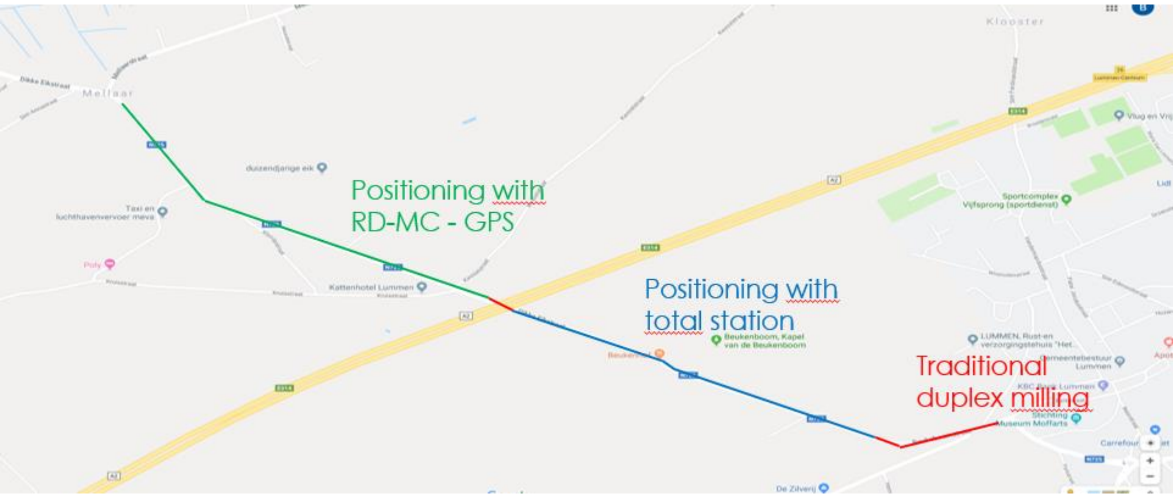

Figure 3: Test site location with indication of the different sections[1]

3.1.2. Realisation of the test case with 3D technology

3.1.2.1. Measuring the initial state

With 3D technology, the actual state of the road can be measured safely and accurately. Various devices are available for this purpose.

Figure 4: Static 3D scanner

[1] Unless otherwise stated, all images in this collection of case studies are © by the author.

Figure 5: Dynamic 3D scanner RD-M1

On the covered part of the road (blue part on the map in

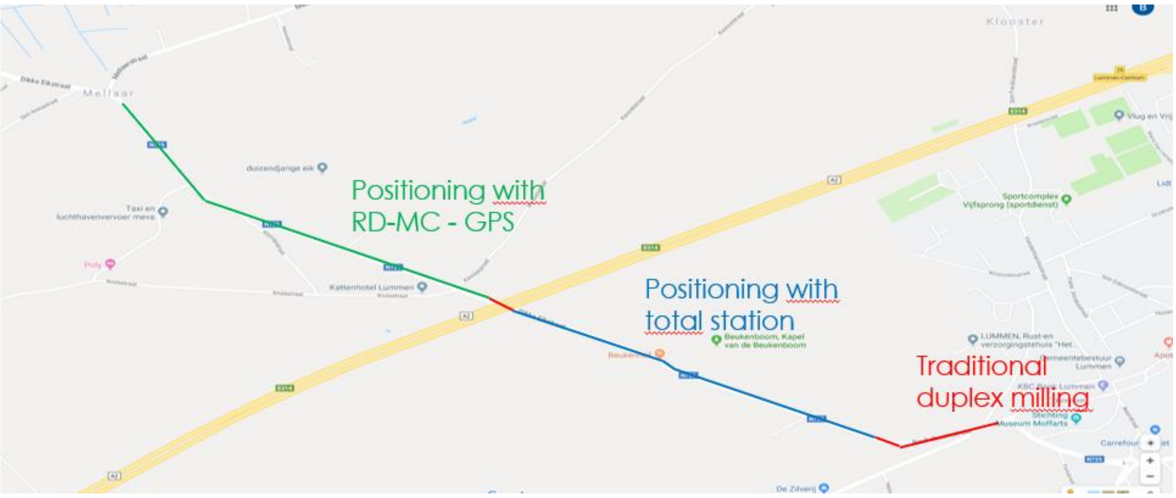

Figure 3), the static 3D scanner and a total station were used to measure the road conditions. Depending on the type of device, the 3D scanner has a scanning range of 100 m to 300 m; a 360° scan takes two to three minutes. Thereafter, the device must be moved.

On the road section located in an open area (green part on the map in

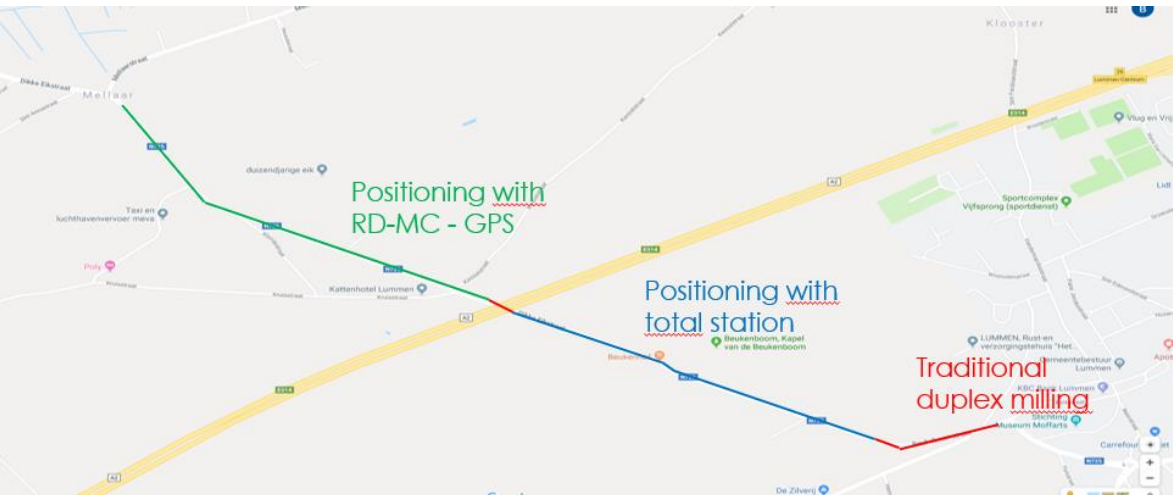

Figure 3) Topcon's dynamic 3D scanner RD-M1 was used. This scanner was mounted on the back of

a vehicle. The road was then scanned in 3D in a safe manner without any obstruction to other road users. The vehicle was able to participate in normal traffic flow. This has a major advantage on the safety of, and the time spent by the surveyors. They are indeed no longer exposed to traffic and surveying with a vehicle is much faster than with a total station or a static scanner, for example.

3.1.2.2. Creating a 3D model

With the data collected during the measurement, a 3D model was created. In this model, a new reference plane was determined, and its evenness was optimized by means of a smoothness algorithm (virtual ski 20 m). The maximum milling depth and the desired crossfalls were defined. The final finished heights were displayed in the model. Through simulation in the model, possible problems, such as connections with side streets or driveways, could be anticipated. After verification and approval of all heights, the model was converted into an execution plan for the milling machine.

3.1.2.3. Guidance of the milling works

The approved execution plan is then transferred to the milling machine's control panel. With the help of geopositioning (GPS or total station), the machine can accurately follow the execution plan. The positioning of the machine on the building site according to the execution plan can be done in different ways. During the Belgian test case, the position of the milling machine was determined via a total station and via RD-MC (GPS).

When a total station is used to determine the position, a prism is mounted on the milling machine (Figure 6). A constant connection between the total station and the prism is necessary. The total station must be set up in such a way that the beam is not interrupted, e.g., by traffic, overhanging trees or waiting trucks. In addition, the working range of a total station is limited to approximately 150 m, after which the device must be moved and calibrated. In order to work efficiently, several total stations were used during the test case.

Figure 6: Milling machine with prism

Figure 7: Total station connected with prism

When GPS was used for the geopositioning, two GPS antennas were mounted on the milling machine (Figure 8). There were no restrictions on the working range when using RD-MC (GPS) control. No equipment had to be moved or set up, and work could continue without any interruptions.

Figure 8: Milling machine with GPS antennas

Figure 9: Control unit

Some problems occurred during the execution, such as the presence of tar, which made it necessary to adapt the model in the control system. The system is flexible and allows easy adjustment of the model and setting of an offset on site.

3.1.2.4. Results of the longitudinal evenness measurements

The longitudinal evenness was measured before and after the reconstruction of the road and the results were promising. Figure 10 and Figure 11, show the evenness results from the BRRC measurements, for VC2.5m and VC10 (evenness coefficients for 2.5 m and 10 m wave length). Before the reconstruction, the road was in a very bad condition and almost completely non-compliant. The results after the reconstruction show a great improvement of the longitudinal evenness.

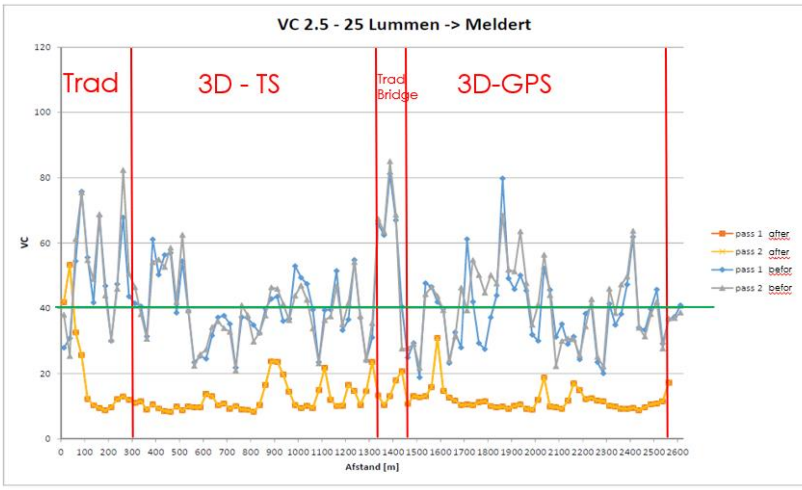

Figure 10: Results of evenness measurements for VC2.5

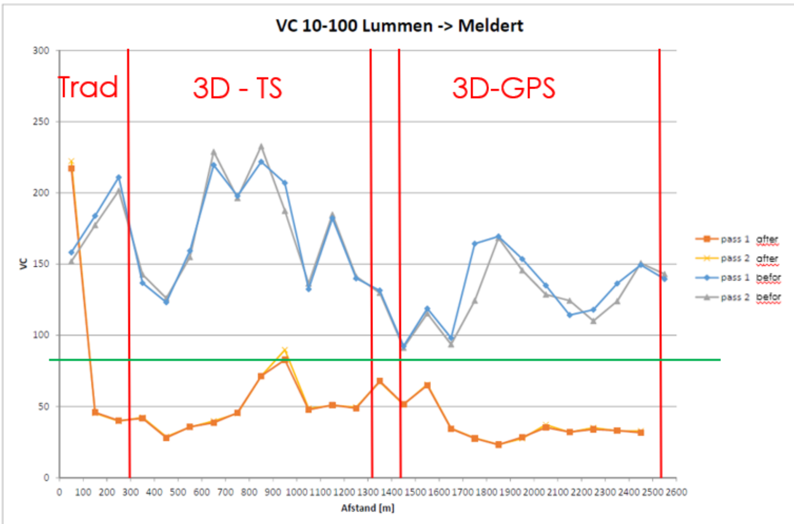

Figure 11: Results of evenness measurements for VC10

3.1.3. Conclusions

The demonstrated 3D technology offers many advantages to both the contractor and the road administration:

- significant improvement of the longitudinal evenness, which benefits the safety and comfort of the road user;
- faster and more efficient measuring;
- safer for the surveyor;
- possibility of simulations in the 3D model (connections with adjacent properties and side streets);
- the model is easy to adapt during execution.

This demonstration project has shown that the technology is ready to be used on Belgian roads. BRRC and the Flemish Road administration will continue to guide and encourage contractors to use this innovative technology in order the raise the quality of maintenance works to an even higher level.

3.2. ALL-WEATHER HIGH PERFORMANCE COLD MIX: REPAIR MATERIAL HARDENED WITH WATER

3.2.1. Introduction

"AQUA PATCH" is an entirely new type of cold mix, it is an ideal repair material which cures by adding water and tamping down. It can even be used in the places where potholes are filled with water. It has high durability and quick hardenability compared to with the conventional asphalt patches. Figure 12 shows the appearance of AQUA PATCH.

Figure 12: The appearance of AQUA PATCH

3.2.2. Hardening Mechanism (How AQUA PATCH is Hardened)

"AQUA PATCH", is a Cold Mix Asphalt which cures fast and works as a Hot Mix Asphalt that uses natural plant-based lubricants instead of mineral oil, as used for "Conventional Cold Mix Asphalt", which ordinarily does not harden enough.

Figure 13 shows the mechanism of strength development of this cold asphalt mixture newly developed. In the Figure 13 the drawing on the left (before) shows that asphalt is soft and pliable while the drawing on the right (after) shows that the special lubricant oil causes chemical reaction with the added water. This reaction makes the asphalt to be harden and aggregates join tightly to each other. AQUA PATCH will show high durability and allows it to last much longer in potholes than any other Conventional Cold Mix Asphalt patches.

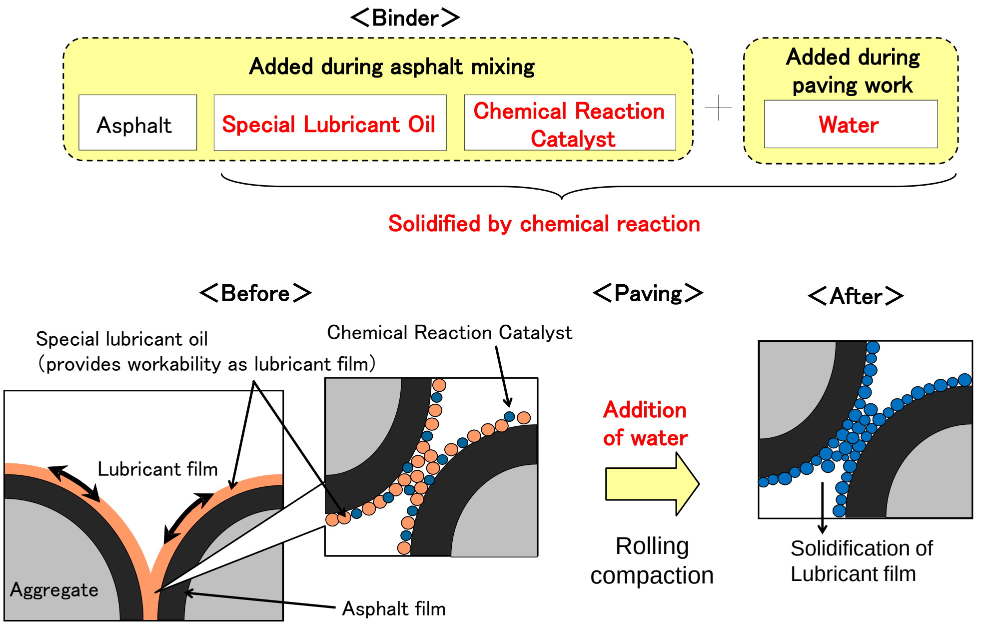

Figure 13: Hardening mechanism

3.2.3. Installation Method

Figure 14 shows the installation method. Once water is poured, a chemical reaction occurs with the plant-based lubricant and the additives.

＜Put "AQUA PATCH"＞
Fill an appropriate quantity of "AQUA PATCH".

＜Pour Water＞
Criteria : 1L/bag
No problem with excess water

＜Compaction＞
By treading down or plate compactor, enough earnestly.

Figure 14: Installation method

3.2.4. Features of AQUA PATCH

These are four major features of this unique mixture.

3.2.4.1. "Durable"

Figure 15 shows the results of some laboratory tests. The result of Marshall Stability Test shows more than 30kN (=6,744lbf). Wheel Tracking Test result as indicated on the right-hand side in the graph of Figure 15 shows that almost 10,000 passes make just 1mm rutting. Each result shows AQUA PATCH is more durable than the other Conventional Cold Mix Asphalt.

Figure 16 shows the repair situation at the entrance/exit of a distribution center. There is an area suffered torsional effect of large vehicles. Repairs had been carried out several times, but the area quickly became damaged again after each repair. When it was repaired by AQUA PATCH, good serviceability was confirmed.

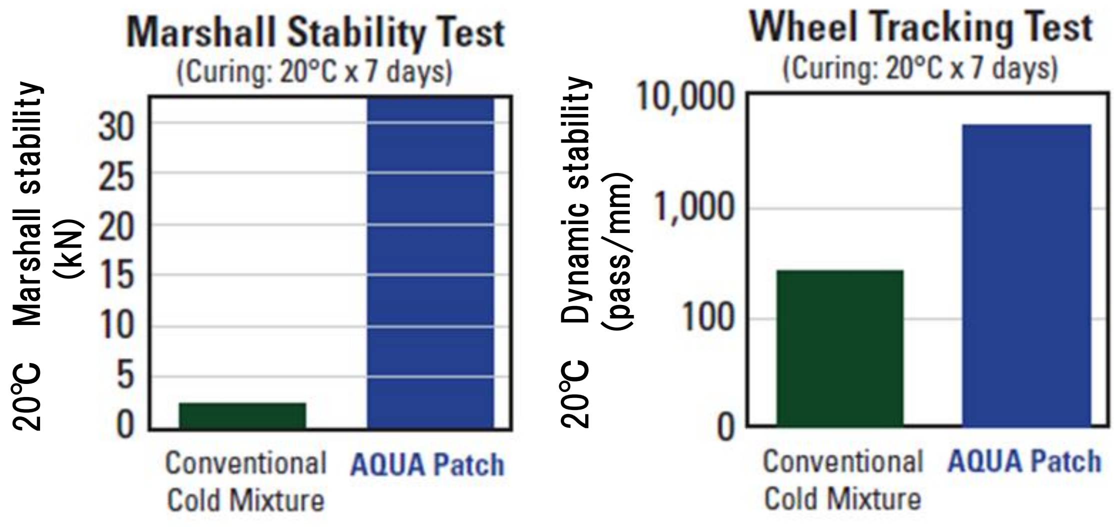

Figure 15: Lab. Tests

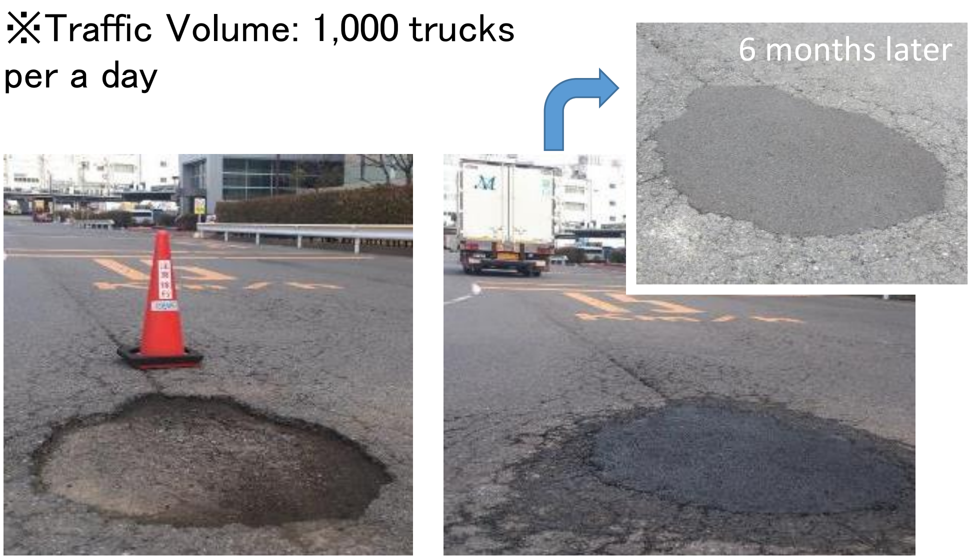

Figure 16: Outdoor evaluation test

3.2.4.2. "Applied in Rain"

Erreur ! Source du renvoi introuvable. shows the repair status in rainy weather. "AQUA PATCH" can be applied even in rainy conditions or on a pothole filled with water. Both of this water will help to be harden rather than bother it.

Figure 17: Evaluation test in rain

3.2.4.3. "Fast Traffic Opening"

To verify the strength development of this new mixture, a car was driven over the road immediately after pothole repair, as shown in Figure 18, and the road surface profile before and after the tires had run over the road were measured, as shown in Figure 18. Photo in the left-hand side is "AQUA PATCH", and right one is other Conventional Cold Mix. Less tire marks can be seen on "AQUA PATCH" on the left. *Table 1* include the test results. Rutting is less compared to conventional cold asphalt mixtures, indicating that the mixture has superior initial durability.

AQUA PATCH Conventional Cold Mix

Figure 18: Durability immediately after repair work

Type	Rut Depth (mm)
AQUA PATCH	2.7
Conventional Cold Mix	5.1

Table 1: Rut Depth

3.2.4.4. "Eco-Friendly"

"AQUA PATCH" replaces asphalt cement to "Plant Based Lubricant" partially. AQUA PATCH can reduce the environmental impact, and this is the first step to "De-asphalting Society" which we and our industry are aiming for.

3.2.5. Conclusion

At last, but foremost, AQUA PATCH is applicable worldwide, and more than 1 million bags are sold in the world per year. https://www.am.jalux.com/asphalt/.

3.3. USE OF FIBERS IN MICROSURFACINGS: TWO CASES OF STUDY IN FRANCE AND SPAIN

3.3.1. Background

For more than a decade, the use of synthetic fibers in microsurfacings has been an innovative and successful technique.

The following case studies carried out in France and Spain show experiences with a product called Gripfibre®, which was developed and commercialized by Eurovía in these countries.

This material is a 0/6, 0/8 or 0/10mm dense or gap graded microsurfacing with added synthetic fibers. It is usually applied in a single layer of about 10mm thickness over properly shaped substrate. The products extends the service life of structurally sound pavements (more info: www.eurovia.com)

Figure 19: Aspect of microsurfacing with the addition of fibers

Mentioned cases of study based on this technology are shown next.

3.3.2. N 260 Route, Girona, Spain

In 2017, a section on the N-260 in the province of Girona, from km 11+000 to 15+200 between the municipalities of Llançà and Colera was completed.

A continuous granulometry Microf-8 type treatment is applied, with fibers and a C60BP4 MIC modified emulsion (a/CEN standards).

3.3.2.1. Microsurfacing design

	Microf-8 (El Pilar quarry)	
Composition	0/6mm sand	75 %
	4/8mm aggregate	25 %
	Cement (%)	-
	Fibers (%)	0,07 %
	Added water (%)	6,0
	C60BP4 MIC emulsion (%)	10,7
	Binder residue (%)	6,4

Table 2: Microf-8 design

3.3.2.2. Microsurfacing laboratory evaluation

Test	Standard	Unit	Microsurfacing Microf-8	Specifications (TO traffic a/Spanish specs)
Flow time	Internal method	s	30	30
Cohesion: time to reach 2 N·m torque	UNE EN 12274-4	s	10	≤ 30
Wear or Loss to wet abrasion	UNE EN 12274-5	g/m2	54	≤ 350

Table 3: Microf-8 lab results

3.3.2.3. Placement details, aspect after construction and current conditions

The surface area treated was 29400 m2, with an application of 11 kg/m2. The work, included the milling of road markings and, was completed in 5 days. The appearance of the treated surface immediately after construction can be seen in Figure 20.

Figure 20: Aspect of a Microf 8 treatment

Current conditions of the route after more than 4 years in service can be seen in Figure 21.

Figure 21: Current conditions of Microf 8

3.3.3. A 87 Freeway, France

The work site is located on the A87 freeway (see Figure 4 below), from km 48+300 to km 56+000, which corresponds to the area between the Cholet north and Cholet south exit (Loire region). The road traffic is type T1 according to French standards.

Figure 22: A 87 freeway

A two-layer 0/4-0/10 continuous particle size treatment is applied based on a polymer-modified emulsion. Synthetic fibers are added to the second layer of 0/10 particle size to facilitate laying and prevent segregation. These fibers also reinforce the resistance to aging.

The existing surface was a semi-dense hot mix bituminous mixture (BBSG) constructed in 2000. The main objective of the treatment was to effectively seal the substrate and provide texture.

3.3.3.1. Microsurfacing designs

	Microsurfacing 0/4 Pont Charron/Meilleraie		ECF 0/10 c Pont Charron	
Composition	0/4 Pont Charron	60%	0/2 Pont Charron	40%
	2/4 La Meilleuraie	40%	2/6 Pont Charron	40%
			6/10 Pont Charron	20%
	Hydrated lime (%)	0,5	Hydrated lime (%)	0,5
	Fibres (%)	-	Fibres (%)	0,07
	Added water (%)	11	Added water (%)	10
	Emulsion (%)	11,8	Emulsion (%)	10,8
	Binder residue (%)	7,1	Binder residue (%)	6,48
	Density (t/m3)	2,638	Density (t/m3)	2,683

Table 4: 0/4 and 0/10 A 87 microsurfacing designs

3.3.3.2. Microsurfacings laboratory evaluation

	Standard	Unit	Specifications	0/4 microsurfacing Pont Charron/Meilleraie	0/10 c microsurfacing Pont Charron
Workability time	Internal method	s	≥ 90	90	110
Breaking time	Internal method	min	≤ 20	4	4
Cohesion (Benedict method)	NF EN 12274-4				

Cohesion at 30 min		kg.cm	≥ 20	23	23
Cohesion at 60 min		kg.cm	≥ 23	24	24
Abrasion test WTAT	MEI				
Mass loss (T = 18°C, HR = 55%)		%	≤ 5	-	0
Mass loss (T = 18°C, HR = 100%)		%	≤ 25	-	2

Table 5: Both 0/4 and 0/10 A 87 microsurfacings lab results

3.3.3.3. Placement details and follow up on surface conditions

The work was executed in 6 and a half days. The treated surface was 117300 m2 constructed in two layers (234600 m2). The daily output was 36,000 m2. Application speeds ranged from 1.5 to 2.5 km/h for a width of 3.8 m.

Figure 23: A 87 treatment application

The follow-up the macrotexture and transverse friction coefficient (TFC) since implementation (2008) and after three years in service (2011), can be seen in Table 6 and Table 7.

	Macrotexture	
	Average value	Deviation

Jun 2008	Roche-sur-Yon direction	1,3 mm	0,11 mm
	Paris direction	1,2 mm	0,13 mm
Jun 2011	Roche-sur-Yon direction	1,0 mm	0,10 mm
	Paris direction	1,0 mm	0,15 mm

Table 6: *A 87 macrotexture follow up*

		TFC	
		Average value	Deviation
Jun 2008	Roche-sur-Yon direction	0,71	0,02
	Paris direction	0,66	0,02
Jun 2011	Roche-sur-Yon direction	0,63	0,02
	Paris direction	0,63	0,02

Table 7*: A 87 TFC follow up*

3.4. LOW ENERGY ASPHALT WEARING COURSES

3.4.1. Background

Anthropogenic pollution and greenhouse gas emissions are increasing global warming and severely changing ecosystems and climate patterns. Therefore, the need for the immediate implementation of sustainable development policies has become more acute than ever. The replacement of the 'end-of-life' concept by reducing, reusing, and recycling materials, in conjunction with the inclusion of waste streams in production processes, should be at the forefront of policies for many sectors, including the construction sector. This sector should strive to provide appropriate solutions for making pavement infrastructure more sustainable.

Considering this challenge, the aim of this study was the design of a 'green' asphalt mixture, that was energy-efficient and durable for implementation on a pavement's construction and maintenance.

3.4.2. Mix design

The target mixture of this study was a semi-open graded asphalt concrete (AC) with a nominal maximum aggregate size of 12.5 mm, which is commonly used in wearing courses of Greek motorways. Three highly recycled mixtures were designed in the laboratory with electric arc furnace steel slag, one of the main by-products of the metallurgical industry, varying amounts (25, 40, and 50 %) of fractionated Reclaimed Asphalt (RA) produced from milling during the rehabilitation and reconstruction of asphalt surfacing and incorporating Warm Mix Asphalt (WMA) technology for lowering the production temperatures by 30°C (WMA-RA). Emphasis was placed on improving the environmental performance of asphalt mixtures by minimizing the consumption of non-renewable fossil fuels and natural resources, without sacrificing their mechanical behavior; parameters which were evaluated based on corresponding analyses and extensive laboratory testing. Moreover, a fourth mixture was designed and produced at conventional temperatures (Hot Mix Asphalt: HMA), for benchmarking purposes. All mixtures had almost the same grading and optimum bitumen content; detailed information about mixtures properties can be found in [1].

3.4.3. Environmental and performance evaluation

The environmental performance of warm recycled mixtures was evaluated in terms of quantifying the potential environmental benefits compared to the reference HMA. The analysis was carried out using a 'cradle-to-gate' approach, and the system boundaries included the extraction and production of raw materials, transportation, plant operations, and construction phases.

Moreover, to characterize the mixtures' performance, both mechanical and functional properties were evaluated, namely, raveling resistance, moisture susceptibility, stiffness modulus, rutting resistance, fracture resistance, and surface macrotexture. For the fabrication of test specimens, a steel-segmented roller compactor was used, which is believed to realistically reproduce the field compaction conditions and enables accurate assessment of the on-site characteristics of field compacted asphalt mixtures.

From an environmental point of view, it has been demonstrated that the warm recycled mixtures show considerable environmental benefits, which generally increase with RA content increase, stemming from lesser demands for raw material extraction, bitumen production, and resource supply [2]. Specifically, 36-39 % reductions were achieved regarding energy and water consumption, hazardous waste generation (HWG), as well as the CO_2 and SO_2 related to global warming and eutrophication, as illustrated in Figure 1. Reductions up to 30 % were achieved in NOx and CO emissions relating to eutrophication and photochemical ozone formation. It can also be noted that lowering the production temperatures leads to reduced exposure of workers to fumes, aerosols and odors which are related to potential carcinogens. Moreover, the reduced transportation needs for new aggregates and asphalt bitumen to the production plants results in a significant reduction of particulate matter emissions related to respiratory disorders. Particularly, reduction of human toxicity potential (HTP) and particulate matter (PM_{10}) by 30 % and 55 %, respectively, is achieved.

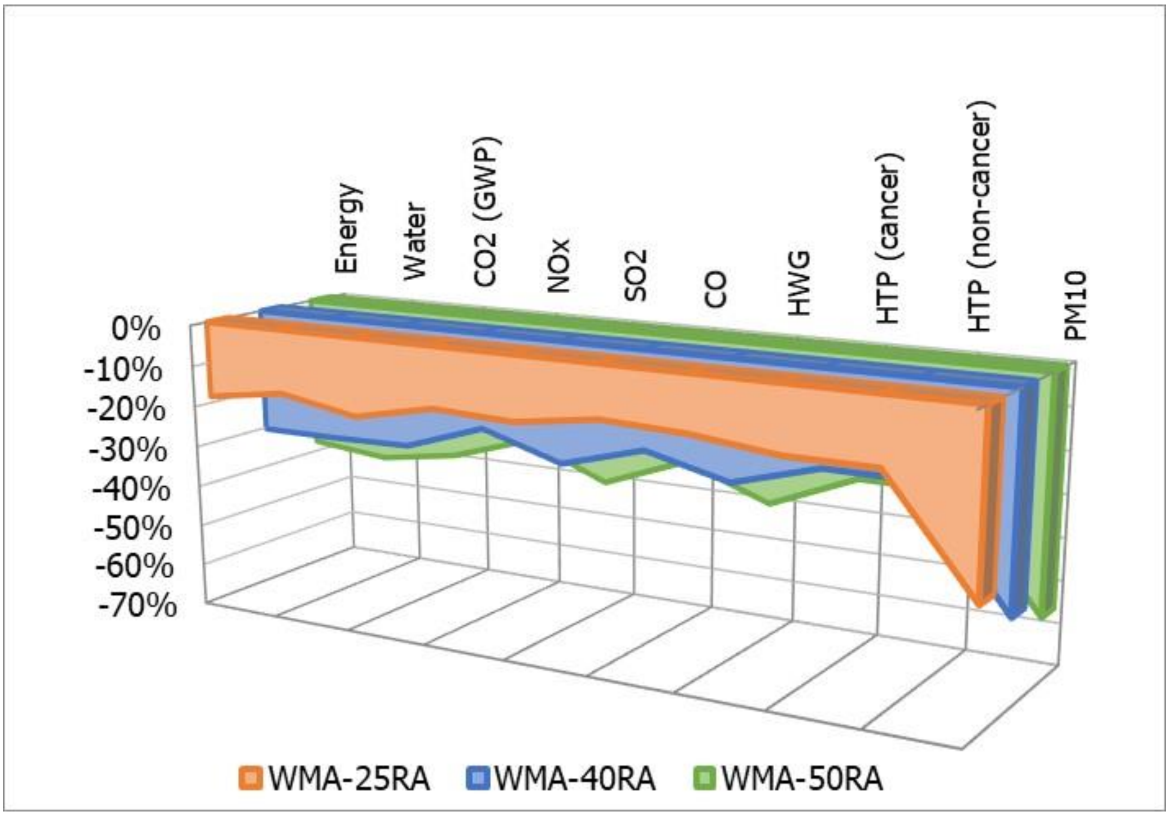

Figure 24: Relative environmental impacts of warm recycled mixtures compared to reference HMA

From a mechanical point of view, it has emerged that WMA-RA mixtures show similar raveling resistance in comparison with HMA, based on Cantabro testing. Furthermore, the indirect tensile strength (ITS) of the warm recycled mixtures is improved with the incorporation of steel slag and increased RA, and the ratio of wet to dry ITS values indicate enhanced moisture damage resistance [3]. Higher stiffness values of warm recycled mixtures compared to HMA are attributed to the presence of high RA content and implies a significant advantage of these mixtures in both pavement design and structural performance of asphalt pavements. It should also be noted that the high-temperature performance of all mixtures is almost equivalent, based on the wheel tracking test, while the fracture energy and flexibility index results, based on the Semi-Circular Bending test and the I-FIT method, indicate that the conventional mixture is more prone to cracking compared to the warm recycled mixtures. This further validates the concept of a balanced mix design. Moreover, the warm mix asphalt with 40 % RA and the HMA were found to offer the optimum texture depths to tackle road safety issues.

Overall, the results of this study generally indicated that the combined reuse and recycling of high reclaimed asphalt content (up to 50 %) and steel slag can boost the development of circular, energy-efficient, and high-performance wearing course mixtures for full-scale implementation on pavement construction and maintenance.

3.4.4. References

[1] *Georgiou, P. and Loizos, A. (2021). Performance evaluation of warm recycled surface mixtures with steel slag. In: M.C.F. Cunha, V., Rezazadeh, M., Gowda, C. (eds) Proceedings of the 3rd RILEM Spring Convention and Conference (RSCC 2020). RSCC 2020. RILEM Bookseries, vol 35, pp. 255-265, Springer, Cham.*

[2] *Georgiou, P. and Loizos, A. (2021). Environmental assessment of warm mix asphalt incorporating steel slag and high reclaimed asphalt for wearing courses: a case study. Road Materials and Pavement Design, 22(sup1), S662-S671, https://doi.org/10.1080/14680629.2021.1906305.*

[3] *Georgiou, P. and Loizos, A. (2021). Characterization of sustainable asphalt mixtures containing high reclaimed asphalt and steel slag. Materials, 14, 4938. https://doi.org/10.3390/ma14174938.*

3.5. Micro Milling with Surface Treatments

3.5.1. Introduction

The Minnesota Department of Transportation (MnDOT) began investigating the performance of micro milling of pavements combined with the application of thin bituminous pavement surface treatments in 2013. Micro milling is defined as:

A similar process to traditional pavement milling which uses a milling drum having about three times as many teeth as a typical milling drum. The additional teeth provide a tighter lacing pattern and smoother surface, providing a better surface than traditional milling for application of thin pavement surface treatments.

Figure 25: Micro Mill Photos: Finished micro mill texture and Micro Milled Pavement

The goal of this investigation is to use data gathered by MnDOT personnel to determine the effectiveness of micro milling with surface treatments, to improve the ride quality. For the purposes of this investigation, the ride quality data is an average of the left and right wheel paths known as the Mean Roughness Index (MRI). This is to keep the data concise between multiple projects being investigated for each treatment type. The MRIs were collected with an inertial profiler using a line laser setup.

The surface treatments placed in conjunction with micro milling include chip seal, micro surface, and Ultra-Thin Bonded Wear Course (UTBWC also known as NovaChip). Several projects were developed to incorporate micro milling with the different surface treatments. This investigation examines the performance of the different treatments when combined with micro milling.

3.5.2. Treatment #1: Micro Mill with Chip Seal

In 2013, micro mill and chip seal was constructed on TH 89. This is a rural road with under 2000 AADT. Ride quality data has been collected annually on the test project and on the control section. The initial MRI for the test project was 1.07 m/km with the control section MRI of 1.37m/km or a 24% improvement. Measurements at year eight continue to show a 7.5% improvement in smoothness of the test project vs. control.

Figure 26: TH 89 after placement of chip seal (2013)

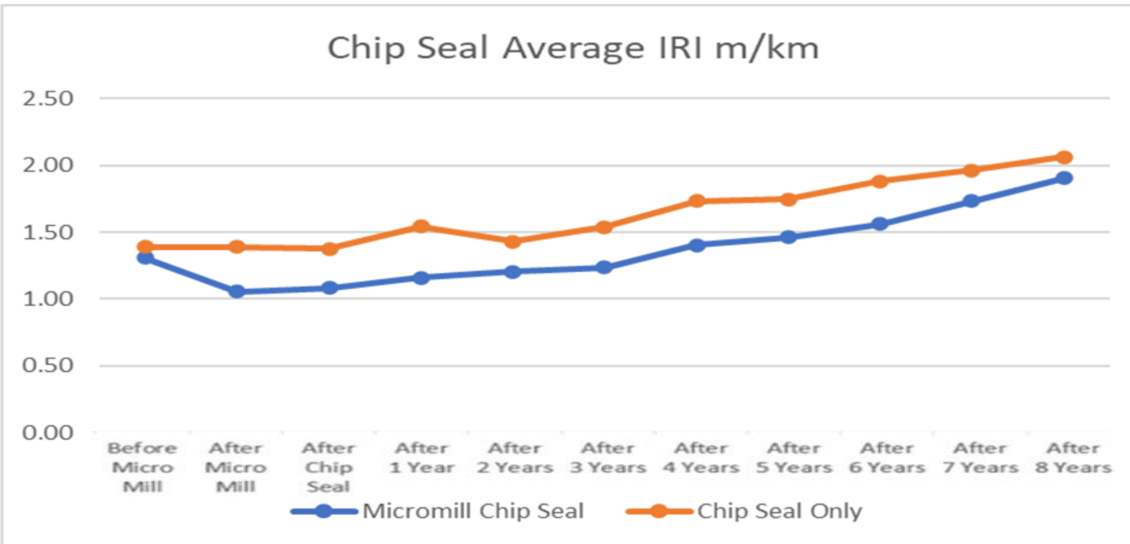

Figure 27: Micro mill with chip seal performance chart

3.5.3. Treatment #2: Micro Milling with Micro Surfacing

In 2014, two projects were micro milled prior to micro surfacing. Performance is documented in the chart below and Table 1. Based on the MRI data trend, these projects will reach their pretreated condition in about year 10.

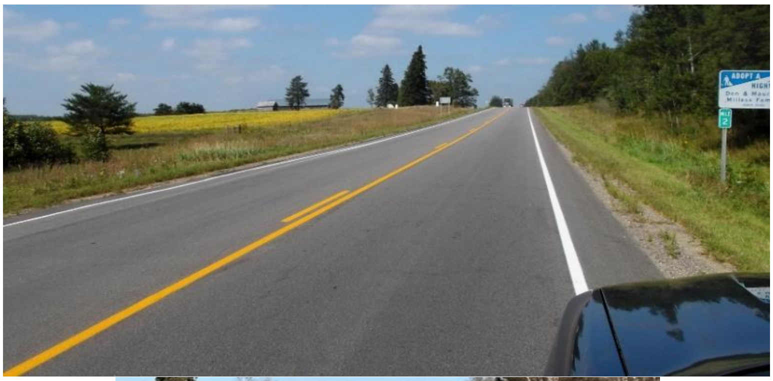

Figure 28: Rural Undivided (TH 64) Photos: After 1 Year (2015) and Year 6 (2020)

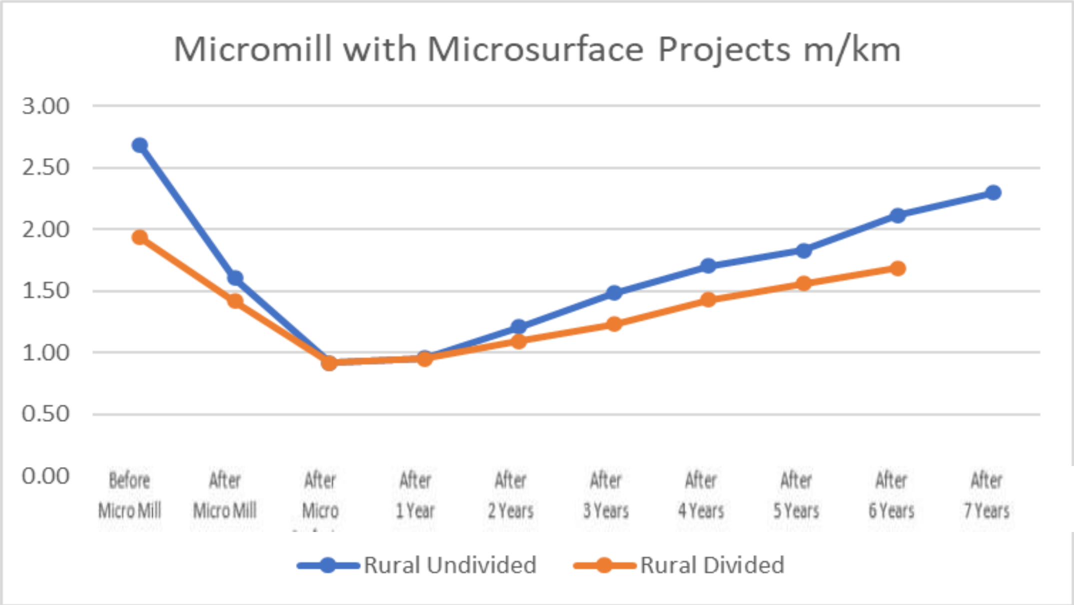

Figure 29: Micro Mill with Micro Surfacing Performance Chart

3.5.4. Treatment #3: Micro Mill with UTBWC

This investigation analyzed the ride data on two different micro mill projects with UTBWC projects. The data shows that ride quality can be significantly improved with this treatment as well. After 5 years, there is an average improvement of 34% on the Rural Divided section (US 10) compared to the pre-treatment MRI. The micro mill and UTBWC placed on I-394 improved the ride quality to a level above its original construction.

As with micro surfacing, more ride data will need to be collected in subsequent years since the pavement sections in this report have not yet returned to their pre-treatment MRI values.

Figure 30: Rural Divided (US 10) After 1 Year

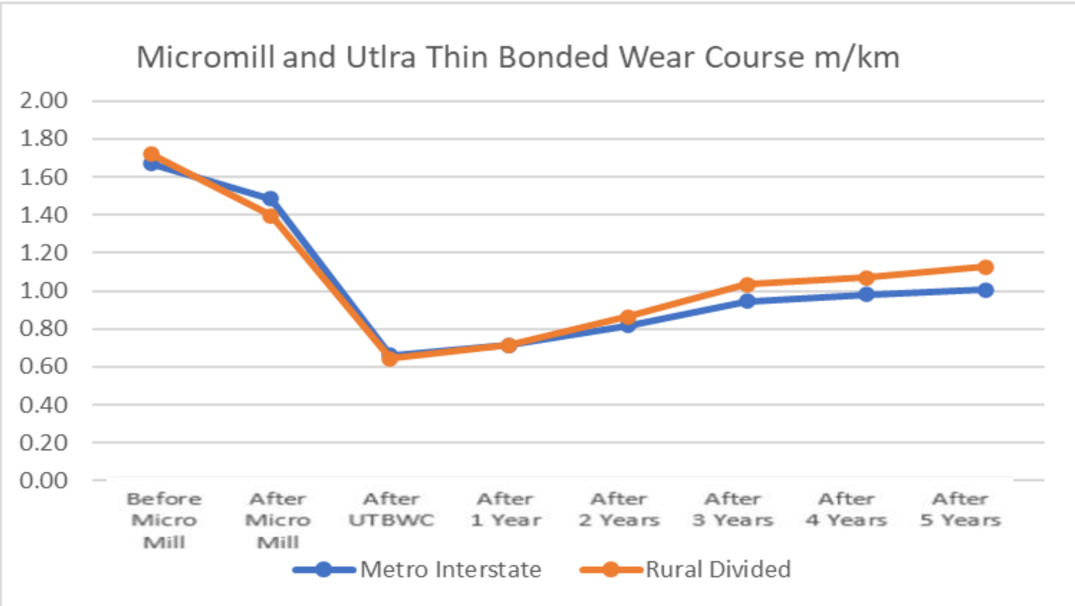

Figure 31: Micro Mill with UTBWC Performance Chart

Section	Before Micro Mill	After Micro Mill	After Surface Treatment	After Year 1	After Year 2	After Year 3	After Year 4	After Year 5	After Year 6	After Year 7	After Year 8
Chip Seal											
Test Project	1.31	1.05	1.08	1.16	1.2	1.23	1.4	1.46	1.56	1.73	1.91
Control Section	1.39	1.39	1.37	1.54	1.43	1.54	1.73	1.75	1.88	1.96	2.06
Microsurfacing											
Rural Undivided	2.68	1.60	0.92	0.96	1.21	1.48	1.70	1.83	2.12	2.30	
Rural Divided	1.94	1.42	0.92	0.95	1.09	1.23	1.43	1.56	1.69		
UTBWC											
Rural Divided	1.72	1.40	0.64	0.71	0.86	1.03	1.07	1.13	1.21	1.22	
Metro Interstate	1.67	1.48	0.66	0.71	0.82	0.94	0.98	1.01			

Table 8: Performance of micro milling with Surface Treatments m/km

3.5.5. Conclusions

As discussed above, since the MRI of most of the micro surfacing and UTBWC sections have not yet returned to the original values, additional ride data will need to be collected in subsequent years to provide a true comparison of cost/benefit ratio and longevity of the different treatments. Based on the available data, micro milling in combination with bituminous pavement surface treatments has the potential to significantly improve ride quality of a bituminous pavement. Higher initial cost treatments using microsurfacing and UTBWC delivered measurably better performance. Micro mill with chip seal provided four years of improvement and continued to outperform the segment of chip seal alone. It also has a lower initial cost than the other two options of micro surfacing and UTBWC. Budget and needs could show that the lower initial cost of a micro mill and chip seal treatment is a valuable option to your network.

3.5.6. References

[1] "Micro-Milling - The Finer Side of Milling." Pavement Interactive

[2] www.pavementinteractive.org/micro-milling-the-finer-side-of-milling/

4. INNOVATIVE STRUCTURAL TECHNICAL MAINTENANCE AND REPAIR STRATEGIES ON ASPHALT PAVEMENTS - MATERIALS AND/OR TECHNIQUES

4.1. USES OF REINFORCEMENT GRIDS

4.1.1. Framework

Considering resources scarcity and sustainable development issues, there is an urgent need in developing innovative maintenance techniques for asphalt pavements. The purpose of this case study is to present a practical solution for maintenance of road pavements based on the uses of reinforcement grids, otherwise known as geogrid.

Geogrids are usually applied on an existing pavement as a maintenance technique that permits to keep some of the existing pavement in place and extend the pavement's service life. Note that such systems can also be used as a reinforcement method for heavy loaded surfaces; for instance airfield pavements. Geogrids will usually be applied at the interface between existing and new asphalt layers, as illustrated in Figure 32. Most of the applications concern the interface between top and binding layer or between binding and base layers.

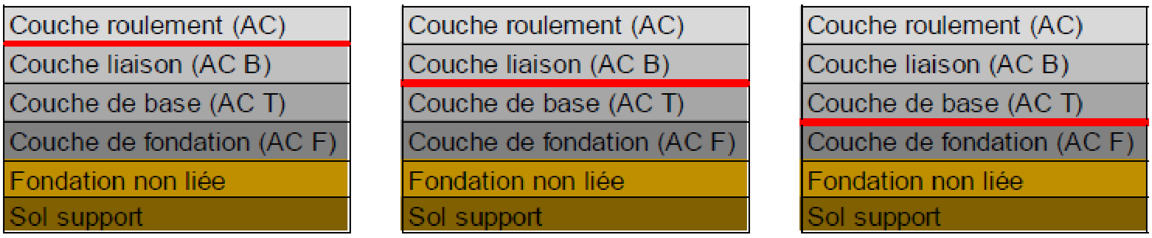

Figure 32: Grid installation alternatives (red line = grid)

Geogrid can be made of different materials. Carbon, glass, polyester, or polypropylene are the most widely used materials and some grids do combine different materials. The type of material (stiffness) will obviously affect the mechanical behavior of the products (and pavement structure). However, grid shape (mesh size), traction resistance and adhesion between grid and (asphalt) layer above and below the geogrid are some other key parameters. It should be noted that steel grid can also be used; however, this type of grid has a different application domain and boundary conditions e.g., recyclability. They are consequently not considered in the framework of this case study.

There are various objectives when using geogrids. One can say that following impacts can be expected:

- Improved resistance to crack propagation (bottom-up cracking);
- Sealing of the interface between existing and new pavement;
- Improvement of permanent deformation resistance ;
- Better homogeneity of pavement bearing capacity.

One can find numerous research and laboratory investigations related to the uses of reinforcement grids: each project corresponding to different materials and testing conditions. To illustrate the potential benefits of using geogrids, one can make some crack propagation tests as illustrated in Figure 33. This crack propagation test has been especially developed for the sake of evaluating reinforcement grids and to demonstrate that geogrid can have a substantial impact on crack propagation resistance. It is however important to keep in mind that the type of products that are tested will have an important influence on the outcome; thus general assumptions have to be avoided.

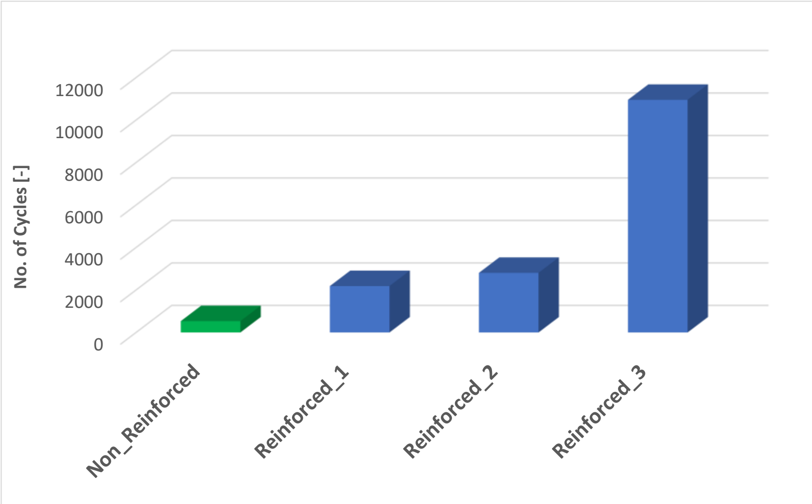

Figure 33: Crack propagation test results (Source: Bern University of Applied Sciences)

The proposed case study aims at providing some practical insight in these techniques and for this purpose, the construction of a test section is briefly presented.

4.1.2. Test section construction

4.1.2.1. Test section "La Cibourg / BE"

The aim of this test section performed in the framework of an industrial development project is to compare various products from a similar supplier and then perform long-term monitoring of the test section. The constructed pavement structure is as follows:

- 40 mm, AC 11 N, PmB
- 80 mm, AC T 22 N, B 70/100
- Reinforcement grid – different products
- Tack coat
- Existing pavement (90-100 mm).

For the sake of the test sections constructed in August 2019, various sensors i.e. stain gauges as well as temperature sensors have been installed within the pavement, this in order to perform some further monitoring campaigns. By using the sensors results, one can further assess the pavement service life, identify potential degradation initiation as well as attain some detailed insights related to pavement mechanical behavior.

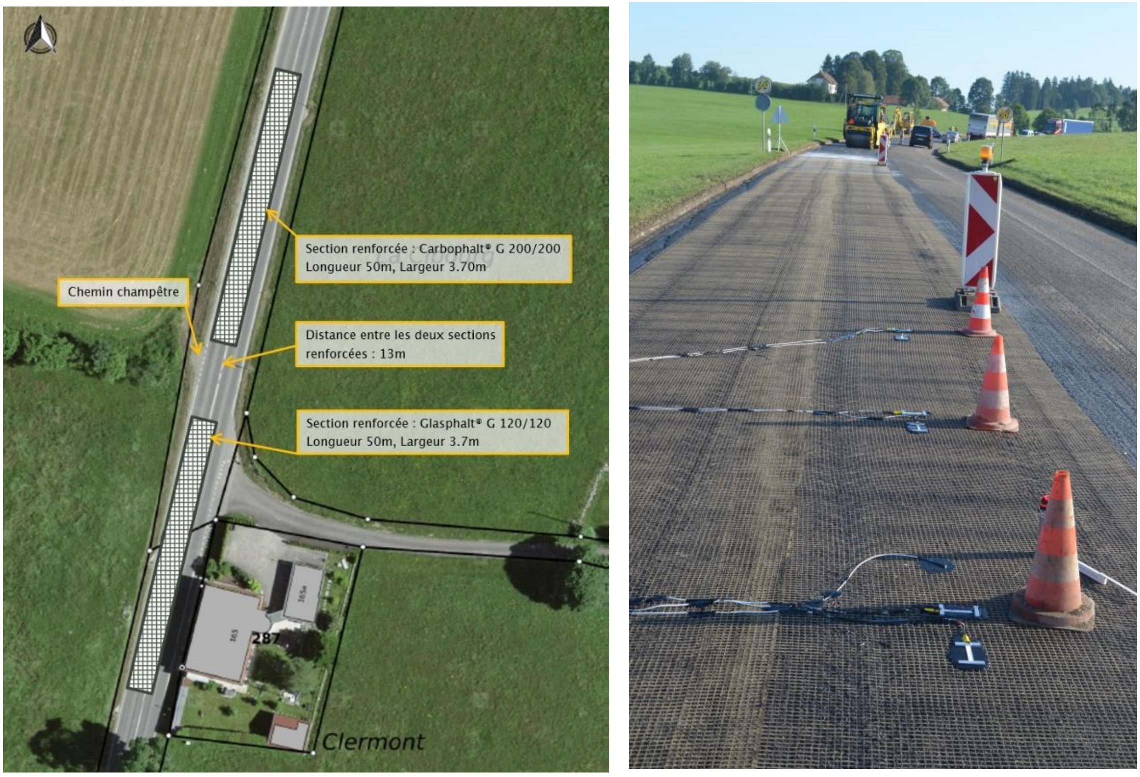

Figure 34: Test section overview and sensors installation

4.1.2.2. Test section "Sierre / Valais"

This test section, constructed in the framework of a research project financed by the Swiss Federal Road Administration (FEDRO) aims at promoting good practices in the field of reinforcement grids. This project contains two majors' phases that are the construction and follow up of the in-situ test section and the realization of laboratory tests.

The test section was constructed in October 2022 where 4 different types of grids as well as a reference section without grid wascompared. Each section had a surface of approximately 350 m^2 (50 m length). The job site consisted of milling 40 mm asphalt and then installing the reinforcement grids before the laying of a new asphalt top layer. The construction of the test section permitted to make an extensive comparison of different products and laying strategies.

Figure 35: Test section overview

One can mention the following points that have been highlighted during the laying phase and that will consequently substantially impact the service life of the pavement:

- Quality of the support (exiting road) and milling method;
- Emulsion: type, dosage, braking, laying, homogeneity;
- Installation period ;
- Uses of chipping or not, this to avoid potential degradations by trucks driving on the job site;
- Laying method for the grids (manual, machine).

nt

An extensive survey of the in-situ test section is planned in the framework of this project. One can mention that the first tests of layer adhesion (interface asphalt-grid; Leutner test) performed on cores taken in-situ highlighted some important differences between the test sections i.e., products. The abovementioned aspects seem to effectively have an important impact on the pavement performances.

Further visual survey campaigns as well as coring campaigns are planned. The in-situ results will finally be completed based on an extensive laboratory analysis in which the layer adhesion under different moisture conditioning methods, low temperature cracking, fatigue resistance as well as permanent deformation performances, are among others to be assessed.

4.1.3. Future perspectives

The experience with reinforcement grids is increasing during the last years and this type of maintenance strategy is an option that must be considered. There is currently a significant amount of interest for such innovative solutions that have various advantages such as the extension of pavement service life and savings in natural resources (i.e., less need for completely new asphalt mixtures). The in-situ and laboratory tests performed thus far, in Switzerland as well as at international level, clearly demonstrated that reinforcement grids can have a positive impact by extending the pavements service life. According to the experience attained in the framework of various projects, it is however worthwhile to highlight the following points:

- There are numerous types of reinforcement grids which vary in the grid characteristics and laying methods. One has to avoid some general assumptions that will usually not be valid for every grid type.

- A strong emphasis is currently placed on the evaluation of the grid reinforcement impacts on the overall pavement service life. It is indeed important to be able to calculate the impact of such reinforcement methods; for instance by using pavement design methods.
- The aspects dealing with the bonding between grid and asphalt layers, resistance to permanent deformation as well as crack propagation of composite structure with embedded grids are some of the major issues that should be considered in the framework of laboratory tests.
- In a lifecycle perspective, the issues related to the recycling of pavement with embedded reinforcement grids have to be tackled. This concerns more specifically the issue of milling an existing pavement with embedded reinforcement grids as well as the re-use of "reclaimed asphalt" with reinforcement grid chips. It should be noted that these aspects will also differ, depending on grid type and installation procedure.

4.1.4. References

[1] Swiss Federal Road Administration (FEDRO). Project VSS 2019/422. Utilisation de grilles de renforcement pour l'entretien des chaussées. En cours.

[2] Bueche N. Potentiel et enjeux des grilles de renforcement. Journée Suisse – Gestion de l'entretien. Bienne. 2021

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4.2. Development and Evaluation of Sustainable Pavement utilizing Renewable Materials

4.2.1. Introduction

In Japan, Asphalt mixture is widely used for over 90% of road pavements and expressways because it is easy to construct and repair. Asphalt, most commonly used for pavement, is a finite resource and all industries are heading towards the formation of an oil-free society. Therefore, the authors have researched and developed plant-based binders (Bio Binder) for Biomass Mixture [1].

4.2.2. Description of Bio binder

Bio binder is synthesized from 87-88 % of the plant-derived component and 12-13 % petroleum-derived component as showen in Figure 37, the biomass ratio is 80% or higher. The natural plants as raw materials are widely available and can be easily procured.

Bio binder has considerably different resin-like properties from asphalt. Table 9 shows the standards of the representative binder often used in Japan, so called "Polymer Modified Asphalt Type 2" (PMA 2) and the characteristics of Bio binder. PMA 2 is suitable for use in continuous grading, such as in dense-graded asphalt. In terms of high-temperature properties, the 180 °C viscosity of the Bio binder is close to PMA 2; therefore so the mixing and compaction temperature of the mixture is almost the same as PMA 2.

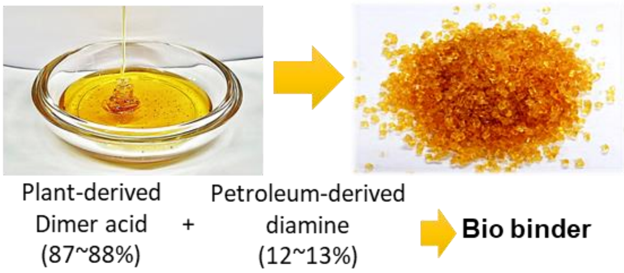

Figure 37: Bio binder synthesis

Items		Bio binder	PMA 2
Penetration(25 °C)	1/10mm	110	Min 40
Density(15 °C)	g/cm3	0.96	Repore
Flash Point	°C	294	Min 260
Viscosity(180 °C)	mPa・s	270	200

Table 9 - Binder properties

Bio binder bonds strongly with aggregates and exhibits high weather resistance. Despite being a thermoplastic material, the strength of the biomass mixture does not depend on temperature sensitively like an asphalt mixture and it has strength close to that of cement concrete in the service temperature range. Although some plant-derived materials may be less resistant to water, Bio binder has a remarkably higher resistance to water. However, Bio binder has lower stress relaxation properties than asphalt and must relieve stress from the change in volume with temperature change. Thereby biomass mixture requires construction joints after every 5–10 m, similar to a cement concrete pavement.

4.2.3. Mixture performance of Biomass mixture

The mixture characteristics of the Biomass mixture are introduced below.

4.2.3.1. Evaluation of complex modulus

The complex modulus using the repeated 4-point bending test measured the rigidity of the Biomass mixture at operational temperatures (5 to 60 °C) . **Table 2** shows the test conditions. The results are shown in **Figure 38**, compared to Fiber-reinforced cement concrete (SFRC), the complex modulus of Biomass mixture slightly decreases as the temperature increases. However, compared to asphalt, the complex modulus of Biomass mixture at 60 °C and that of the asphalt at 20 °C are almost equivalent.

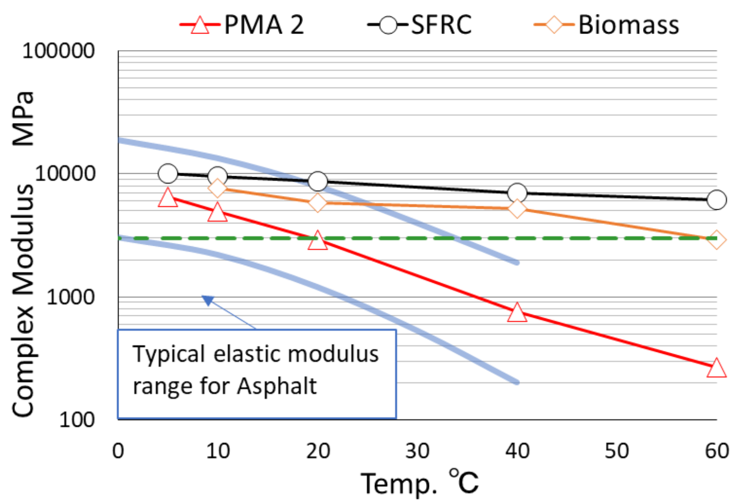

Figure 38: Test result of Complex Modulus

Items	Conditions
Test method	4-Point Bending Test
Loading method	Sin wave, 5 Hz, ε 400μ
Specimen dimension	400 mm × 40 mm × 40 mm

Table 10: Test condition of 4-Point Bending Test

4.2.3.2. Evaluation of Bending characteristics

Bending testing at different temperature was conducted to evaluate the flexibility of the Biomass mixture. Table 11 shows the test conditions, and Figure 39 shows the relation between the test temperature and flexural strength, and relation between the temperature and flexural breaking strain. The flexural testing revealed that the flexural strength of the Biomass mixture is high in the range from −10 to 60 °C. Biomass mixture shows similar temperature dependence to asphalt; however, as with the complex modulus, the flexural strength of the Biomass mixture at 60 °C is equivalent to that of the asphalt mixture using PMA2 at 20 °C.

Items	Conditions
Test method	Central load, 2-Point Support
Loading Speed	50 mm/ min
Specimen dimension	300 mm × 100 mm × 50 mm
Span length	200 mm

Table 11: Test condition of Bending characteristics

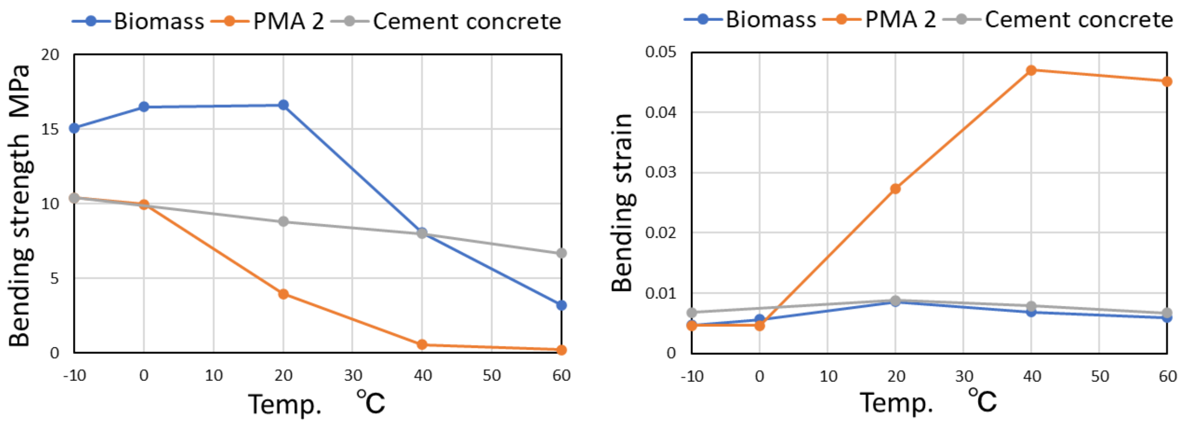

Figure 39: Test result of Binding characteristics

4.2.3.3. Evaluation of water resistance

Water immersed wheel tracking (WT) test was conducted to evaluate the water resistance of Biomass mixture. The water immersed WT is a test in which the wheel is traveled for 6 hours on the specimen immersed warm water at 60 °C. Thereafter, breaking the specimen into four parts manually. The stripping area ratio is calculated by dividing the area of exposed aggregate by the total cross-sectional area. Figure 40 shows the stripping status after this test.

In the left-hand side of Figure 40, the aggregate is exposed, this asphalt indicates low water resistance. Biomass mixture shows high adhesion even at 60 °C, and manual partitioning into four parts was not possible. Some aggregates broke when a compressor was used to forcefully partition it into two parts. There was no observation of stripped binder from the aggregate in the Biomass mixture after the water immersed WT test.

Figure 40: The result of immersed wheel tracking test

4.2.4. Various field verifications of Bio binder

Bio binder could be used alone or mixed with asphalt in a certain proportion to cope with various situations. Hybrid binder containing 20 % plant-based resin and 80 % asphalt does not require construction joints, enabling it to be processed in the same way as asphalt, and has high resistance to plastic deformation [2]. It has been more than 10 years since its development, and its practicality has been verified in heavy-traffic roads and roads in harbor facilities. Moreover, as asphalt for reinforcing steel decks on bridge, high rigidity asphalt pavement in which the blend ratio of plant-based resin is increased to 45 % is studied for practical use. This steel plate deck reinforcement method is characterized in that the asphalt with high rigidity is firmly adhered to the steel plate deck with similar plant-based adhesive. As a result of analyzing the cumulative damage degree based on the temperature data, the traffic volume data, loading test and so forth, It was confirmed that the effect of reinforcing the deck plate by high-rigidity asphalt pavement is smaller than that of SFRC, but 3.1 times that of the conventional method (Gussasphalt).

Figure 41: Various field verification of Bio binder

4.2.5. References

[1] T. HIRATO, H. QU, F. KATO, S. TAKAHASHI, Development and Evaluation of Pavement Materials utilizing Renewable Resources deriving form Plants, 7th E&E CONGRESS, 2020.

[2] T. HIRATO, et al, DEVELOPMENT OF HIGH STABILITY HOT MIX ASPHALT CONCRETE WITH HYBRID BINDER, ISAP2012 International Symposium, 2012, 12-115

4.3. THE USE OF ASPHALTENES IN HIGH-MODULUS CONCRETE MIX DESIGN AND STABILIZATION OF GRANULAR BASE COURSE

4.3.1. The Performance of High-modulus Asphalt Concrete and Granular Base Course

4.3.1.1. Overview

Asphaltenes is a by-product of deasphalting oil sands and given its ubiquity and the lack of practical applications in the current practice, this material could pose problems for the oil recovery process through precipitation, flocculation, and deposition in reservoir pores, wellbores, or pipelines. Alberta oil sands facilities produce a considerable amount of asphaltenes. The bitumen processed in these refineries is composed of approximately 17.5% asphaltenes, and this material has no significant use in the pavement industry [1]. Dissociation of asphaltenes prior to any such occurrences is thus critical [2,3]. Asphaltenes is characterized as a homogenized solid in crude oil, n-alkane insoluble, highly polar, and heteroatomic. It is essential to determine the composition of the source bitumen, particularly the proportions of saturates, aromatics, resins, and asphaltenes these components often being referred to collectively as "SARA" ,to identify the quantity and study the separate components. Finding a practical and environmentally friendly solution to this material is essential [2,4]. Bitumen is also often characterized in terms of polar and non-polar components. Asphaltenes, as one of the polar fractions of bitumen, is responsible for its elastic behaviour, while non-polar components such as maltenes govern its viscous behaviour [3,5,6]. Figure 42 shows the asphaltenes before and after processing.

Figure 42: Asphaltenes in the forms of solid and powder [7]

This research project is divided into two phases. In the first phase, the low- and high-temperature properties of an asphaltenes-modified high-modulus asphalt concrete (HMAC) base course layer were evaluated, and the results were compared with the properties of the control mixture. Indirect tensile strength (ITS) at low temperature, flow number, and Hamburg wheel-tracking tests at high temperatures were conducted to evaluate the mechanical properties of the mixtures. In the second phase, the low- and high-temperature properties of a well-graded granular base course stabilized with a slow setting (CSS-1H) asphalt emulsion were investigated before and after modification with a source of asphaltenes derived from Alberta oil sands bitumen. The ITS creep compliance and strength, and Hamburg wheel-tracking tests were conducted to evaluate the low- and high-temperature properties of the mixtures.

4.3.2. Performance Evaluation of High-Modulus Asphalt Concrete (HMAC) Prepared using Asphaltenes-Modified Binders

This research aims to incorporate the asphaltenes from oil sands in high-modulus asphalt binder (HMAB) and HMAC design procedure. Asphaltenes sourced from Alberta oil sands bitumen was used to modify a straight-run binder (control binder) and two other binders from separate oil sands bitumen sources to evaluate the possibility of using these binders in asphalt pavement. In addition to the control binder (M1) with PG 70-22, four modified binders were prepared: PG 70-22+ 12% asphaltenes (M2), Oil sand A + 12% asphaltenes (M3), and Oil sands B + 6% asphaltenes (M4).

The dynamic modulus test results show high modulus values for all modified samples under high loading frequencies, meaning that, as the frequency increases, the dynamic modulus, and therefore the viscoelasticity and stiffness of the asphalt mixtures, also increases (Figure 43 (a)). Meanwhile, increasing the temperature significantly decreased the dynamic modulus values. As can be observed form Figure 2 (b), the ITS results at 0°C show higher values for all the modified samples in comparison to M1 (the control sample). In addition, the fracture energy (FE) values of the modified samples were lower than the control sample, by margins of 19.8%, 21.5%, and 51.9% for M2, M3, and M4, respectively. According to Figure 43 (c), the Hamburg wheel tracking test results indicated that the rut depth would remain less than 4 mm for the mixes with asphaltenes modified binder. Accordingly, the stripping inflection point (SIP) was calculated to be 15,376 for the control sample and 19,999 for all the modified mixtures. The Rutting resistance indices (RRIs) were higher for the modified samples than for M1, which was 7,803. The RRIs of the modified samples, calculated using the number of passes and the depth of rutting, were 18,566.9 (M2), 17,236.2 (M3), and 19,622 (M4). Figure 43 (d) presents the results for the flow number test carried out at 60°C. All the tests were terminated at the maximum number of cycles because the maximum strain level of 50,000 microstrains was not reached after 20,000 cycles. Considering the accumulated microstrain value for the samples, M4 had the lowest deformation and therefore the highest rutting resistance, at

1,704.49 με. M1, as the control mixture, had the highest microstrain, 346.6% higher than M4, while M2 was found to be 50.4% higher and M3 81.2% higher in comparison to M4.

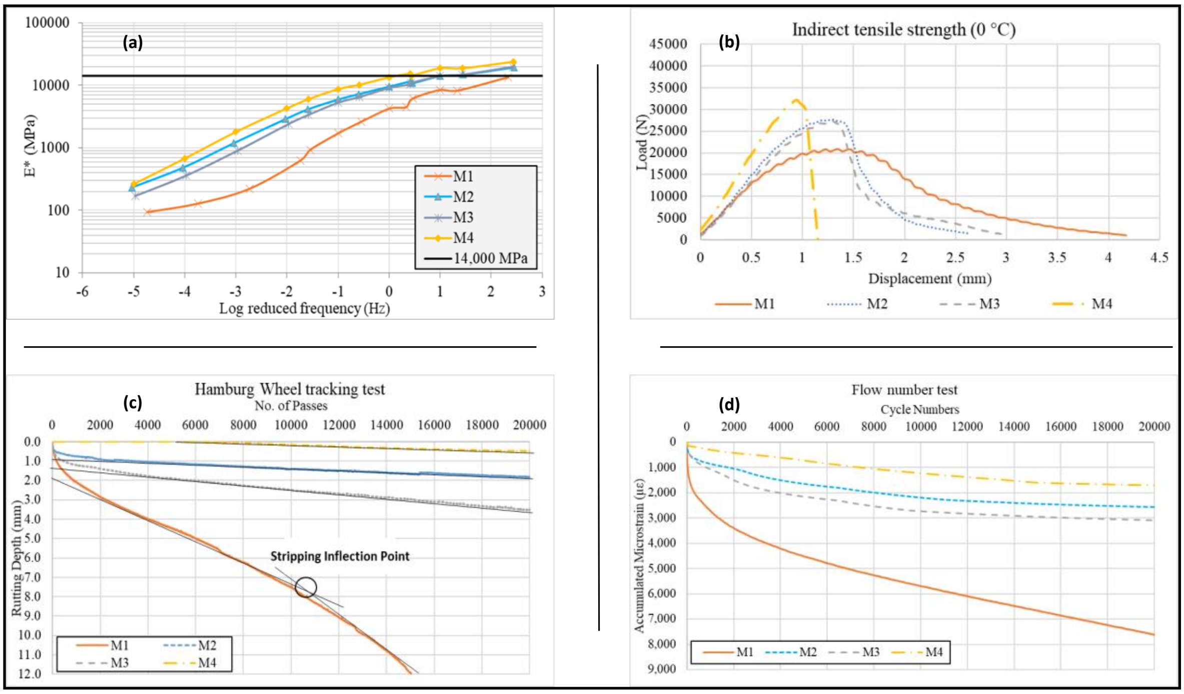

Figure 43: HMAC performance results: (a) Dynamic modulus; (b) Indirect tensile strength. (c) Hamburg wheel tracking; (d) Flow number [7]

4.3.3. Performance Evaluation of Stabilized Base Course using Asphalt Emulsion and Asphaltenes

In this study, Cationic slow setting (CSS) is the typical asphalt emulsion used for base stabilization because of the aggregate charge and the minimum time required for the mixing and laying of the base layer. The asphalt emulsion used in this study contained 61% hard binder and 39% water, and it is classified as CSS-1H. The asphaltenes used in this study were sourced from Alberta oil sands bitumen, having been processed through a solvent deasphalting process. The asphaltenes were obtained in solid form as shown in Figure 1 and, to achieve adequate dispersion, they were crushed into powder and sieved through a No. 100 sieve. Using ASTM D6997 [8] method, the approximate asphalt emulsion content was determined to be 4.89% per total mixture, and four different contents with 1% intervals were prepared to determine the optimum emulsion content (OEC).

According to Figure 44, the stability value at 3.98% asphalt emulsion content per total weight of the mix provided the highest stability for the mixtures; however, the trends for density and stability show that maximum values were attained at about 3.7% asphalt emulsion. This proportion of asphalt emulsion per total mix was thus chosen as the OEC for the performance tests.

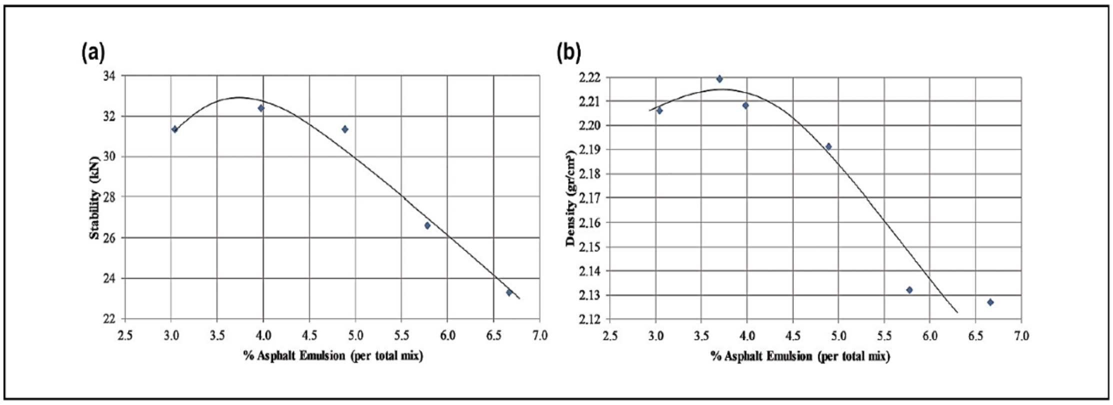

Figure 44: Stability (a) and density (b) values for asphalt emulsion design matrix

The ITS test was conducted on both the modified and unmodified mixture samples at OEC, with the results presented in Figure 45. The results from the ITS test show that modification with asphaltenes had a significant effect on the strength of the samples. The S1-2-25 samples with 2% asphaltenes were found to have the best response for tensile strength; however, an increase in asphaltenes content to 3% was found to cause a decrease in tensile strength of the modified mix. To understand the effect of adding extra water to the mix, samples with 2% asphaltenes but different amounts of extra water content (S1-2-25 and S1-2-50) were compared, and the results indicate that this increase in water content had an adverse effect on the tensile strength of the modified samples. Figure 45 also presents results for a TSR test for samples tested after conditioning at 25°C inside a water bath for 24 h. Control samples for the saturated samples had very similar results to those of the dry subsets, which indicates that TSR is about 1. However, this value decreases after modification of samples to 0.9 and 0.7 for 1% and 2% samples. This indicates that the moisture sensitivity of the modified samples increases.

The creep compliance test was conducted at temperatures of 0°C and -10°C for both the unmodified and the modified samples. The vertical load versus deformation graphs are presented in Figure 46. The results of the ITS at 0°C show that the maximum failure load increased slightly, while the FE for the modified samples decreased (8% and 7.5% increases in tensile strength and 24% and 17.7% decreases in FE of the 1% and 2% asphaltenes samples, respectively, were observed).

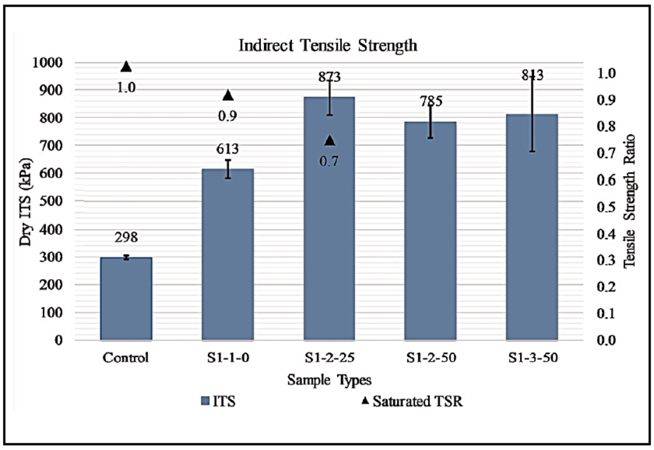

Figure 45: Indirect tensile strength (ITS) and tensile strength ratio (TSR) for control and asphaltenes-modified mixes.

Comparing the results at 0°C for the different levels of asphaltenes content, it can be seen that there was not a significant difference with respect to either tensile strength or FE as a result of an increase in asphaltenes content from 1% to 2%. However, the slopes of the graphs after the peak point for the modified samples are steeper, and this is indicative of more rapid crack propagation.

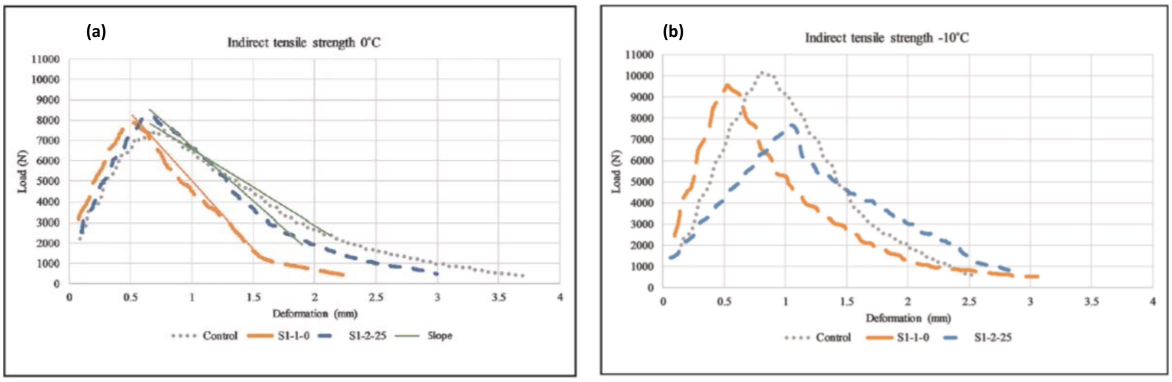

Figure 46: Load-deformation results: (a) 0°C; (b) -10°C

Table 12 - Rutting Resistance and Moisture Sensitivity Results presents the rutting test results. This table shows an increase in the number of passes before failure for the modified samples as compared with the control sample. This increase for the modified mixes indicates a higher resistance to rutting. In addition, the SIP value for the control samples was found to be approximately 3,800 passes, whereas adding asphaltenes increased this value to 8,200 and 7,400 passes for the 1% asphaltenes and 2% asphaltenes samples, respectively. Furthermore, both the 1% and 2% asphaltenes samples showed a significant increase in rutting resistance performance compared with the control sample. The moisture sensitivity of the samples, calculated by dividing the SIP values by the number of passes, had a decreasing trend, indicating the sensitivity of the modified samples to moisture.

Sample ID	SIP	Number of passes at 12mm rutting	RRI	Moisture sensitivity index
Control	3,800	3,940	2,219.74	0.96
S1-1-0	8,200	8,712	5,360.97	0.94
S1-2-25	7,400	8,604	5,291.12	0.86

Table 12 - Rutting Resistance and Moisture Sensitivity Results

4.3.4. Summary

The use of asphaltenes as an additive was investigated on the performance of high-modulus asphalt concrete and stabilized granular base course. In the first application, it was evident that although asphaltenes modification increases the tensile strength of the mixtures, this comes at the cost of decreased resistance to the crack propagation. This result indicates the effect of increased asphaltenes resulting in higher stiffness of the samples compared to the unmodified samples, which subsequently will help with the resistance of the sample to higher loading. However, the cracking propagation is faster once it fails. Similar to the low-temperature properties, higher asphaltenes content helps with the stiffness of the binder and, consequently mixtures. Asphaltenes modification also significantly improves high-temperature properties, as confirmed by the flow number test. A comparison of the moisture sensitivity index shows that modification of the binders with asphaltenes decreased the susceptibility of the mixture to moisture damage by approximately 42.9% for all mixtures.

In case of the granular base stabilization application, the outputs from the creep test indicated an increase in the brittleness of the mixes after adding the asphaltenes to the asphalt-emulsion stabilized samples. Moreover, while increasing the asphaltenes content has a considerable increasing effect on the strength of the samples for intermediate temperatures, a similar effect was not observed at the lower temperatures. The results of the Hamburg wheel-tracking test and RRI values show that modification of asphalt-emulsion stabilized mixtures with asphaltenes has a significant impact on the rutting resistance of the base course layer. The stiffness of the modified samples was found to increase at higher temperatures according to the wheel tracking results.

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5. INNOVATIVE STRUCTURAL TECHNICAL MAINTENANCE AND REPAIR STRATEGIES FOR WIDENING RURAL ROADS AND EDGE STRENGTHENING

5.1. ENLARGEMENT OF LOW TRAFFIC ROADS THANKS TO SELF COMPACTING CEMENTITIOUS MATERIAL

5.1.1. General presentation

In France, an important part of the low traffic interurban roads network needs to be enlarged at least up to 6 meters, to ensure safe crossing conditions for vehicles. The traditional method to do so generally consists in the construction of a 0.5 to 1 m large edge beam made of a well graded aggregate covered by a bituminous wearing course. Yet, this method generally gives disappointing results in terms of durability. In fact, compaction in such narrow conditions is not easy and often leads to under-compaction and then to rapid degradation of the roadside. The maintenance cost of such structures is then increased.

In that context, a new material was developed from 1999, known as "MACES" (acronym of structural self-compacting material for road structure, in French) ([1], [2], [3]). It is a generic self-compacting cementitious material which belongs to the family of products known as Controlled Low Strength Material in USA (ACI 229R-99) or trench filling cementitious materials in France. But unlike these products, its mechanical properties in the hardened state are the same as a classical cement-treated well graded aggregate of class at least T3 (as described in EN 14227-1). It can then have a structural role in road construction.

The implementation of the material is carried out by simply pouring from a truck mixer into the excavation (see Figure 47: The material MACES is simply poured from truck mixes (left: RD 952 in 2003; right RD 19C in 2006), followed by a light manual raking, which depends on the desired surface texture (smooth if the wearing course is a surface dressing or rough if it is a bituminous layer). The left-to-right agitation of the truck mixer gutter promotes placement of the material, especially when the water content has been reduced to be able to hold steep slopes.

Figure 47: The material MACES is simply poured from truck mixes (left: RD 952 in 2003; right RD 19C in 2006)

These materials can be used regardless of the permeability of the supporting soil: on permeable soil, excess water is evacuated from below, on impermeable soil it is evacuated from above. In both cases, this water departure is done without degrading the homogeneity of the material.

The bearing capacity of the MACES is given by hydraulic settlement, then by hydration and setting of the cement present in the material. Experience shows that, on site, the edge beam can be opened to pedestrian traffic in one to two hours, to that of light vehicles in about six hours, and to that of heavy vehicles in 24 hours. Thus, the work could be carried out under traffic, without any stoppage linked to the setting time of the materials.

Figure 48: Surface dressing spread on the surface of the edge beam after setting

5.1.2. Mix design and control

The MACES should be at least of class T3 according to EN 14227-1. It generally leads to typical values of splitting tensile stress between 0.8 and 1.5 MPa and elastic modulus between 10 and 25 GPa à 28 days.

Typical composition includes sand, coarse aggregate with D_{max} around 20 mm, 140 kg of cement and 200 kg of free water per cubic meter.

Figure 49: Measurement of the self compactability of the material by filling Ø16cmx 32 cm cylinders with the Glanville apparatus (from [2] and [3])

To adjust the water content for the appropriate workability, measurement with the Abrams cone remains possible. The values obtained are commonly between 15 and 25 cm but are not discriminating. It is preferable to measure the filling coefficient using the upper cone of the Glanville apparatus (Figure 49). This method allows the material to be placed with a controlled and constant energy. The filling coefficient is calculated by dividing the experimental density obtained on the cylinder by the theoretical density of the material (i.e., calculated assuming no voids remaining in the material). Figure 50 gives a typical evolution of the filling ratio as a function of the water content of the material. The blue arrow indicates the ideal quantity of water which corresponds to the stabilization of the filling ratio. A significantly lower water content leads to a very stiff material that is no longer self-compacting. A higher water content does not improve self-compacting ability but leads to excessive bleeding, a decrease in mechanical performances and does not make it possible to hold longitudinal slopes during pouring.

Control Ø16 cmx 32 cm cylinders for tensile strength and elastic modulus measurement must be cast with the same procedure.

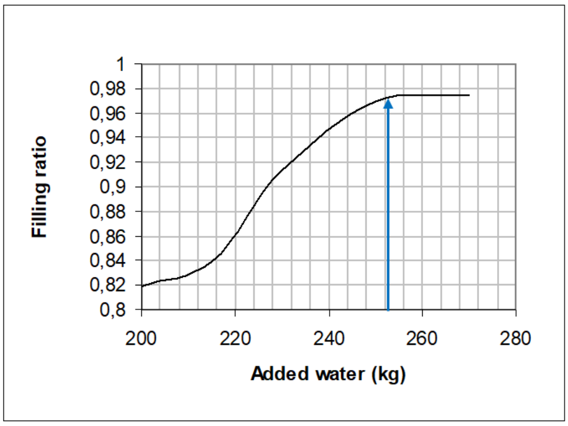

Figure 50: Typical evolution of the filling ratio vs water content of the MACES (adapted from [3])

5.1.3. State-of –the art and dissemination

Since 2003, several kilometers of enlargement have been done with this self-compacting cementitious material MACES. Some examples are documented in [4], [5] and [6].

They behave well up to now, which means no settlement, no longitudinal cracks visible on the wearing course between the old structure or the edge beam, provided the following conditions are respected:

- the self-compacting material MACES should be at least of class T3 according to EN 14227-1;
- thickness of the edge beam should be greater than 35 cm;
- the traffic must be low (<50 heavy vehicle/day).

The MACES material is now available from the main concrete providers, under different trademarks.

The use of a MACES has the following advantages when used for road enlargements with the edge-beam technique:

- it is not necessary to provide for extra width to ensure a good compaction as it is the case with untreated well graded aggregate. This allows to limit or to avoid the land acquisition along the road;
- rapidity of casting and low noise nuisance;
- the relative important tolerance towards water content, the insurance of a good compaction and of the in-place quality of the product makes the technique safe, durable, and economically interesting.

5.1.4. References

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5.2. EDGE STRENGTHENING BY USE OF GEOGRIDS AND FOAMGLASS

5.2.1. Introduction

Large parts of the current Norwegian road network have developed from old paths and cart roads. Evidently, it is difficult for these roads to meet with the geometrical and structural standards and requirements of today’s traffic. Broad and heavy trucks on narrow roads cause a large amount of damage, and edges and road shoulders (if any) are vulnerable. Due to heavy topography, road widening is often complicated.

Thus, some innovative solutions for edge strengthening have been tried out during the last years, combining different “new materials” and repair methods. This case study deals with road edge/shoulder strengthening by combining geogrids and foamglass (light weight, good insulation properties, good bearing capacity).

5.2.2. Foamglass as lightweight fill material

The concept is based on the process of transforming finely ground glass powder from different glass sources into glass foam. The origin raw material is recycled glass (jars etc.) collected from households throughout Norway. After sorting out glass that goes to new glass production, the remaining material is crushed into a fine powder, and an activator is added. The powder is then spread on a steel belt conveyor running through a high temperature tunnel oven. In the oven the powder expands 5-6 times and comes out as a plate. This plate cracks up immediately when it is cooled down, resulting in the foam glass material, typically with grain size 10-60 mm and 80 % air voids. A thin impervious glass wall encloses each air bobble, so that the water absorption is very low.

Figure 51: From glass waste to Foamglass [1]

The product does not react with other materials, is chemically stable, gives no emissions or harmful gases and is non-flammable. Due to the modern production process and energy sources, the carbon footprint is also low. This is documented by EPDs (Environmental product declarations), see [3].

Some of the material qualities listed by the producer:

- Low unit bulk density, 180 kg/m^3
- High thermal insulation qualities, λ = 0,097 W/mK (dry) – 0,107 W/mK (wet)
- High material strength, 80 – 120 kN/m^2
- Angle of repose 45°
- Low moisture absorption
- Chemically and thermally stable.

More detailed material data, product descriptions and case examples are to be found on the Norwegian producer's website [3].

5.2.3. Description of the strengthening method

The road edges are often unstable due to bad soil/subgrade conditions (soft clay and silt), and deformations and cracking are frequently seen. Heavy traffic and inadequate road width will of course increase these problems, as shown on Figure 52.

The most common and easiest method to repair such damages is laying of new asphalt. However, this will often not be the best measure. Asphalt is a high-density material, giving high ground pressure, and may in these cases in fact increase the problems. As shown in the figure, the wooden pile for the guard rail in the slope becomes more and more stressed and is eventually nearly in horizontal position. By observing the total thickness of asphalt and the deformed wooden piles, the "history" of repair is clearly visible.

Figure 52: Longitudinal cracking and damage at the edges of the road due to settlements [4]

By using the lightweight material foam glass, the ground pressure causing such settlements can be reduced by 80 %. The method is described in [2], a principle drawing is shown in *Figure 53*.

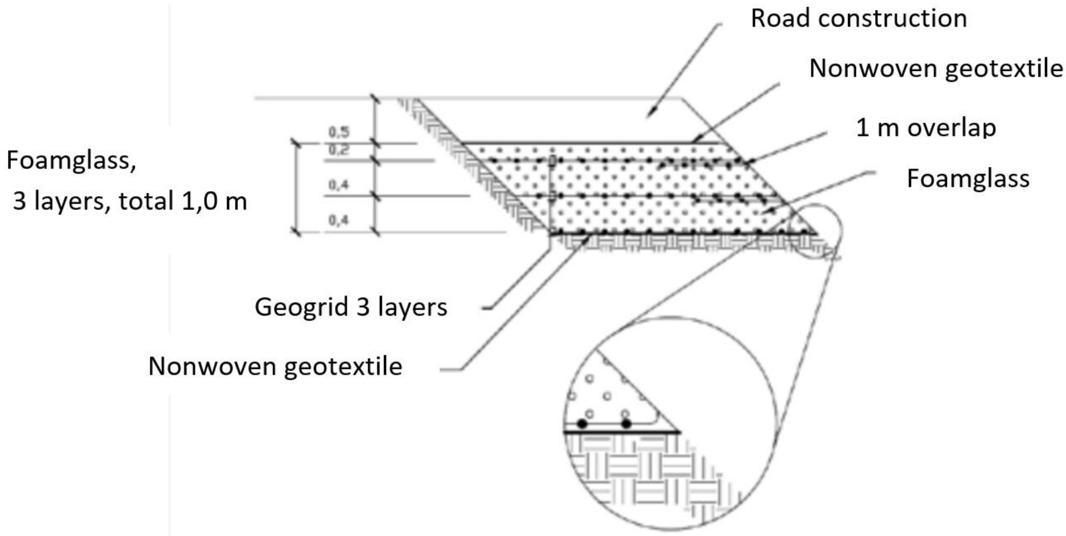

Figure 53: Foamglass and geogrid for edge strengthening [2]

A typical reconstruction of an edge damaged Norwegian road is shown by photos in Figure 54 to Figure 57. First the existing soil and road materials under the outer lane are removed down to 1,5 m depth. Thereafter, a nonwoven geotextile is placed on the subsoil, followed by the first layer of geogrid and the first 40 cm with foamglass (*Figure 54*). Then the next layers of foamglass is placed (Figure 55).

Figure 54: Nonwoven geotextile, geogrid and 40 cm foamglass is placed [4]

Figure 55: The next layers of foamglass is placed (Photo: Jan Vaslestad)

The geogrid is then wrapped around the foamglass (Figure 56). The anchor length (overlap) of the geogrid should be a minimum of 1.0 m, as shown in *Figure 53*.

Figure 56: The geogrid is wrapped around the foamglass [4]

The geogrid typically has a short time strength of 50 kN/m both in machine and cross machine direction.

Figure 57: After strenghtening with foamglass and geogrid (Photo: Jan Vaslestad)

When the lightweight foamglass-geogrid edge construction is done, the appurtenant road layers (sub-base, base, pavement) are laid on top.

The final rehabilitation is shown in Figure 57. Before strengthening with foamglass and geogrid, there was a need for repair every year with new asphalt. The problem increased significantly the following year due to added weight from the asphalt.

5.2.4. Conclusions

In Norway, several road edge/shoulders strengthening projects have been conducted by combining geogrids and foamglass (light weight, good insulation properties, good bearing capacity). Properly constructed, this concept has shown to be a practical and cost-effective measure on many roads, in different parts of the country. Inspection of edge damaged roads that have been repaired by this method shows no deflections or cracking after more than 10 years.

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6. INNOVATIVE SURFACE TECHNICAL MAINTENANCE AND REPAIR STRATEGIES ON CONCRETE PAVEMENTS - MATERIALS AND/OR TECHNIQUES

6.1. CONTINUOUSLY REINFORCED CONCRETE PAVEMENT WITH HOTMIXED ASPHALT OVERLAY ON MOTORWAY A94 IN GERMANY

6.1.1. Motivation

Since the 1950s, the volume of traffic and the proportion of heavy traffic with high axle loads has been increasing almost continuously. This development will further continue in the future. Furthermore, the shortage of fossil raw materials is to be expected in the medium term. Individual and freight transport on roads and motorways are of fundamental importance for life and the economy in Germany and Europe. It is to be feared that the previous standard construction methods in asphalt and concrete will reach their limits in terms of durability, availability, and economy, especially on motorways with heavy traffic loads. To be able to guarantee the necessary mobility in the future, innovative solutions are required. The composite construction method described here, consisting of a Continuously Reinforced Concrete Pavement (CRCP) with a thin Hot Mixed Asphalt (HMA) overlayer, can represent a solution here. To gain practical experiences a trial site on a motorway in Germany was set up.

6.1.2. Functionality of a composite structure

The composite construction consists of a rigid structural layer of concrete and a flexible HMA overlayer. Protected by the asphalt, the construction layer made of concrete achieves permanent load transfer without the need for maintenance measures. A service life of 50 years is aimed for.

Both Jointed Plain Concrete (JPC) and CRCP with a free crack pattern can in general be used for this. The unavoidable cracks caused by temperature- and moisture-dependent changes in length occur in JPC in transverse contraction joints at a distance of 5 m. In the worst case, the opening widths can be up to 4 mm, as shown in Figure 58 on the right. In CRCP, free transverse cracks appear at a distance of about 0.7 m to 2.5 m. These are limited to a maximum opening width of 0.5 mm by a longitudinal reinforcement.

In principle, all types of asphalt top layers that meet the requirements for skid resistance and noise reduction can be used as a flexible overlay. These must be renewed at intervals of 10 to 20 years. Asphalt top layer can be e.g., stone mastic asphalt, porous asphalt or thin HMA on sealing, but the use of mastic asphalt would also be conceivable.

To achieve a permanent bond on the concrete, it must have sufficient strength and loose components on the surface must be removed. A bitumen emulsion is applied to the concrete immediately before the HMA is laid.

Asphalt surface layers are basically able to bridge the above-mentioned crack opening widths of maximum 0.5 mm in CRCP. In the case of JPC with opening widths of a maximum of 4 mm, reflection cracks would appear from the concrete in the asphalt and there would be a risk of water penetrating the construction. To avoid this, the joint grid must be transferred to the asphalt top layer and sealed.

In principle, concrete pavements are impermeable. When laying the HMA overlayer, any moisture that evaporates cannot escape downwards and blisters are formed in the dense top layer. To prevent this, the residual moisture in the concrete at the time the asphalt is built, must be limited and the requirement for void content in the asphalt must be complied with.

According to the current state of knowledge, the following three points must be considered for a composite construction:

- A permanent, full adhesion between concrete and asphalt

- The prevention of reflection cracks from the concrete into the asphalt and

- The prevention of blistering in the asphalt wearing course.

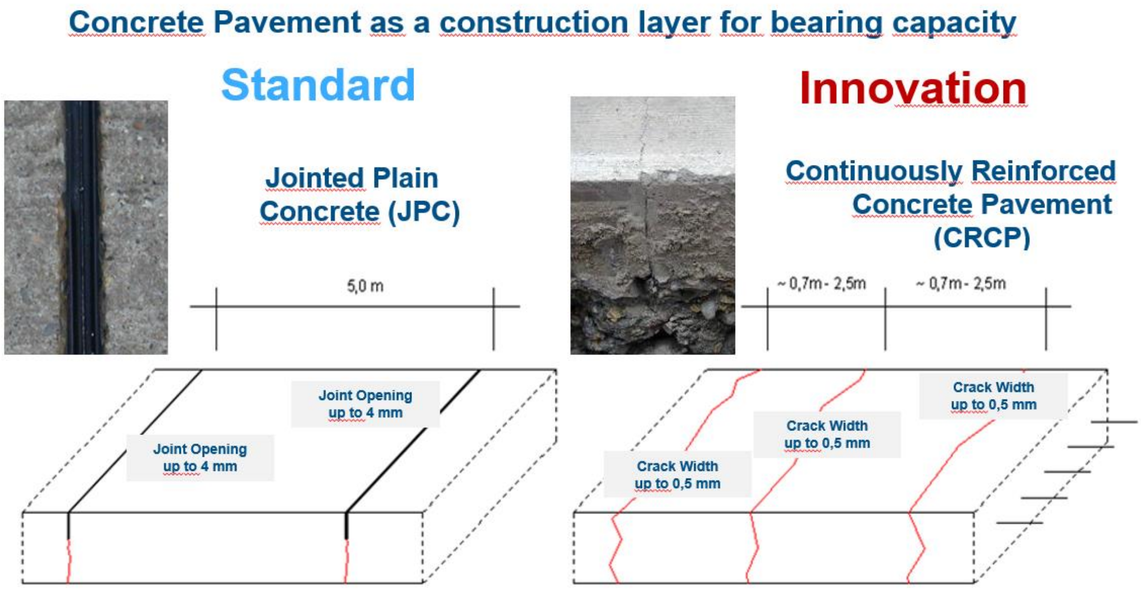


Figure 58 - JPC with slabs of 5 m length with transverse contraction joints and CRCP with free crack pattern

6.1.3. Concept of the trial site and construction

The concept of the trial site includes a rigid construction layer as a CRCP overlaid with HMA on sealing, Section 1. In order to enable direct comparisons, in Section 2 a JPC overlaid with HMA on sealing and JPCP with grinding texture in section 3 were planned, see Figure 59.

The conceptual design was based as closely as possible on the current German road construction regulations and combined these with our own and foreign experiences on CRCP.

A standard road concrete of the quality C30/37 was used in all sections. In sections 1 and 2, this was carried out in a single layer with round-grain aggregates 0/32 mm. In order to meet the surface properties, section 3 also received a thin top concrete with polishing-resistant crushed aggregate 0/22 mm. The requirements listed in Table 12 were formulated for the reinforcement in Section 1. They correspond to the Belgian standard [7]. In [6], CRCP in Europe and North America were examined and compared. It could be shown that those on flexible base courses show the best long-term performance. Accordingly, an asphalt base course and an anti-freeze course were uniformly arranged for all sections of the trial site. Figure 59 shows the construction of the three test sections with the respective layer thicknesses.

Section 1 was planned with free transverse cracks. Longitudinal joints were arranged lane by lane. Immovable end anchors were to be implemented at the end areas. This was realized with reinforced end anchors.

In sections 2 and 3, conventional JPC were provided with dowels and tie bars.

To ensure a permanent bond between the concrete and the HMA top layer, the concrete surface had to be cleaned with a high-pressure water jet, dried and a bitumen emulsion applied. Surface strength and residual moisture for the concrete were specified as requirements.

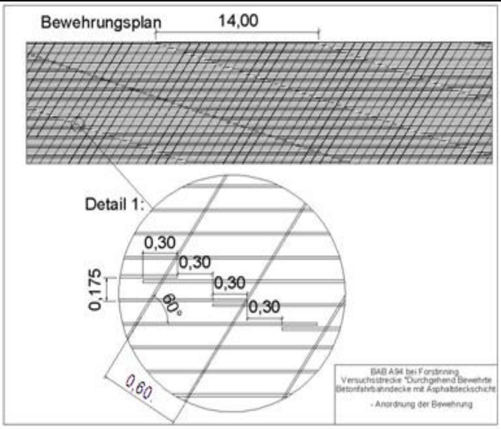
Steel Quality	Construction Steel 500 N/mm², profiled	
Longitudinal Reinforcement	Content 0,75 % Diameter 20 mm Distance 17,5 cm In the centre line Positioned in driving direction	
Transversal Reinforcement	Diameter 16mm, Distance 70 cm In an angle of 60° to the longitudinal reinforcement	

Table 13: Reinforcement requirements

There were several options in the State of Bavaria for the practical implementation of the concept described. In coordination with the Federal Ministry of Transport, Building and Urban Development (BMVBS), the Supreme Building Directorate of Bavaria and the Federal Highway Research Institute (BASt), the A 94 east of Munich near Forstinning was selected because this was a newly constructed motorway. Compared to the fundamental renewal of a section of motorway, the temporal and local boundary conditions are somewhat more favorable here. In addition, this section of the BAB A94 has the advantage that there are uniform conditions with a low longitudinal gradient and no tight radii. *Figure 59* shows the layout of the three test sections. Each section has a length of approx. 4 km. The total length spread over two directions is about 12 km.

The interruptions represent bridge structures. The concrete pavement was interrupted there. The end anchors described were arranged in section 1 with continuous reinforcement.

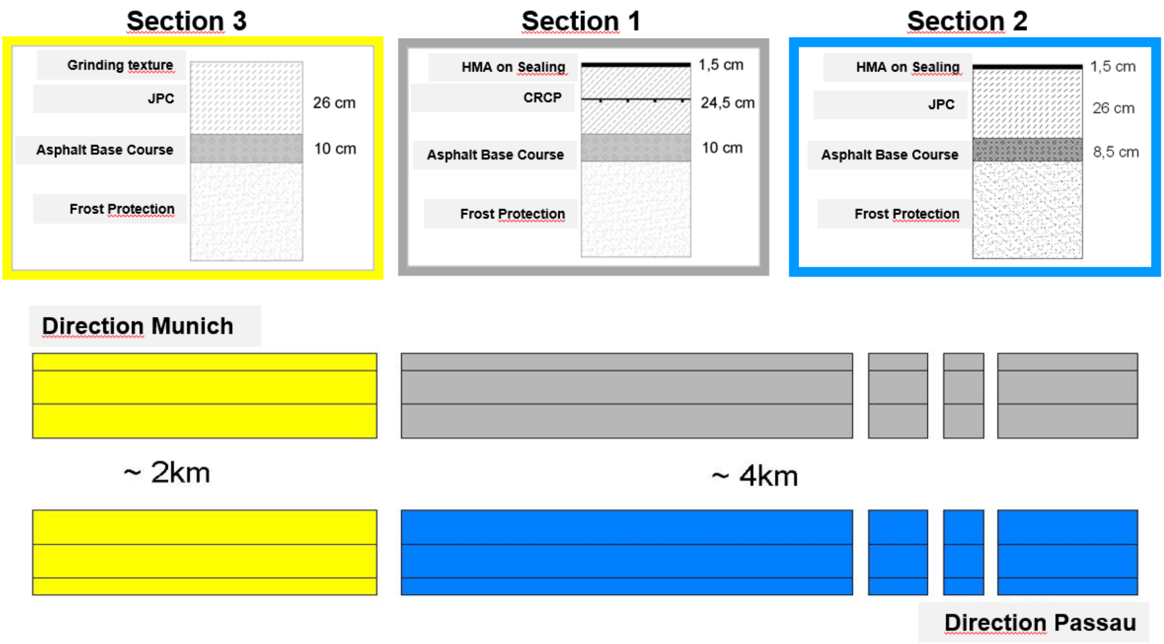


Figure 59: Structure and layout of the trial site

The trial site was executed in the years 2010 - 2011 by the companies Rädlinger as the main contractor and Berger Bau for the concrete pavement. The paving was carried out from April to June 2011 using a Wirtgen SP 1500 slipform paver.

The reinforcement was laid immediately before the production of the CRCP, as can be seen in *Figure 60*.

Figure 60: Placed transverse and longitudinal reinforcement

Figure 61 shows the single-layer concrete installation in Section 1. It can be seen the fundamental difference to the production of JPC. Due to the installed reinforcement, it is not possible to deliver fresh concrete directly in front of the paver. This happened in the opposite driving direction. To get this from the truck to the paver, two variants were discussed by the construction company: the use of a large grab excavator or a side feeder. The grab was chosen for reasons of capacity and economy.

Figure 61: Concreting of the continuously reinforced concrete slab

Figure 62: Production of the grinding texture of the asphalt surface course (DSH-V)

In the summer of 2011, the "grinding" surface texture was produced on test section 3. The grinding wheels had a groove spacing of 2.8 mm in the direction of Passau and 3.2 mm in the direction of Munich. It was ground in working widths of 1.2 m each, as can be seen in *Figure 62* on the left. The HMA on sealing was also carried out in the summer of 2011, as can be seen in the figure on the right. Two asphalt pavers with spray devices were used to apply the bitumen emulsion.

At the end of August, the A94 construction section near Forstinning was opened to traffic.

6.1.4. Scientific monitoring of the triale site

A program for metrological and scientific monitoring of the trial site was set up by the BASt. Three themes were the focus of attention

- The performance of CRCP and JPC;
- The adhesion between concrete and asphalt;
- The surface properties of the executed textures.

The most important results are presented below.

6.1.5. Performance of the concrete pavement

The installation of the concrete slab in the three test sections took place in spring 2011 in mild to warm weather. The required layer thicknesses of 24.5 cm and 26 cm were fully achieved. The actual layer thicknesses were 25 cm to 29 cm. Compressive strengths of 45 N/mm² to 81 N/mm² were achieved on drill cores and thus the required compressive strength class C30/37 was confirmed.

Deflection measurements using the Falling Weight Deflectometer (FWD) were performed shortly after construction. Minor depressions were determined in the three test sections. These stand for good bearing capacity of the construction.

Inspections with visual assessments of the condition of the constructed JCP, Sections 2 and 3, did not reveal any abnormalities. Damage to edges, broken corners, surface damages or unevenness could not be determined.

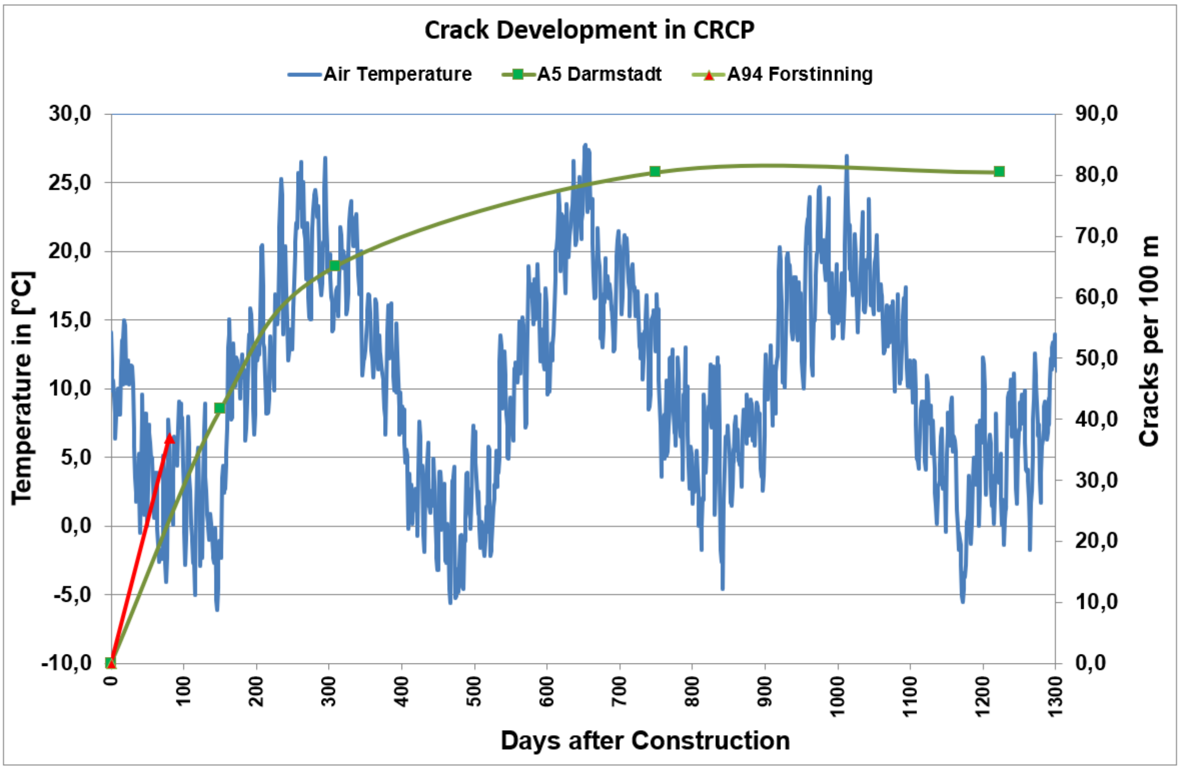


Figure 63: Crack development in the CRCP construction layer

Fine transverse cracks were expected in test section 1 with a CRCP. It was shown in [6] that free transverse cracks at average distances of 0.7 m to 2.5 m and opening widths of a maximum of 0.5 mm achieve the best long-term behavior. The resulting free crack pattern was therefore of great interest. On July 5th, 2011, a manual crack monitoring was carried out with the recording of stationing and opening widths.

In *Figure 63*, the result is shown as a red line as the number of cracks per 100 m 79 days after concrete production. During this time, 38 cracks per 100 m or an average crack spacing of 2.6 m have formed.

In 2004, a test section with CRCP was built on the A5 motorway near Darmstadt. In addition to other types of base course, an asphalt base course was also laid. The crack development and the daily mean temperatures of this measure in the first three years after production are entered in the figure as green and blue lines. It can be seen that most of the cracks formed in the first year. Fewer cracks appeared in the 2nd and 3rd year. After about three years, crack development was complete. If these results are transferred to the trial site A94, it can be concluded that the crack formation is not yet over. In [6] it could be shown that sections that were concreted in cooler weather led to slower crack development than those in warmer weather. This also applies here. On the trial site A94 near Forstinning, there were higher installation temperatures than on the section of the trial site A5 Darmstadt under consideration. Correspondingly, the red line, Forstinning, lies above the green line, Darmstadt, in the figure.

By 2014, around 80 cracks per 100 m or an average crack spacing of 1.25 m are expected as the "final crack pattern". However, this cannot be checked due to the HMA overlay.

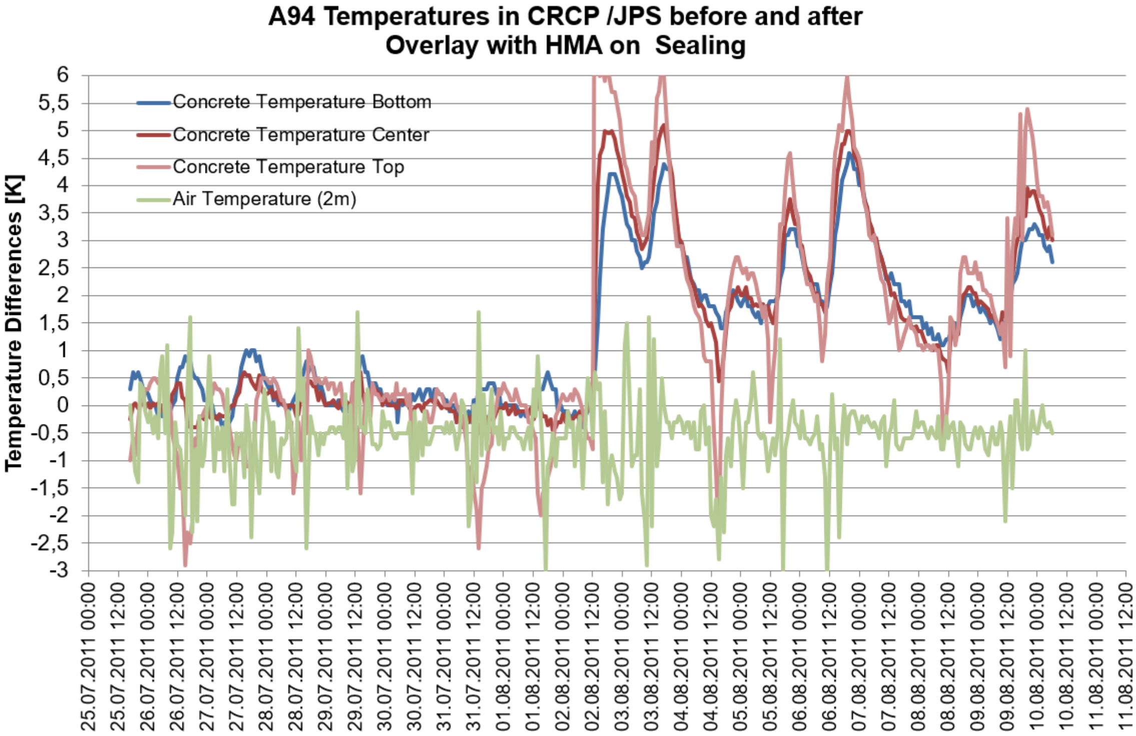


Figure 64: Temperatures in the concrete slabs with and without superstructure

Furthermore, the temperatures in the concrete are continuously measured and recorded at two cross-sections. Measurement cross-section 1 is in test section 1 "JPC with grinding texture" and measurement cross-section 2 in test section 2 "CRCP with HMA on sealing". *Figure 64* shows the temperature differences between the two measurement cross-sections with the top of the concrete, center of the concrete, bottom of the concrete and the air temperature at a height of 2 m. The period 10 days before and after the overlay with HMA is shown.

Before the overlay with HMA was carried, both areas under consideration are theoretically directly accessible concrete surfaces. The temperature conditions in the concrete are the same at both measuring cross-sections with low tolerances. After the placement of the HMA, the two areas differ. Temperatures four to six degrees Celsius higher than in the directly driven concrete pavement were measured at the cross-section with HMA.

However, it should be noted that these temperature conditions refer to the new condition. At this point, the aggregates of the HMA are still completely covered with a bitumen film. As this film wears away, the aggregates emerge, and the surface becomes lighter. This effect influences the temperatures in the underlying concrete. It is to be expected that the temperature conditions of both measuring cross-sections will adjust in the next few years.

End anchors must be implemented at the end areas of CRCP so that incoming horizontal compressive forces do not act on neighboring road constructions or components and cause damage there. [4] discusses which compressive forces can occur depending on the section length, the subsoil conditions, and the installation temperatures. The trial site was used to quantify these calculations in situ.

For this purpose, sections of the CRCP were equipped at the ends with one or four reinforced end anchors, as shown in *Figure 65*. Extensometers were placed behind them, which continuously record horizontal movements. Behind the end anchors, unreinforced concrete slabs were produced as abutments for the extensometers, separated by an expansion joint without a joint insert.

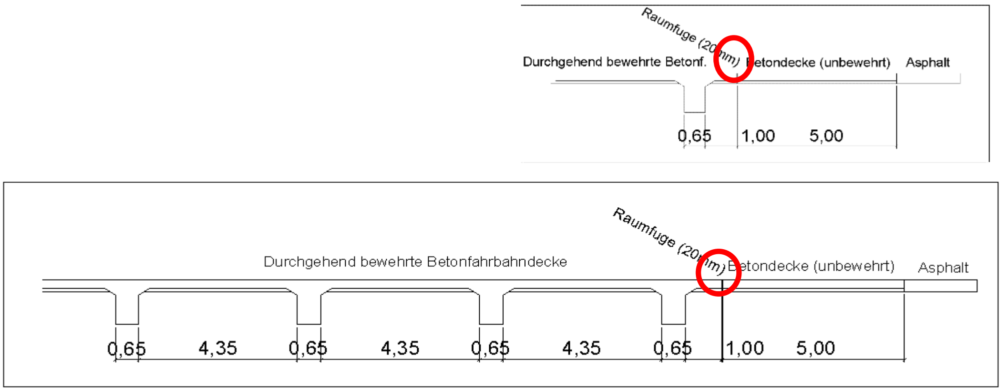


Figure 65: One or four end anchors in test section 1

The extensometers take measurements every hour. These are recorded by a data logger. *Figure 66* shows the results of previous extensometer measurements. The blue scatterplot shows the horizontal displacements in millimeters versus temperature in degrees Celsius at the end of the four anchor system and the red scatterplot at the end of the single anchor region. The extensometer on the four end anchors was installed at approximately 20°C, the extensometer on the single end anchor at 28°C. There are displacements from -10 mm to +26 mm. With the system of four end anchors there is a displacement of +14 mm at 0°C. With one end anchor at 0°C, the displacement is 24 mm. This means that neither of the two design variants creates a complete fixed point. But with the system of the four end anchors, the horizontal movements can be reduced more effectively. Additional end anchors or larger dimensioned end anchors would be required to create complete fixed point.

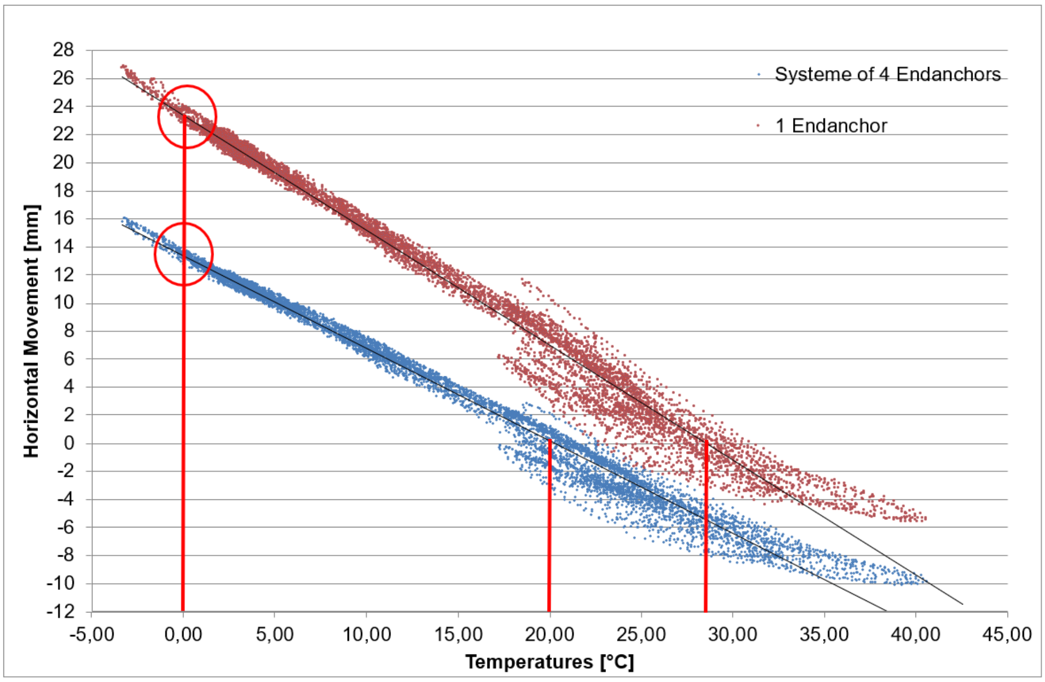


Figure 66: Results of the extensometer measurements on the end anchors

6.1.6. The overlay with HMA

On August 2nd, 2011, in dry, sunny weather, the concrete pavements in test sections 1 and 2 were covered with HMA on sealing. The following requirements were fixed for this:

- surface tensile strength min. 1.0 N/mm²;
- residual moisture content of the concrete for a maximum of 3.0%.

This took place on May 07th 2011 before the treatment with high-pressure water jet method, and afterwards. At operating km 13+130 and operating km 16+600, the surface tensile strength and the residual moisture of the concrete were determined on the hard shoulder, the 1st lane and the 2nd lane. *Figure 67* shows the surface tensile strength and the respective age of the concrete in days. It was 54 to 79 days and the strengths were 0.3 N/mm² to 2.3 N/mm². The requirement of 1.0 N/mm² has been shown as a red line. The results show that all areas with a concrete age of 65 days and older meet the requirements. Only the most recently installed concrete, which is a concrete age of 54 days, does not yet meet the requirements.

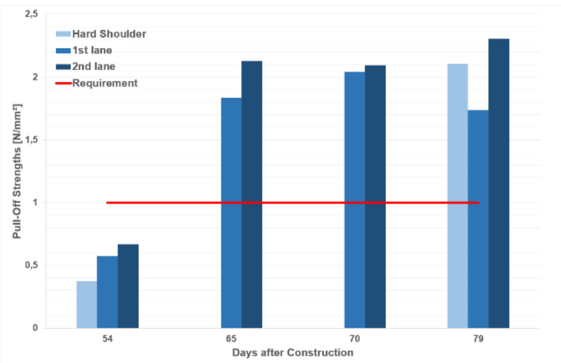


Figure 67: Pull-off strengths of the concrete surface

Furthermore, on July 5th, 2011, the residual moisture in the concrete was determined using an electromagnetic method, measuring device HI 520, and the CM method. The measurement results of the HI 520 are shown in figure 68 for the concrete ages 54 days to 79 days in four diagrams. In each diagram, the measured moisture content of the concrete is plotted at depths of 10 mm to 40 mm. The values range from 2.0% to about 4.6% residual moisture. In all areas, the highest values were determined near the surface and lower values with increasing depth. Most values are still above the permissible 3.0%. A relationship between the age of the concrete and moisture or drying out over time could not be established here. The measurements according to the CM method resulted in 3.0% residual concrete moisture for all areas.

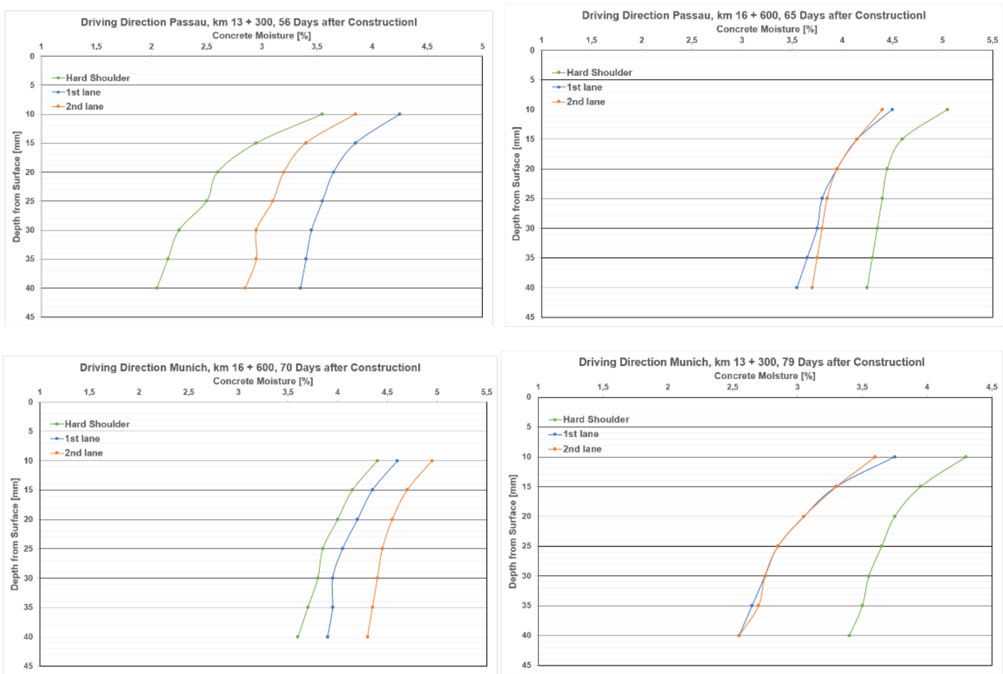


Figure 68: Residual moisture in the concrete

After another month in dry, warm weather and treatment with the high-pressure water jet method, the measurements were repeated. Then all areas met the requirements for surface tensile strength and residual moisture. Then the HMA including the sealing was installed in thicknesses of 1.5 cm to 2.0 cm.

As part of the control tests, drill cores were taken to test the layer thickness and strength. The tensile strengths between concrete and asphalt were also determined on these cores. With two deviations of 0.9 N/mm², all strengths were above the required 1.0 N/mm².

A few months after the production of the HMA, transverse cracks were found in the HMA. On closer inspection, it was evident that these were reflective cracks from the free transverse cracks from the CRCP. The weather conditions when installing the HMA can be described as optimal. See also *Figure 63*. The requirements for the concrete in terms of residual moisture and surface tensile strength were met, so that these aspects are no longer the cause of reflection cracks. Two possible reasons remain: the development of cracking over time and the layer thickness of the asphalt surface course.

In [6] it is described that crack formation in CRCP takes place in the first two to four years, depending on the installation temperatures. In [3] it is described that the stresses and horizontal displacements are greatest directly at the crack formation. This means that the CRCP was covered with a thin HMA during the active phase of cracking. Thus far, it has been assumed that the requirements for residual moisture and surface tensile strength for overlaying concrete with HMA are sufficient and that concrete can essentially be overbuilt with all types of asphalt and layer thicknesses. The trial site has shown that this is only true to a limited extent and that further requirements are necessary:

In the case of overlaying CRCP, the age of the concrete or the stage of crack formation and the layer thickness of the HMA overlay must also be considered. Further investigations are necessary for this.

6.1.7. Summary and Outlook

The test section A94 near Forstinning with the sections "CRCP with HMA overlay on sealing", "JPC with HMA overlay on sealing" and "conventional JPC with grinding texture" was successfully set up in 2011. In all sections, concrete, asphalt, and the adhesion between both are in perfect condition after production. The reinforced end anchors in CRCP have brought new insights. The metrological equipment of the site is complete. Temperature measurements have shown that HMA overlays lead to higher temperatures in the underlying concrete. When new, all test sections were in perfect condition. After a few months, reflective cracks from CRCP appeared in the HMA. To prevent this in the future, overlays for CRCP must meet additional requirements for the age of the concrete and the layer thickness of the HMA. The trial site will continue to be monitored by the BASt together with the State of Bavaria. Of particular interest will be when and to what extent the first differences between the individual sections become apparent. For example, when the asphalt surface layer must be renewed.

The previous findings on CRCP and on the HMA overlay are presented in the "Notes on the CRCP of the FGSV" [8].

6.1.8. References

[1] Ernst Neußner: Road pavements with layers of asphalt and concrete - overview of national and international concepts, road and highway 09/1995

[2] Ministerie van de Vlaamse Gemeenschap: Standaardbestek 250 voor de wegenbouw – version 2.0 Deel I, June 2000

[3] CROW: Doordgaand gewapende betonverhardingen - Autosnelwegen en overige toepassingenn, Publicatie 160, December 2001

[4] Dr Lissi Pfeifer: Stress and constructive formation of the end areas of concrete ceilings, research report BASt 2004

[5] Stefan Höller: Testing the design of the continuously reinforced concrete road, FGSV Concrete Road Day, Erfurt 2007

[6] Stefan Höller: Optimization of the continuously reinforced concrete road surface, diploma thesis at the Technical University of Dresden, 2009

[7] Stefan Höller: Continuously reinforced road surface made of concrete, test section BAB A5 near Darmstadt, BASt research report, February 2010

[8] Research Society for Roads and Traffic: "Notes on the construction of continuously reinforced concrete pavement, HDBB", Version 2020

6.2. CONCRETE ROAD PRESERVATION BY MICROMILLING THE SURFACE

6.2.1. Introduction

Surface treatments are important preservation techniques for concrete road surfaces. They allow to improve the surface characteristics of old, worn-out surfaces. The concerned surface characteristics are evenness, skid resistance, rolling noise and rolling resistance. The main surface treatment techniques for concrete are milling, grinding and the NGCS (Next Generation Concrete Surface, a combination of longitudinal grinding and grooving). Thanks to these techniques, it is not necessary to overlay the concrete surface with an asphalt wearing course or to replace the pavement over full depth.

For the technique of milling, different finishing levels are possible: standard milling, fine milling and micromilling. They are all based on the use of machines equipped with a rotating drum with picking tools. The difference is in the spacing of the picking tools. For road surfaces, fine milling is mostly applied, with a spacing of 8 mm between the picking tools. However, a better, more comfortable, and uniform result is obtained by micromilling, in which case the picking tools are closer spaced: 6 cm instead of 8 cm. In combination with a 3D-guidance of the machine, very accurate finishing becomes possible.

Figure 69 : Fine milling- from left to right: milling machine – rotating drum equipped with picking tools – result of surface after finemilling (©L. Rens, FEBELCEM)

6.2.2. Description of the technique – influencing parameters

Pavement milling is the process of removing part of the surface of a paved area. Milling removes anywhere from just enough thickness to level and smooth the surface to a full depth removal. As a concrete pavement preservation technique, only a few mm are removed. This is done with a milling machine, equipped with a hydraulic leveling system and a rotating drum with a number of picking tools. Depending on the spacing of these picking tools (or their number), we talk about standard milling, finemilling or micromilling. Standard milling is used for removal of the pavement over partial or full depth; finemilling is for corrective work on road profiles and is often used on local roads where demands of smoothness and comfort are not very high. Micromilling is the best choice for the highest demands on macro- and microprofile.

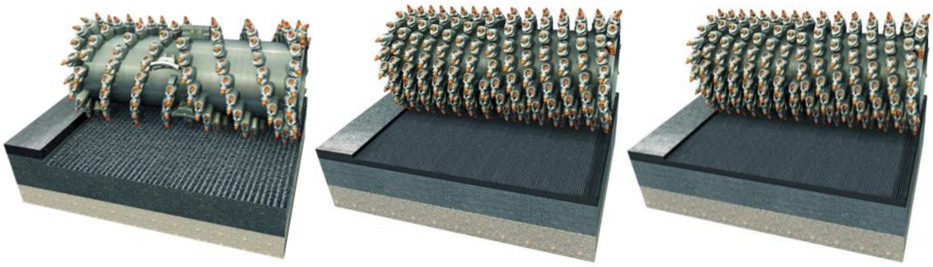


Figure 70 : Rotating drums equipped with picking tools – from left to right: standard milling (tool spacing 15 mm – number of pics: 162) – finemilling (tool spacing 8 mm – number of pics: 274) – micromilling (tool spacing 6 mm – number of pics: 672) (©Wirtgen)

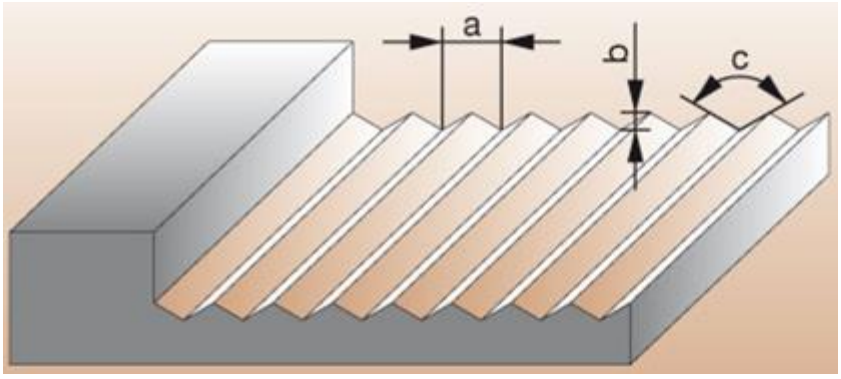


Figure 71 : Representation of a milled surface with a= tool spacing; b=base height; c=break-out angle (©Wirtgen)

A larger tool spacing also results in a larger base height of the milled profile and thus a rougher surface. The break-out angle is set at 120°. However, the tool spacing is only one of the influencing parameters. The result will also depend on the advance speed of the machine and the rotating speed of the milling drum. A high advance speed of the milling machine, e.g., 20 m/min, will result in a rougher surface; a low speed, e.g., 10 m/min, will give a finer surface. On the other hand, a low milling drum speed, e.g., 96 rounds/min, gives a rougher surface and a high rotating speed, e.g., 127 rounds/min, a finer surface.

Figure 72 below, gives the macrotexture of the pavement, using the sand patch test, for different types of milling (different values of the tool spacing 'LA') in function of the advance speed of the machine. It is expressed as the diameter of the sand patch; a larger diameter means a smaller texture depth. We notice that the largest diameters, thus the smallest texture depths, are obtained for low advance speeds and small spacing of the pics ('LA6' and 'LA3').

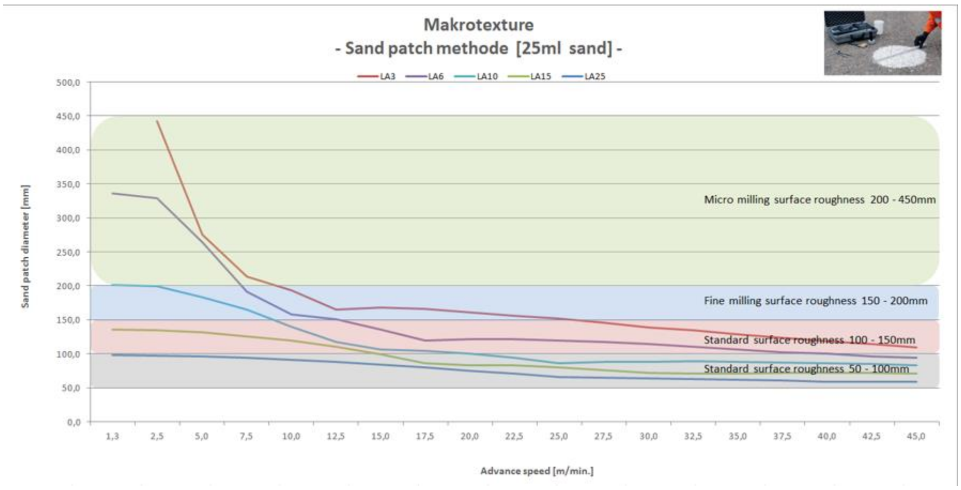


Figure 72 : Graph showing the macrotexture with the sand patch test in function of the advance speed for different types of surface milling (©Wirtgen)

6.2.3. Cases

Finemilling has already been applied on many local and regional roads in Belgium. Recently (2020-2022), also micromilling has been done on some surfaces.

6.2.3.1. Hasselt, Belgium – micromilling of a local road

Figure 73 : Hasselt, BE – surface of a local road after micromilling (©Topoff, Belgium)

6.2.3.2. Maasmechelen, Belgium - micromilling of a bicycle path

Figure 74 : Maasmechelen, BE – surface of a bicycle path in red concrete after micromilling (©Topoff, Belgium)

6.2.4. References

[1] Holl, B., Cold Milling Manual – Technology and Application, Wirtgen, 2019

6.3. SELF-HEALING LIQUID FOR CONCRETE CRACK REPAIR

6.3.1. Introduction – presentation of the product

Few solutions are available for the repair of fine cracks, e.g. plastic shrinkage cracks, in concrete pavements.

"Basilisk" is a new product, based upon the technology of self-healing concrete, consisting of a 2-component low-viscous solution. It can repair cracks with a width up to 0,8 mm. It has already successfully been used in several projects, such as a bus lane, a parking garage and public spaces.

The technology was developed and patented in collaboration with the Delft University of Technology. After successful testing the interest from the (concrete) market grew strongly. The commercial establishment of Basilisk Self-Healing Concrete became a fact and, in the meantime, a broad introduction of the self-healing concrete technology on a large scale is made possible.

6.3.2. General working mechanism of self-healing products

Several products exist, which enable the self-healing properties of concrete. The technology is based on micro-organisms that produce limestone, as a result crack formation in concrete structures can be autonomously repaired. In this way, the durability of the concrete structure is greatly improved. The autonomous repair system is implemented in several products that are applicable for both new constructions and existing structures.

When cracks appear in the concrete specially selected bacteria and nutrients will facilitate an autonomous repair system. The technique and time of adding the bacteria depend on the chosen product. The bacteria is triggered when they get in contact with water and oxygen, which will be present due to prior crack formation. The bacteria needs a certain alkalinity which is either provided by the concrete itself or by the healing product. When in the presence of water, oxygen, and nutrients the bacteria will start to multiply. This will ensure a wide dispersion of bacteria inside the entire crack. The widely dispersed bacteria will start to convert the present nutrients into calcium carbonate (limestone), which will eventually seal the crack. Due to the formation of limestone the crack is autonomously repaired, increasing the durability of the concrete structure.

6.3.3. Self-healing repair liquid – description and application method

One of the developed products is a liquid repair system, which allows an easy repair for small, narrow cracks in concrete structures or pavements. Traditional repair methods such as manual injections are expensive, require a large amount of effort, time and are difficult to apply on narrow cracks. Due to its low viscosity, Basilisk ER7 penetrates easily into small cracks and pores. After application, the liquid forms a gel which seals the crack and pores. Subsequently, during the healing process, the environmentally friendly bacteria present in the liquid, convert the nutrients into limestone, providing a concrete compatible and permanent sealing of the concrete crack and surface. Because cracks are sealed watertight, the reinforcement is protected against corrosion and leakage issues are solved. Furthermore, this densified concrete surface now prevents growth or regrowth of unwanted fouling organisms and significantly increases its resistance against frost damage.

The repair liquid is applied as a two-component spray mixture, and it is quick and easy to apply. Both components are supplied as a powder mixture and must be separately dissolved in water before application. If required, these solutions can be transferred to separate (handheld) pressure sprayers. Component 'A' must be applied in two passes in an amount sufficient to saturate the existing cracks and pores, while the second component 'B' must be applied afterwards (within 5 to 10 minutes after the last application of component 'A'). As soon as component 'B' is applied and comes into contact with component 'A', a firm gel is formed that covers and seals cracks and pores. The cracks and pores of the concrete surfaces to be treated must be clean and dry to allow the repair liquid to penetrate as effectively as possible.

The application rate for component 'A' is between 0.15 and 0.2 l/m² for crack repairs and between 0.30 and 0.50 l/m² for surface treatment. The amount of product is largely dependent on the number and size of the cracks and pores. A test section allows for determining the specific quantity. The volume ratio of component 'A' to 'B' is 2:1. With the right equipment, a production of 500 m² per hour is possible. For cracks up to 0.2 mm wide, just one treatment is sufficient while for larger cracks multiple sequential treatments may be necessary to ensure a durable surface repair. The interval between the treatments is at least 6 weeks. When required, the excess of the repair material can be removed after 24h of application allowing almost immediate accessibility for usage.

Figure 75 : Application of the repair liquid on a crack

6.3.4. Cases

This new type of self-healing repair liquid has already been used in several projects, e.g., at Brussel Airport, for a Dutch bus lane near Schiphol Airport and on several smaller worksites in Belgium.

6.3.4.1. The Netherlands – buslane near Schiphol airport

Plastic shrinkage cracks occurred on a concrete bus lane near the Dutch airport of Schiphol. The self-healing repair liquid was selected as the best solution for both a crack repair and a general surface treatment. This proposed treatment causes both a significant decrease in the permeability of the crack and a strong increase in the freeze-thaw resistance of the concrete surface. In addition, it outperforms existing solutions favorably in terms of cost, availability of the bus lane and environmental impact.

Figure 76: Surface application on a bus lane

6.3.4.2. Belgium – Putte – repair of plastic shrinkage cracks

Insufficient surface protection and a strong wind caused several plastic shrinkage cracks in a concrete pavement for an access road and parking lot near a school of the town Putte. The cracks were treated in 2020. Two years later, the cracks have not disappeared and are still visible, especially after rainy weather. However, the crack widths have decreased and are now below the permissible width, ensuring the durability of the pavement.

Figure 77: Shrinkage cracks, right after application of the repair liquid (2020)

Figure 78: Situation after 2 years (2022)

6.3.5. References

[1] https://www.basiliskconcrete.com/producten/product-liquid-repair-system-er7/

6.4. NGCS TO IMPROVE ACOUSTIC PERFORMANCE OF CONCRETE PAVEMENTS IN BELGIUM

6.4.1. Context

In Belgium, a large amount of concrete pavements were built in the 1960s and 1970s. At that time, surface texturing was done by transverse tining. Currently, a surface of exposed aggregate is the standard concrete surface. However, several of these old pavements are still in service and are quite noisy.

The traditional maintenance method in Belgium to reduce road noise is the use of a bituminous overlay, consisting of a SAMI (stress absorbing membrane interface) and a wearing course of 3 or 4 cm SMA. This technique is not always possible: it increases the total pavement thickness, and sometimes requiring additional road works, e.g., to lift kerbs or traffic barriers.

6.4.2. Next Generation Concrete Surface (NGCS)

NGCS is a new technique which was developed in the USA, further research was done in Germany. It consists of a combination of longitudinal grooving and diamond grinding. Diamond blades are used to grind a negative texture in the longitudinal direction with each time one deep groove (grooving) and four shallow grooves (grinding). This technique can be applied to new concrete surfaces as well as to existing pavements. In Belgium it is currently only used to reduce the road noise of old and noisy concrete pavements.

After building a test section [1], a standard NGCS profile was developed. The profile consists of a repetition of one deep groove of 4 mm deep and four shallow grooves of 1 mm deep. The grooves are 2.8 mm wide and are 1.1 mm apart (see *Figure 79*).

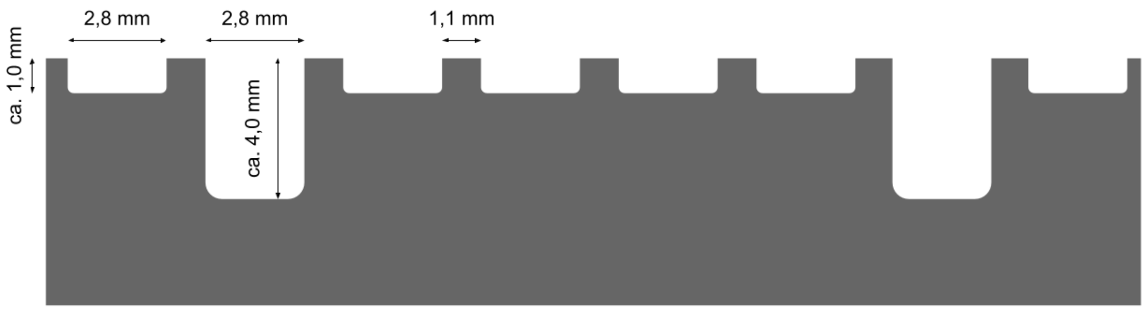


Figure 79: Standard NGCS profile with one deep and four shallow grooves

6.4.3. Test section on the N44

A test section of 100 m long was carried out in October 2015 on the N44 in Maldegem. This section was an existing jointed concrete pavement with an exposed aggregate surface, built in 1958 with a slab thickness of 23 to 25 cm.

The main focus of this test section was to study the acoustic performance of the NGCS profile, to determine the effect of the treatment, before and after the work noise measurements were carried out with the Close-Proximity method (CPX). The CPX method is an acoustic measuring method whereby the contact noise between tyre and road surface is measured by driving on the road with a measuring trailer. The measurements were carried out at a reference speed of 80 km/h with SRTT tyres, the SRTT tyre corresponds with the behavior of a car tyre. [2]

In August 2015, two months before the treatment, a first measurement was carried out and showed an average road noise level of 101.1 dB(A). Immediately after applying the NGCS treatment, the average road noise level dropped by about 6 dB(A). Since then, CPX measurements were repeated and the noise reduction proved to be reasonably stable over time (see *Figure 80*). For comparison, the reference pavement is a SMA type surface with a road noise of 99.3 dB(A). Even six years after construction this surface is still about 2 dB(A) quieter than the reference pavement.

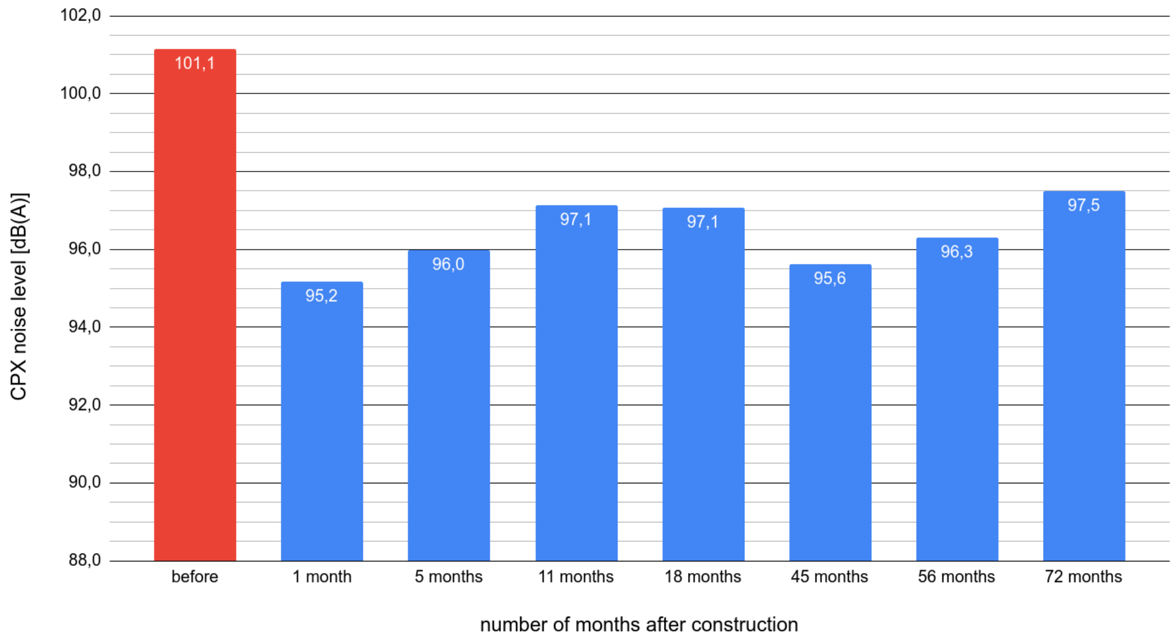


Figure 80: CPX road noise levels, SRTT tyre, 80 km/h

6.4.4. Conclusion

The NGCS treatment is a durable and efficient way to reduce the road noise of old concrete pavements. It results in a surface which is even quieter than a standard asphalt pavement.

This maintenance method has been included in the Flemish standard tender specifications since 2019 where an acoustic performance is required of an average CPX level less than 97.5 dB(A) immediately after construction.

Since then, a larger construction site has been carried out on a 1 km section of the R1, the ring road around the city of Antwerp (see *Figure 81*).

Figure 81: application of the NGCS profile on the R1
(picture by Kris Van de Sande, Agency for Roads and Traffic)

6.4.5. References

[1] "Next Generation Concrete Surface (NGCS). Finally A quiet and sustainable road pavement?", Barbara Vanhooreweder et al, 13th International Symposium on Concrete Roads, Berlin, 2018

[2] Standard ISO 11819-2, "Acoustics - Measurement of the influence of road surfaces on traffic noise - Part 2: The close-proximity method"

7. INNOVATIVE ORGANIZATIONAL AND STRATEGIC ASPECTS ON PAVEMENT MAINTENANCE.

7.1. MAINTENANCE LEADERSHIP ACADEMY (MLA)

7.1.1. Background in the United States

Today's transportation environment requires a delicate balance of human resources and funding to maintain our roadway infrastructure. In the USA, many States rely on a Maintenance Management System (MMS). But this system is only as good as the information placed in it. Maintenance managers also rely on information that comes directly from the field by people who manage infrastructure resources locally. Many factors come into play when managing these infrastructure pieces. Maintenance operations, design practices, and organizational funding are some of the key components in the decision-making process. These decisions are also made while keeping long-term investments of the roadway infrastructure in mind. A key component is considering how much of the future investments are spent on future maintenance. A maintenance management system (MMS) helps in this decision-making process.

Human resources are a critical investment. In today's environment, transportation organizations are faced with the growing need to maintain human capital. Depleted human resources due to retirements and the inability of agencies to maintain new employees make this investment even more critical. New employees are expected to take on multiple responsibilities and come up to speed at a rapid pace on a variety of projects often with additional duties.

Maintaining a level of competence in maintenance operations is critical. Maintenance leaders across the nation are looking for effective ways to target these professionals so that new supervisors and employees can quickly get up to speed on a wide range of maintenance issues. The preparation and development of these employees can help advance an agencies maintenance program. Effective training for these roles can be hard to find and few courses cover the breadth of information required of maintenance professionals.

7.1.2. Investing in Resource Development through Training

The Federal Highway Administration worked with The National Highway Institute (NHI) to develop the Maintenance Leadership Academy (FHWA-NHI-134063). This comprehensive course provides an opportunity for transportation agencies to develop and maintain the required level of competencies in this specialized transportation work force. The academy supports the development of career supervisors that manage maintenance programs at the local and State level, while advancing new technologies in the field of maintenance. This course is a unique comprehensive training for state, district, and county maintenance supervisors who need to acclimate quickly to an expanding role(s). The course provides comprehensive education into six key areas:

- Maintenance Administration and Asset Management ;
- Roadways and Shoulders ;
- Roadside Maintenance and drainage ;
- Weather-related issues ;
- Traffic services ;
- Environmental issues, regulations, and compliance.

NHI's Maintenance Leadership Academy has been developed with the mindset of developing maintenance personnel who strive to be successful leaders.

MLA participants are typically maintenance supervisors with minimal to moderate levels of experience in their States, regional, or county maintenance operations. The MLA course also provides operations personnel an expanded view of the maintenance function to help support collaborative work efforts.

The Maintenance Leadership Academy is delivered in a unique way. The academy has been developed with an active maintenance worker in mind. The course utilizes a variety of instructional delivery methods including classroom, remote learning, and independent study. Participants and their supervisors should plan for the necessary time needed to complete the course. The suggested schedule for completing all course work is 9-12 weeks. The schedule can be modified to some extent at the request of the host state to accommodate workload demands.

7.1.3. Success of the Maintenance Leadership Academy

Participants who complete the academy leave with the in-depth understanding they need to support their organization's bridge and highway systems and the complex decision-making surrounding it. They can immediately apply new knowledge on collecting, recording, and communicating data for agency decision-making and for supporting funding requests to internal and external stakeholders.

Figure 82 : MLA participants engage in a variety of engaging activities. This photo shows MLA participants using a tabletop exercise to confirm work zone traffic safety as applied to several scenarios. (Photo: Vanessa Almony)

7.1.4. References

[1] https://www.nhi.fhwa.dot.gov/course-search?sf=0&course_no=134063

7.2. Pavement Preventive Maintenance as an Integral Part of an Appropriate Network Management Strategy

7.2.1. Framework

The purpose of this case study is to present an operational solution for maintenance on road pavements, as a part of a network global management, explaining its assumptions and applicability. It will also be highlighted the technical and economic advantages that can be drawn from it, to increase the useful life of road pavements, delaying the need for deep major structural maintenance, with advantages in good budget management, and in the quality perceived by the road users.

IP - Infraestruturas de Portugal carries out its short/medium term planning, prioritizing in a reasoned manner the interventions to be carried out on its Road Assets, with the primary objective of preserving it in adequate functional and safety conditions, and to provide a better service to its clients.

Road rehabilitation needs are assessed based on a Prioritization Strategy, supported by the technical urgency of the intervention and the adequacy of the investment in relation to traffic. Rehabilitation interventions should occur with the most convenient frequency/intervention cycle, based on the expected infrastructure degradation patterns and investment scenarios.

The best way to manage a road network is based on a strategy supported by a combination of rehabilitation interventions (major maintenance) with preventive interventions at a stage when the degradations are not yet significant, thus preventing their increase, without underestimating the complementarity with minor maintenance actions.

Given the financial framework of the country in recent years, with strong containment of investment in road infrastructure maintenance, it is necessary to make a good management of scarce resources, providing conditions for an increase in the cycle of interventions.

7.2.2. Preventive Pavements Maintenance Programmes

Since 2018, IP has been implementing annual programs of Preventive Pavement Maintenance (IPV), which are lighter in terms of investment and technical solutions; and carried out at the first signs of degradation of the pavement. They aim to improve performance and extend the pavement's life span, postponing the medium term execution of major maintenance (structural rehabilitation) actions. The strategy of these programs is based on three pillars, Financial, Planning and Technical, as follows:

7.2.2.1. Financial

The investment value of the IPV’s to be executed are within the necessary budgetary framework, which has been ensured given the contingencies of the execution of the annual Company Investment Plan for road interventions: minor, preventive, and major maintenance works.

7.2.2.2. Planning

Programming compatible with a full implementation in the year, which results from the adoption of an intervention model focused on Pavements, although with strong concerns about Road Safety, reflecting the growing importance of matters related with the reduction of Road Accidents, and based on projects developed with the collaboration between the Operational Areas and the Engineering Projects Department.

7.2.2.3. Technical

Evaluation of the interventions and their selection based on the company's planning instruments, considering some anticipations and/or actions that allow the rethinking and/or reprogramming of eventual deeper planned actions. The technical solutions result from the interpretation of the preliminary investigations and the results obtained for the various surface condition parameters, within the scope of the principal pavement inspection campaigns, which allow an understanding of the pavement degradation state, causes and possible evolution.

The preventive pavements maintenance, carried out every year since 2018, has represented a significant increase in the capacity to act in pavement maintenance, even more so given the recessive effect resulting from the economic circumstances. The effect of this increase was reflected in the extent of the network intervened, as shown in the following graph.

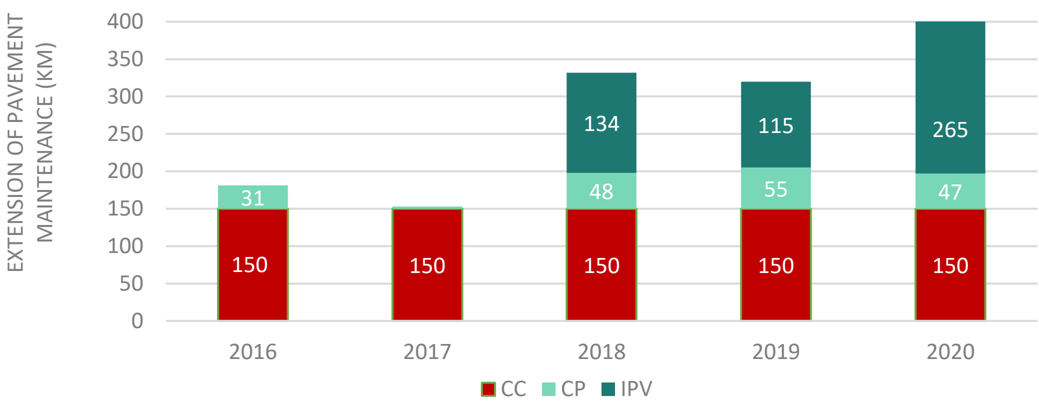


Figure 83 : Extent of Major Pavement Maintenance (CP), Minor Pavement Maintenance (CC) and Preventive Pavement Maintenance (IPV)

7.2.3. Type of technical solutions used in Preventive Pavement Maintenance

The technical solutions usually adopted in Preventive Pavement Maintenance (IPV), are usually classified as a light pavement reinforcement[1] , which may correspond to milling and replacement of the surface course with previous small, localized repairing works.

The pavement to be the object of an IPV should not present evidence of structural severe degradations. The purpose of an IPV is to extend the life of pavement that is still in an average-good condition.

The type of paving works predicted in an IPV usually follow the scheme below:

Predicted works	Works allocation	
Milling - depth between 0,05 m and 0,10 m	1/1 (100%)	

Additional milling - depth between 0,05 m and 0,10 m	0,10/1 (10%)	
Binder course or regulating course with a thickness of 0,05m average	0,10/1 (10%)	
Replacement of failed area	0,10/1 (10%)	
Surface layer	1/1 (100 %)	

Table 14: Type of paving works on an IPV

7.2.4. Quality Index and Maintenance Index variations after the execution of the Preventive Pavements Maintenance Interventions

IP's Pavement Management System (SGPav) is a supportive tool for asset management and supports the Quality Assessment Methodology of the Portuguese National Road Network. It is based on the functional and structural quality of the pavements, resulting from the parameters obtained during the principal pavement inspection campaigns.

The principal pavement inspection activity is based on the collection of the pavement surface condition parameters, with an RST Laser equipment and the measurement of the sideway force coefficient (CAT) with an SKM equipment.

The values obtained for each of the parameters: Longitudinal Unevenness – International Roughness Index (IRI); Transverse Unevenness – Rut Depth (RD) and Macrotexture – Mean Profile Depth (MPD), are collected with the RST Laser equipment. The assessment of the "alligator skin" cracking (Cr) data is obtained by visual observation.[2]

The Quality Assessment Methodology is based on the combination of a global assessment, supported by the indicators Quality Index (QI) and Maintenance Index (CI), and additionally by the pavement surface condition parameters.

The QI is a global assessment index, based on the PSI (Present Serviceability Index) value, which results from AASHTO [3] road test studies, in where the greatest contribution to its value is given by the pavement's longitudinal unevenness (IRI). This makes the Quality Index (QI) an indicator of special interest in the assessment of the functional performance of pavements, which essentially translates the convenience and comfort perceived by the users.

The QI varies in the interval between 0 (pavement in very poor condition) and 5 (ideal pavement that corresponds to the absence of irregularity and other degradations). In this interval, four quality classes, Good, Average, Mediocre and Bad, are defined according to the distribution presented in the following Table.

Quality Index - QI

Good	*Average*	*Mediocre*	*Bad*
3,5 ≤ IQ ≤ 5	*2,5 ≤ IQ < 3,5*	*1,5 ≤ IQ < 2,5*	*0 ≤ IQ < 1,5*

Table 15 : Quality Index Classes - QI

Considering the need to obtain a better characterization of the structural quality of pavements, with a more accurate and better adjusted decision-making to the real need for intervention, a new indicator was developed, the Maintenance Index (CI), which, in a perspective of complementarity to the QI, essentially aims to better reflect the structural state of pavements.

The Maintenance Index (CI) is based on the assumptions underlying the study that integrates the COST 354 Action[4] and on the principles of the calculation methodology and aggregation of parameters contained in the German Model [5], with the necessary adaptations and adjustments to the national reality. It is a global assessment index obtained as a function of the different parameters of the state of its surface, IRI, RD, MPD, CAT and percentage of cracked area. The parameters are combined into two components, the structural indicator and the functional indicator, the CI assuming the index value with the highest severity.

The CI assumes values in the interval between 0 (Pavement in very good condition, without degradation) and 5 (pavement in very bad condition). In this interval, five states (or classes) of conservation, Very Good, Good, Acceptable, Insufficient and Bad, are defined according to the distribution presented in the following table

Maintenance Index - CI				
Very Good	*Good*	*Acceptable*	*Insufficient*	*Bad*
0 ≤ IC < 1	*1 ≤ IC < 2*	*2 ≤ IC < 3*	*3 ≤ IC < 4*	*4 ≤ IC ≤ 5*

Table 16 : Maintenance Index Classes – CI

In the present study, the overall quality improvement obtained because of the execution of Preventive Pavements Maintenance works, are calculated, namely, at the level of the pavement surface condition parameters and of the two global indicators. The improvements are estimated by the comparison of the inspection data before and after the execution of the of Preventive Pavements Maintenance works. Alligator cracking is considered null after the execution of the work, since all the interventions imply the replacement of the surface course.

For the present study,256 km of road network has been analyzed, subjected to the Preventive Pavements Maintenance Program (IPV's) since 2018, with a total of 37 road sections. The results include the average values of the parameters and indicators characteristics of rehabilitation (values recorded after the work) and the average improvement after the intervention. The study regarding an increase in quality is continuous work and has not yet been extended to the total road network undertaken by Preventive Pavements Maintenance Programs.

In the following table it is possible to see the variation of the pavement surface condition parameters and of the two global indicators, after the IPV's works.

Parameters/ indicators	∆ Variation
IRI - International Roughness Index	-980 mm/km
RD - Rut Depth	-1,8 mm
MPD – Mean Profile Depth	+023 mm
IQ – Quality Index	+0,71
IC – Maintenance Index	-1,5

Table 17: Variation of the pavement surface condition parameters and of the two global indicators, after the IPV's works

The following graphs shows the average quality evolution of the two global indicators, IQ and CI, over the years, between 2018 and 2020.

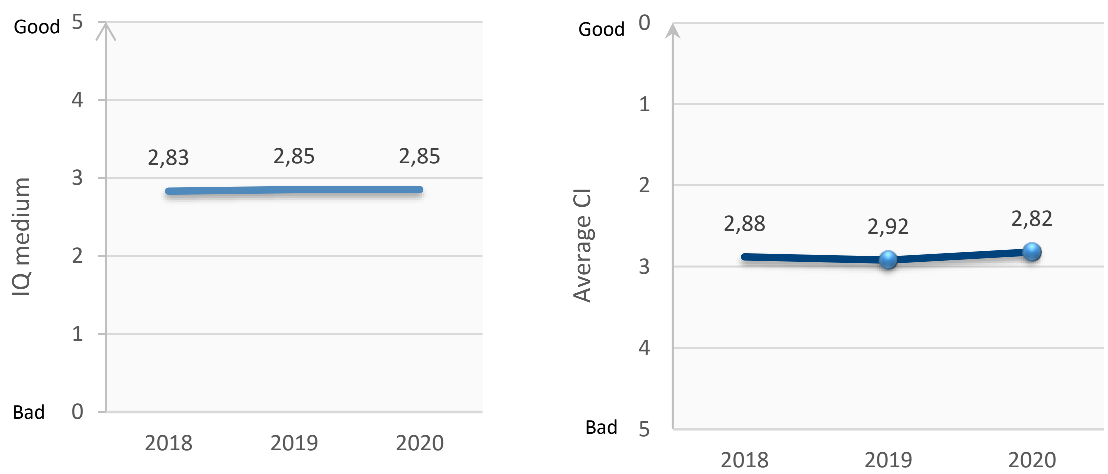


Figure 84: Annual evolution of IQ and IC between 2018 and 2020

The values observed suggest a regularity in the average QI, and a slight tendency towards improvement in the IC, even though they do not yet consider the IPVs carried out in 2021.

This result stems from a consolidated action in the context of pavement maintenance based on systematic minor maintenance works and major maintenance, although limited by the company's operational capabilities, and complemented by preventive interventions on pavements, allowed by the proper use of budget gaps.

7.2.5. References

[1] Infraestruturas de Portugal (2020) Tipologias de intervenção – Pavimentos Rodoviários Flexíveis, Direção de Asset Management.

[2] Lopes S. et al. (2019), INSPEÇÃO E INDICADORES DE AVALIAÇÃO DO ESTADO DE CONSERVAÇÃO DOS PAVIMENTOS DA RRN, CRP 2019.

[3] Highway Research Board (1962) "The AASHO road test", Report 5 - Pavement Research, Special Report 61E, National Academy of Sciences.

[4] COST 354 (European cooperation in the field of scientific and technical research) (2008). "Performance Indicators for Road Pavements.

[5] Ruess M. (2016) ZEB 2016 auf Kreisstraßen in Rheinland-Pfalz Zustandsbewertung Dokumentation Markus Ruess, HELLER Ingenieurgesellschaft mbH Darmstadt, 12. September 2016.

7.3. INTEGRATED NETWORK MAINTENANCE MANAGEMENT, FROM THE PERSPECTIVE OF ROAD PAVEMENTS

7.3.1. Introduction

This case study intends to present the operational instruments used by INFRAESTRUTURAS de Portugal (IP), the Portuguese Road and Rail Infrastructure Manager, to perform a holistic view the road network maintenance, noting its effectiveness in relation to the asset pavement, demonstrated by an overall indicator of the functional status, and its evolution over time to accommodate the needs of a structural intervention (major pavement maintenance - CP), which ensures that the decision is on its timely renewal.

7.3.2. Minor maintenance contracts (CCC) Framework

The minor maintenance of the road network is carried out through three-year district minor maintenance contracts (CCC), in a total of eighteen districts. This strategy of minor maintenance contracts was implemented in 2010 and IP had until now concluded 3 contracts 2010-2013, 2013-2017 and 2017-2020. The data shown in this case study is referred to the last minor maintenance Contract (CCC 2017-2020).

These contracts aim to ensure that the minor maintenance works in all the constituent components of the road and bridges, that are proven as necessary, as well as the operation of Intervention Brigades and the performance in emergency situations to reset the conditions of circulation, by intervention of an Emergency Brigade and mobilization of Complementary Equipment.

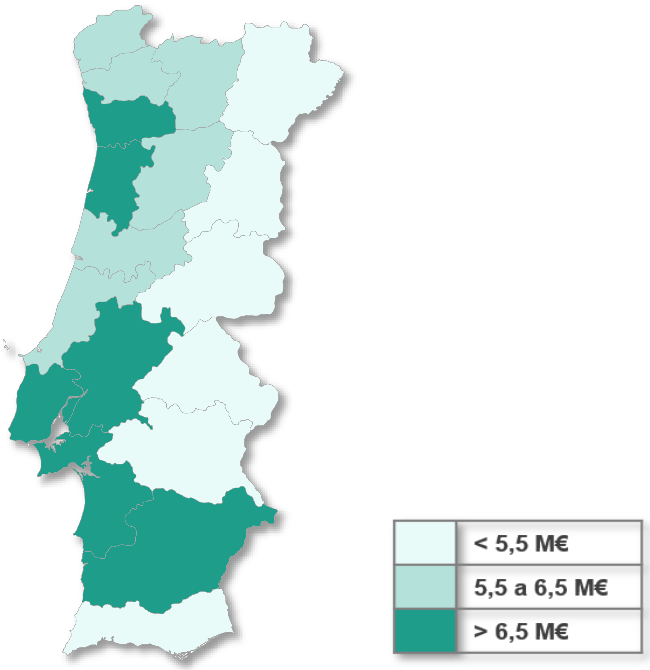


Figure 85: Contract Investment per 3 years (107 M €), per year (34,8 M €) and per kilometer in one year (2.500,00 €/km/year), and by Portuguese district.

These minor maintenance contracts include all routine maintenance activities, both curative and preventive, planned and/or reaction, to ensure conditions of comfort in circulation, and greater conditions of road safety.

Activities of relatively low technical complexity and often with intensive application of labor are carried out, and their timely execution is a fundamental condition for the preservation of investments made on the road, as well as for the safety of its users.

The activities are planned based both on the knowledge that IP has of its network, through routine inspections (IR) that are performed every 2 years, through the daily network surveillance activities, and the information transmitted by users through the established channels.

In these contracts, specifically those which concerns the pavement maintenance, include the treatment of pavements degradations, the maintenance of the bituminous surface, as well as interventions to maintain or improve the skid resistance conditions in pavements.

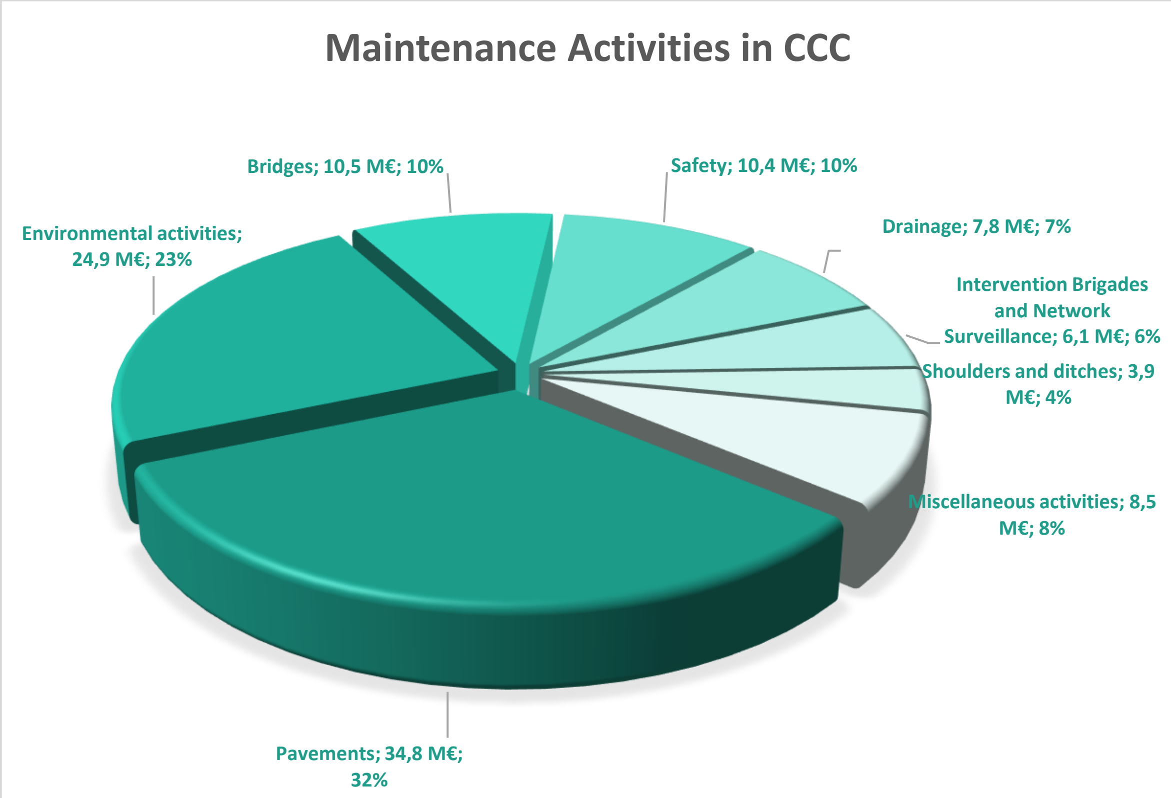


Figure 86: Contract Investment per maintenance activity – 32 % of the investment is in pavements minor maintenance works: 34.8 M€.

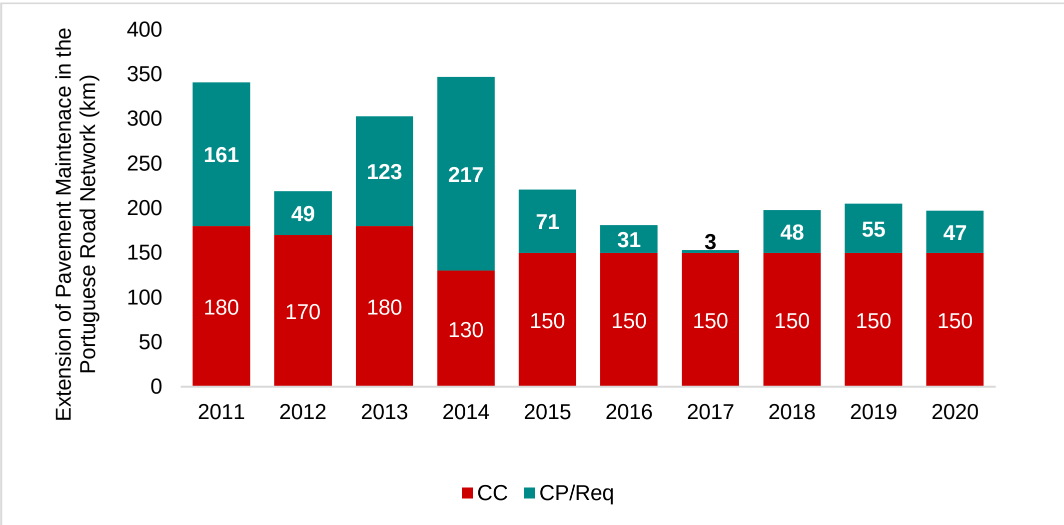


Figure 87 :Extension of pavement maintenance through the years in the Portuguese Road Network – Major Pavement maintenance (CP) and Minor Pavement Maintenance (CC).

The knowledge is attainted over years with this type of contracts and the knowledge of the maturity of the Portuguese Road Network has allowed IP to adjust the type of works and percentage of budget to each type of work, in each district, allowing a wiser allocation of the financial and technical resources as show in the above figures.

7.3.3. Typical pavement technical solutions used in the Minor Maintenance Contracts

The solutions adopted in these contracts, for the pavement maintenance are typified, have fixed quantities priorly approved, and include:

- Punctual pavement sanitation and replacement with an adequate structure;

Figure 88: Typical punctual sanitation works before and after

- Pavement milling, including filling in with an adequate bituminous mixture;

Figure 89: Pavement milling, including filling in with an adequate hot bituminous mixture

- Regularization and/or reprofiling of settlements and depressions in the existing pavement (variable thickness) with an adequate cold or hot bituminous mixture, according to the identified need;
- Execution of surface treatments in cold bituminous mixtures;
- Replacement of the skid resistance conditions of the pavement by mechanical means through mechanical abrasion of the pavement surface by steel shot blasting or by "ultra-high pressure" (UHP) water jet, or other techniques.

7.3.4. Assessment of the pavement quality

The IP Pavement Management System (SGPav), is a tool that supports asset management, supports the quality assessment methodology, and it is based on the functional and structural quality of the pavements resulting from analysis of the state condition parameters obtained in the Principal Inspections.

The Principal Inspection activity of the pavements is based on the continuous collection of the pavement condition parameters, designated by surveying the surface characteristics of the pavement, with Laser RST equipment and testing the skid resistance with an SKM equipment for measuring the coefficient of cross friction (CAT).

The values for each of the parameters, Longitudinal Unevenness (IRI), Transversal Longitudinal Unevenness (RD) and Macrotexture (MPD), are obtained by mechanical observation, with the collection of cracking data type "alligator skin" (Cr) obtained by visual observation[2].

The Quality Assessment methodology is supported by the global indicator Quality Index (IQ) and the status parameters. The IQ for flexible pavements is based on the PSI (Present Serviceability Index) value, developed based on information obtained from the AASHO test, and adopted by the Nevada State Pavement Management System[3].

The coefficients used were adapted to the reality of the network under IP management.

Equation (1) translates, according to the reasoning, the IQ in year t.

$$\mathrm{IQ_t} = 5 \times e^{-0{,}0002030 \times \mathrm{IRI_t}} - 0{,}002139 \times \mathrm{R_t}^2 - 0{,}03 \times \mathrm{C_{3_t}}^{0{,}5} \quad (1)$$

Equation 1: Determination of the Quality Index

In this equation:

- IRI_t – is the longitudinal irregularity of the pavement in year t (mm/km);
- R_t – is the average depth of the ruts in year t (mm);
- C_{3t} – is the alligator-skin cracking area coefficient in year t ($m^2/100m^2$).

The IQ varies in the interval between 0 (pavement in very poor condition) and 5 (ideal pavement that corresponds to the absence of irregularity and other degradations). In this interval, four quality classes, Good, Average, Mediocre and Bad, are defined according to the distribution presented in the following Table.

Quality Index - IQ			
Good	*Average*	*Mediocre*	*Bad*
3,5 ≤ IQ ≤ 5	*2,5 ≤ IQ < 3,5*	*1,5 ≤ IQ < 2,5*	*0 ≤ IQ < 1,5*

Table 18: Quality Index Classes - QI

7.3.5. Quality annual evolution of the network

The following graph shows the evolution of the global average quality over the years, between 2018 and 2020. The observed values suggest a regularity both in the average IQ and in the distribution of the network extension by IQ classes.

However, there has been a downward trend in the network extension in the good class, which in 2020 represents a 4% reduction (decrease of 92 km) compared to 2018, which is considered a natural evolution. This fact stems from the fact that minor maintenance is affecting mainly the mediocre/reasonable class to delay the degradation process and maintain the network in adequate conditions of circulation and safety.

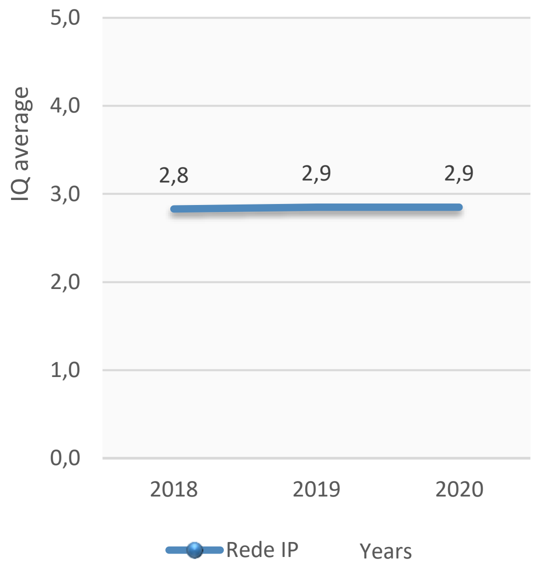


Figure 90: Quality Evolution of the Portuguese Road Network between 2018 and 2020

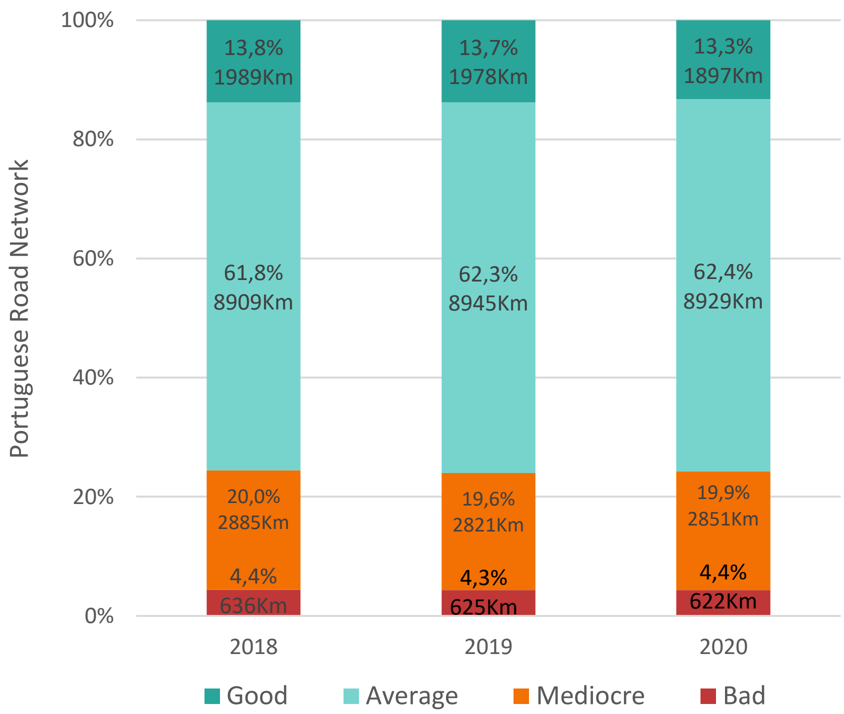


Figure 91: Annual quality evolution by class between 2018 and 2020 in the Portuguese network

The systematic minor maintenance intervention on the pavements in the Portuguese network, has as objective for the safe operation of the infrastructure, acting with mitigating actions, correcting specific degradations, as well as intervening in areas with greater extension; thus allowing to stop the existing degradation, increasing the life use of the pavements, and postponing the periodic maintenance interventions, which are normally more costly.

The articulation between minor maintenance triennial contracts and major pavement maintenance interventions leads to a "back-to-back" partnership, translating into a benefit for the final quality of the network and for the good management of public funds.

7.3.6. References

[1] Lopes S. et al. (2019), INSPEÇÃO E INDICADORES DE AVALIAÇÃO DO ESTADO DE CONSERVAÇÃO DOS PAVIMENTOS DA RRN, CRP 2019.

[2] Highway Research Board (1962) "The AASHO road test", Report 5 - Pavement Research, Special Report 61E, National Academy of Sciences.

[3] COST 354 (European cooperation in the field of scientific and technical research) (2008). "Performance Indicators for Road Pavements.

[4] Ruess M. (2016) ZEB 2016 auf Kreisstraßen in Rheinland-Pfalz Zustandsbewertung Dokumentation Markus Ruess, HELLER Ingenieurgesellschaft mbH Darmstadt, 12. September 2016.

8. CONCLUSIONS AND NEXT STEPS

The contributions for this collection of case studies had several geographic origins, mainly coming from Europe, North America, and Asia, and they result from examples provided by the Technical Committee members.

These examples may be of great use for low-medium income countries, as some of these techniques can be implemented, with traditional pavement equipment, as explained in the dedicated chapters.

This document is destined to pavement engineers and decision makers, this in order to provide some thoughts and incentive in the framework of innovative maintenance techniques. However, the detailed technical issues are not the purpose of this report.

The report presents several types of pavement maintenance case studies, addressing both asphalt and concrete, surface, and structural aspects, with several degrees of complexity according to the countries' experience. The case studies present the advantages of each technique and why they should be considered.

In this document a tendency for presenting surface treatments for both asphalt and concrete is illustrated, and this could be an issue to be addressed in a future cycle, as surface treatments not only improve the quality of surface characteristics, like comfort, safety, noise reduction, less energy consumption, skid resistance, among others; but also prevent the pavement deterioration, improving its durability.

Furthermore, this collection presents an experience with reinforcement grids, highlighting the various advantages of these type of materials, such as the extension of pavement service life and savings in natural resources.

It also presents new materials for asphalt layers with a view to increase durability and sustainability, explaining the materials and the results obtained.

Two solutions for widening rural roads and edge strengthening are explained, showing it's particularities.

Finally, there is a chapter with a strategic view, targeting decision makers, where it explains the importance of having an Academia for providing in-depth understanding to the attendees, so they can support their organization's maintenance decisions regarding bridge and highway systems; as well as supporting funding requests to internal and external stakeholders.

This final chapter also presented two case studies, where the technical and financial advantages for an Organization to have dedicated Maintenance programs are shown .

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