Report
2L-PA Combined Trial Sections A73
HRL 23.600-21.600

Part CEDR-FIBRA
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Report 2L-PA Combined Trial Sections A73 HRL 23.600-21.600 Part CEDR-FIBRA

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Table of Content

1. Introduction

Roads have great importance in the life of millions of citizens by enabling their mobility and by boosting the economic growth. However, maintaining reliable road performance is becoming increasingly difficult and continuous maintenance of roads is required but presents economic, environmental and social impacts. The historic Paris Agreement on Climate Change aims to keep the global temperature rise limited to preferably 1.5°C but no more than 2.0°C in this century. The Dutch government and Rijkswaterstaat (Dutch National Road Authority) also stated their ambition of having a 50% circular and 100% climate neutral asphalt industry in 2030. As a result, fostering durable, cost-effective and eco-friendly practices to reduce maintenance and achieve higher service lives is indispensable. Asphalt mixtures with high sustainability and/or high durability are increasingly important in this regard. BAM, together with Rijkswaterstaat and other road owners, are busy developing technologies required to produce such asphalt mixtures. Currently two of these projects are ready for field evaluation in test sections: LEAB-LE2AP high sustainable/circular porous asphalt and CEDR FIBRA fibre reinforced porous asphalt. Short introductions of both projects are given hereafter.

1.1 Fibre reinforced porous asphalt - CEDR FIBRA

Four European research centres (University of Cantabria, EMPA, TU Braunschweig and SINTEF), and two contractors (Veidekke Industri from Norway and BAM from the Netherlands) formed a consortium for the 2-year (2019-2020) research project FIBRA. FIBRA stands for Fostering the Implementation of Fibre-Reinforced Asphalt mixtures by ensuring its safe, optimized and cost-efficient use. The project is funded by CEDR (Conference of European Directors of Roads).

The overall objective of this project is to overcome the technical barriers for the safe and cost-efficient implementation of fibre-reinforced asphalt mixes by National Road Administrations (NRAs). The FIBRA project comprises literature research, lab research, pilot sections and LCA analysis.

With the positive results of the laboratory tests, the phase of field testing is started. Both Porous Asphalt, PA, mixes and dense Asphalt Concrete, AC, mixtures developed in the laboratory are produced at two different asphalt plants in two different countries and are thereafter installed in pilot road sections. The fibre reinforced AC dense asphalt test section is be constructed in Norway by Veidekke together with her NRA Statens Vegvesen and the fibre reinforced PA test section is constructed in the Netherlands by BAM in collaboration with her NRA Rijkswaterstaat.

On the other hand, Rijkswaterstaat and BAM already have quite some experience since 2005 by applying fibre reinforced porous asphalt and thin noise reducing asphalt mixtures in practice. Indications are that the use of the fibre can be an effective way of improving durability of the open graded surface mixtures, thus ensuring a longer lifespan.

As a result, both Rijkswaterstaat (RWS) and BAM agreed on the importance of field evaluation of fibre reinforced Porous Asphalt in practice. This includes two types of Porous Asphalt, PA, often used in RWS areal, i.e. top-layer of 2-layer PA (2L-PA 8, in Dutch 2L-ZOAB 8) and single layer PA (PA+, in Dutch DZOAB).

From an environmental point of view the benefits of fibre is largest when the application in the top-layer of 2-Layer PA. This is because 2L-PA8 is normally produced using PMB whereas single layer PA is produced using pen bitumen. It is anticipated that the use of fibre will make the use of PMB in PA8 unnecessary. This will lower production temperature and will make recycling of the top-layer of 2-layer PA easier. Also the 2-

Layer PA has better noise reducing properties than single layer PA. For this reason the application rate of reason 2-Layer PA is increasing.

Combined the previous suggests that it is more beneficial if the FIBRA sections are constructed with the application of fibre in 2-layer PA8. The installation of similar PA16 test sections are still under discussion as this report is written.

1.2 High sustainable porous asphalt - LEAB 80% circular / LE2AP 95% circular

BAM has been actively developing sustainable/circular asphalt products for the use in high quality surface layers such as Porous Asphalt. The basic principle of this development is that a true environmentally friendly asphalt product must be, circular, climate-neutral, energy-neutral and durable at the same time. A product comprising an ultra-high percentage of reclaimed material but having limited quality and as a result a shortened service life may thus be circular but is not a truly environmentally friendly alternative.

In its quest for truly environmentally friendly asphalt two main developments are the bitumen foaming technology LEAB and the high percentage low temperature recycling technology LE2AP.

LEAB

LEAB is a Dutch acronym for low energy asphalt (Laag Temperatuur Asfalt Beton), a technology with almost 20 years of history. This LEAB technology allows almost all asphalt mixtures to be produced at a lower production temperature (around 100°C) than traditional hot production (150-160°C) by foaming of bitumen. This technology has been widely applied by BAM for their asphalt mixtures, in combination also with RAP materials. This technology is accepted as a low temperature alternative for the hot production for binder/base layer asphalt (RWS 2014), surface layers (RWS 2019), SMA (Provinces Gelderland and Noord-Brabant 2018) and porous asphalt (RWS ongoing). A LEAB bitumen foaming nozzle array has been installed in 5 asphalt plants across the Netherlands with a total production of in total 800,000 ton till now. Recently BAM is also awarded a large project from Ministry of Transport of UK to promote the LEAB technology in England. At the moment of writing, the LEAB technology has been evaluated by the experts of the independent asphalt quality assessment desk (Asfaltkwaliteitsloket). LEAB is positively judged at the highest Technology Readiness Level of TRL9.

LE2AP

LE2AP is a technology that aims for sustainable and circular recycling with focus on horizontal recycling of especially surface layers into surface layers, i.e. recycling instead of downcycling. With the support of the European LIFE+ program (2013-2016), under a project LE2AP (Low Emission2 Asphalt Pavement), such a technology has been developed allowing the surface-to-surface recycling up to 95% at a production temperature of 100-110°C. The key advantages of this technology are the following.

- This LE2AP technology first decomposes Porous Asphalt RAP into its basic components then reuses them: the reclaimed stone (>2 mm) with 1% bitumen and the reclaimed mortar (bitumen-sand-filler system, <2 mm) with 10-12% bitumen. This decomposition process resolves the inhomogeneity problem from general recycling practice.
- The reclaimed mortar, which contains most of the bitumen, is treated separately involving indirect heating, rejuvenating, enriching and homogenizing. This process eliminates that issues of partial blending, inhomogeneity, oxidation or burning of bitumen in traditional asphalt production.

- To be able to produce the mixture in a sustainable way, the abovementioned mortar is foamed and mixed with pre-heated reclaimed stones of approximately 100°C, producing a mixture with up to 95% recycling at a temperature of 100-110°C.

With the development of the LE2AP technology, new types of construction materials become available, reclaimed stone (PA-stone) and reclaimed mortar (PA-mortar).

The **PA-stone** is certified and can be used directly as an aggregate replacing virgin aggregate. BAM has produced and applied more than 200,000 ton for production of different types of asphalt mixtures.

The **PA-mortar** is the bitumen rich fraction with high added value to be used in the new asphalt productions. There is no readily available industrial mortar line that may be retrofitted to exciting AC plants to heat, treat and foam PA-mortar. In the LE2AP project, a prototype mortar line was developed on basis of Guss Asphalt technology in 2015 and 2016 with makeshift equipment. This technology has been applied successfully in constructing a 600m^2 LE2AP PA 0/16 mixture section (2015) and an underlayer of LE2AP 2LPA in 2016 on Dutch provincial road N338 in Province Gelderland. In 2018 the LE2AP technology was further optimized during the construction of the LE2AP SMA 8B test sections on Dutch provincial road N625 in Province Noord-Brabant and N317 in Province Gelderland. The production speed of the LE2AP SMA mixture was highly improved to 80 ton/hour (with a maximum mortar capacity of 50 ton in the kettle, a maximum of 200 ton SMA or 300 ton porous asphalt can be produced). This production method was proven to have less temperature fluctuation than the hot produced reference mixtures. To date all LE2AP surface layers installed on public roads perform at least equal to their hot produced equivalents comprising no or very limited amounts of reclaimed material.

Sieved PA RAP above 8 mm (HZU/LZU8)
In general practice PA RAP is difficult to use for the production of new porous asphalt. This is basically due to two problems.

- Black Rock and Partial Blending: The highly aged bitumen (penetration of 10) in the reclaimed asphalt are difficult to active again and to participate in the new mixture during recycling, especially for a recycling percentage up to 100%, which creates the so-called “Black Rock” problem. The use of rejuvenators or soft bitumen can cause a phenomenon called “partial blending” due to the limited blending and diffusion action during the recycling process.
- Inhomogeneity: Inhomogeneity is one of the main reasons that favours in-plant technologies over that of in-situ recycling technologies (e.g. recycling trains) with very limited temperature variation and limited variations in material composition (bitumen content and gradations). However, due to the high variability of PA RAP, especially in the fine fractions and the bitumen content, plant produced mixtures cannot contain more than, e.g. 30% of the RAP for surfacings layers such as PA.

The abovementioned problems are also the drive in developing the LE2AP technology. However, another relatively cheap pre-treatment has been developed by sieving PA RAP over the 8 mm sieve. The sieved PA RAP above 8 mm contains less fines and less bitumen (around 3%) than conventional RAP and can be used for the production of high quality new porous asphalt. To maintain control over quality and composition the new PA may contain up to 30% and in occasion even 50% of sieved PA RAP. The sieved product with a good quality aggregate (steenslag III, PSV>58) is called HZU8 and the sieved product with a less quality aggregate (steenslag II, PSV>53) is called LZU8. The advantage of this HZU/LZU8 technology is that it is cheap in comparison to the decomposition process used in LE2AP. BAM successfully followed a blue-print (blauwdruk) validation procedure of RWS in 2018-2019 to prove the quality of PA comprising 30% of HZU8/LZU8 and is able to produce porous asphalt mixtures comprising 30% HZU8/LZU8.

Sustainable Asphalt Awards
Early 2019 BAM has been awarded two sustainable asphalt awards (Prijsvraag Duurzaam Asphalt) from Rijkswaterstaat for its plans to develop two types of highly sustainable Porous Asphalt, PA, mixtures: LEAB PA 80% circular and LE2AP PA 95% circular with combinations of above-mentioned technologies.

Package 1 LEAB PA 80% circular
This mixture emerges when the LEAB, PA-stone and HZU/LZU8 technologies are combined. The mixture contains 30% sieved PA RAP and 50% PA-stone and is produced using the LEAB technology at a production temperature of 115°C. Due to the combination of different sustainable technologies this mixture can reduce the emission of CO_2 with 43% in the production phase (cradle to gate, A1-A3) and relative to that of the reference hot mixture without recycling.

Package 2 LE2AP PA 95% circular
This mixture combines the PA-stone and LE2AP PA-mortar technologies. The mixture contains 85% PA-stone and 10% PA-mortar and is produced with the LE2AP mortar foaming technology at a production temperature of 105°C. Due to the use of LE2AP sustainable technologies this mixture can reduce CO_2-emission in the production phase (cradle to gate, A1-A3) with about 49% relative to that of the reference hot mixture without recycling.

In the test section in A73, next to the FIBRA sections, BAM and Rijkswaterstaat are planning to evaluate the field performance of two variants of highly sustainable 2L-PA16 comprising 80% and 95% reclaimed asphalt and produced at 105°C and 115°C.

1.3 Combi-trial section A73

BAM and Rijkswaterstaat aim to combine the ambition of both projects and construct a 2-km combi-test section in the A73 (HRL 23.600-21.600) in the last week of August 2020 (week 35). In the combi-test section the following mixtures are tested.

CEDR FIBRA fibre reinforced asphalt
- **FIBRA 1,** reference, conventional 2L-PA 8 mixture with PMB produced at temperature of 185 °C
- **FIBRA 2,** reference, 2L-PA 8 with straight run bitumen produced at a temperature of 165°C. This mixture comprises 0,20% cellulose fibre to prevent binder drainage. This section is an additional reference section to evaluate the effect of fibre reinforcement (FIBRA 3 and 4) and to confirm that the use of PMB in 2L-PA 8 mixtures has a positive effect on service life (FIBRA 1).
- **FIBRA 3,** 2L-PA 8 with straight run bitumen and 0,15% panacea fibre produced at a temperature of 165°C**.**
- **FIBRA 4,** 2L-PA 8 with straight run bitumen and 0,05% aramid fibre produced at a temperature of 165°C

Prijsvraag Duurzaam Asfalt sustainable asphalt
- **Sustainable under-layer 2L-PA 16 Package 1,** LEAB 2L-PA 16 80% circular, produced at 115°C,
- **Sustainable under-layer 2L-PA 16 Package 2,** LE2AP 2L-PA 16 95% circular, produced 100°C.

1.4 Report CEDR FIBRA

This document presents the results for the FIBRA trial sections in the A73, including laboratory research, plant preparation and plant trials, and construction and evaluation of the test sections. Results for the sustainable asphalt (Prijsvraag Duurzaam Asfalt) test sections are reported elsewhere.

2. FIBRA Trial Sections A73

2.1 Trial Location

The A73 is a more than 100 km long motorway in the south of the Netherlands. The A73 runs from the A50 near the city of Nijmegen in province of Gelderland to the A2 near the city of Maasbracht in province of Limburg. This motorway is a very important connection between the north and south of the province of Limburg and is the sole connection between some larger cities (Nijmegen, Venlo and Roermond). This motorway is also very close to the border between the Netherlands and Germany, which creates connections to the German motorways A57, A40 and A52 at different locations to major German cities like Duisburg and Dusseldorf.

The combined test sections in the A73 is located near the city of Roermond. Figure 1 presents the location of the test section. The combined section is about 2 km long, with 2 traffic lanes and 1 emergency lane. The section runs from the northern direction to the southern direction. It starts directly after the Tunnel Swalmen (A73 HRL 23,600) and ends before the A73 exit number 19 Roermond (A73 HRL 21,600). Google photos of different locations of the test sections can be found in **Appendix 1**.

The traffic intensity of the A73 is ranging from 44,000 to 98,000 vehicles per working day depending on the location. The traffic intensity at the test sections is about almost 50,000 vehicles per working day.

The surface layer installed in this test location is a two-layer PA (2L-PA, in Dutch 2L-ZOAB). In a standard situation this 2L-PA consists of a 25 mm 2L-PA 8 polymer modified top layer and a 45 mm of 2L-PA16 under layer with conventional pen bitumen. Typically the 2L-PA 8 has a void ratio of about 22%, the void ratio of the 2L-PA16 typically is about 25%.

Figure 1. *Location of the A73 (left) and the combi-test location in the A73 HRL 21,600-23,600 near the city of Roermond by google maps (right).*

2.2 Description of trial sections

The combi-trial location is divided into 6 different sub-sections each comprising different innovative asphalt mixtures. These different innovative asphalt mixtures were discussed earlier and follow from two research projects: CEDR FIBRA project and Prijsvraag Duurzaam Asfalt project.

Table 1 gives details of these sections with indicative locations. Table 2 gives an overview of all the planned mixtures for the FIBRA sections. Please note that no innovations were stacked implying that each test section either comprises a regular 2L-PA 16 underlayer (2L-ZOAB 16 "regulier") or regular 2L-PA 8 top layer (2L-ZOAB 8 "regulier").

Table 1. *Indicative illustration and location of all sub-sections*

← A73 HRL 21,600		2000 m			A73 HRL 23,600 →
333 m	333 m	333 m	333 m	333 m	333 m
2L-ZOAB 8 "regulier"		Fibra 4	Fibra 3	Fibra 2	Fibra 1 2L-ZOAB 8 "regulier"
2L-ZOAB 16 P1	2L-ZOAB 16 P2	2L-ZOAB 16 "regulier" uit ACL			

Table 2. *Overview of mixtures to be applied in the FIBRA sections*

Section	Location	Mixtures	Mixture code	Maximum aggregate size	Bitumen	Fibre or polymer	Production temperature [°C] and method		Reclaimed materials
FIBRA 1	Top-layer	2L-PA 8 PMB	FIBRA 1/ BL ref	8 mm	PMB	SBS	170-190	std.	0%
FIBRA 2	Top-layer	2L-PA 8 Pen	FIBRA 2	8 mm	pen		165-170	std.	0%
FIBRA 3	Top-layer	2L-PA 8 Panacea	FIBRA 3	8 mm	pen	panacea	165-170	std.	0%
FIBRA 4	Top-layer	2L-PA 8 Aramid	FIBRA 4	8 mm	pen	aramid	165-170	std.	0%
FIBRA 1-4	Under-layer	2L-PA 16 30% PR	OL ref	16 mm	pen		165-170	std.	30%

The purpose of these CEDR FIBRA trial sections is to evaluate the use of fibre reinforcement in porous asphalt in practice. Based on the experiences of the CEDR FIBRA research, Rijkswaterstaat and BAM, the top layers of these sections incorporate two sections with different variants of fibre reinforced 2L-PA 8 and two reference sections without fibre reinforcement and made by PMB and regular pen bitumen next to each other. The under layer of all FIBRA sections is a conventional 2L-PA 16 with 30% RAP (OL ref).

All these FIBRA mixtures have the same gradation and type of aggregate. The only difference is in the use of bitumen and fibre reinforcement. As a result of different bitumen used, the production temperature for these mixtures also varies.

- **FIBRA 1,** reference section, conventional 2L-PA 8 mixture with **PMB** with a production temperature of 185 °C.
- **FIBRA 2,** reference section, 2L-PA 8 with only **straight run** bitumen with a production temperature of 165°C. This section is an extra reference section to evaluate the effect of fibre reinforcement in

the mixture (FIBRA 3 and 4). In this mixture 0,20% cellulose fibre is used to prevent the possible drain down of binders. The aim of this reference section is to confirm that PMB in 2L-PA 8 mixtures has a positive effect on service life (FIBRA 1).

- **FIBRA 3,** 2L-PA 8 with straight run bitumen and 0,15% **panacea** fibre with a production temperature of 165°C**.** In this mixture 0,15% cellulose fibre is used to prevent the possible drain down of binders.
- **FIBRA 4,** 2L-PA 8 with straight run bitumen and 0,05% **aramid** fibre with a production temperature of 165°C. In this mixture 0,15% cellulose fibre is used to prevent the possible drain down of binders.

2.3 Global planning

This project has three phases with are summarised hereafter. Details of planning will be explained in Section hereafter.

- **Phase 0. Laboratory research**
  In this phase laboratory tests are conducted for different types of mixtures. The tests include standard Type Tests. After the completion of all the laboratory research, a CE certificate will be prepared for the tested mixtures so that they may be produced and installed.

- **Phase 1. Plant preparation/modification and production trials**
  After laboratory research, necessary preparation of the asphalt plant is carried out in the asphalt plant BAC in Helmond. Production/installation trials for those mixtures with which no or very limited experience exists are carried out at the asphalt plant BAC (FIBRA 4). The goal of these trials is to evaluate the production and compaction performance of the mixture. Depending on the results of these trials minor changes in the process of production or installation may be adopted for the production and installation of the real test sections in A73.

- **Phase 2. Construction and evaluation of test sections**
  The construction of test sections is part of the maintenance project GVO Zuid Nederland (ZN). The combi trial section is planned to be re-surfaced in the last week of August 2020 (week 35). The production of the required mixtures is carried out by the asphalt plant BAC in Helmond. The distance between the BAC in Helmond and the combi-test sections in the A73 is approximately 60 km. This results in a transport time of about 1 hour. Laying and compaction are carried out using standard equipment and standard practices. For the special mixtures minor adjustments to standard practices may depending on the installation advice prepared during the production and installation trials in phase 1. Standard quality control of the whole production, transportation and construction process is be followed. After construction, initial field evaluation is done based on different tests including skid-resistance test, drainage test (Becker), longitudinal evenness measurements, noise reduction test and visual inspection. Hopper monsters are taken from the test section for laboratory performance evaluations such as the DSR test.

2.4 Time planning

Table 3 summarises the time planning of the installation of the A73 test sections.

- **Phase 0. Laboratory research (May-July 2020, week 22-week 31)**
  Most of the lab research is conducted from May to July 2020. The CE-certificate of the mixtures are expected to be issued in week 31.

- **Phase 1. Plant preparation and production trials (May-July 2020, week 21-week 34)**
  The first plant preparation is the acquisition and evaluation of necessary raw materials, bitumen, fibres, and aggregates. This action is expected to be conducted from in July 2020.

  The production trials of FIBRA 4 are carried out in week 34 in august 2020. In week 34 some last minute arrangements are foreseen in preparation of both production and laying of the sections.

- **Phase 2. Construction and evaluation of the test section (end August-October 2020, week 34-week 47)**
  The preparation and construction of the test sections are carried out in week 35. Week 0 evaluation is carried just before the sections are opened to traffic including skid resistance, longitudinal evenness, drainage test (Becker). Hopper materials are collected during construction of the test sections for further research.

  Further evaluation of the test section is carried out after the sections are opened to traffic. These are skid resistance in week 36, 37 and 38, CPX noise measurement and visual inspection in week 47.

  Laboratory evaluation of field materials such as hopper materials is carried out till the end of September 2020.

- **Report (July-November 2020, week 28- week 49)**

  Phase 0 report will be ready in week 33.

  Phase 1 report will be ready in week 38.

  Phase 2 report will be ready in week 49.

Table 3. *Time planning of A73 trial sections*

Month		May				June				July					August				September					October				November				December			
Week		19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
																		aanleg																	
Phase 0	**Laboratory research**																																		
0,1	Type Test Fibra mixtures																																		
0,2	Type Test and extra tests sustainable asphalt																																		
0,3	CE-certificate																																		
Phase 1	**Plant preparation and production trials**																																		
1,1	Preparation and quality controle of bitumen and fibres																																		
1,2	Preparation and quality controle of reclaimed materials																																		
1,3	Production trials																																		
Phase 2	**Construction and evaluation of test section**																																		
2,1	Production																																		
2,2	Transportation																																		
2,3	Laying and compaction																																		
2,4	Field evaluation before open to traffic																																		
2,5	Evaluation after open to traffic																																		
2,6	Laboratory evaluation of test sections																																		
Report																																			
R1	Raport Phase 0																																		
R2	Raport Phase 1																																		
R3	Raport Phase 2																																		

2.5 Milestones and Go/NoGo

Table 4 gives a list of milestones and Go/NoGo decision points. These are important decision points to ensure the success of the project.

Table 4. *Key events and Go/NoGo decision points.*

Week	What
22	Start of Type Test of mixtures
30	Type Test of ready
34	Production trials by the BAC FIBRA 4
35	**Go/NoGo BABOS** Decision of construction due to weather conditions by the use of BABOS
35	Construction of combi-test sections

Go/NoGo BABOS

BABOS is an objective decision-making tool that is developed by BAM Infra Asfalt and is applied in regular projects for many years. BABOS uses highly detailed weather forecasts to generate an objective Go/NoGo decision advice for asphalt installation activities taking into account the specific installation circumstances demanded by individual types of asphalt. The minimal weather requirement for installation PA on the A73 is

- No or very limited rainfall (<0,1 mm/hour)
- Air temperature (°C) – wind speed (m/s) ≥ 5 [according to Dutch regulation RAW 2015]

There are two Go/NoGo decisions to be made by BAM in collaboration with RWS

- ➔ First Go/NoGo decision 2 days before construction (about 12:00) based on the 7-day weather forecast for construction.

- ➔ A final Go/NoGo decision 1 day before construction (about 12:00) based on the 36-hour weather forecast for construction.

3. Phase 0 Laboratory Research

3.1 Research plan

Table 5 gives an overview of laboratory research for FIBRA mixtures. The FIBRA laboratory research is conducted to evaluate the performance of mixtures containing fibre reinforcement in comparison to reference mixtures without fibre. All the mixtures are designed to equal the reference mixture, FIBRA 1, in terms of aggregate type (Bestone), gradation and bitumen content (5.3%). The only difference between mixtures is in the type of bitumen and fibres if any. The combined the executed laboratory tests form a complete Dutch standard type test for porous asphalt, including volumetric performance and water sensitivity performance.

Table 5. *Overview of laboratory research for FIBRA sections*

Mixture code		FIBRA 1/ BL ref	FIBRA 2	FIBRA 3	FIBRA 4
Phase 0	**Laboratory research**	2L- PA 8 PMB	2L-PA 8 Pen	2L-PA 8 Panacea	2L-PA 8 Aramid
0.1	Type Test FIBRA	*1x*	*1x*	*1x*	*2x*

- **Mixture FIBRA 1 (2L-PA 8 PMB)**

In the Netherlands 2L-PA 8 PMB is a mixture with a maximum grain size of 8 mm that is widely used on the primary road network. This mixture is designed with 25 mm thickness and design air voids of 23%. Compared with a traditional single layer PA 16, this mixture has a smaller grain size (8 mm vs. 16 mm) and slightly higher air voids (23% vs. 20.6%). Commonly an SBS polymer modified bitumen is used in PA 8. In this research a Styrelf 65/105-80 A AP is used.

- **Mixture FIBRA 2 (2L-PA 8 pen)**

The 2L-PA 8 pen mixture is identical to the reference 2L-PA 8 PMB mixture (FIBRA 1) with the exception that the applied type of bitumen differs. In this FIBRA field research, 2L-PA 8 pen serves as a second reference FIBRA 2, next to the regular 2L-PA 8 PMB. Comparison of the field performance of this mixture, comprising pen bitumen, and that of 2L-PA 8 PMB should confirm the general belief that the use of PMB lengthens the service life of PA 8.

As such, the mixture design of the 2L-PA 8 pen is obtained by copying the design of the mixture with PMB. However, the PMB is replaced with 5.3% 70/100 pen bitumen. 0.20% cellulose fibre is added in this mixture to prevent the possible drain down of binders.

- **Mixture FIBRA 3 (2L-PA 8 panacea)**

FIBRA 3, 2L-PA 8 panacea, is a mixture with almost the same composition as FIBRA 2 but with addition of Panacea fibre. Panacea is a trademark of a type of polyacrylonitrile fibre. This fibre has been applied in different types of porous asphalt mixtures for RWS since 2005. From these experiences indications are that Panacea fibre acts to lengthen the service life of PA. This has also been confirmed in the CEDR FIBRA project. According to experience of RWS-BAM and the CEDR FIBRA project, Panacea fibre with a length of 3.2 mm is used in this research at an application rate of 0.15% (m/m) of the mixture. In addition 0.15% cellulose fibre is added to the mixture to prevent binder drainage.

- **Mixture FIBRA 4 (2L-PA 8 aramid)**

FIBRA 4, 2L-PA 8 aramid, a mixture with an almost identical composition as FIBRA 2. However, aramid fibre is added. Similar to polyacrylonitrile fibre also aramid fibre has been used in other fields as a means of reinforcing materials. One type of the aramid fibre, the Forta-FI, has been used to reinforce asphalt mixtures internationally for years. According to the experience of the CEDR FIBRA project, aramid fibre has good potential to be used in PA. The advised application rate is 0.05% (m/m).
Four types of aramid fibres were potentially to be used for this test section, as also shown in Figure 1.

- 4A, Forta-FI: blends of aramid and polyolefins (1:7) with a length of 19 mm, produced in US
- 4B, Twaron 1080: Aramid fibre with a length of 6 mm, produced in NL
- 4C, Twaron 1095: Aramid fibre with a length of 1 mm, produced in NL
- 4D, Twaron 3500: blends of aramid and polyolefins (4:6) with a length of 1 mm, produced in NL

For the use of these fibres in FIBRA 4, 2L-PA 8 aramid, a stepwise research plan is followed.

Step 1: Mixing/Marshall test and first selection
The candidate FIBRA 4 mixtures listed above were produced in the laboratory and are then compacted using the Marshall test. A first selection was made on basis of workability, compatibility, lifecycle cost, price and application experiences. Two fibres were selected for further research.

Step 2: Type test and second selection
Two type tests were conducted with the 2 above selected FIBRA 4 mixtures. Based on the results a final FIBRA 4, 2L-PA 8 aramid, mixture to be used for the test sections is selected.

On basis of the laboratory research, CE-certificates and the mixture design of each individual mixture were issued. With this the FIBRA mixtures are approved for plant production and application on the test sections.

3.2 Experimental results

3.2.1 Mix design FIBRA 1-4

As described in the project plan, the four FIBRA mixtures follow the same mixture design with Bestone 4/8 as the stone fraction. To determine the Bestone 4/8 application rate at which the design void ratio of 23% is obtained a mix design procedure is followed for the FIBRA 1 mixture. In this procedure the FIBRA 1 mixture was made using three different percentages Bestone 4/8 in the mixture. These three laboratory produced mixtures were compacted by the use of the Marshall compactor giving 50 blows to each side of compacted tablets. Figure 2 gives the results of this mix design. As indicated a void ratio of 23% in the FIBRA 1 2L-PA 8, is obtained when the aggregate percentage is about 91.5%. This design parameter will be used for all four mixtures.

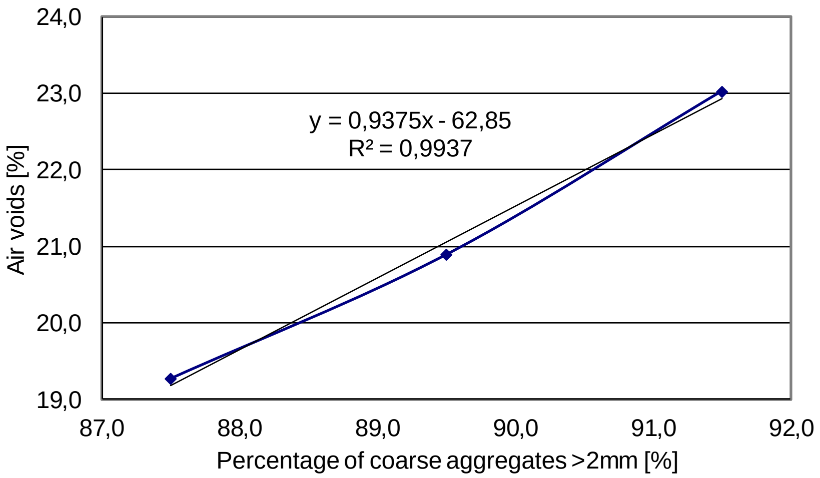


Figure 2. *Results of mix design FIBRA mixtures*

3.2.2 Selection of aramid fibres for FIBRA 4

As mentioned in the research plan the type of fibre to be used in the FIBRA 4 mixture is determined through a two-step selection process. In the first step two out of four types of fibre are selected on basis of workability, compactability, lifecycle cost, price and application experiences. Figure 3 gives a visual impression of the four types of fibre considered.

Figure 3. *Four types of aramid fibres used in the first selection*

The evaluation of workability and compactability was carried out as follows:

- The four types of aramid fibre were applied at the same application rate of 0.05% (m/m).
- Aggregate and bitumen 70/100 were pre-heated in an oven at a temperature of 155°C.
- Mixing was carried out with the following sequence: 1. bitumen 70/100; 2.aggregate, sand and fillers; 3. Mixing for 20 seconds; 4. adding 0,05% fibres; 5. Mixing another 40 seconds 6. End of mixing
- The end temperature of the mixtures is around 140-145°C.
- Mixtures with four abovementioned fibres were compacted using Marshall compactor.

Table 6 and Figure 4-7 present the results of the evaluation of workability and compactability. All four mixtures indicate no cluster develop during handling. Only limited differences in compaction behaviour are observed between the four mixtures. In the FIBRA 4A and 4B mixtures the fibres can be visually observed in the mixtures 4C and 4D this is not the case due to the difference in fibre length. The mixture containing Forta-Fi fibre and the Twaron 3500 fibre (4A and 4D), the fibres containing polyolefins, have shown binder drainage during the mixing process.

Table 6. *Initial performance of FIBRA 4 mixtures with four different aramid fibres*

Mixture	**Fibre**	**Observation mixing**	**Density Marshall [kg/m³]**	**Air voids Marshall [%]**
FIBRA 4A	Forta-Fi	Mixture is very shining and fibres can be observed. Binder drainage is observed at the bottom of the mixer.	1890	24.0
FIBRA 4B	Twaron 1080	Mixture is with normal appearance and fibres can be observed. No binder drainage is observed.	1898	23.7
FIBRA 4C	Twaron 1095	Normal, no binder drainage is observed.	1916	23.0
FIBRA 4D	Twaron 3500	Mixture is very shining. Binder drainage is observed throughout the mixer.	1901	23.6

Figure 4. *Illustration of the FIBRA 4A mixture comprising Forta-FI fibres.*

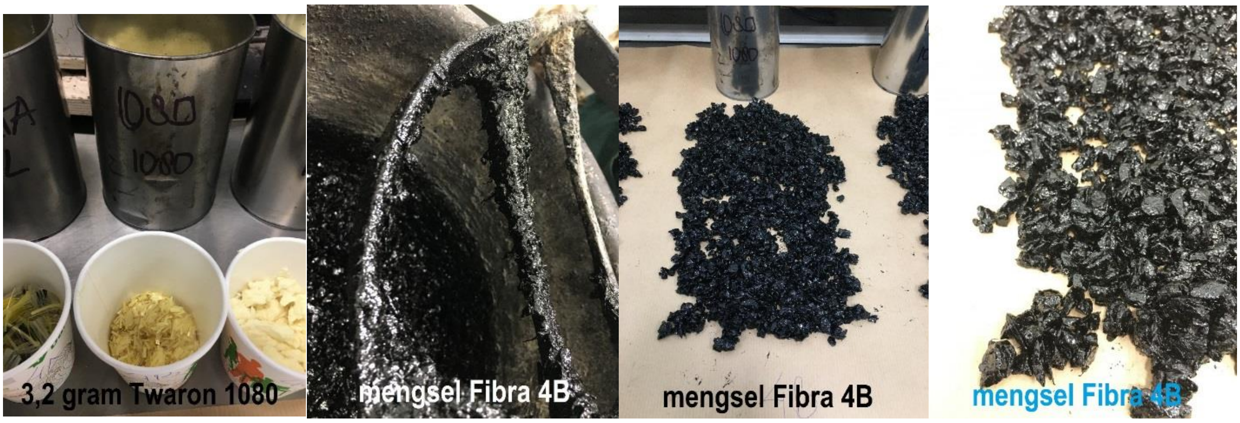


Figure 5. *Illustration of FIBRA 4B mixture comprising Twaron 1080 fibres*

Figure 6. *Illustration of FIBRA 4C mixture comprising Twaron 1095 fibres*

Figure 7. *Illustration of FIBRA 4D mixture comprising Twaron 3500 fibres*

The quickscan of the life cycle cost of all four fibres was conducted by the University of Cantabria. This quickscan focused on the A1-A3 (cradle to gate) environmental impacts of 1 ton of mixture containing different types of fibre. In this evaluation the CML2016 characterization factors were analysed and converted into an Environmental Cost Indicator (ECI). The results of this analysis are shown in Table 7 and 8. It can be observed from the results that although the Forta-Fi fibres has to travel a long distance from the US to the Netherlands, it has still a very competitive LCA which is similar to that of the reference mixture made with polymer modification. The ECI of other the other mixtures with aramid fibres are higher and do not fluctuate much between mixtures.

Table 7. *LCA quickscan of FIBRA 4 mixtures with four different aramid fibres (A1-A3) expressed into ECI* €/ton asphalt mixture

Characterization factors	Weighing factors For ECI [€/KG eq]	1 ton 2L-PA Reference [€]	1 TON FIBRA 4A [€]	1 TON FIBRA 4B [€]	1 TON FIBRA 4C [€]	1 TON FIBRA 4D [€]
			FORTA-FI	TWARON 1080	TWARON 1095	TWARON 3500
CML2001 - Jan. 2016, Abiotic Depletion (ADP elements)	0,16	1,93E-06	2,22E-06	3,76E-06	3,77E-06	3,18E-06
CML2001 - Jan. 2016, Abiotic Depletion (ADP fossil)	0,16	2,42E-01	2,48E-01	2,52E-01	2,53E-01	2,51E-01
CML2001 - Jan. 2016, Acidification Potential (AP)	4	1,18E+00	1,19E+00	1,21E+00	1,21E+00	1,21E+00
CML2001 - Jan. 2016, Eutrophication Potential (EP)	9	5,11E-01	5,09E-01	5,20E-01	5,21E-01	5,17E-01
CML2001 - Jan. 2016, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	0,03	2,76E-02	2,84E-02	2,86E-02	2,86E-02	2,85E-02
CML2001 - Jan. 2016,	0,05	4,62E+00	4,67E+00	4,89E+00	4,90E+00	4,82E+00

Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO2 eq.]						
CML2001 - Jan. 2016, Human Toxicity Potential (HTP inf.) [kg DCB eq.]	0,09	5,29E-01	5,39E-01	5,61E-01	5,62E-01	5,55E-01
CML2001 - Jan. 2016, Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	0,0001	4,17E-01	4,28E-01	4,51E-01	4,53E-01	4,45E-01
CML2001 - Jan. 2016, Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	30	1,20E-11	1,26E-11	1,49E-11	1,50E-11	1,41E-11
CML2001 - Jan. 2016, Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	2	7,25E-02	7,33E-02	7,47E-02	7,48E-02	7,43E-02
CML2001 - Jan. 2016, Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	0,06	6,77E-03	6,62E-03	6,80E-03	6,81E-03	6,77E-03
Total		**7,61**	**7,69**	**7,99**	**8,02**	**7,90**

Table 8. *LCA quickscan of FIBRA 4 mixtures with four different aramid fibres (breakdown into different modules)*

Mixture	**Fibre**	**ECI value in euro/ton asphalt mixture**			
		A1	**A2**	**A3**	**A1-A3**
FIBRA 4A	Forta-Fi	3,52	2,54	1,64	7,69
FIBRA 4B	Twaron 1080	3,81	2,51	1,67	7,99
FIBRA 4C	Twaron 1095	3,83	2,51	1,67	8,02
FIBRA 4D	Twaron 3500	3,72	2,51	1,67	7,90

As a result of the previous, FIBRA 4A was selected for further testing on basis of its low ECI, despite the observed drainage of binder. FIBRA 4B was selected because it indicates the lowest ECI of the mixtures that did not show binder drainage.

Step 2: Type test and final selection

For final selection type tests were conducted on mixtures comprising the 2 above selected fibres, Forta-Fi and Twaron 1080. To prevent binder drainage 0.15% cellulose fibre was added to the mixtures. Results are shown in Table 9. The following can be observed,

- By adding 0.15% cellulose fibre the drainage performance of the FIBRA 4A mixture improves.
- The compactability of the mixtures does not differ much as indicated by the gyrator cycles needed to compact the mixtures.
- Both 4A and 4B mixtures have similar ITS strength.
- Both mixtures have a ITSR water susceptibility that is lower than the CE requirement of 80%. Especially FIBRA 4A with Forta Fi has extremely low ITSR of 60%.

In consultation with Rijkswaterstaat, it was decided to use the FIBRA 4B as the aramid reinforced mixture in the test section of the A73 highway.

Table 9. *Mixture performance of two FIBRA 4 mixtures*

	FIBRA 4A	FIBRA 4B
	Forta-FI	Twaron 1080
Drainage test @150°C without extra cellulose fibres	1.08%	0.17%
Drainage test @150°C with 0,15% cellulose fibres	0.15%	0.09%
ITS dry [MPa]	0.565	0.578
ITS wet [MPa]	0.340	0.446
ITSR	60%	77%
Gyrator cycles needed [-]	50	52
Air voids specimen [-]	23.9%	23.5%

3.2.3 Definitive mixture compositions and laboratory performance of FIBRA 1-4

Based on the above mentioned results and the selection of FIBRA 4B as the FIBRA 4 mixture, definitive mixture compositions of all four mixtures can be made. Table 10 presents the final compositions of all four mixtures. It has to be noted that these mixtures are made without the need of fine aggregate or sand. Table 11 presents the practical parameters to be used for producing FIBRA mixtures.

Table 10. *Final mixture compositions Fibre mixtures 1-4*

Materials	FIBRA 1	FIBRA 2	FIBRA 3	FIBRA 4
	2L-PA 8 with PMB (1 KG)	2L-PA 8 PEN + cellulose (1 KG)	2L-PA 8 PEN + PAN (1 KG)	2L-PA 8 PEN + Aramid (1 KG)
Bitumen (kg)	0.0530	0.0530	0.0530	0.0530
Aggregate coarse fraction 4/8 (kg)	0.8910	0.8890	0.8880	0.8890
Aggregate fine fraction (kg)	0.0000	0.0000	0.0000	0.0000
Filler (kg)	0.0460	0.0460	0.0460	0.0460
Filler baghouse dust (Kg)	0.0100	0.0100	0.0100	0.0100
Fibre cellulose (kg)	0.0000	0.0020	0.0015	0.0015
Fibre (kg)	0.0000	0.0000	0.0015	0.0005
Type of aggregates (coarse)	Bestone (Norwegian sandstone)	Bestone (Norwegian sandstone)	Bestone (Norwegian sandstone)	Bestone (Norwegian sandstone)
Type of aggregates (fine)	Bestone (Norwegian sandstone)	Bestone (Norwegian sandstone)	Bestone (Norwegian sandstone)	Bestone (Norwegian sandstone)

Table 11. *Practical parameters of FIBRA mixtures in laboratory research*

	FIBRA 1	FIBRA 2	FIBRA 3	FIBRA 4
	2L- PA 8 PMB	2L-PA 8 Pen	2L-PA 8 Panacea	2L-PA 8 Aramid
Temperature of aggregates	180°C	155°C	155°C	155°C
Temperature bitumen	180°C	155°C	155°C	155°C
Temperature during mixing	180°C	150°C	150°C	150°C
Order of addition of the different materials	1. bitumen 2.aggregates	1. bitumen 2.aggregates 3. cellulose fibre	1. bitumen 2.aggregates 3. panacea fibre+cellulose fibre	1. bitumen 2.aggregates 3. aramid fibre+ cellulose fibre

Addition of the fibre (procedure, equipment)		Pre-dried Fibre added manually	Pre-dried Fibre added manually	Pre-dried Fibre added manually
Mixing times after the addition of the different material	After adding aggregates for about 60 seconds	after adding aggregates for about 20 seconds after adding fibres for about 40 seconds	after adding aggregates for about 20 seconds after adding fibres for about 40 seconds	after adding aggregates for about 20 seconds after adding fibres for about 40 seconds

Table 12 gives the results of the type testing of all four FIBRA mixtures. All the mixtures have similar volumetric properties and compaction performance with similar cycles of compaction using gyration compactor. The FIBRA 2, 3 and 4 show similar strength performance and the reference mixture FIBRA 1 shows a higher strength. The water sensitivity of FIBRA 1 and FIBRA 2 do not differ significantly. The ITSR water susceptibility of FIBRA 3 is 80% and that of FIBRA 4 is 77%. With this information being determined we can proceed with the next step of bringing the FIBRA mixtures into the plant production.

Table 12. *Results of laboratory type testing of all FIBRA mixes*

	FIBRA 1	FIBRA 2	FIBRA 3	FIBRA 4
	PMB	70/100	Panacea polyacrylonitrile	Twaron 1080 aramid
Gyrator cycles needed to reach air voids [-]	48	61	45	52
Air voids specimen	23.0%	22.8%	23.4%	23.5%
ITS dry [Mpa]	0.72	0.61	0.572	0.578
ITS wet [Mpa]	0.63	0.52	0.455	0.446
ITSR	88%	86%	80%	77%

4. Phase 1. Plant Preparation and Production trials

4.1 Research plan of production trials

In advance of production and installation of the test sections production trials are done that include different necessary arrangements and tests. The application of fibres in PA has certain risks. Below the potential risks and possible solutions are listed.

a. Binder drainage

The synthetic fibres are used in PA as reinforcement. For bitumen/mortar rich PA mixtures mortar drainage forms a potential risk. To ensure ample resistance to binder drainage some extra % of cellulose fibre had to be used in combination with the synthetic fibre. In practice two steps can be followed for examining binder drainage performance of synthetic fibres in porous asphalt. Step one is to conduct a laboratory binder drainage test. Step two is to simulate the transportation process by means of plant trials. In this research, the plant produced asphalt mixtures was loaded into a truck for a transport simulation of 1 hour to verify that the issue of binder drainage is by the application of cellulose fibre evaluate the binder drainage performance during the plant trials.

b. Inhomogeneity

The use of synthetic fibres in PA can cause problem such as inhomogeneity. At the production plant the fibres are added manually into the mixer by use of low melt bags. Due to the nature of the fibre there is a chance that the fibres distribute inhomogeneously in the mixture. As such, it is important to carry out a plant production trial to visually inspect the homogeneity of the fibre distribution in the mix.

c. Possible influence on laying and compaction

For the use of fibres in Porous Asphalt, PA, it is very important to understand the possible influence on the laying and compaction process. In this research a plant installation trial was carried out at the asphalt plant using a paver with a 5 m screed over a length of 50 meter to evaluate this.

BAM has no experience with the production and installation of the FIBRA 4 2L-PA 8 Aramid mixture. As a result, production trials were conducted on 21 august 2020.

Table 13 gives the plan of the plant trials. During these trials, about 30 ton (10-12 charge) of the FIBRA 4 2L-PA 8 Aramid mixture was produced. Mixture samples were collected for further laboratory research, e.g. composition and compaction. The produced mixture was loaded into a truck for a 1-hour transport simulation to evaluate possible draindown. After that the mixture feed to the paver for installation in a trial test section on the asphalt plant yard. During this of the workability, compactability and temperature was monitored. Interviews with members of the installation teams were conducted for first impression of this material. Water drainability test (Becker Test) and coring were done one day after installation. From the core specimen information about realized thickness was evaluated.

Finally, on the above-mentioned results, an installation advise was made for installation of 2L-PA 8 Aramid in the test sections on the A73. Based on the installation advice for the FIBRA 4 mixture and the standard 2L-PA 8 reference mixture, FIBRA 1, the installation advice for FIBRA 2 and FIBRA 3 were derived.

Table 13. *Overview of Phase 1 plant preparation and production trials*

Phase 1	**Production trials**	FIBRA 4: 2L-PA 8 Aramid
1.1	Preparation and quality control of bitumen, fibres and additives	
1.1.1	*Pen & Softening point*	*1x PMB* *1x 70/100 pen bitumen*
1.2	Preparation and quality control of reclaimed materials (not for FIBRA mixtures)	
1.3	Production trials	
1.3.1	*Production and construction*	*50ton*
1.3.2	*Gradation and bitumen content plant mix*	*2x*
1.3.3	*Lab compaction gyrator*	*2x*
1.3.4	*Temperature evaluation*	*1x*
1.3.5	*Laying evaluation*	*1x*
1.3.6	*Compaction evaluation*	*1x*
1.3.7	*Becker test*	*3x*
1.3.8	*Thickness from cores*	*3x*

4.2 Results of production trials

4.2.1 Mixing process

Table 14 describes the production process of the FIBRA 1 and FIBRA 4 mixture. During the trial production, special attention was given to the mixing process of mixtures with synthetic fibres. The experience of handling panacea fibres helped with handling aramid fibres. As shown in Figure 8, the aramid fibres were packed into a low melt bag with a constant weight of 1.5 kg for a batch mixing of 3000 kg mixture (addition of 0.05%). The synthetic fibres are manually fed into the mixer after the aggregates. The cellulose fibre was added automatically into the mixer using mechanical blowing. The mixing time of the fibre reinforced mixture was slightly increased with 5 second to ensure proper dispersion of the fibres in the mixture.

Table 14. *Production process of reference and experimental mixtures at the asphalt plant*

	FIBRA 1	FIBRA 4
	2L- PA 8 PMB	2L-PA 8 Aramid
Temperature of aggregates	224°C	204°C
Temperature bitumen	180°C	155°C
Temperature during mixing	181°C	165°C
Order of addition of the different materials	1. aggregates 2. filler 3. bitumen	1. aggregates 2. aramid fibre+cellulose fibre 3. filler 4. bitumen
Addition of the fibre (procedure, equipment)		Cellulose fibre was added automatically by blowing Aramid fibre was added manually using low-melt bag in the mixer
Mixing times after the addition of the different material	after adding all materials mixing for 25 seconds	after adding all materials mixing for 30 seconds

Figure 8. *Example of aramid fibres in low-melt bag (left) and the inspection opening of the mixer (right) used to manually insert the bags into the mixer.*

4.2.2 Mixture performance

Table 15 gives the results of the production control of the trial production. The following can be observed,

- The composition of the material in charge 3 and in the hopper hardly differ, indicating that no significant variation in material composition occurs during production and 1 hour transport.
- The percentage passing 5.6 mm is on average 35%, significantly lower than that of the type test. It has to be noted that the produced FIBRA mixture has only 1 type of coarse fraction Bestone 4/8 and has no sand. The grading of the mixture is solely dependent on the grading of the aggregates Bestone 4/8.
- The percentage passing 2 mm, which is closely related to the air voids content of the mixture is under control.
- The bitumen content is around 5%, which is within production limits.
- Due to limited production amount, the mixture temperature was approximately 180°C, 25°C higher than required. This is non-favourable for the mix (Short Term Aging), but is good for practical evaluation, e.g. binder drainage. Combined with the first observation on gradation, it can be seen that this mixture has no issues of binder drainage.
- The results of the laboratory compaction show that the air voids of the mixture from both Marshall and gyrator are on the higher side than that of the Type Test mixture.

Table 15. *Production control of trial production of FIBRA 4 mixture*

Sieve passing	#1 Charge 3	#2 In hopper	Average	Type Test	Minimum	Maximum
11.2 mm [%]	100.0	100.0	100.0	100.0		
8 mm [%]	88.8	88.5	88.65	89.3	86.3	92.3
5.6 mm [%]	33.6	36.5	35.0	41.6	38.1	45.1
4 mm [%]	14.1	15.5	14.8	17.1		
2 mm [%]	7.2	8.0	7.6	8.5	6.0	11.0
0.5 mm [%]	6.3	6.7	6.5	6.5		
0.063 mm [%]	6.0	6.0	6.0	6.0	5.4	6.6
Bitumen content [%]	5.0	5.0	5.0	5.3	5.0	5.6
Mixture temperature [°C]	182		182	155	140	170
Density Marshall compaction [kg/m³]	1889		1889	1913		
Air voids Marshall compaction [%]	24.4		24.4	23.0		
Density Gyrator compaction [kg/m³]	1833		1833	1862		
Air voids gyrator compaction [%]	26.7		26.7	25.1		

4.2.3 Plant construction trials

Figure 9 illustrates the location of the trial sections next to the asphalt plant with 2 sections with a combined width of 6 m and a length of 50 meter. During the trial production and installation different process parameters on laying and compaction were investigated. After installation, interviews with the installation crew, water drainability and cores were taken to evaluate the applied laying and compaction strategy. Combination of these two results a final laying and compaction strategy for this mixture can be made.

Figure 9. *Plant construction site during plant trials*

Figure 10 and Table 16 present the results of the plant installation trials. The following can be observed about the plant installation trials,

- The installation of the FIBRA 4 mixture by the installation team of the A73 test sections went smoothly.
- The trial installation gives the team also a first feel for the mixtures to be constructed in A73. The whole team was interviewed after the construction. According to the team the FIBRA 4 mixture is easier to handle with handwork and has less emission. There is almost no influence on the machinery laying and compaction.
- The compacted FIBRA 4 mixture is homogenous, no fat spot is noticed.
- The trial section shows good water drainability. Becker tests indicate an outflow time of around 10 second on average, lower than that of the Dutch standard for 2-layer porous asphalt of maximum 17 second on average and maximum 20 second of individual measurement.
- The thickness of the FIBRA 4 layer top layer is about 29 mm, which fulfils the requirement of 25 mm.
- The measurement of air voids of individual layers of 2-layer porous asphalt is not accurate according to the Dutch standard due to the open structure and the small thickness. As a result, the measured air voids are only indicative. In this section, an air voids average of 27.5% of the top layer is found.

Figure 10. *Illustration of core samples from plant construction trials*

Table 16. *Results of plant construction trials*

Nr.	Nuclear total layers		Water drainability	Thickness			Air voids top layer (indicative) [%]
	Density [kg/m3]	Air voids [%]		Underlayer [mm]	Top layer [mm]	Total [mm]	
A1	1932	22.3	10.3s	51	28	79	
A2	1900	23.5	11.1s	45	28	73	26.4
A3	1929	22.3	9.4s	40	33	73	27.6
A4	1893	23.8	10.0s	50	32	82	27
A5	1812	27.1	12.3s	42	28	70	26.4
A6	1851	25.5	9.3s	42	28	70	26.5
A7	1913	23.0	10.8s	55	30	85	
A8	1880	24.3	10.8s	42	28	70	31.3
A9	1851	25.5	9.4s	45	28	73	
Average	1885	24.1	10.14s	46	29	75	27.5
Requirement			Average ≤ 17s Individual ≤ 20s	45 mm	25 mm	70 mm	

4.3 Summary plant trials

The following can be summarised from the plant production and installation trials,

- The FIBRA 4 mixture with aramid fibre can be produced in the plant without difficulty. The fibre can successfully be fed manually into the mixer using the inspection opening and a pre-packed low-smelt bags.
- The produced FIBRA 4 mixtures are homogenous with limited variation. The production temperature is around 180C due to limited production amount. No segregation or binder drainage is observed during production and also after the simulation of 1-hour transport.
- The produced FIBRA 4 mixtures are slightly more porous than the laboratory produced mixtures.
- The construction of FIBRA 4 mixture can be carried out with regular equipment and the installation strategy of standard 2L-PA 8. The workability of the FIBRA 4 mixture is better than that of the standard 2L-PA 8 with PMB, FIBRA 1.
- The constructed trial sections at the plant yard have good water drainability and proper layer thickness.

As a result, it is concluded that the plant trials are successful and enough information is obtained for installation of the test sections in the A73. A slight modification of the recipe is recommended, by improving the filler content by 0.5% to ensure better compaction.

5. Phase 2. Construction and Evaluation of FIBRA Test Sections A73

5.1 Research plan

Phase 2 is the installation and evaluation of the test sections on A73. Table 17 gives an overview of the planned research. Detail explanations are given hereafter.

Table 17. *Overview of construction and evaluation of FIBRA test sections*

Mixture code		FIBRA 1	FIBRA 2	FIBRA 3	FIBRA 4
Phase 2	**Construction and evaluation of test section**	2L- PA 8 PMB	2L-PA 8 Pen	2L-PA 8 Panacea	2L-PA 8 Aramid
2.1	Production				
2.1.1	*Bitumen content and composition*	*1x*	*1x*	*1x*	*1x*
2.1.2	*Lab compaction*	*2x*	*2x*	*2x*	*2x*
2,2	Transportation				
2.2.1	*APEX registration*	*1x*	*1x*	*1x*	*1x*
2.2.2	*Colour labelling for trucks*	*1x*	*1x*	*1x*	*1x*
2,3	Laying and compaction				
2.3.1	*Temperature monitoring Road-scanner*	*1x*			
2.3.2	*Hopper materials*	*2kg per 100meter, maximum 6x per mixture*			
2,4	Evaluation before open to traffic				
2.4.1	*Skid resistance test (week 0)*	*2x 2km (fast lane, lane 1 and slow lane lane 2)*			
2.4.2	*Longitudinal unevenness*	*2x 2km (fast lane, lane 1 and slow lane lane 2)*			
2.4.3	*Becker test*	*1x per 100 meter both lanes (maximal 6x per sub-section)*			
2,5	Evaluation after open to traffic				
2.5.1	*Skid resistance test*	*1x 2km (slow lane lane 2) in week 1, 2 and 3*			
2.5.2	*Noise measurement CPX*	*1x 2km (slow lane lane 2) in week 12*			
2.5.3	*HD video inspection*	*2x 2km (fast lane, lane 1 and slow lane lane 2) in week 12*			

2,6	Laboratory evaluation of test sections				
2.6.1	*Bitumen content and composition*	*2x*	*2x*	*2x*	*2x*
2.6.2	*DSR mortar test virgin*	*1x*	*1x*	*1x*	*1x*
2.6.3	*DSR mortar test aged*	*1x*	*1x*	*1x*	*1x*

Production

Table 18 gives an overview of the mixture amounts to be produced for the test sections. These mixtures can all be produced in the asphalt plant BAC in Helmond.

Table 18. *Overview of production of FIBRA mixtures for A73*

Section	Location	Code	Mixtures	Amount
FIBRA 1	Top-layer	BL ref	2L-PA 8 PMB	183 ton
FIBRA 2	Top-layer	FIBRA 2	2L-PA 8 Pen	183 ton
FIBRA 3	Top-layer	FIBRA 3	2L-PA 8 Panacea	183 ton
FIBRA 4	Top-layer	FIBRA 4	2L-PA 8 Aramid	183 ton
FIBRA 1-4	Under-layer	OL ref	2L-PA 16 30%PR	1321 ton

During production standard evaluation of mixture quality will be executed; extraction (composition and bitumen content, 1x) and gyrator compaction (2x) will be performed every 200 ton production.

Transportation

The transportation will be carried out using special isolated trucks for transporting asphalt. The transport distance is about 60 km (see Figure 11) between asphalt plant BAC and project location A73 and will take almost 1 hour for the trucks to reach the jobsite.

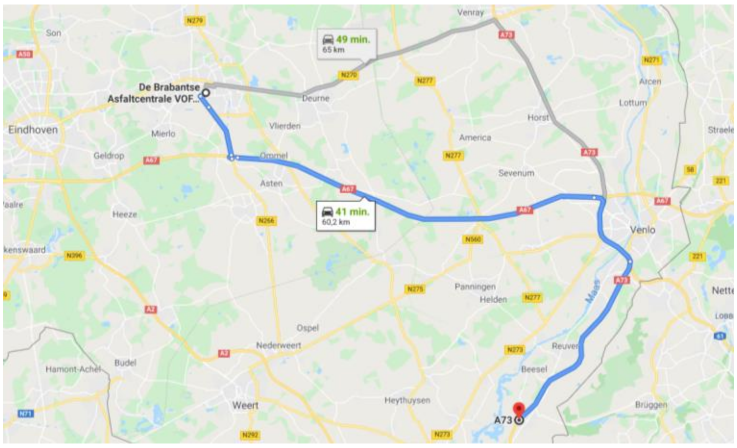


Figure 11. *Transport distance between location asphalt plant BAC in Helmond and the jobsite A73*

APEX and Labelling

For the A73 test section different mixtures have to be transported to the jobsite. In order to ensure good logistical arrangements for these mixtures, the logistic registration system APEX will be used. Also, colour labels that indicate mixture name and section name will be made. These labels are shown on the front of each asphalt truck. Figure 12 gives an example of these labels. The labels will help communication between asphalt plant, transporters and the installation workers at the jobsite.

A73 combi-test sections	A73 combi-test sections
Mixture name: 2L-ZOAB 8 PMB Mixture code: top-layer BL ref	Mixture name: 2L-ZOAB 8 Aramid Mixture code: top-layer FIBRA 4
Section code: FIBRA 1	Section code: FIBRA 4

Figure 12. *Examples of colour labels indication the mixture name and section name. Note that ZOAB is PA in Dutch.*

Laying and compaction

The installation of the test sections will be done in the direction of traffic. I.e. installation will start at location A73 HRL 23,600 near tunnel Swalmen to the direction of Helmond. Two layers will be laid and compacted separately. Different types of mixtures will be laid according to the installation plan, see Table 1. Mixture changes are done on the fly, i.e. the paver machine is not stopped when it finished paving a section. The next variant of the mix is simply fed into the hopper while paving continuous. This means that there is always a transition zone of about 30 meters between two mixture sub-sections. The transition of each mixture will be registered with marking and also with GPS. The laying and the compaction of mixtures will be carried out according to standard guidelines and advice from production trials in phase 1.

The following actions are proposed to monitor the installation process

→The laying temperature will be continuously monitored with a roadscanner located right after the paver.

→2kg hopper materials will be collected every 100 meter with a maximum 12kg per mixture (maximum 6x hopper materials per mix). GPS registration is also needed.

Evaluation before opening to traffic

It is important to evaluate the newly constructed 2L-PA test sections before they are opened to traffic. Evaluations should be carried out regarding safety performance (skid resistance and longitudinal evenness) and noise reducing performance (using a water drainability test; the Becker test). These tests will be carried out for both the fast lane (lane 1) and the slow lane (lane 2). The outflow time requirement for the Becker test is less than 17 seconds.

Evaluation after opening to traffic

The initial development of performance after the trial sections are opened to traffic is be evaluated in this research.

→ Skid resistance test of slow lane (lane 2) in week 1, 2 and 3.

→ CPX noise measurement in week 12.

→ HD visual inspection in week 12.

Laboratory evaluation of test sections

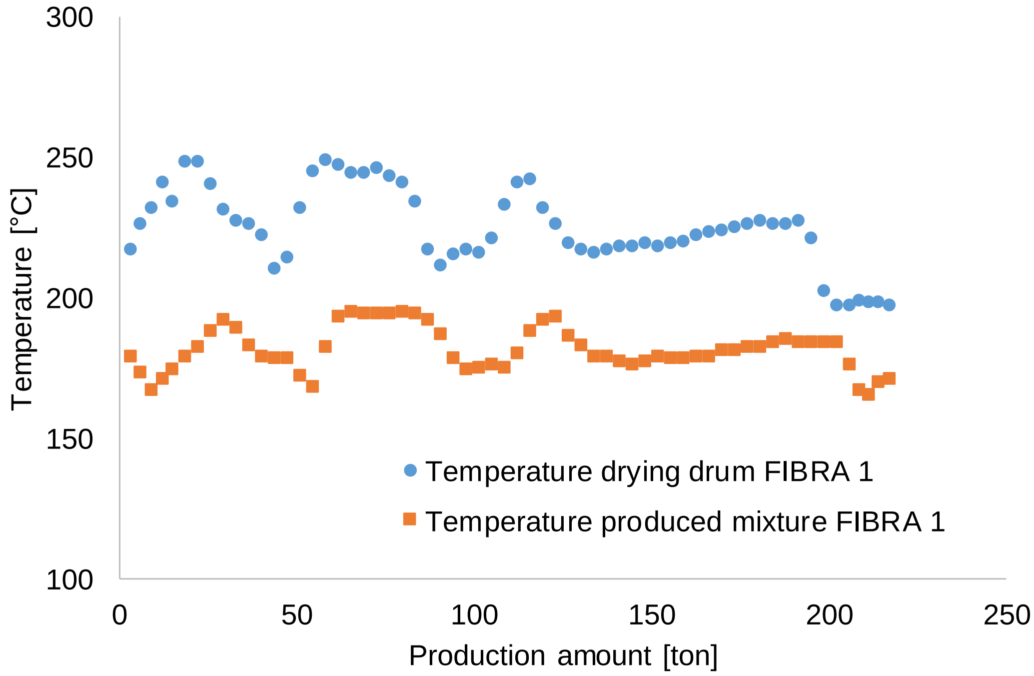
Laboratory evaluations will be conducted on the hopper monsters, 2x per mixture type. DSR mortar tests will be conducted for all mixtures. For all top-layer mixtures mortar tests will be done on virgin and laboratory aged mixtures.

5.2 Mixture production

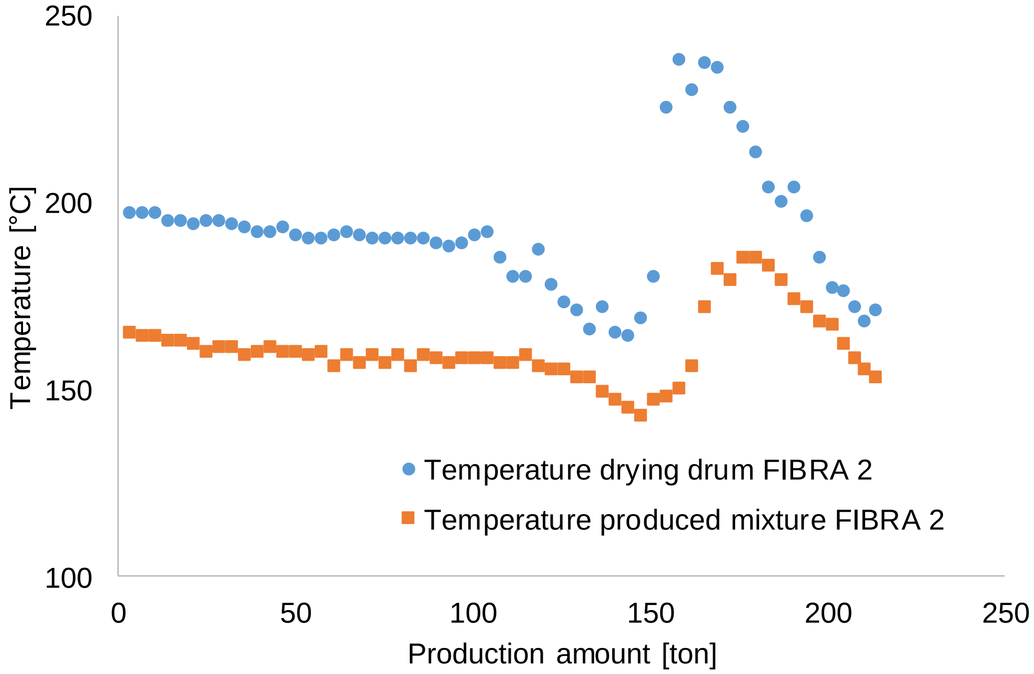
The mixtures were produced at the BAM asphalt plant BAC in the city of Helmond. Table 19 gives an overview of the production process of all FIBRA mixtures. Figure 13 gives the temperature registration for all FIBRA mixtures. These registration include the temperature of the mineral exiting the drying drum and the temperature of the produced mixture.

Table 19. *Production process of reference and experimental mixtures at the asphalt plant*

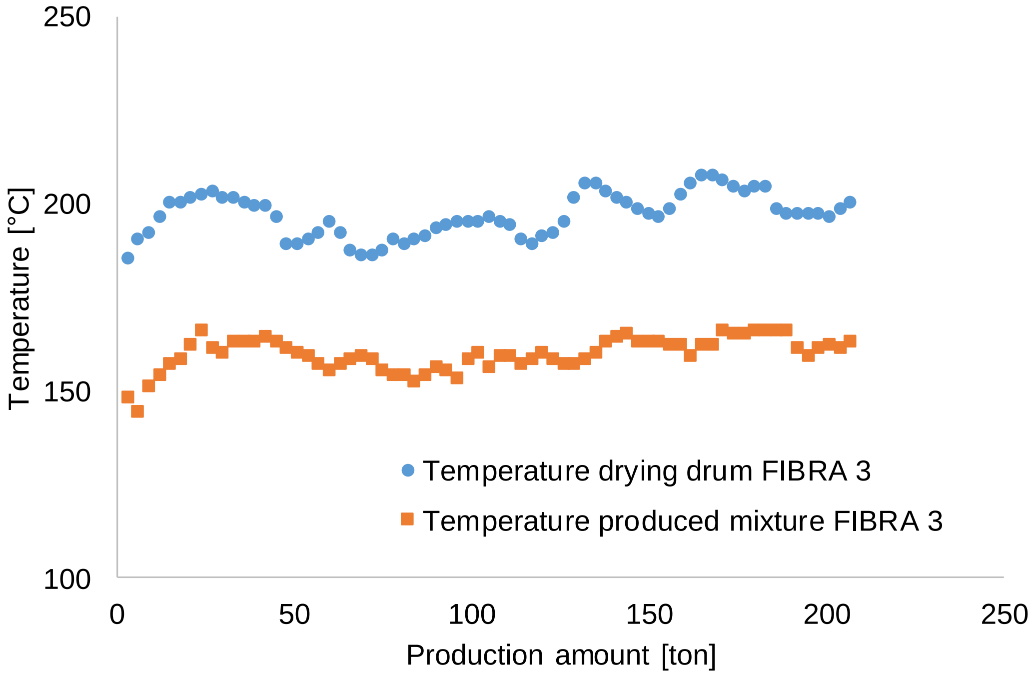
	FIBRA 1	FIBRA 2	FIBRA 3	FIBRA 4
	2L- PA 8 PMB	2L-PA 8 Pen	2L-PA 8 Panacea	2L-PA 8 Aramid
Temperature of aggregates	224°C	192°C	196°C	204°C
Temperature bitumen	180°C	155°C	155°C	155°C
Temperature during mixing	181°C	160°C	159°C	165°C
Order of addition of the different materials	1. aggregates 2. filler 3. bitumen	1. aggregates 2. cellulose fibre 3. filler 4. bitumen	1. aggregates 2. panacea fibre+cellulose fibre 3. filler 4. bitumen	1. aggregates 2. aramid fibre+cellulose fibre 3. filler 4. bitumen
Addition of the fibre (procedure, equipment)		Cellulose fibre was added automatically by blowing	Cellulose fibre was added automatically by blowing Panacea fibre was added manually using low-melt bag in the mixer	Cellulose fibre was added automatically by blowing Aramid fibre was added manually using low-melt bag in the mixer
Mixing times after the addition of the different material	after adding all materials mixing for 25 seconds	after adding all materials mixing for 30 seconds	after adding all materials mixing for 30 seconds	after adding all materials mixing for 30 seconds



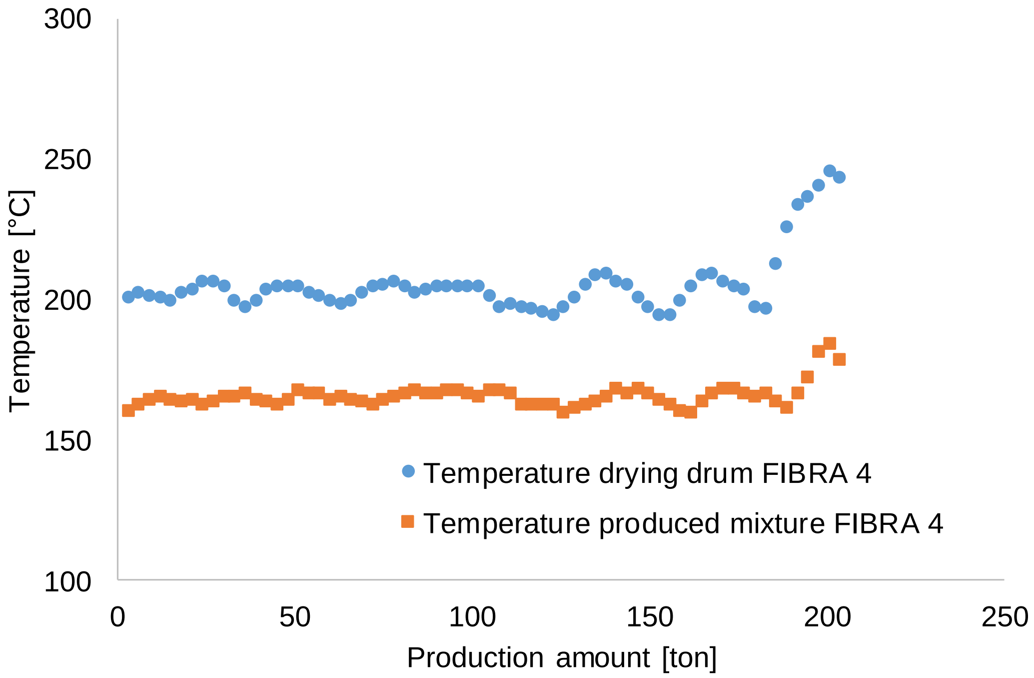
(a) Temperature registration of FIBRA 1 mixture



(b) Temperature registration of FIBRA 2 mixture



(c) Temperature registration of FIBRA 3 mixture



(d) Temperature registration of FIBRA 4 mixture

Figure 13. *Temperature registration of four FIBRA mixtures*

Table 20 and Figure 14 give the overview of the production parameters. The following can be observed,

- The production temperature of the drying drum is about 30-40°C higher than that of the mixture temperature.
- The production temperature of mixture FIBRA 1 is approximately 20°C higher than that of the mixtures comprising pen bitumen.
- The variation in temperature does not differ significantly between mixtures.
- Due to the manual addition of fibres, the production speed of FIBRA 3 and 4 is about 130 ton/hour, slightly lower than the automatically produced mixture FIBRA 1 and 2 (around 145 ton/hour).

Table 20. *Overview of production parameters*

	FIBRA 1	FIBRA 2	FIBRA 3	FIBRA 4
Temperature drying drum [°C]	224,6	192,0	196,5	205,4
standard deviation drying drum [°C]	14,1	17,5	5,7	11,7
Temperature produced mixture [°C]	181,2	160,6	159,5	165,5
standard deviation mixture [°C]	7,7	9,4	4,5	5,3
Total production amount [ton]	217	214	206	201
Total production time [hour]	1,50	1,43	1,58	1,57
Production speed [ton/hour]	145	149	130	128

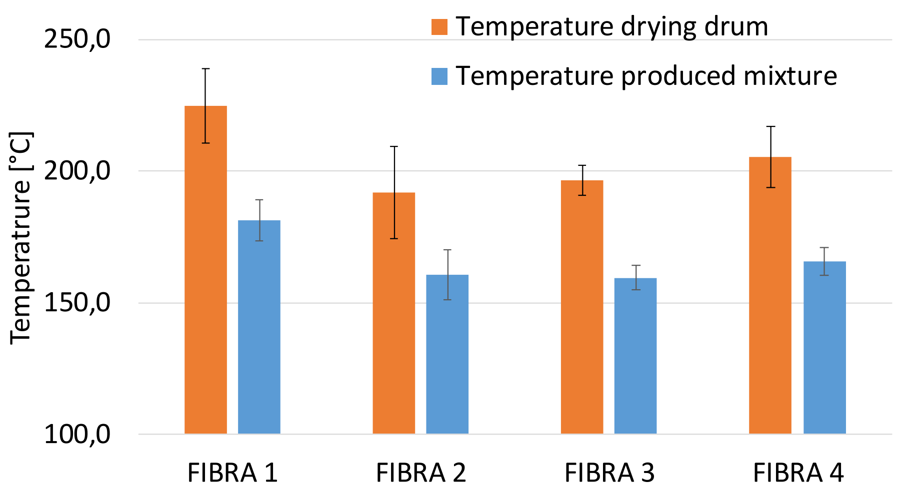


Figure 14. *Temperature of produced mixtures for A73 test sections.*

5.3 Laying and compaction

The test sections in the A73 motorway are located near the city of Roermond. Table 21 gives details of the realized sections and their location. Four types of FIBRA 2L-PA 8 mixtures were be constructed with a thickness of 25 mm on top of 45 mm of standard 2L-PA 16. To prevent the introduction of unwanted surfacing damage the transition from one mixture to the next was done on the go by simply feeding the next mix to the paving machine whilst finishing the previous section without stopping the installation process. As a results test sections are not separated by a straight manmade joint. Instead, a transition zone of approximately 20-30 meter long (15 m before and 15 m after) may be expected between sections.

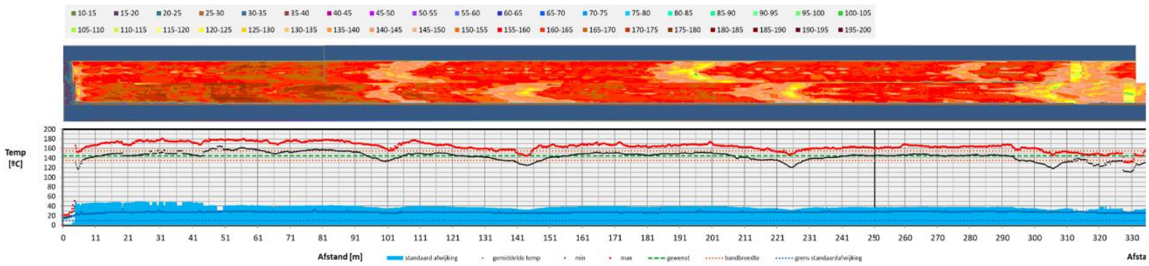
In the A73 a total of six test sections are constructed. The remaining two test sections are part of another project (Prijsvraag Duurzaam Asfalt) of BAM in collaboration with Rijkswaterstaat and are outside of the scope of this report.

Table 21. *Location of realized combi-test sections in A73 (FIBRA+Prijsvraag Duurzaam Asfalt)*

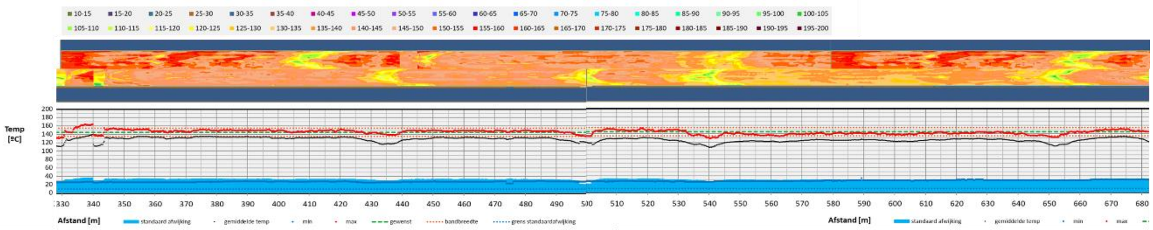
Section	Section code	Location	Length	Under layer	Top layer
1	FIBRA 1/ref	A73 HRL 23.600-23.270	330 m	OL Ref	FIBRA 1/ref
2	FIBRA 2	A73 HRL 23.270-22.920	350 m	OL Ref	FIBRA 2
3	FIBRA 3	A73 HRL 22.920-22.570	350 m	OL Ref	FIBRA 3
4	FIBRA 4	A73 HRL 22.570-22.250	320 m	OL Ref	FIBRA 4
5	P2	A73 HRL 22.250-22.121	129 m	75901	Ref
6	P1	A73 HRL 22.121-21.888	233 m	75329	Ref
7	Ref	A73 HRL 21.880-21.590	290 m	OL Ref	Ref

An Infrared line scanner was used to monitor the temperature distribution during laying. The Infrared line scanner was located on the paver to record the surface temperature of the mixture 2 m behind the screed. Figure 15 gives the temperature counterplots of all four mixtures. The counterplots were re-constructed using data from two pavers. Table 22 gives the statistics of the temperature distributions obtained from the line scanner. In order to avoid the influence of the transition zone and start-stop, the statistical analysis was carried out with section length without the data of 30 m at the beginning and the end of the section.

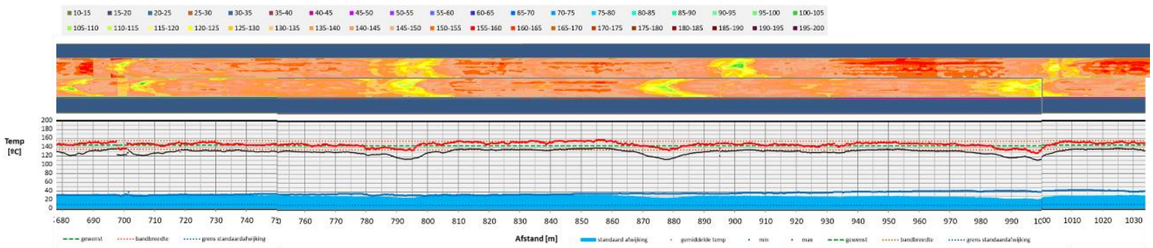
- The installation temperature of the FIBRA mixtures with pen bitumen (FIBRA 2, 3 and 4) is 10-20°C lower than that of the FIBRA reference with PMB (FIBRA 1).
- No temperature difference between FIBRA 2, 3 and 4 can be observed.



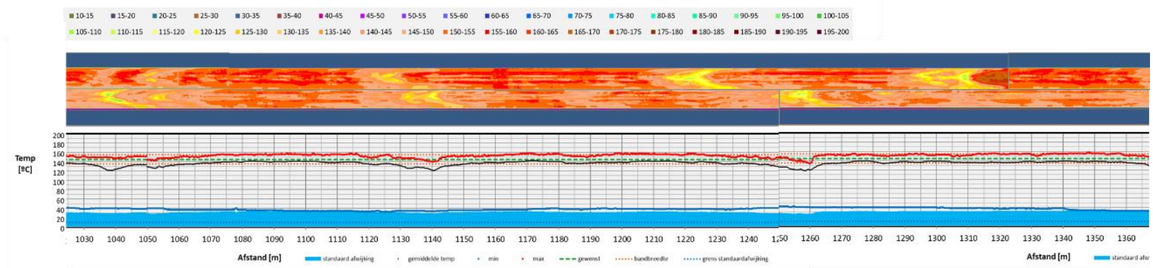
(a) FIBRA 1 section (0-330 m) 2L-PA 8 PMB



(b) FIBRA 2 section (330-680 m) 2L-PA 8 Pen



(c) FIBRA 3 section (680-1030 m) 2L-PA 8 Panacea



(d) FIBRA 4 section (1030-1350 m) 2L-PA 8 aramid

Figure 15. *Temperature counterplots of temperature distribution after the paver*

Table 22. *Statistics of paving temperatures of FIBRA mixtures obtained from Infrared line scan data*

Section	Analyse	Paver 1	Paver 2
FIBRA 1	Average Temperature	156.20 °C	156.88 °C
	Standard deviation	8.98 °C	11.12 °C
FIBRA 2	Average Temperature	145.02 °C	135.89 °C
	Standard deviation	11.32 °C	8.14 °C
FIBRA 3	Average Temperature	144.43 °C	139.60 °C
	Standard deviation	8.00 °C	8.32 °C
FIBRA 4	Average Temperature	149.25 °C	146.32 °C
	Standard deviation	10.08 °C	6.72 °C

Compaction of all sections was carried out using the same equipment and followed the same standard compaction procedure for all 2L-PA 8 mixtures. No difference between compaction behaviour was observed.

All mixtures are homogenous without clusters of fibres (see Figure 16). The FIBRA mixtures are easier to handle by handwork than the reference mixture with PmB.

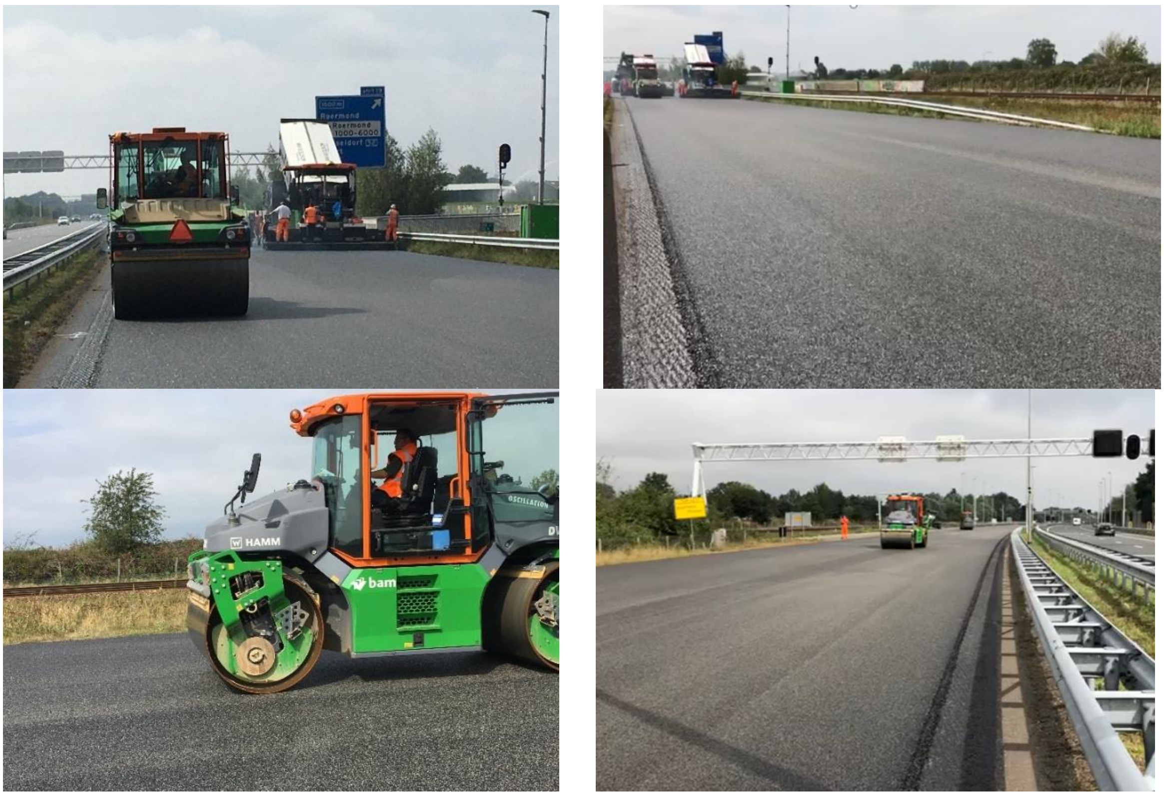


Figure 16. *Laying and compaction process of FIBRA mixtures*

Table 23 summarises the fuel consumption of the equipment during the laying and compaction process. This information is back calculated from the total consumption of the whole test section with a length of 2 km and assigned according to the length of each sub-section. In this work all the equipment was using Hydrotreated Vegatable Oil (HVO) as fuel.

Table 23. *Fuel consumption of equipment during laying and compaction of FIBRA mixtures*

FIBRA 1:

Type	Equipment	Consumption (l/h)	Time (h)
Paver	V1900 (630.201)	15.4 L/h HVO (Hydrotreated Vegetable Oil)	2.0
Paver	V1900 (631.199)	13.3 L/h HVO	2.0
Compactor	DV90 (616.348)	5.2L/h HVO	2.0
Compactor	V800 (630.202/616.342)	3.6L/h HVO	2.0
Compactor	HD140 616.340	7.5L/h HVO	2.0
Compactor	DV70 (616.355)	6.9L HVO	2.0

FIBRA 2:

Type	Equipment	Consumption (l/h)	Time (h)
Paver	V1900 (630.201)	15.4 L/h HVO	2.1
Paver	V1900 (631.199)	13.3 L/h HVO	2.1
Compactor	DV90 (616.348)	5.2L/h HVO	2.1
Compactor	V800 (630.202/616.342)	3.6L/h HVO	2.1
Compactor	HD140 616.340	7.5L/h HVO	2.1
Compactor	DV70 (616.355)	6.9L HVO	2.1

FIBRA 3:

Type	Equipment	Consumption (l/h)	Time (h)
Paver	V1900 (630.201)	15.4 L/h HVO	2.1
Paver	V1900 (631.199)	13.3 L/h HVO	2.1
Compactor	DV90 (616.348)	5.2L/h HVO	2.1
Compactor	V800 (630.202/616.342)	3.6L/h HVO	2.1
Compactor	HD140 616.340	7.5L/h HVO	2.1
Compactor	DV70 (616.355)	6.9L HVO	2.1

FIBRA 4:

Type	Equipment	Consumption (l/h)	Time (h)
Paver	V1900 (630.201)	15.4 L/h HVO	2.0
Paver	V1900 (631.199)	13.3 L/h HVO	2.0
Compactor	DV90 (616.348)	5.2L/h HVO	2.0
Compactor	V800 (630.202/616.342)	3.6L/h HVO	2.0
Compactor	HD140 616.340	7.5L/h HVO	2.0
Compactor	DV70 (616.355)	6.9L HVO	2.0

5.4 Lab evaluation of test sections

5.4.1 Mixture compositions

Table 24 and 25 summarise the mixture composition of all mixtures at the plant, directly after production, and, just before installation, in the hopper of the paver. The following can be observed,

- There is hardly any difference in gradation and bitumen content between mixtures.
- The production temperature of FIBRA 1 mixture is about 20-30°C higher than that of the FIBRA 2-4.
- The Marshall and gyrator compaction results show that the FIBRA mixtures made with pen bitumen is slightly easier to compact than the FIBRA 1 mixture with PMB. The influence of fibres in FIBRA 3 and 4 on compaction is not significant.
- The results of hopper materials are almost identical than that of the production. This means that the mixture is homogenous and no segregation or draining down of the binder is observed.

Table 24. *Production control of the FIBRA mixtures*

Sieve passing	FIBRA 1	FIBRA 2	FIBRA 3	FIBRA 4	Type Test	Minimum (FPC)	Maximum (FPC)
11.2 mm [%]	99.9	99.9	100.0	100.0	100.0		
8 mm [%]	90.8	91.2	91.6	91.0	89.3	81.3	94.3
5.6 mm [%]	36.5	38.7	38.9	35.3	41.6	34.6	48.6
4 mm [%]	15.7	16.8	16.0	17.5	17.1		
2 mm [%]	7.8	9.3	8.7	8.5	8.5	2.5	14.5
0.5 mm [%]	6.7	8.3	7.5	7.3	6.5		
0.063 mm [%]	6.1	7.6	6.8	6.9	6.0	4.0	8.0
Bitumen content [%]	4.87	5.05	5.00	5.05	5.3	4.8	5.8
Mixture temperature [°C]	189	162	163	170			
Density Marshall compaction [kg/m^3]	1902	1945	1936	1957			
Air voids Marshall compaction [%]	24.0	22.2	22.6	21.7	23.0		

Density Gyrator compaction [kg/m^3]	1826	1860	1835	1850			
Air voids gyrator compaction [%]	27.0	25.6	26.6	26.0			

Table 25. *Composition control of the FIBRA mixtures in the hopper*

Sieve passing	FIBRA 1	FIBRA 2	FIBRA 3	FIBRA 4	Type Test	Minimum	Maximum
11.2 mm [%]	100.0	99.8	100.0	100.0	100.0		
8 mm [%]	89.4	90.1	90.7	87.8	89.3		
5.6 mm [%]	31.4	37.4	32.9	40.8	41.6		
2 mm [%]	7.2	9.2	8.4	8.6	8.5	3.1	13.9
0.063 mm [%]	5.93	7.47	7.0	7.0	6.0	3.7	8.3
Bitumen content [%]	4,57	4.93	4.87	5.00	5.3	4.7	5.9

5.4.2 DSR mortar response test

Porous asphalt, PA, is one of the typical asphalt mixtures with a stone skeleton. This type of mixture can be seen as a system of coarse aggregates bonded with mortar bridges (mix of sand, filler and bitumen). Generally speaking PA encounters three types of mechanical loading during service,

- Load type 1: Load through passing wheels. This introduces both compression and shear stresses onto individual stones at the PA surface. In order to withstand this load, PA has to be strong enough.
- Load type 2: Passing vehicles deform the pavement construction: deflection. PA thus has to be flexible enough to deform with pavement deflection without problem.
- Load type 3: PA wants to shrink when temperatures drop, e.g. during the decline of temperature at the end of the day. However, the length of the road does not change, implying that surrounding material prevents this desired shrinkage by imposing equal but opposite deformation. PA must be able to absorb this imposed deformation without the buildup of stresses. This again demands that PA is flexible.

Combined the three phenomenon result in raveling damage that may follow from early damage due to a lack of strength (type 1) and damage after long term service, raveling, due to lack of flexibility after aging (type 2 and type 3). In the Netherlands, raveling after long term of service is the predominant type of damage for Porous Asphalt, PA, and terminates the lifespan of PA. The flexibility of PA is very much dependent on the flexibility of its mortar. As a result, the raveling susceptibility of PA may be evaluated by determination and interpretation of the flexibility of its mortar.

In this research, a DSR mortar test was conducted to evaluate the flexibility of the mortar with the procedure developed during the LOT program [Huurman et al. 2010] as shown in Figure 17. For the production of test specimens mortar is retrieved from the mixtures with a hot spatula. The mortar is then made into a 20 mm high column having a 6 mm in diameter. During the DSR testing, these columns were subjected to sinusoidal loading at pre-set frequency and temperature. The mortar response to this mechanical loading was measured at a range of frequencies and temperatures. Through the combined data master curves of stiffness, G*, and phase lag, δ, were fitted at a reference temperature of -10°C.

Figure 17. *DSR mortar response test of hopper materials on A73 test sections*

The FIBRA mixtures to be evaluated were obtained from the hopper for the quality in the virgin state. A laboratory accelerated aging process was also conducted on the FIBRA mixtures for evaluating the flexibility after aging according to the procedure of Jemere [Jemere Y. 2010]. In this procedure 5 cm thick layer of uncompacted loose FIBRA mixture is aged in an oven for 44 hours at 135°C. It is expected that the aging hardening that is obtained in this manner is equivalent to 10 years of aging of porous surfacing PA 16 in the Netherlands [Jemere Y. 2010].

For making a good comparison of the performance of the mortar in different FIBRA mixtures, a comparison of the bitumen performance is first presented, see Figure 18. Figure 18 gives the results of bitumen mastercurves of both 70/100 pen bitumen and Styrelf 65/105-80 A AP bitumen at a reference temperature of -10°C which were obtained from the database of BAM. Please note that the figures hereafter present fitted models through measured data. The combination of fitted models with original data can be found in **Appendix 2.**

- At high frequency/low temperature range, the complex modulus of the 70/100 pen bitumen is slightly higher than that of the Styrelf bitumen.
- At low frequency/high temperature range, the complex modulus of the Styrelf bitumen is higher than that of the 70/100 pen bitumen due to the working of the polymer.
- The phase angle of 70/100 bitumen ranges from around 15-90° in the whole range. The range of the Styrelf bitumen is 20-60°, clearly indicating the presence of the SBS polymer, especially at low frequency range.

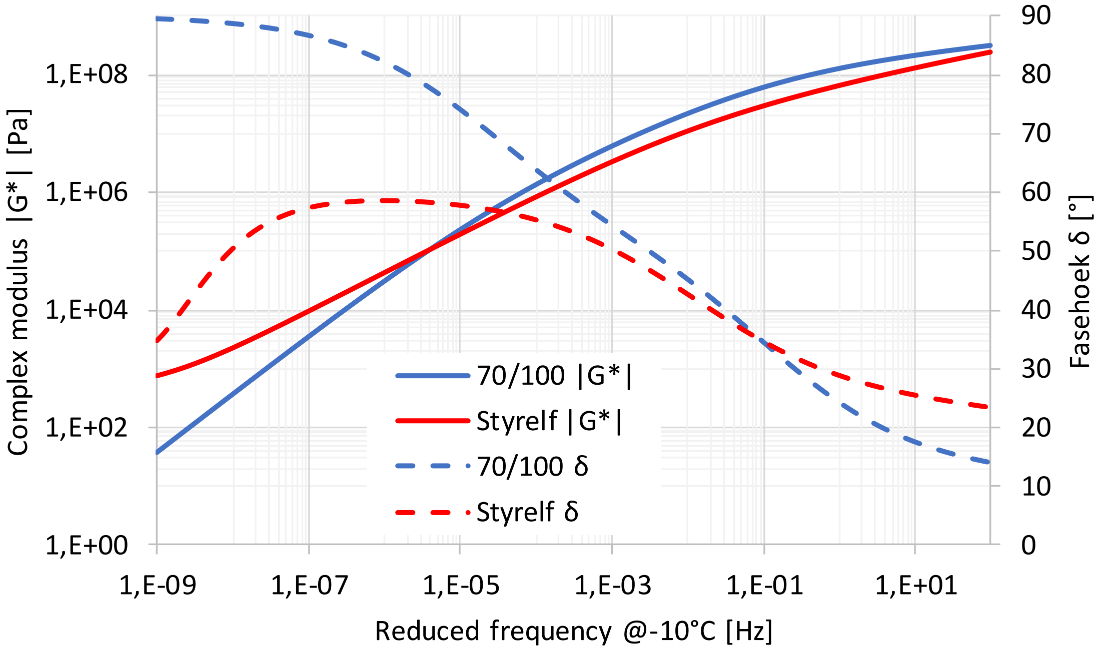
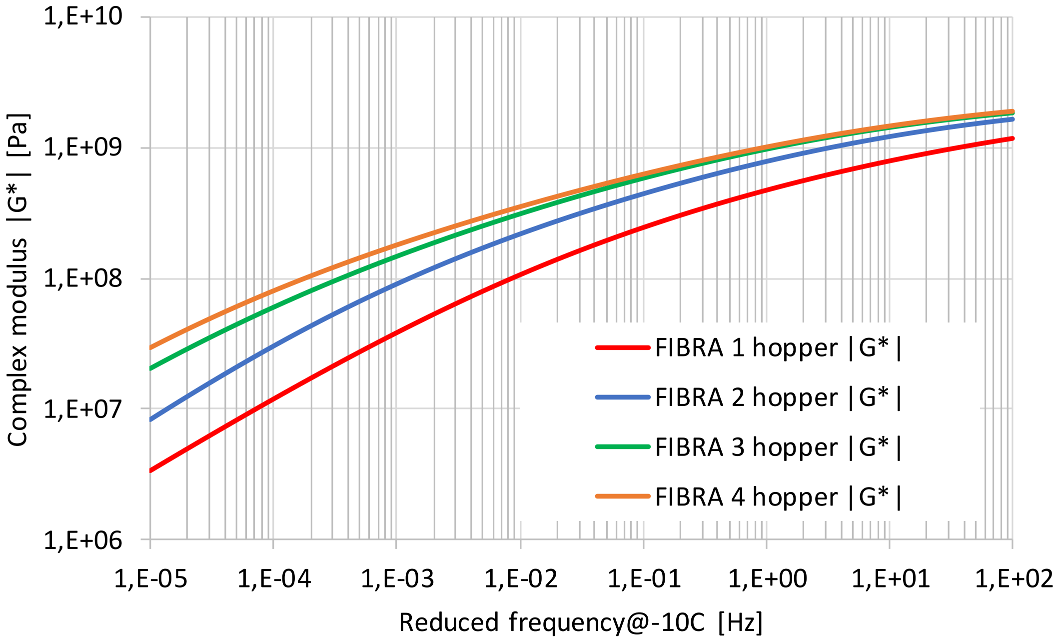


Figure 18. *Comparison of the mastercurves of 70/100 PEN bitumen and Styrelf 65/105-80 A AP*

Figure 19 and Figure 20 present the mastercurves of 4 FIBRA mixtures in the hopper and also after laboratory long-term aging LTA. The following can be observed,

- The mortar of FIBRA 1 mixture obtained from the hopper has lowest complex modulus and a high phase angle due to the presence of the polymer than that of the other three mortars. The mortar of FIBRA 2 mixture has a higher complex modulus and a similar phase angle than that of the mortar from FIBRA 1 mixture. These observations in mortar corresponds also to the observations of bitumen as discussed above in Figure 18.
- The response of the mortar of the mixtures containing fibres FIBRA 3 and 4 are almost similar to each other. The complex modulus of both mortars are higher than that of the mortar from FIBRA 2 as a result of the fibre reinforcement. The phase angle of both mortars are lower than that of the mortar from FIBRA 2.
- After aging, the response of the mortars with 70/100 pen bitumen are almost the same. The influence of the fibre reinforcement is not significant. The complex modulus of the mortar with Styrelf bitumen is still lower than that of the other mortars. The phase angle of the mortar with Styrelf bitumen is higher than that of the mortars with 70/100 pen bitumen.



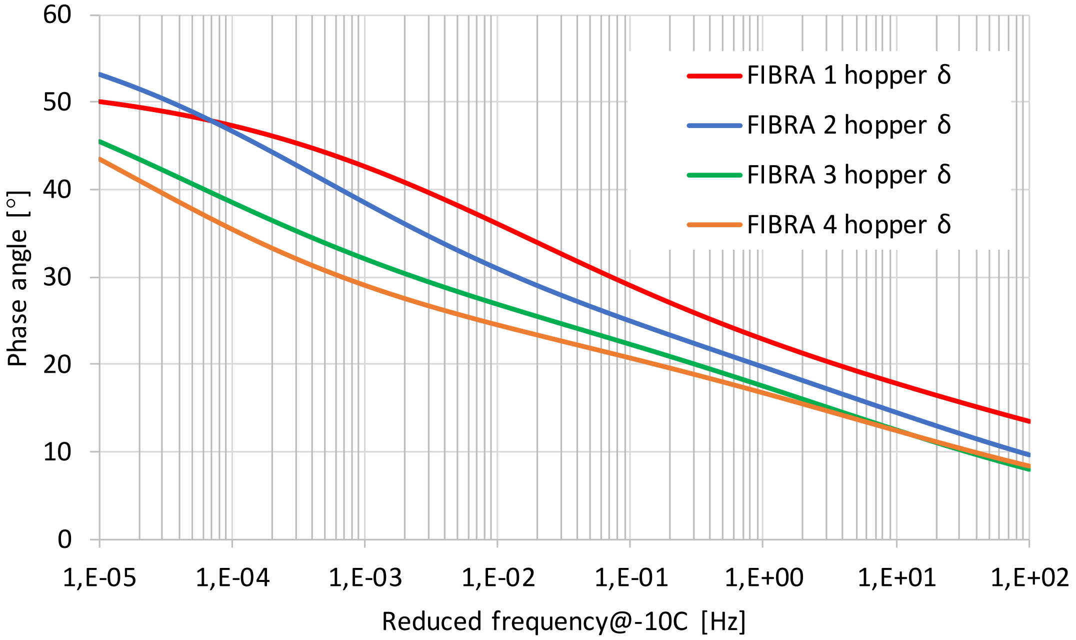


Figure 19. *Comparison of the mastercurves of four FIBRA mixtures obtained from hopper*

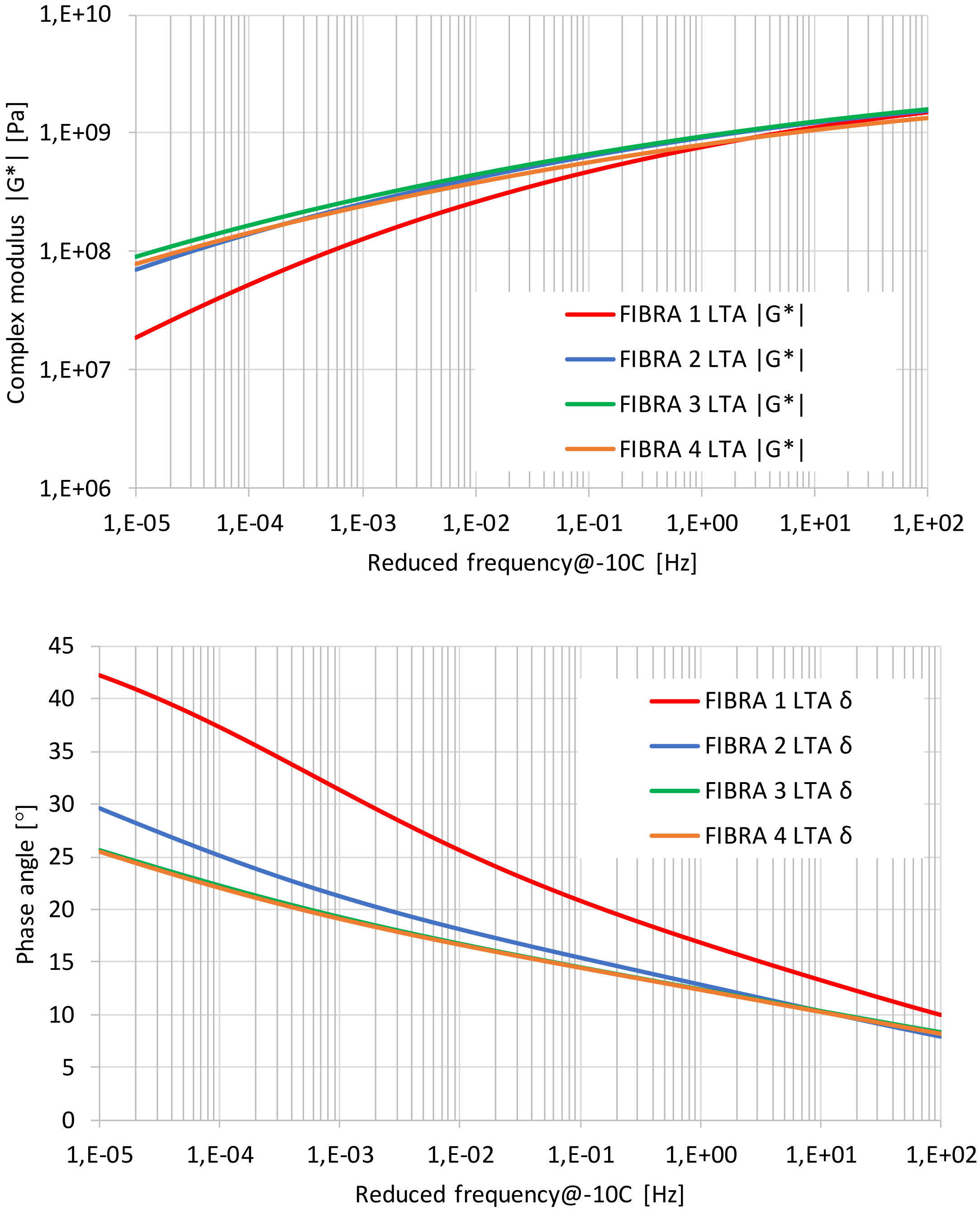


Figure 20. *Comparison of the mastercurves of four FIBRA mixtures after laboratory long-term ageing (LTA)*

Figure 21 presents the aging index of the four FIBRA mixtures. The aging index is calculated as the ratio of the complex modulus of the long term aged mortar and that of the mortar from the hopper. The following can be observed,

- The long-term laboratory aging increases the complex modulus of all four mixtures. As indication, the complex modulus at around 1E-5 Hz, the frequency close to the day-night cycle, increases to 2.7 to 8.2 times for different materials.
- The FIBRA 2 mortar experiences the larges increasing of the complex modulus at low frequency range.
- The increase of the complex modulus at low frequency of FIBRA 1 mortar is smaller than that of FIBRA 2 mortar. However, the aging susceptibility of the FIBRA 1 mortar at high frequency range is the highest of all mortars.
- The fibre reinforced FIBRA 3 and 4 mortar show the lowest aging susceptibility of the four tested types of mortar. It seems the presence of the fibre retards ingression of the oxygen into porous asphalt mixtures during the aging process. However, more research is needed to verify this explanation.

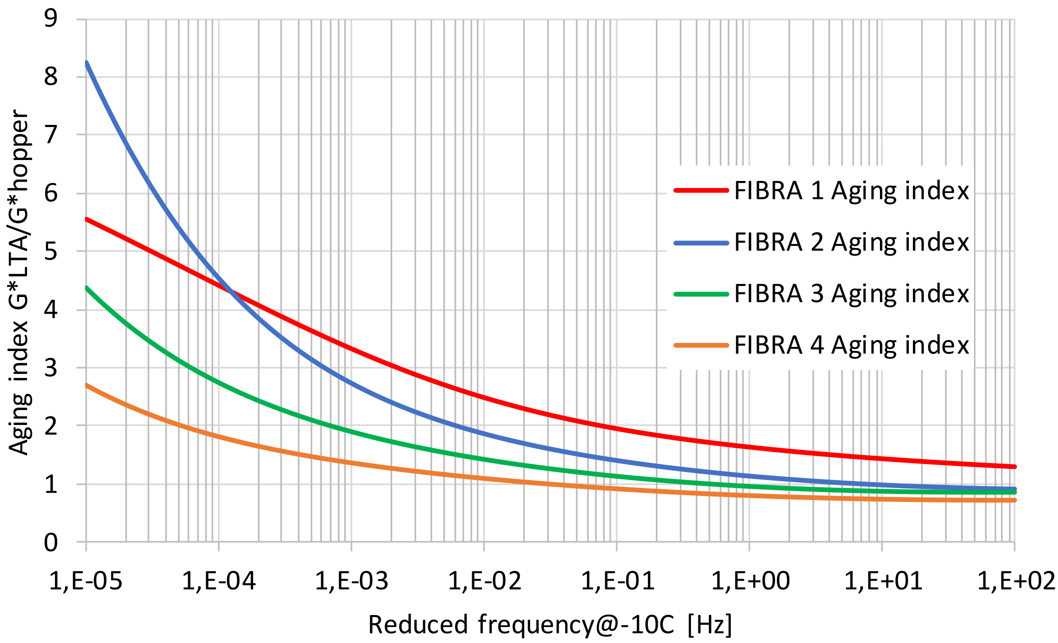


Figure 21. *Comparison of aging index of 4 FIBRA mixtures*

5.5 Field evaluation of the test sections

5.5.1 Water drainability

The evaluation of the water drainability was carried out on the sections before opening to traffic by the use of Becker Test as shown in Figure 22. The Dutch requirement for drainability of 2-layer PA expressed in the Becker outflow-time is maximum 17 second on average and 20 second individual. It can be seen from the results that all the mixtures have similar water Becker outflow times of 11-14 seconds, all FIBRA mixtures fulfil the requirement.

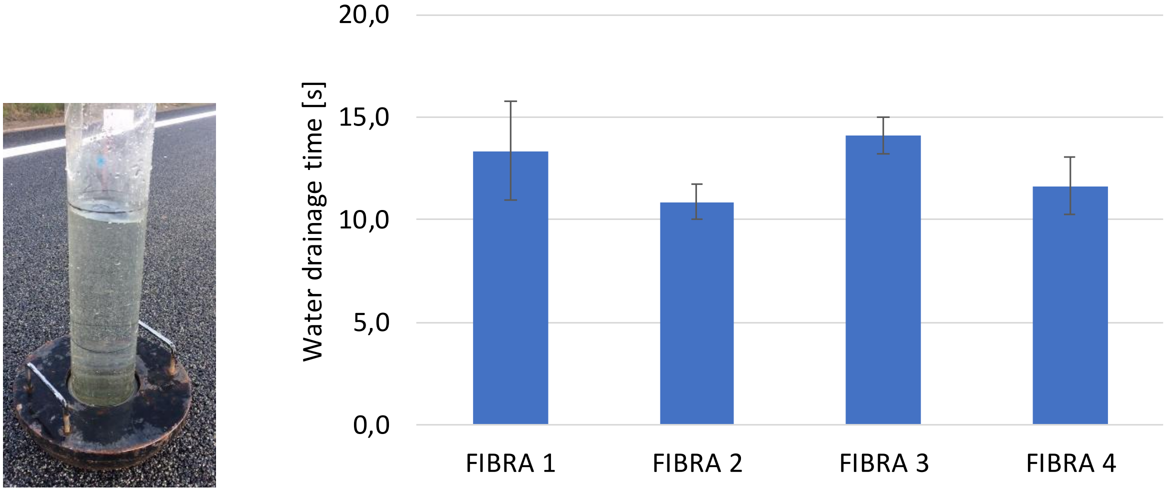


Figure 22. *Illustration of water drainability test (Becker Test, left) and the results of Beker test of A73 test sections before opening to traffic (right)*

5.5.2 Longitudinal evenness

The longitudinal evenness of the installed FIBRA sections was evaluated by measuring the longitudinal profile according to Dutch standard RAW 2015/71. Based on the results, the parameters f5 and C5 are determined. f5 is the number of bumps and depressions deeper or higher than 5 mm per section of 100 m. C5 is the percentage of the road surface that should be considered as a bump or depression per section of 100 m. For a new road surface the demand is that C5<2%. The measurement of this research was carried out by a third party, Kiwa KOAC, by the use of a High Speed Road Profiler (Q), see Figure 23. The measured profile was then evaluated by the use of the parameters f5 and C5 as mentioned above.

Figure 23. *Illustration of measurement of longitudinal evenness by the use of a High Speed Road Profiler*

Table 26 gives the results of the longitudinal evenness of all the sections after three weeks of trafficking. The results indicate that all the sections have a smooth longitudinal profile without unevenness.

Table 26. *Results of Longitudinal evenness evaluations of A73 sections.*

		# of sections	# sections with f5>0	Maximum C5	Requirement C5
FIBRA 1	2L- PA 8 PMB	0	0	0	<2%
FIBRA 2	2L- PA 8 Pen	0	0	0	<2%
FIBRA 3	2L- PA 8 Panacea	0	0	0	<2%
FIBRA 4	2L- PA 8 aramid	0	0	0	<2%

5.5.3 Skid resistance

The skid resistance was measured in the longitudinal direction with a slip ratio of 86% and with a standardized non-profiled PIARC test tyre according to Dutch standard RAW 2015/72. Measurements were carried out with at 70km/hour and repeated up to 3 weeks after opening to traffic. The goal of this short monitoring program is to evaluate the initial development of the skid resistance of the FIBRA sections. In addition week 0 and week 3 the skid resistance measured by the side way force measurement was also carried out. Figure 24 gives an impression of both measurement devices.

Figure 24. *Illustration of measurement of skid resistance by the use of RAW 2015/72 (left) and side way force (right)*

Table 27 and Figure 25 present the results of the development of skid resistance performance of the slow land of the A73 test sections during the first 3 weeks of trafficking. The minimum requirement of the skid-resistance for Dutch regulation is 0.42. The week 0 measurement was not conducted for the first 900 meter (km 23.6-22.7) of the A73 test section due to joint-repairing activities carried out at the same time of the measurement.

Obtained results indicate that all test sections fulfil the standard and behave good. During the first 3 weeks of trafficking, FIBRA 2, 3 and 4 experience the phase of declining skid resistance due to loss of sanding sand applied during construction in the first week which followed by a phase of increasing skid resistance performance in the following weeks due to the wear-off of the surface mortar films. Due to the use of polymer modification for the reference mixture, the phase of wear-off of the mortar films lasts longer and is not so much observed during the first 3 weeks.

Table 27. *Results of skid resistance measurement of both RAW 2015/72 and side way force*

	RAW 2015/72 70 km/hour				SWF 80 km/hour	
Location	2R-L	2R-L	2R-L	2R-L	2R-L	2R-L
Time	Week0	Week1	Week2	Week3	Week0	Week3
FIBRA 1		0.531	0.513	0.517		0.587
Standard deviation FIBRA 1		0.018	0.012	0.006		0.025
FIBRA 2		0.560	0.575	0.560		0.655
Standard deviation FIBRA 2		0.014	0.021	0.028		0.007
FIBRA 3	0.550	0.537	0.537	0.570		0.650
Standard deviation FIBRA 3		0.012	0.015	0.000		0,010
FIBRA 4	0.565	0.530	0.535	0.555	0.905	0.645
Standard deviation FIBRA 4	0.007	0.014	0.007	0,007	0.007	0.007

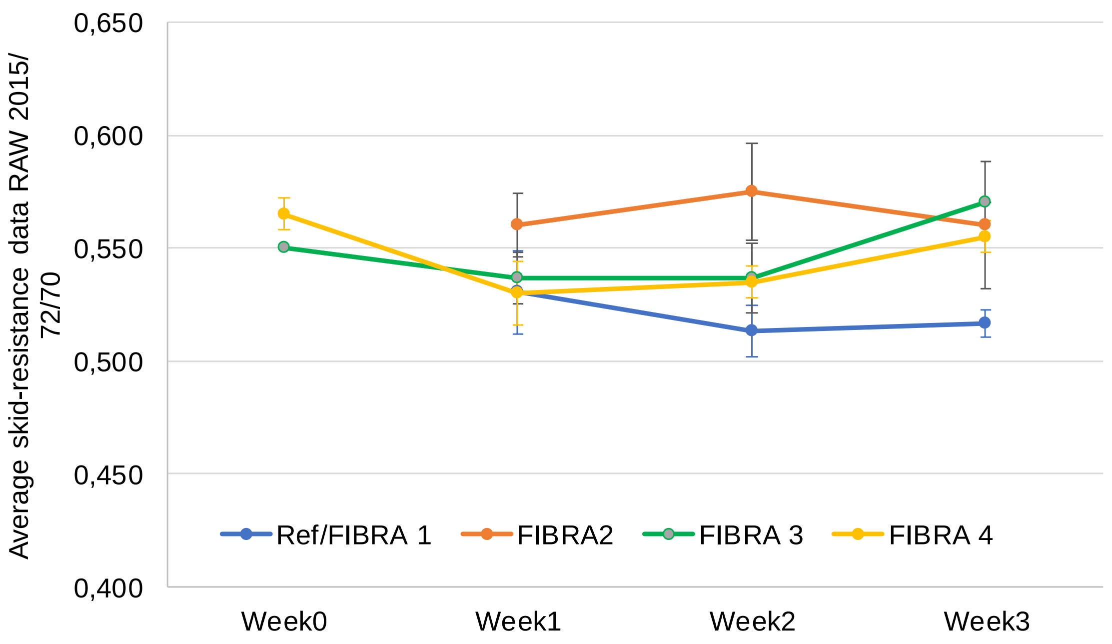


Figure 25. *Development of skid resistance performance of slow lane (lane 2) of A73 test sections during 3 weeks of service*

5.5.4 Noise measurement

On 25 November 2020, 12 weeks after construction of the test sections, a noise measurement was carried out using a Close Proximity (CPX) method as shown in Figure 26 according to ISO 11819-2. The measurement was carried out with a special designed trailer with microphone. Two different types of tyres were used (Figure 27) being standard tyre P1 and H1 according to ISO 11819-3. The P1 tyre is representative for light vehicles (as in de result CPXP) and the H1 tyre is representative for heavy vehicles (as in the result CPXH). Both the slow lane and the fast lane were measured with a speed of 80km/hour.

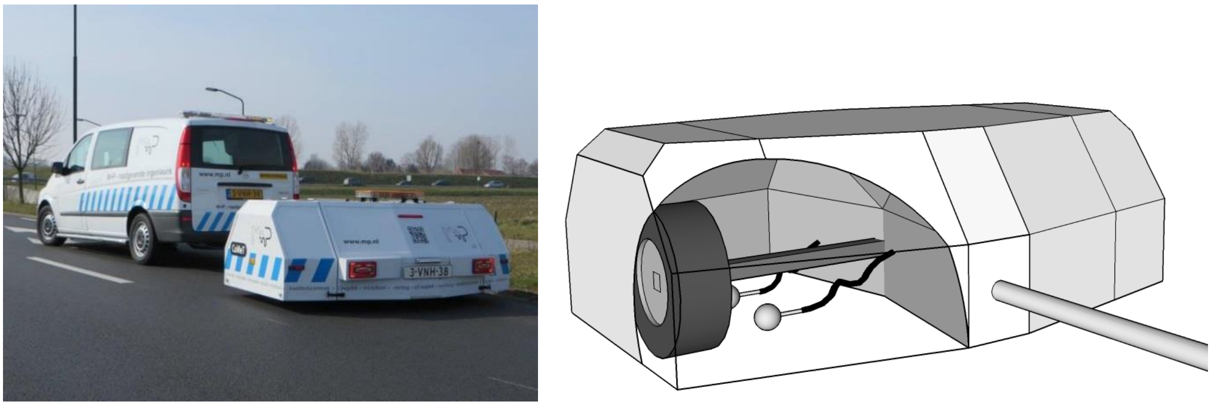


Figure 26. *CPX noise measurement.*

Figure 27. *Two different type of standard tyres used in the CPX noise measurement according to ISO/TS 11819-3: P1 (left) and H1 (right).*

The results of the noise measurement of FIBRA sections are present in Table 28.

- As shown for light vehicles on average the rolling noise on the right lane is 1.2 dB(A) higher than on the left lane.. This can be due to the wearing off of the bitumen film on the right lane due to more intense traffic. For heavy vehicles the difference between two lanes is limited to about 0.5 dB(A).
- The CPXH value for heavy vehicles is slightly 0.2-0.5 dB(A) higher than the CPXP for light vehicles for the left lane. Almost no difference can be found for the right lane.
- The difference between different test sections is neglectable.

Table 28. *Results of noise measurement of FIBRA sections by the use of CPX method*

Section	Location	CPXP [dB(A)] for light vehicles		CPXH [dB(A)] for heavy vehicles	
		Left lane lane 1	Right lane lane 2	Left lane lane 1	Right lane lane 2
FIBRA 1	23.600-23.270	91.3 (0.5)	92.8 (0.3)	92.5(0.8)	92.5 (0.1)
FIBRA 2	23.270-22.920	91.6 (0.4)	92.9 (0.5)	91.9 (0.1)	92.4 (0.2)
FIBRA 3	22.920-22.570	91.4 (0.4)	92.4 (0.4)	91.9 (0.3)	92.4 (0.2)
FIBRA 4	22.570-22.250	91.3 (0.2)	92.5 (0.3)	91.7 (0.2)	92.3 (0.1)

(*) standard deviation

5.5.5 Visual inspection

A visual inspection of the test section (lane 1, lane 2 and emergency lane) was carried out in week 47 by the use of a HR (High Resolution) video camera, which is able to obtain 360° view. Furthermore the video information is evaluated by an inspection expert according to Dutch standard “DWW handbook Damage Evaluation and Intervention levels for pavement maintenance”. The result indicate that after 3-month of service the test sections are in good condition and no damage is observed.

5.5.6 Monitoring

The A73 test sections will be in monitored for long term performance by BAM in collaboration with Rijkswaterstaat. At this moment a year 2 and year 5 HD video inspection is planned. These test sections will also be part of the yearly monitoring program of Rijkswaterstaat of visual inspection and skid resistance.

5.6 Summary construction and evaluation of test sections

The following can be summarised from the construction and evaluation of the FIBRA test sections in the A73,

- For the production of the fibre reinforced PA the fibres were pre packed in melt bags and fed into the mixer manually. As a result, the production speed was decreased slightly to 130 ton/hour when compared to that of the automatic process of reference mixture of 150 ton/hour. Similar temperature homogeneity of all mixtures can be observed.
- The installation temperature of fibre reinforced porous asphalt is 20 °C lower than that of the PMB reference section. No difference is observed in the compaction process. No fibre clusters or other production or installation problems occurred.
- Laboratory results show that all FIBRA mixtures have very limited variation in composition both directly after production at the mill and just in advance of installation in the paver hopper.
- The DSR mortar response test show that the PMB mixture is the most flexible mixture before and after aging. The addition of fibre increases the complex modulus and decrease the phase angle of the mortar. The mixture with fibre reinforcement shows less aging susceptibility than that of the

reference mixture without fibre and also the PMB mixture with limited increasing of complex modulus after ageing.

- The filed evaluation shows that all FIBRA sections have good performance. All FIBRA sections have identical water drainage performance, longitudinal evenness. The fibre reinforced PA sections have better skid resistance performance than that of the reference section with polymer during the first 3 weeks after opening to traffic. The wearing off of the bitumen film is faster than that of the polymer modified section.
- The noise measurement by the use of a CPX method after 3-month of service indicate that all the sections have similar noise-reducing performance. In general the right lane generates more rolling noise than the left lane.
- Visual inspection results indicate that after 3months of service the test sections are in good condition and no damage is observed.
- The test long term performance of the FIBRA test sections will be monitored by BAM in close collaboration with Rijkswaterstaat. At this moment a year 2 and year 5 HD video inspection is planned. These test sections will also be part of the yearly monitoring program of Rijkswaterstaat of visual inspection and skid resistance.

6. Conclusions and Recommendations

Conclusions from laboratory research,

- Porous asphalt can be reinforced using synthetic fibres (Polyacrylonitrile and aramid).
- The fibres are homogenously distributed in the mix for laboratory produced mixtures. No clusters of fibres can be found. Aramid fibres with different lengths have no influence on the homogeneity of the mixture.
- The use of synthetic fibres does not prevent binder drainage due to limited percentage of added fibre, especially when a fibre blend is used such as aramid/polyolefin blends. Instead a combination of synthetic fibres and cellulose fibres is used to prevent mortar drainage in bitumen-rich mixtures such as 2L-PA 8 which is used in this trial.
- The use of synthetic fibres in combination of a pen grade bitumen for 2L-PA 8 allowed to reduce the production temperature by approximately 20°C compared to that of the reference mixture produced with polymer modified bitumen. Given the difference in production temperature, no differences in laboratory production and compaction were observed. This implies that differences in bitumen properties are compensated with the difference in production temperature.
- The mechanical strength of fibre reinforced PA is similar to that of PA produced with a pen grade bitumen. The water sensitivity of the fibre reinforced PA is slightly lower than that of the pen grade bitumen mixtures.

Conclusions from plant trials,

- The FIBRA 4 mixture with aramid fibre can well be produced in an existing production plant. Addition of fibres can be carried out manually through the inspection gate of the mixer with a pre-packed low-smelt bag.
- The produced FIBRA 4 mixture was homogenous with limited variation. The production temperature was around 180 °C due to limited production amount. No segregation or binder drainage is observed during production and also after 1 hour transport simulation.
- The mixture in the trial production are slightly more porous than that equivalent laboratory produced mixture.
- The installation of the FIBRA 4 mixture can be carried out with regular equipment and the strategy of standard 2L-PA 8. The workability of the mixture is better than that of the standard 2L-PA 8 with polymer modification.
- The constructed test sections at the plant yard have good water drainability and good layer thickness.

Conclusions from field trials A73,

- For the production of the fibre reinforced PA the fibres were pre weighed and pre packed in melt bags and fed into the mixer manually. As a result, the production speed slightly decreased to 130 ton/hour compared to that of the automatic process of reference mixture of 150 ton/hour. Similar temperature homogeneity of all mixtures can be observed.
- The installation temperature of fibre reinforced porous asphalt is 20 °C lower than that of the PMB reference section. No difference is observed on the compaction process. No fibre clusters or other production or installation problems occurred.
- Laboratory results show that all FIBRA mixtures have very limited variation in composition both directly after production at the plant and just in advance of installation in the paver hopper.

- The DSR mortar response test show that the PMB mixture is the most flexible mixture before and after aging. The addition of fibre increases the complex modulus and decrease the phase angle of the mortar. The mixture with fibre reinforcement shows less aging susceptibility than that of the reference mixture without fibre and also the PMB mixture with limited increase of the complex modulus after ageing.
- The filed evaluation shows that all FIBRA sections have good performance. All FIBRA sections have identical water drainage performance, longitudinal evenness. The fibre reinforced PA sections have better skid resistance performance than that of the reference section with polymer during the first 3 weeks after opening to traffic. The wearing off of the bitumen film is faster than that of the polymer modified section.
- The noise measurement by the use of a CPX method after 3 months of service indicate that all the sections have similar noise-reducing performance. Right lane generates in general more noise than the left lane.
- The visual inspection results indicate that after 3months of service the test sections are in good condition and that no damage is observed.
- The test long term performance of the FIBRA test sections will be monitored by BAM in close collaboration with Rijkswaterstaat. At this moment a year 2 and year 5 HD video inspection is planned. These test sections will also be part of the yearly monitoring program of Rijkswaterstaat of visual inspection and skid resistance.

7. Reference

Huurman, M., Mo, L.T. and Woldekidan, M.F. (2010 I), "Mechanistic Design of Silent Asphalt Mixtures and its Validation", *Journal of Assoc. Asphalt Paving. Technol.*, Vol 79, 2010, pp. 365-402.

Huurman, M., Mo, L.T. and Woldekidan, M.F. (2010 II), "Unravelling Porous Asphalt Concrete, Towards a Mechanistic Material Design Tool", *Road Materials and Pavement Design*, Vol 11(3), 2010, pp. 583-612.

Huurman, M., Mo, L.T. and Woldekidan, M.F. (2010 III), "Porous Asphalt Ravelling in Cold Weather Conditions", *International Journal of Pavement Research and Technology*, Vol 3(3), 2010, pp. 110 -118.

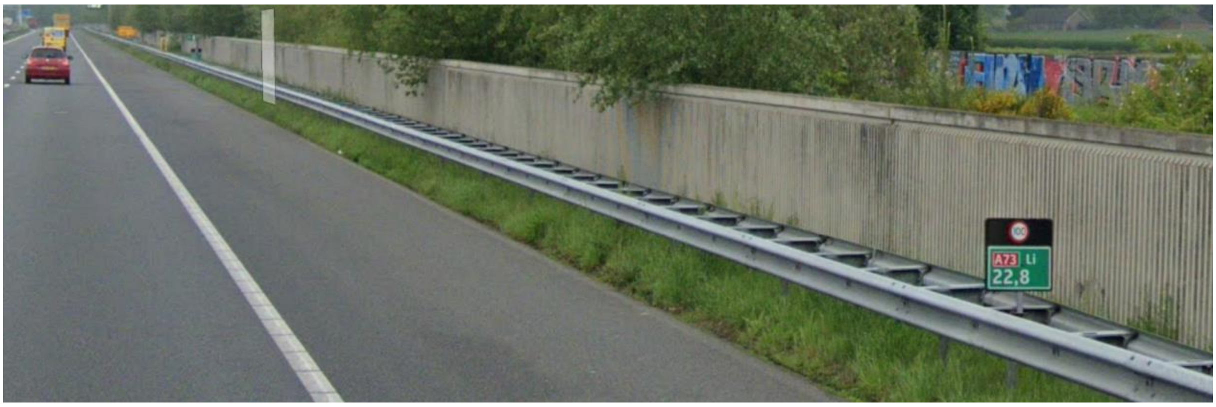
Jemere, Y., "Development of a Laboratory Ageing Method for Bitumen in Porous Asphalt", *MSc thesis, Delft University of Technology*, The Netherlands, 2010.

RAW 2015, "Dutch Standard for Quotations in Earth Works, Road Construction and Water Works" (in Dutch), 2015.

Appendix 1: Photos A73 HRL km 23.600 – km 21.600


Eindhoven
volg E
A73


A73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Designer Outlet
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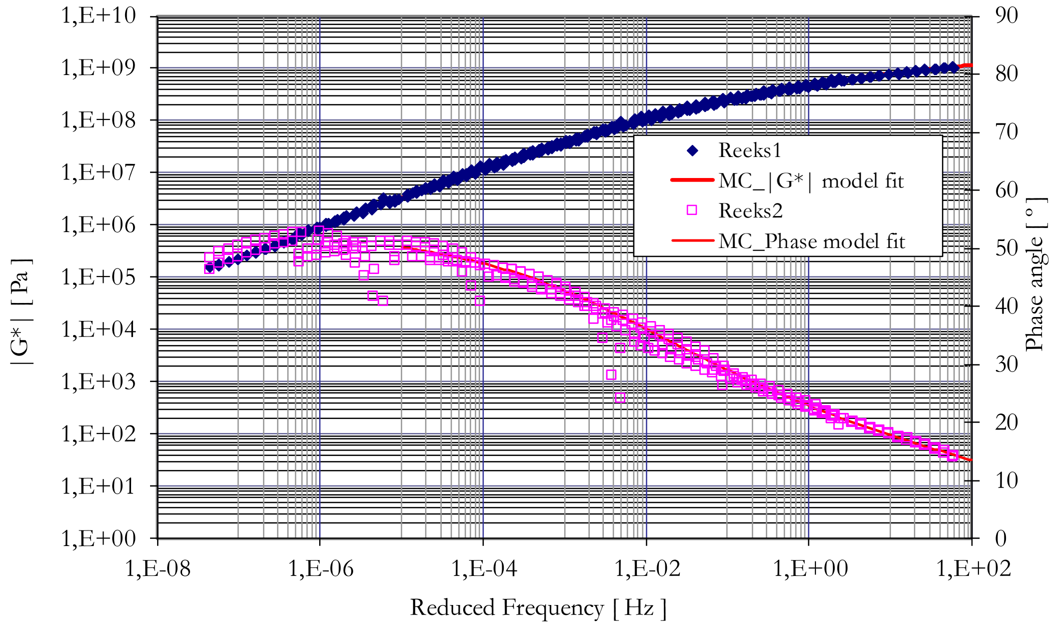
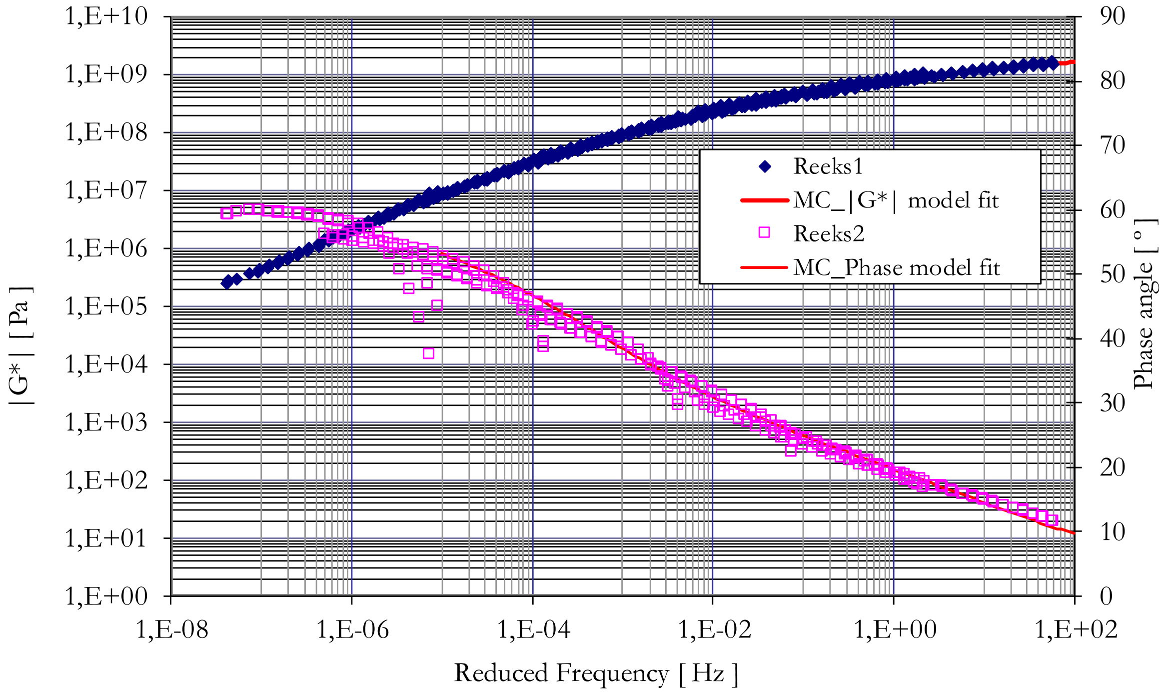
Appendix 2: Fitting of DSR data

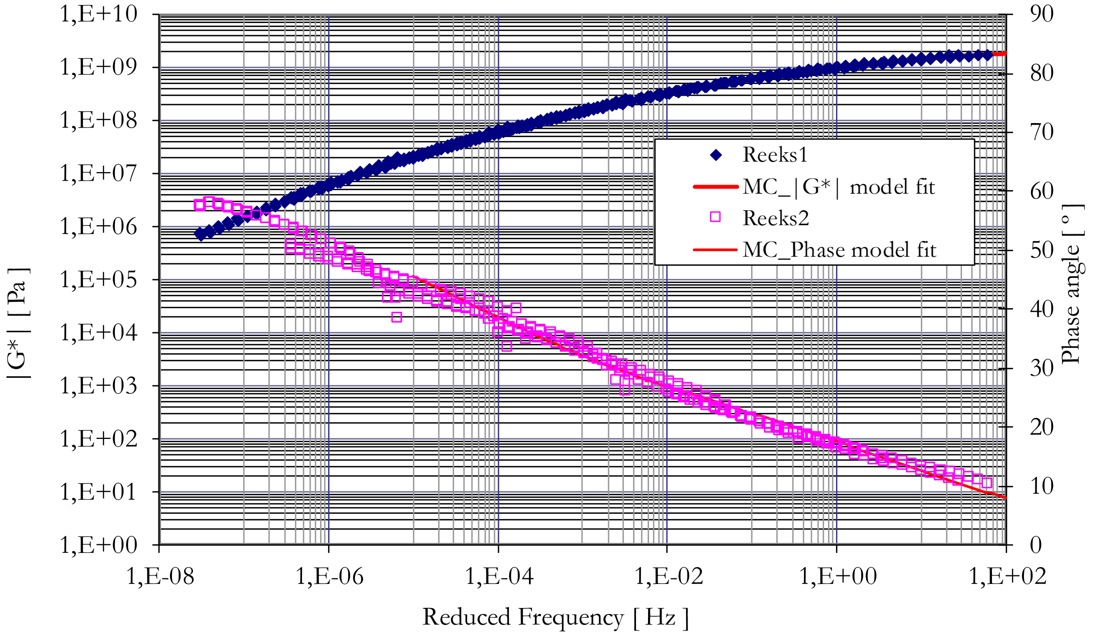
a. FIBRA 1 hopper



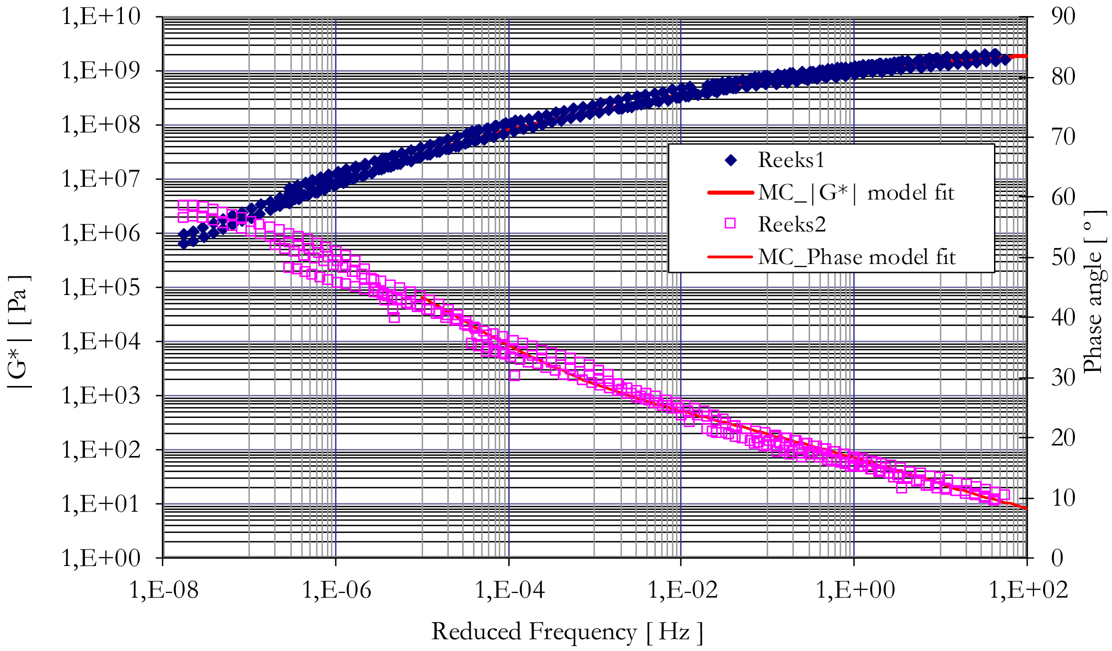
b. FIBRA 2 hopper



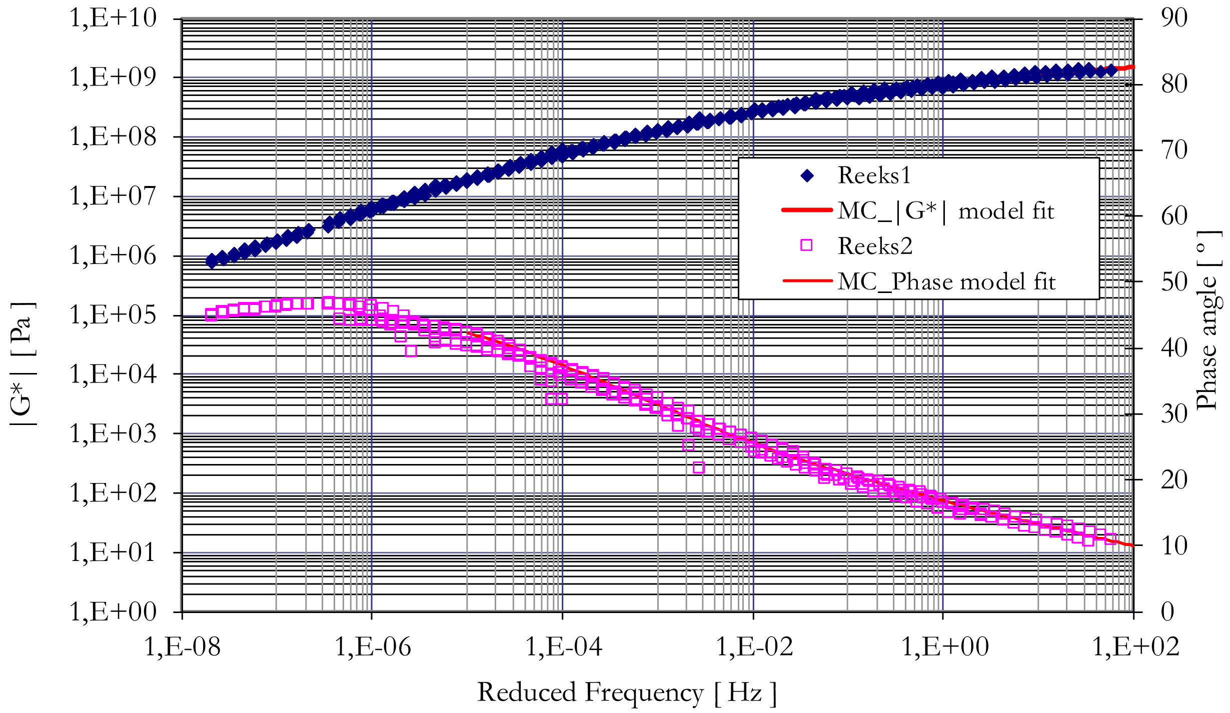
c. FIBRA 3 hopper



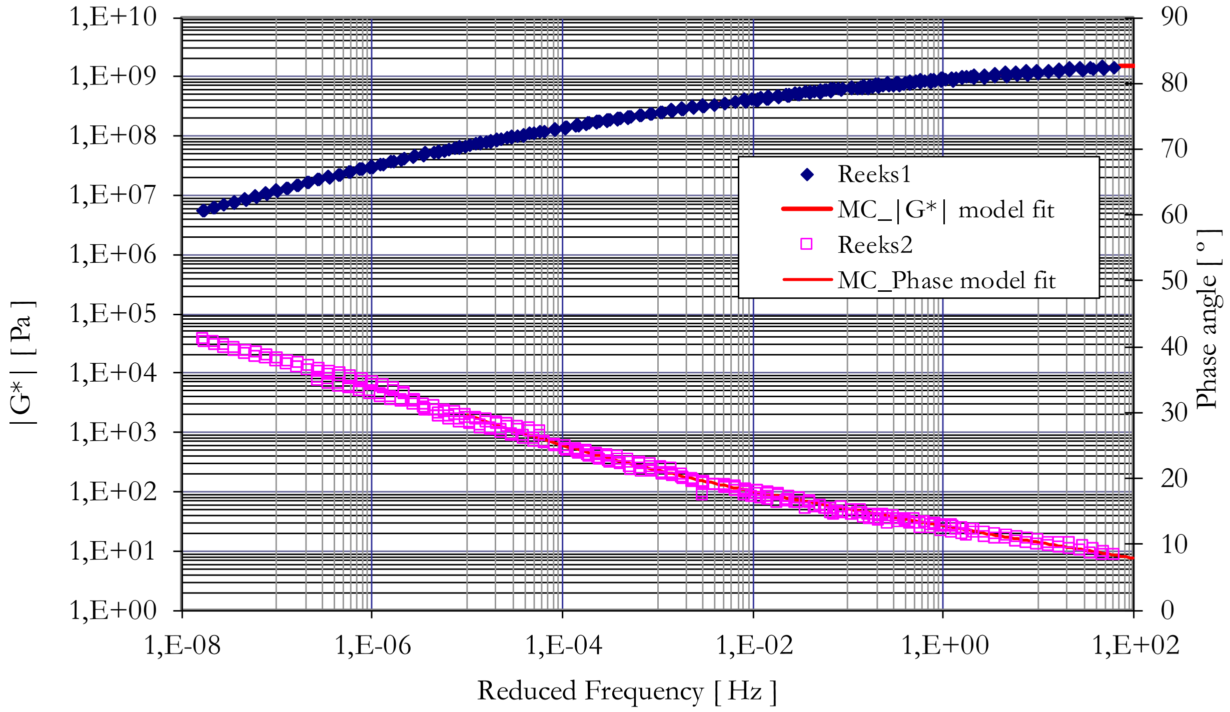
d. FIBRA 4 hopper



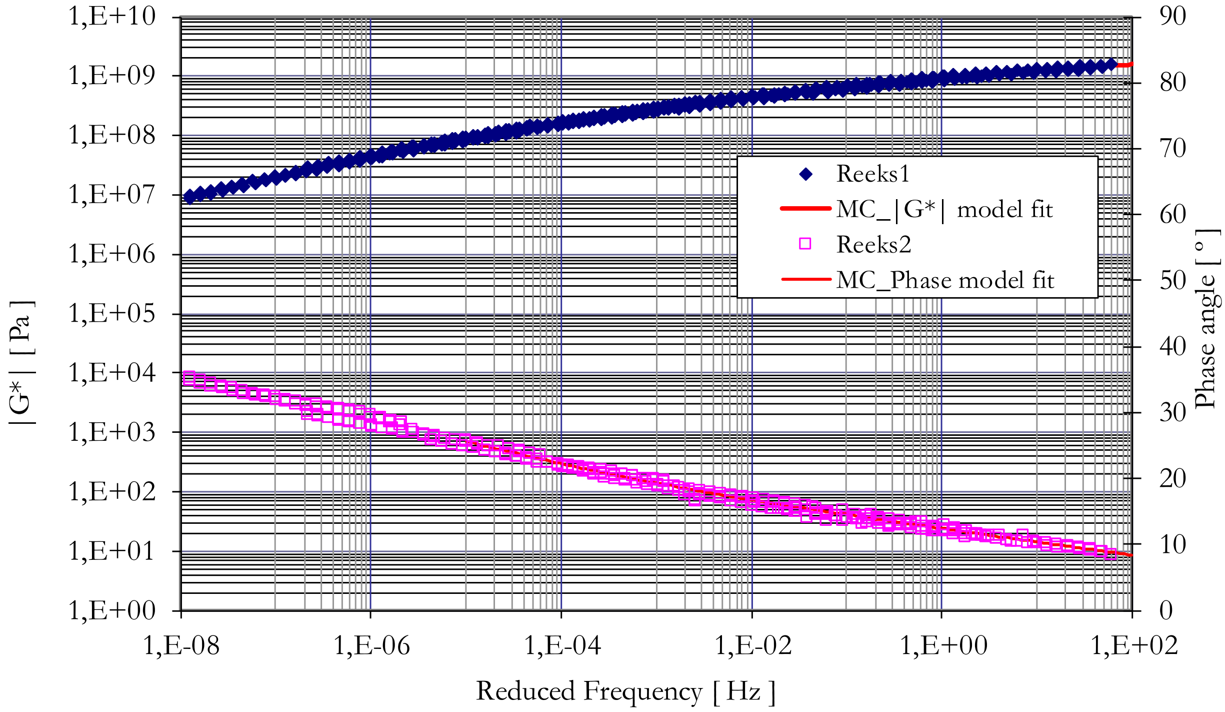
e. FIBRA 1 LTA



f. FIBRA 2 LTA



g. FIBRA 3 LTA



h. FIBRA 4 LTA