Onderzoek naar geoptimaliseerde toepassing van vezels in asfalt: het CEDR-FIBRA project

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Samenvatting

Deze bijdrage geeft een samenvatting van de ontwikkeling van vezelversterkte ZOAB binnen het CEDR-FIBRA project. De gedetailleerde resultaten worden gerapporteerd op het EATA congres 2023 [1].

In de afgelopen jaren (2017-2021) heeft AsfaltNu (voorheen BAM), samen met vier Europese onderzoeksinstituten (Universiteit Cantabrië, EMPA, TU Braunschweig en SINTEF) en een Noordse aannemer Veidekke Industri in opdracht van CEDR (Conference of European Directors of Roads) de toepassingsmogelijkheden van vezels in asfaltmengsels onderzocht. Dit onderzoek heeft de toepasselijke naam FIBRA gekregen, FIBRA -Fostering the implementation of fibre reinforced asphalt mixtures by ensuring its safe, optimized and cost-efficient use. FIBRA heeft als doel de belangrijkste aspecten en aandachtpunten van toepassing van vezels in asfalt voor NRAs te onderzoeken, zoals veiligheid en kosteneffectiviteit. Het project bevat onderzoeken van vezels in asfalt op alle niveaus, o.a. de eigenschappen van vezels, mastiek en mengseleigenschappen, hergebruikbaarheid, praktijkonderzoek en LCA/LCCA-analyse. Het FIBRA onderzoek is in 2020 afgesloten met de aanleg van demonstratievakken van in Nederland en Noorwegen met als doel de techniek van vezelversterkte asfalt te valideren. De Nederlandse FIBRA proefvakken hebben zijn in samenwerking met Rijkswaterstaat aangebracht in de snelweg A73. In deze proefvakken zijn een viertal 2L-ZOAB 8 mengsels toegepast, zowel vezel-versterkte vakken (met panacea en aramide vezels in combinatie met pen bitumen) als referentie-vakken (met PMB en pen bitumen). FIBRA eindigde met een advies aan de Europese alle NRAs voor geoptimaliseerde en kosteneffectieve manier van toepassing van vezels.

Sleutelwoorden
Vezels, asfalt, optimalisatie, kosteneffectiviteit, ZOAB, duurzaamheid, CEDR, FIBRA

1. FIBRA

Existing transport infrastructures are facing important challenges to maintain a reliable performance of the road network, which is being threatened by the increase of heavy traffic, the opening of new freight corridors and the effect of climate change, among others. Maintaining a satisfactory service level currently implies frequent roadworks that generate environmental, economic and societal impacts, reducing at the same time mobility and reliability of the road network and increasing the travel time.

In the last years, fibre-reinforcement has become a promising alternative to improve the mechanical properties and durability in road pavements. However, many uncertainties have been identified by National Road Authorities (NRAs) concerning the implementation of this technology.

The FIBRA project was born with the objective of filling existing gaps in the state of knowledge about Fibre-Reinforced Asphalt Mixtures (FRAM) and thus identifying and providing solutions to overcome potential technical barriers for their the cost-effective use by NRAs. FIBRA stands for Fostering the implementation of fibre-reinforced asphalt mixtures by ensuring its safe, optimized and cost-efficient use [2]. This project is funded by CEDR (Conference of European Directors of Roads). Figure 1 shows the project methodology.

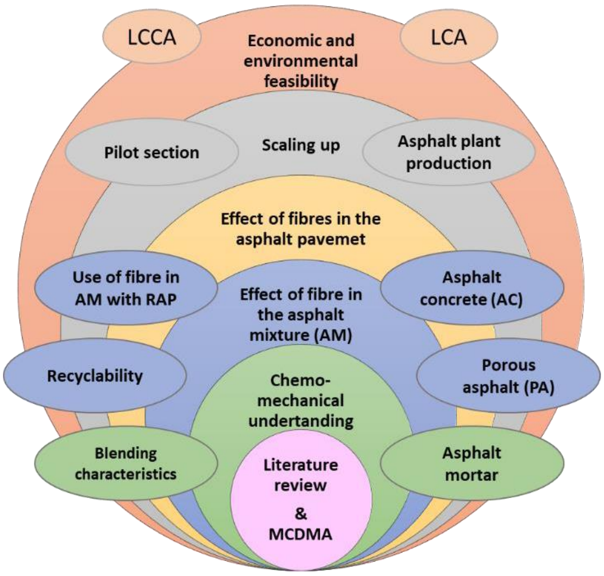

Figure 1. FIBRA project methodology

To achieve the objective and to increase the understanding of the functioning of fibres and reduce uncertainties and gaps in their large-scale implementation, different experimental, theoretical and real scaled studies have been carried out. The FIBRA project started by analysing previous experiences with fibres to select the most promising ones. The next step consisted of improving the understanding of the functioning of fibre reinforced asphalt mixtures (FRAM) by means of studying aspects such as blending procedure, rheological behaviour or microstructural properties. This knowledge lays the foundation for the optimal design of the mixtures that were characterized by mechanical tests. Afterwards, the optimal position of the FRAM layer were defined in terms of service life extension of the pavement in a life cycle perspective while considering its performance in different climatic conditions. The recyclability potential of the mixtures as well as the effect of fibres on asphalt mixtures with high RAP content were also analysed at lab scale. Furthermore, the technology was up-scaled by producing FRAMs at real asphalt plants. Two pilot roads were built at two different countries (the Netherlands and Norway) to validate the technology with different regulations and weather conditions. Finally, the LCA and LCCA methodology were used to assess the technology from an environmental and economic point of view, where potentially toxic and hazardous pollutants measured during the project were considered.

2. FIBRA Dutch test sections A73

With the positive results of the laboratory tests, the phase of field testing was started in 2021. Both Porous Asphalt, PA, mixes and dense Asphalt Concrete, AC, mixtures developed in the laboratory were produced at two different asphalt plants in two different countries and were thereafter installed in pilot road sections. The fibre reinforced AC dense asphalt test section was constructed in Norway by Veidekke together with NRA Statens Vegvesen and the fibre reinforced PA test section was constructed in the Netherlands by BAM in collaboration with NRA Rijkwaterstaat.

The Dutch FIBRA test sections have been constructed on the motorway A73 near the city of Roermond at the exit of the Tunnel Swalmen (HRL 23.600-21.600) in the last week of August 2020. 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 50,000 vehicles per working day. Table 1 gives an overview of all the planned mixtures for the FIBRA test sections [3,4]. This trial section consists of four sub-sections with four different types of FIBRA 2L-PA8 mixtures. Each mixture section is about 330 meter long.

- **FIBRA 1,** non-fibre reinforced reference section, conventional 2L-PA 8 mixture with **PMB**, production temperature of 185 °C.
- **FIBRA 2,** non-fibre reinforced reference section, 2L-PA 8 with **straight run** bitumen, 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 bitumen drainage. 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,** fibre reinforced 2L-PA 8 with straight run bitumen and 0.15% **panacea** fibre, production temperature of 165°C**.** In this mixture 0.15% cellulose fibre is used to prevent possible bitumen drainage.
- **FIBRA 4,** fibre reinforced 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 possible bitumen drainage.

Table 1. Overview of mixtures to be applied in the FIBRA sections

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

3. Mix design and performance

The FIBRA laboratory research was conducted to evaluate the performance of the 2L-PA 8 mixtures comprising fibre reinforcement relative 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 found in the type of bitumen and fibres if any.

Table 2 gives the type test results 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%. Furthermore, the water sensitivity of the FIBRA 4 mixture has been re-evaluated in 2021 when constructing test sections A50 with 86%.

Table 2. Results of laboratory type testing of all FIBRA mixes

	FIBRA 1	FIBRA 2	FIBRA 3	FIBRA 4	FIBRA 4 (2021 A50)
	PMB	70/100	Panacea polyacrylonitrile	Twaron 1080 aramid	Twaron 1080 aramid
Gyrator cycles needed to reach air voids [-]	48	61	45	52	45
Air voids specimen	23.0%	22.8%	23.4%	23.5%	23.5%
ITS dry [MPa]	0.72	0.61	0.572	0.578	0.782
ITS wet [MPa]	0.63	0.52	0.455	0.446	0.675
ITSR	88%	86%	80%	77%	86%

The mixtures were produced at the BAM asphalt plant BAC in the city of Helmond. 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 2). The FIBRA mixtures are easier to handle by handwork than the reference mixture with PmB.

Figure 2. Pilot sections in the Netherlands (up) and in Norway (down).

4. Performance evaluations of test sections

4.1 Field performance

The evaluation of the water drainability was carried out on the sections before opening to traffic by the use of Becker Test. 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.

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 at 70km/hour and repeated up to 3 weeks after opening to traffic. Obtained results indicate that all test sections fulfil the standard and perform well. During the first 3 weeks of trafficking, FIBRA 2, 3 and 4 experience the well-known phase of declining skid resistance due to loss of sanding sand applied during construction in the first week which is 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.

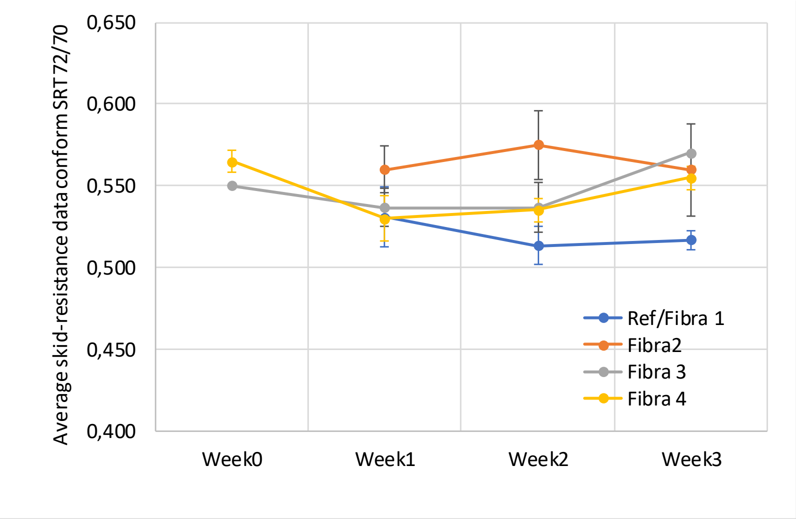

Figure 3. Development of skid resistance performance of slow lane (lane 2) of A73 test sections during 3 weeks of service [4]

The noise measurement was carried out 12 weeks after construction of the test sections using a Close Proximity (CPX) method according to ISO 11819-2. The measurement was carried out with a special designed trailer with microphone. Two different types of tyres were used; i.e., the standard P1 and H1 tyre according to ISO 11819-3. The P1 tyre is representative for light vehicles (as in the 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. The results indicate that all four sections have the same noise reduction performance and the difference between different test sections is neglectable.

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 a 360° view. Furthermore, the video information is evaluated by an inspection expert according to the Dutch standard "DWW handbook Damage Evaluation and Intervention levels for pavement maintenance". The result indicates that after 3-month of service the test sections are in good condition and no damage is observed.

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

4.2 Accelerated load testing CRS

Three produced FIBRA mixtures obtained from test sections A73 (FIBRA 1, 3 and 4) were subjected to accelerated load testing using Circular Road Simulator (CRS) at VTI in Sweden, with the help of the research project PavementLCM also funded in the CEDR research call 2017 [5].

The objective of the study was to investigate the evolutions of the mixtures in a simulated traffic environment in different climatic situations and in different state of ageing. The test should investigate the mixes propensity to rutting and deformation, ravelling, friction loss, and in the final phase also their sensitivity to cracking in case there are deficiencies in the bearing capacity of the road structure.

Figure 4 gives the impression of the CRS. This ALT has a diameter of 5.25 meter and has mounted four tires, Cooper Discoverer S/T MAXX, LT 235/85 R16. This ALT has a maximum speed of 70 km/hour. The inflation pressure was 3.5 Bar. Each tyre was loaded with 450 kg.

Figure 4. The CRS setup in VTI and illustrations of fixing the FIBRA plates to the track [5]

Table 3 gives the overview of the performance indications of FIBRA mixtures when compared with a reference ZOAB+ mixture.

- The FIBRA 1 mixture outperformed ZOAB+ in terms of resistance to ravelling, rutting, cracking and friction (polishing) in the fresh state. The FIBRA 3 and 4 have similar performance as ZOAB+ in terms of ravelling, rutting and cracking in the fresh state.
- All three aged FIBRA mixtures indicate equally worse performance than ZOAB+ in terms of resistance to ravelling.

Table 3. Overview of performance indication of FIBRA mixtures when compared with a reference PA 16 mix (ZOAB+) [5]

The relative performance is indicated with - -, -, =, +, ++ where - - and - indicates much worse and worse, = indicates equal performance and + and ++ indicates better or much better performance.

	Test	Fibra 1 / PA8	Fibra 3 / PA8 panacea	Fibra 4 / PA8 aramid
Traffic	ALT / CRS	+ ravelling + rutting + cracking + friction	= ravelling = rutting = cracking + friction	= ravelling = rutting = cracking + friction
Traffic/aging	ALT / CRS aged material	- - ravelling + rutting = cracking + friction	- - ravelling + rutting = cracking + friction	- - ravelling + rutting = cracking + friction
Traffic/climate	ALT / CRS Water sensitivity and freeze-thaw cycles	=	=	=

An estimated service life of the PA mixes can be derived from abovementioned observations combined with expert judgements, as shown in Table 4. It is noticed that the FIBRA 1 mixture comprises a specially selected PMB aiming to come to a 2L-PA 8 that outperforms normal 2L-PA 8 PMB mixtures according to the LOT philosophy [7]. It can be concluded that the FIBRA mixtures comprising pen bitumen with fibres have a service life estimation of 10 year, similar to that of the reference mixture.

Table 4. Estimated lifetimes of PA mixes on high volume roads based on the CRS results and expert judgement [5]

Country\Mix	PA16 (ZOAB+)	PA8 (Fibra 1)	PA8 panacea (Fibra 3)	PA8 aramid (Fibra 4)
Sweden, Netherlands and Germany	12	11	10	10

5. LCA analysis

Cradle-to-gate and cradle-to-grave Life Cycle Assessments (LCA) were carried out to evaluate the environmental performance of road pavements that include a FRAM in the surface layer comparing to conventional pavement designs (see Figure 5 and 6). This analysis was carried out according to EN 15804:2012 + A2:2019. Both types of FIBRA mixtures (FIBRA 3 and 4) have similar impact than the reference with pen bitumen (FIBRA 2). The FIBRA 1 mixtures shows clearly different environmental impacts, specifically high impacts was noticed in categories of freshwater eutrophication and water use. Two different LCA indexes (EF and MKI) were applied for further normalizing the effect of fibre reinforcements in the mixtures. In the cradle-to-gate analysis, the addition of fibres (FIBRA 3 and 4) results in an environmental impact increase of 5-8% in when compared with mixtures with pen bitumen (FIBRA 2), whereas the use of PMB (FIBRA 1) results in an environmental impact increase of 9-11%. In the cradle-to-grave analysis the environmental impacts of all the variants (fibres and PMB) are limited. The use of fibre shows in any case still less environmental impact than that the use of the PMB.

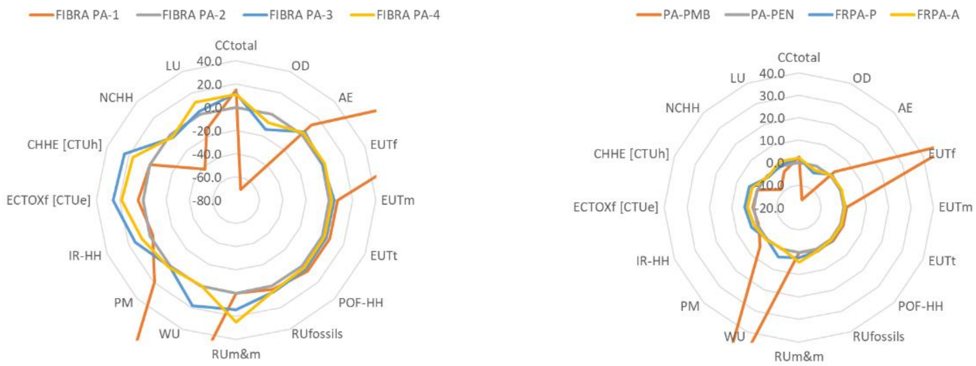

Figure 5. The increase/decrease (%) in the environmental impacts indicators of the 4 PA mixtures under study comparing to the reference FIBRA-PA2 (assigned as 100%). Cradle-to-gate analysis (left); Cradle-to-grave analysis (right) [6]

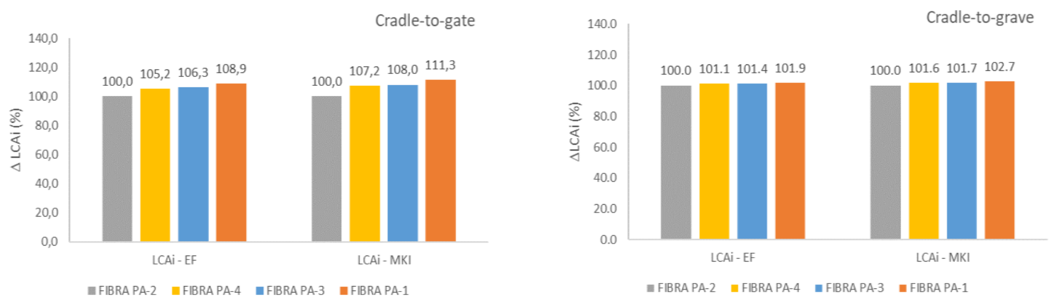

Figure 6. Variation (%) in the LCA index of the 4 PA mixtures comparing to FIBRA-PA2 (assigned 100%). Cradle-to-gate (left); Cradle-to-grave (right). [6]

6 Conclusions and recommendations

6.1 Conclusions

This paper presents the results from the CEDR FIBRA project, which is aimed at safe and cost-effective use of fibres in asphalt mixtures. The following can be concluded from the paper:

- Porous asphalt can be reinforced using synthetic fibres (both polyacrylonitrile and aramid). Both fibres can be integrated into current mix design and production/installation process of porous asphalt without technical difficulty. The use of fibre reinforcement may positively contribute to mixture performance as indicated by the strength and stiffness of the mortar. It is anticipated that mortar with fibre reinforcement will have better ageing resistance than mortar without reinforcement and also than mortar containing polymer modified bitumen.
- The use of fibre in 2L-PA 8 makes the use of polymer modified bitumen superfluous. An advantage of this is that fibre-reinforced 2L-PA 8 with pen bitumen is produced at a lower temperature than its polymer-modified equivalent (e.g. FIBRA 1, 2L-PA 8 with PMB). In addition, the workability of fibre-reinforced 2L-PA 8 is better than that of polymer modified 2L-PA 8.
- The field evaluation shows that all FIBRA sections have good performance. All FIBRA sections have identical water drainage performance. 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 noise measurement by the use of a CPX method after 3 months of service indicates that all the sections have similar noise-reducing performance. The visual inspection results indicate that after 3 months of service the test sections are in good condition and that no damage is observed.
- The accelerated load testing CRS concludes that our FIBRA mixtures without addition of PMB but pen bitumen with fibres have a service life similar to that of the reference mixture.
- The LCA analysis shows that the use of fibre reinforcement results in less increase of environmental impact than the use of PMB in asphalt mixtures.

6.2 Recommendations

- A further optimization of fibre type, aspect ratio (length/diameter) and application rate is recommended in terms of mechanical performance, ageing resistance, ravelling resistance and weathering resistance. A comprehensive understanding in this aspect is important for further application of fibre reinforcement.
- Long term monitoring of the constructed test section and the formation of a portfolio of test sections by constructing more new sections is recommended. It is believed that the presence of the fibre retards ingression of the oxygen into porous asphalt mixtures during the aging process. This will delay the process of mortar aging so lengthening the PA service life. This hypothesis can only be verified through field monitoring followed by analysis of field data of fibre reinforced porous asphalt. This underlines the importance of the suggested portfolio.
- The findings and recommendations of the FIBRA project form a good basis for further optimalisation applying of fibres in asphalt. RWS and market parties form at this moment a workgroup of “Vezels in Asfalt” to further validate the use of fibres in terms of field performance, laboratory performance and environmental performance.

Acknowledgements

The financial support of CEDR to the FIBRA project - Fostering the implementation of fibre-reinforced asphalt mixtures by ensuring its safe, optimized and cost-efficient use – is highly appreciated. The authors are thankful of the project partners University of Cantabria, EMPA, Technische Universität Braunschweig, SINTEF and Veidekke Industri. The support from CEDR PavementLCM project and VTI on the CRS testing are also greatly appreciated.

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