Binder performance and testing

New type of chemical modification of asphalt binders to enhance the performance of flexible pavements

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Abstract

Enhancing the performance of asphalt pavements has been certainly the focus of the research in flexible pavements since the introduction of the Superpave specification. So far, in Germany, the most common solution to achieve this has been using polymers like SBS to modify the asphalt binder. These kinds of polymers create a two-phase system that increase the elasticity of asphalt binders but are susceptible to storage phase separation problems. With this in mind, our research lab tested a new kind of reactive compounds that mimic the performance enhancing capabilities of elastomers but by changing the inner chemical structure of the asphalt binder, thus avoiding any phase separation problems. The additive, which is a low viscous black fluid, creates a chemical bond between the asphaltenes. The purpose of this study was to verify this network through rheology and to investigate the effect of the additive on the performance of flexible pavements. Depending on the quality of the asphalt binder, an amount between 1.5 % and 2.2 % of the additive is required. In order to compare different binders, a 2% additive was used in all variants. The samples were then characterized on an asphalt binder level through tests like dynamic shear rheometer and bending beam rheometer, among others. Afterwards, asphalt tests were performed to address rutting (uniaxial cyclic compression teste and wheel tracking test), fatigue (cyclic indirect tensile strength test) and cold behavior (thermal stress restrained specimen test and direct tensile strength test). After exhaustive laboratory testing, the results show an increase in the performance against rutting and fatigue, without affecting the cold temperature behavior. This was again confirmed after real scale testing, where 12 tons were modified in a mixing plant and afterwards three modified layers were successfully built on our institutes test track.

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1 INTRODUCTION

Roads have to withstand different climate conditions as well as increasing traffic each day. Engineered materials like asphalt binders are reaching its limit to withstand such significant distresses and are, nowadays, almost standardly being modified with polymers to extend their performance.

The most common solution used in Germany to enhance the performance of flexible pavements is the use of a styrene-butadiene-styrene (SBS) modified asphalt binder. SBS increases the performance against rutting; has shown an increased fatigue resistance and prevents low temperature cracking as well [1]. But on the other hand, it requires very special handling. For the modification, a separate tank with a high shear mixer for the dosage is needed. And before being able to produce, a given swelling time has to go by. Furthermore, SBS has a poor compatibility with asphalt binder, mainly due to it being a physical modification [2-3]. The binder is divided in two phases, and if not carefully manufactured, storage stability problems can occur. Only by using additional additives (like sulphur, shale oil, among others) some of these problems can be solved [4-5].

In this research report, a new type of chemical modification is introduced. The additive, called AS20 [6] in this report, is a black reactive low viscous fluid, that as well as SBS, decreases the thermal susceptibility and increases the elastic response of asphalt binders. But being it a chemical modification, the modified binder continues to be a one phase component. Throughout the report, the AS20 modification is compared with the neat (unmodified) binder, to evaluate the effect of the additive. Due to very similar performance and material characteristics, AS20 modified binders are also compared with SBS modified bitumen.

2 OBJECTIVES

The objective of the research report is to present the findings of a two-year joint research project between the Institute of Highway Engineering of the RWTH Aachen (ISAC RWTH), the ISAC GmbH and BASF SE. The aim of the project was to study the suitability of a reactive thermosetting monomer as an asphalt binder additive that increases the performance of flexible pavements. The secondary goal was to identify through rheological tests, the polymeric network that this monomer creates within the chemical structure of the binder.

3 METHODOLOGHY

To study the effect of AS20 as an additive for flexible pavements, the research project was divided in three parts (Figure 1). Firstly, conventional and rheological (performance-oriented) binder tests were performed. After a comprehensive analysis of the influence of the AS20 additive on the binder properties, the effects on the performance on an asphalt level were studied. Mainly the resistance against rutting, fatigue and low temperature cracks were investigated on laboratory produced specimens. Finally, the last part consisted of real scale tests. The binder was modified at an asphalt mixing plant and then asphalt mixtures were produced. A three-layered pavement was built on the ISAC test track and specimens were drilled from the test track and were subsequently tested in the laboratory.

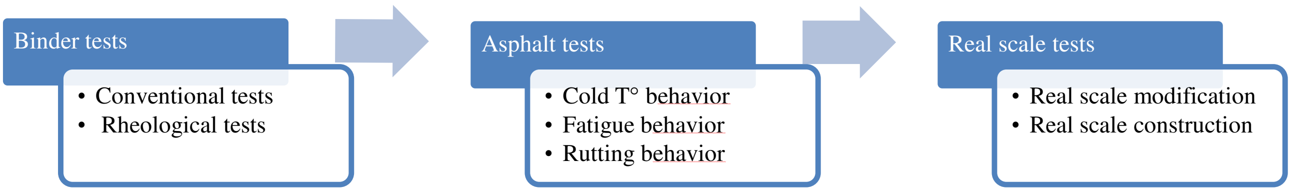

Figure 1 - Test program of the project

3.1 Binder tests

The first trial comprised 4 different variants plus a benchmark polymer modified binder for comparison (Table 1). The following tests were performed: needle penetration (EN 1426), softening point (EN1427), force-ductility (EN 13589), dynamic viscosity, temperature sweeps (T-Sweep) and multiple stress creep recovery test (MSCR) with the dynamic shear rheometer (EN 14770 and EN 16659), and low temperature tests with the bending beam rheometer (BBR - EN 14771). Specific tests were carried out after short-term aging with the rolling thin film oven test (EN 12607-1), and long-term aging with the pressure aging vessel (EN 14769).

3.2 Asphalt tests

The asphalt testing comprised the analysis of the deformation, fatigue and cold behaviour of asphalt mixtures. To characterize the deformation behaviour, the following tests were done: uniaxial cyclic compression test (EN 12697-25) and the wheel tracking test (EN 12697-22). To study the low temperature behaviour, two tests were chosen: the uniaxial tensile strength test and the thermal stress restrained specimen test (EN 12697-46). Finally, to characterize the fatigue behaviour, the cyclic indirect tension (EN 12697-24) test was performed.

3.3 Real scale tests

Two real scale trails have been conducted. For both trials, a commercial asphalt mixing plant was used to modify the binder and produce the asphalt mixtures. The mixing plant is located approximately 30 km from the ISAC RWTH. In both cases 12 tonnes of binder were modified using a high shear mixer (HSM) to blend the AS20 additive. In the first trial, 1,5 wt.% AS20 was added to the binder by weight, while in the second trial, 2,0 wt.% was employed. In both cases, the modification was done at a temperature of 150 °C in the asphalt binder tank.

In the first trial, after producing the mixtures at the plant, three layers were paved in the 30 m long test track. For the construction of the layer, a VÖGELE Road Paver SUPER 800-3i a HAMM compacter was used.

Samples of unmodified binder were taken from the tank prior to the modification to compare with later modified one. On the second trial, unmodified binder was additionally modified in the laboratory to compare the unmodified and mixing plant modified binder with an "ideally" (laboratory) modified one.

4 MATERIALS

AS 20 [6] is a thermosetting reactive monomer developed by BASF SE, that due to its functional groups, reacts with the components of asphalt binder, in particular, the asphaltenes and aromatics, changing the inner-structure by interlocking the asphaltenes and aromatics (Figure 2). The formed polymeric network increases the elasticity of the binder, making it less susceptible to temperature changes, and enhancing the performance of asphalt binders as it will be shown in the following chapters. To date, no methods have been found to physically visualize this network. So, as mentioned previously, the only alternative is to identify the network through rheological tests.

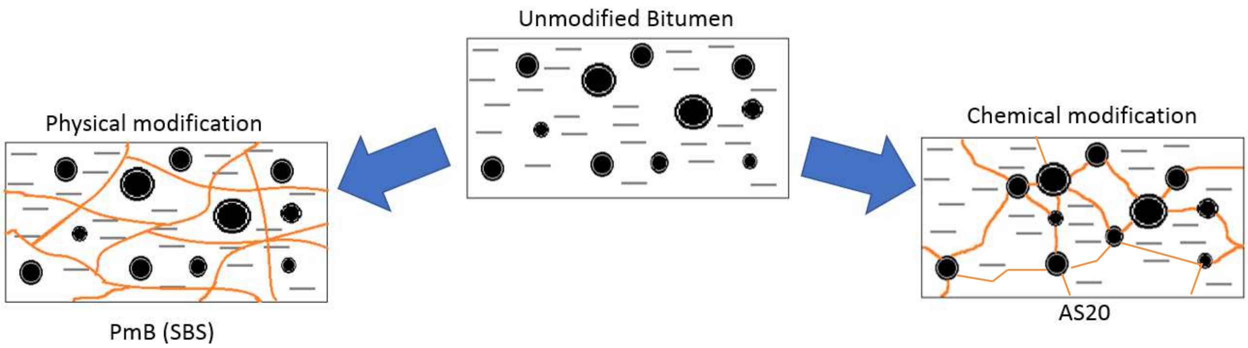

Figure 2 - Chemical modification with AS20 compared with a PmB (SBS modification)

4.1 Chemical modification

For the binder tests, the blending of AS20 was done by adding 2,0 wt.% of AS20 to a sample of asphalt binder at 150 °C, while stirring it at 400 rpm. The blending of the additive was monitored with Fourier-Transform Infrared Spectroscopy (FTIR) measurements. With this instrument, AS20 can be identified in the binder, and the completion of the reaction can be monitored.

4.2 Asphalt Binders

For this project, different binders from different companies were chosen (Table 1). For comparison, an SBS modified PmB was also tested.

Table 1 - Overview of the asphalt binder variants

Variant	Softening Point [°C]	Needle Penetration [dmm]	State
Bit A.1	51,8	42	Neat
Bit A.2	66,0	20	Modified with 2 wt.% AS20
Bit B.1	50,4	44	Neat
Bit B.2	63,0	26	Modified with 2 wt.% AS20
Bit C.1	45,2	82	Neat
Bit C.2	52,6	45	Modified with 2 wt.% AS20
Bit D.1	46,4	63	Neat
Bit D.2	54,9	32	Modified with 2 wt.% AS20
PmB	63,7	41	PmB

4.3 Asphalt mixtures

The asphalt mixture chosen for the first laboratory asphalt tests was a split mastic asphalt (SMA) with a maximum aggregate size of 8 mm (an SMA 8 S). The selected binders are shown in Table 2. The specimens for all three SMA 8 S variants were produced in the laboratory with the same asphalt mixtures recipes.

Table 2 - Overview of SMA 8 S variants

Variant	Binder Type
REF	B.1 from Table 1, no AS20
AS20	B.2 from Table 1, 2 wt.% AS20
PmB	25/55-55, no AS20

4.4 Real scale asphalt mixtures

For the first real scale trial, the chosen asphalt mixtures are shown in Table 3 [7]. Although three layers were built, only the surface layer was fully tested, while the binder layer was only partially tested. For all three layers a PEN 50/70 binder was modified. To study the effect of the additive, unmodified binder was taken from the tank before the modification to reproduce reference specimens in the laboratory with the same mixture design, for comparison. The second trial was focused on the optimization of the modification.

Table 3 - Overview of test track layers

Variant	Binder Type	Asphalt Mix	Max. Aggregate Size
Surface layer	50/70 + 2 wt.% AS20	SMA 8 S	8 mm
Binder layer	50/70 + 2 wt.% AS20	AC 16 B S	16 mm
Base layer	50/70 + 2 wt.% AS20	AC 22 T S	22 mm

5 RESULTS AND DISCCUSION

In the following chapter, the results of the three stages of the research project are presented: asphalt binder tests, laboratory asphalt tests, and finally the results of the real scale modification and construction.

5.1 Conventional binder test results

The results (Table 1 and 4) show that the additive increases the softening point and decreases the needle penetration in all cases, which indicates that the additive increases the elasticity of the binder. Looking at the force ductility test results, AS20 increases the maximum load. Figure 3 compares the force displacement results of neat binder, PmB and the AS20 modified binder. The working principle of AS20 can be clearly seen here. As the binder specimen is pulled apart, the network of asphaltenes acts against the pulling force. Compared to the polymer modified and the neat variant, the AS20 modified binder shows a lower susceptibility to deformation at small elongations, like the ones produced by real traffic in flexible pavements. Due to the characteristics of the modification, no resistance at large displacements can be seen, as in the PmB variant.

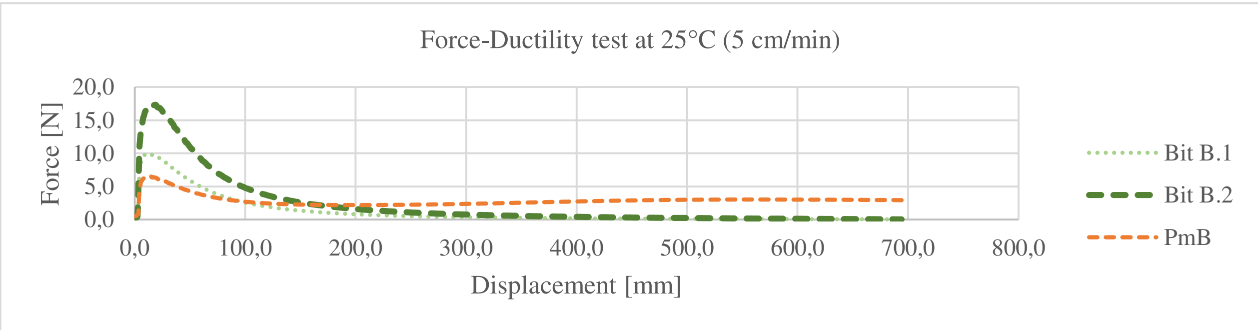

Figure 3 - Force ductility test results of variant Bit B compared to a PmB

Table 4 – Force-Ductility test results

Variant	Force-Ductility max. Load [N]*
Bit A.1	6,7 / 16,3
Bit A.2	22,0 / 30,4
Bit B.1	9,9 / 18,8
Bit B.2	17,4 / 26,0
Bit C.1	1,9 / 3,6
Bit C.2	3,8 / 4,3
PmB	6,5 /14,7

*before and after RTFO

5.2 Rheological asphalt binder test results

In Table 5 the results of the dynamic viscosity of variants B and the PmB variant are presented. The AS20 additive increases the viscosity of the neat binder, but to a much lower extent than SBS modification. This indicates that the workability of an AS20 modified asphalt mixture can be improved when compared with asphalt mixtures containing polymer modified binder while binder performance is increased by the AS20 additive at the same time. Ongoing research confirms this hypothesis.

Table 5 - Dynamic viscosity test results

Variants	Dynamic Viscosity [mPa s]	
	@ 135°C	@ 150 °C
Bit B.1	4800	240,0
Bit B.2	1.250,0	550,0
PmB	2.430,0	1.210,0

In Figure 4 and Figure 5 the T-Sweeps of all variants are shown, the ascending curves corresponding to the phase angle, and the descending curves to the complex shear modulus. In both cases, the complex shear modulus shifts upwards and the phase angle shifts downwards along the entire temperature range. This effect confirms the existence of a network between constitutive components within the binder. The increase in elasticity is only possible due to the network between asphaltenes and aromatics within the binder.

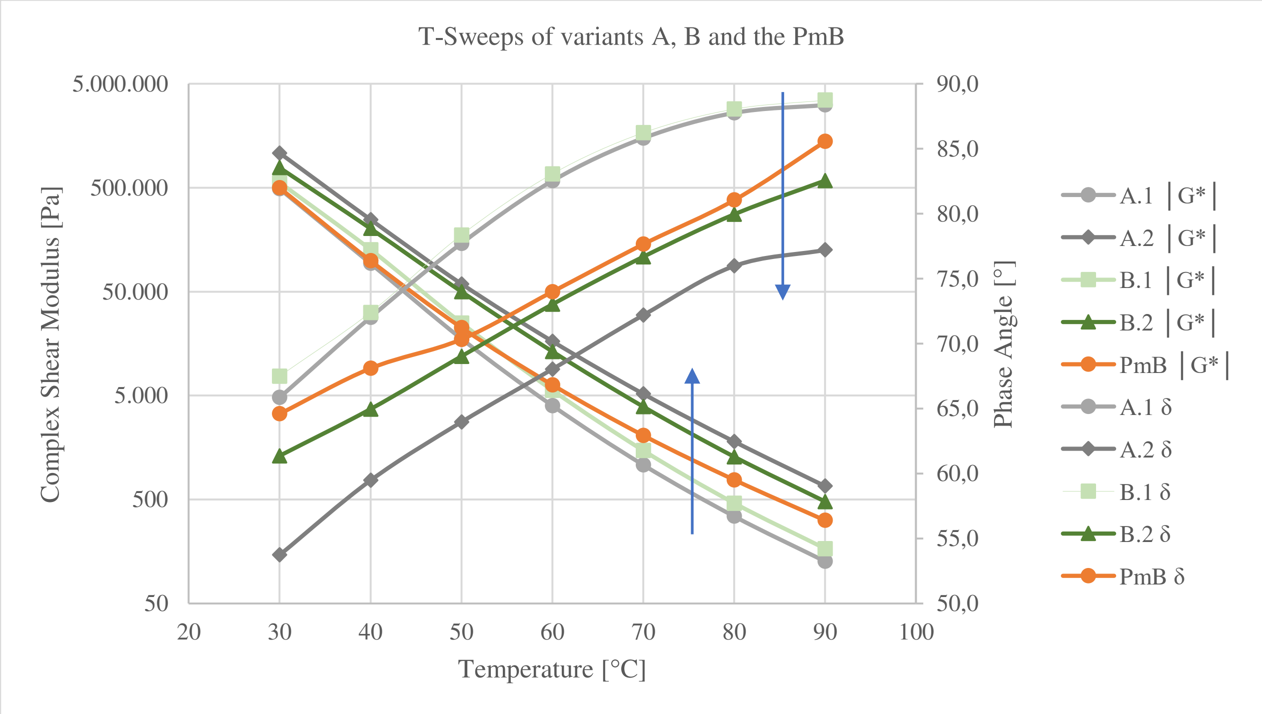

Figure 4 - T-Sweeps of variants A, B and PmB

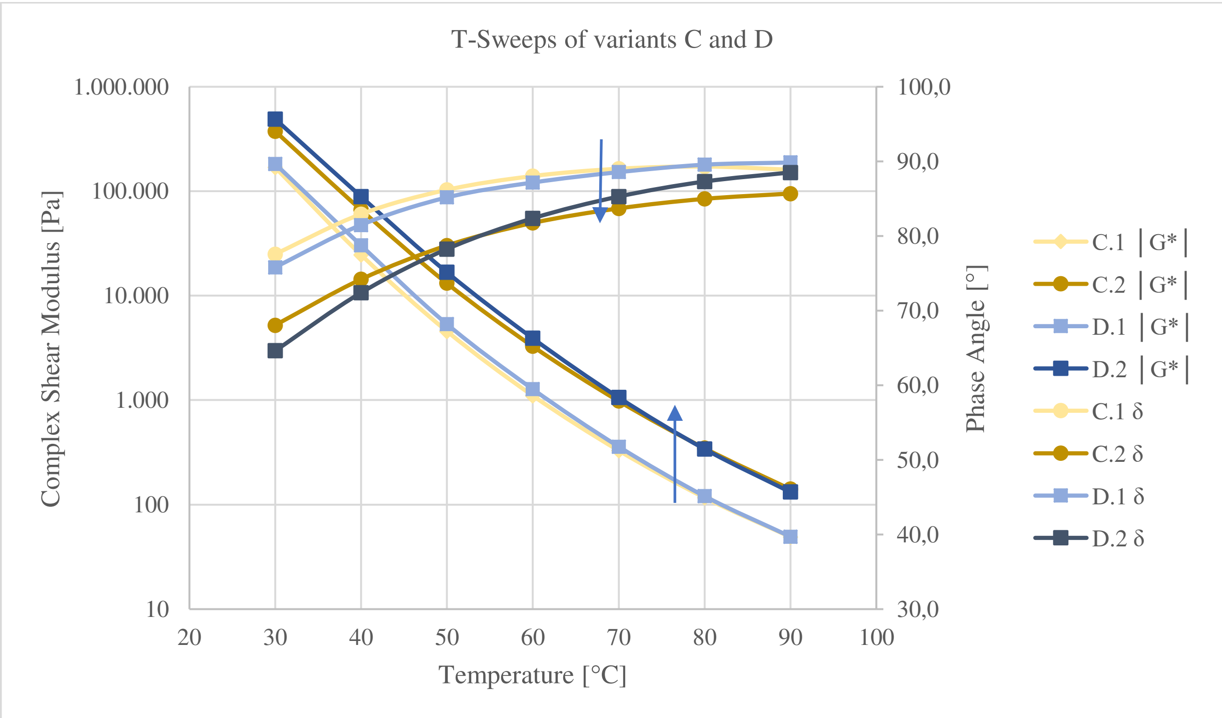

Figure 5 - T-Sweeps of variants C and D

With respect to the MSCR, the results after short-term aging show an interesting trend (Table 6). The recovery values increase, while the non-recoverable creep compliance (Jnr) decreases. The measurements are usually done after short-term aging, when rutting is more probable to occur. There is a high correlation between a reduction of the Jnr value and the rutting susceptibility of a road [8]. AS20 reduces by more than half the Jnr values in all cases. The MSCR test has gained importance [9], as it can be a better way of characterizing modified asphalt binders, in comparison, for example, with the elastic recovery test.

Table 6 – MSCR results after short-term aging (RTFO)

Variants	RN (3,2 kPa) [%]	Jnr (3,2 kPa) [kPa-1]
Bit A.1	6,5%	98,0
Bit A.2	43,3%	13,8
Bit B.1	5,4%	81,0
Bit B.2	29,5%	29,0
Bit C.1	0,0%	367,9
Bit C.2	6,6%	123,1
Bit D.1	0,0%	412,1
Bit D.2	8,1%	96,4
PmB	30,2%	42,9

Results after RTFOT aging (at 60°C)

In Table 7 the results of the BBR are shown. The m-value is an indicator of the stress relaxation capability of binders at a defined temperature [10]. The stiffness, on the other hand, correlates with the thermal cracking of a road. Using [11], the lower continuous grade for the different variants is estimated. This is done by calculating where the m-value is equal to 0,300 [-] and/or the stiffness (S) is equal to 300 [MPa]. The higher temperature is then the continuous PG grade. AS20 shows a very small influence on the low temperature behaviour which might be attributed to the minimal oxidative aging triggered by the modification procedure.

Table 7 – Bending beam rheometer test results

Variants	Temperature at m-value = 0,300 [-] or S = 300 [MPa] [°C]
Bit B.1	-20,5
Bit B.2	-18,3
Bit D.1	-35,9
Bit D.2	-34,1
PmB	-20,6

All results presented in Table 7 are obtained after long-term aging. This procedure was performed that way because the performance of binders at low temperatures is most critical when it has been affected by oxidative aging. After long-term aging, binders become stiffer and are more susceptible to thermal cracking due to brittleness at low temperatures.

Summarizing all binder results, it can be stated that the same amount of AS20 modifies different binders to a different extent. This could be explained by varying chemical compositions of the binders. Asphaltene-richer binders (gel) are easier to modify with AS20 than binders with lower amounts of high polarity asphaltenes (sol) [12]. From the results, it can be concluded that the additive extends the elastoplastic span of the binder. The lower limit remains similar, but the high temperature range is extended, being able to use the modified binder for more loaded roads, slower heavy traffic and warmer climate conditions.

5.3 Laboratory asphalt tests results

Mainly due to improved modifications which were achieved and the asphalt binder availability, binder B was selected for the asphalt laboratory tests. As mentioned before, an extensive test plan was implemented to assess the performance of AS20 against rutting, fatigue and thermal cracking.

5.3.1 Rutting

To study the rutting resistance of the AS20 modified asphalt, the wheel tracking test (results in Figure 6), and the uniaxial cyclic compression test (results in Figure 7 and Table 8) were done. Both tests are the current standard in Germany to assess the rutting performance of surface and binder layers and have been proven to have good correlations to rutting in flexible pavements as presented in [13].

In Figure 6, the average rut depth of a rubber wheel track over 20.000 cycles at 50 °C in the asphalt sample is plotted. The difference between the variants can be clearly seen in the graph. The AS20 modified surface layer shows the best performance against rutting, outperforming the polymer modified variant. This confirms what was observed at the binder tests in the MSCR and T-Sweeps.

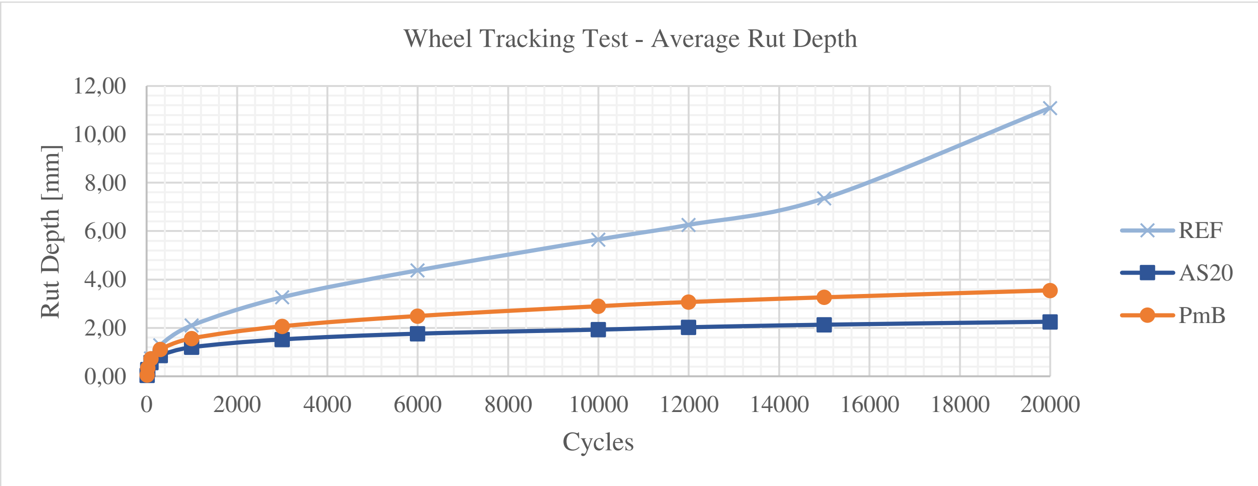

Figure 6 - Wheel tracking test results of laboratory asphalt samples

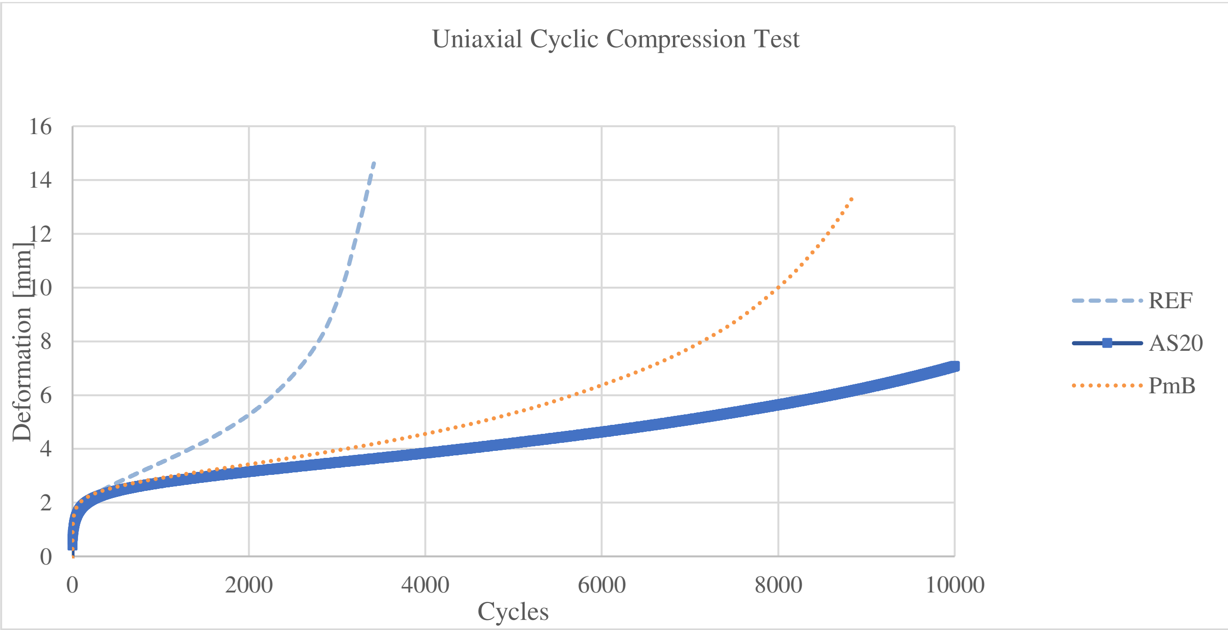

Figure 7 - Uniaxial cyclic compression test results

In the uniaxial cyclic compression test (UCCT), a Haversine-shaped load is applied to a specimen at 50 °C, with an upper and lower compression load of 0,35 MPa and 0,025 MPa, respectively. The accumulated deformation of cylindric asphalt specimen over the loading cycles (Figure 7) demonstrated the best performance of the AS20 modified asphalt. Both inflexion point and deformation rate at the inflexion point (Table 8) are performance indicators which describe the change in the accumulated strain rate (from constant to accelerated) and are a very good way to compare the rutting susceptibility of different asphalt mixtures [10]. Considering that the only substantial difference between the three variants is the binder used in the mixtures, AS20 displaced the inflexion point by a factor of three, positioning it even higher than the PmB variant. Moreover, the deformation rate is considerably reduced, thus confirming once again the increase in performance against rutting.

Table 8 - Uniaxial cyclic compression test results - Inflexion point and deformation rate

Variant	Inflexion Point [Cycles]	Deformation Rate [‰]
REF	1.002	16,1
AS20	3.307	3,0
PmB	1.937	4,3

5.3.2 Thermal cracking

The performance of AS20 at low temperatures was studied with the TSRST and the UTST (Figure 8). The TSRST is a good test to predict thermal cracking of asphalt roads, while the UTST is a good test to assess the strength of a layer at low temperatures [14]. At the intersection of the two curves, the temperature at which each layer is expected to fail can be predicted. These values are: -39 °C, -34 °C and -24 °C for the REF, AS20 and PmB variants respectively. The latter shows that both additives affect the low temperature behaviour by shifting the cryogenic stress curves to the right. Although AS20 shifts the low temperature performance of the layer slightly upwards, this can be, for example, compensated by choosing a softer binder for the modification since AS20 extends the high temperature range.

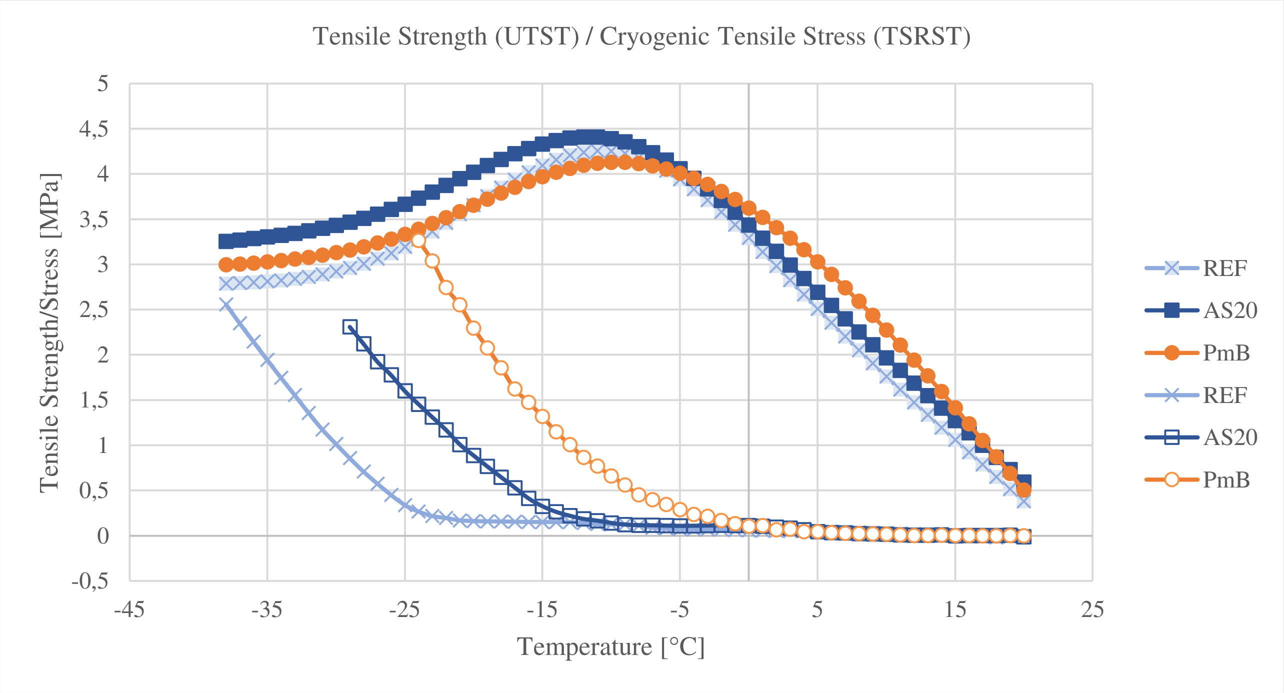

Figure 8 – Results of the UTST and TSRST tests

5.3.3 Fatigue

The German standard to assess the fatigue behaviour of asphalt mixes is the cyclic indirect tensile strength test. In this test, a cylindric specimen is diametrically cyclically loaded at 20°C. The curves (Figure 9) represent the number of cycles until failure for a given elastic strain. From the curves, the REF and PmB variants have a similar behaviour, while the AS20 modified asphalt shows a shift to the right, which means an increase in the performance against fatigue. For example, assuming an elastic strain of 0,1 ‰, the cycles to failure for the REF, AS20 and PmB variants would be: 5.181, 15.743, and 4.864 respectively. The AS20 modified variant would then resist three times more load cycles than the other two variants.

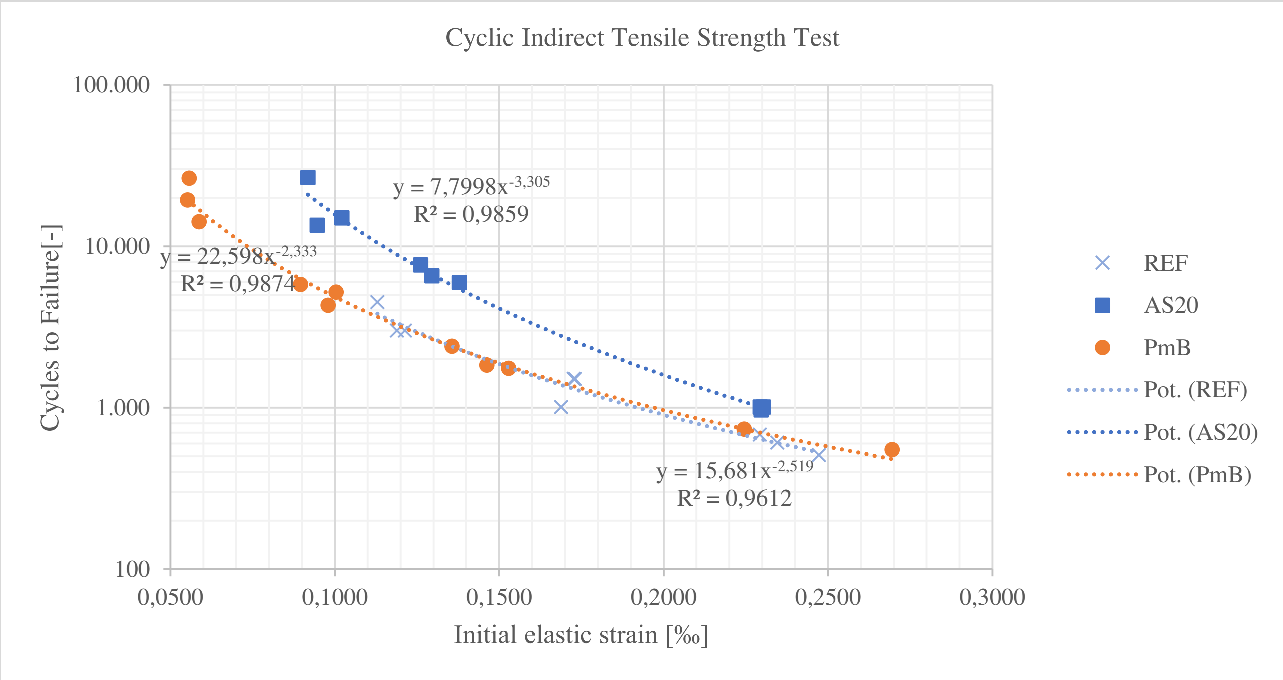

Figure 9 - Results of the cyclic indirect tensile strength tests

5.4 Test track results

After completing the laboratory tests, the next step was to study the additive on a real scale, by modifying asphalt binder in a commercial asphalt mixing plant and then paving the modified asphalt. The AS20 additive and neat binder were continuously dosed into a small stirred tank and subsequently pumped into a large binder storage tank via an HSM (recent studies revealed that an HSM is not necessary to modify the binder with AS20). Thereafter, the production of asphalt can be started directly. The modification could be monitored through the FTIR, by taking binder samples through a small spigot on the side of the binder tank periodically.

In contrast to PmB, the modification with AS20 does not require a separate tank nor a swelling period to start the production of asphalt. The asphalt was produced on the same day of the modification directly at the mixing plant.

5.5 Binder modification in the mixing plant

In the first real scale trial, the modification was done using only 1,5% AS20. In the second trial, the modification was carried out with 2,0% AS20 (Table 9 and Figure 10).

Table 9 - Binder test results of the real scale trials

Variants	Softening Point [°C]	MSCR* Recovery 3,2 kPa (%)	MSCR* Jnr [kPa^{-1}]	BBR** Temperature at m = 0,300 [-] [°C]
TT-1 REF	51,0	2%	172,2	-24,8
TT-1 PlantMod (1,5%)	54,5	5%	139,0	-30,8
TT-2 REF	50,41	2%	174,9	-30,8
TT-2 PlantMod (2%)	57,19	24%	37,0	-30,5
TT-2 LabMod (2%)	60,52	46%	13,3	-29,4

* Results after RTFO aging ** Results after RTFO+PAV aging

The results presented in Table 9 show that the modification on the second trial was much more effective, mainly due to the amount of AS20 used. Looking at the MSCR results, the non-recoverable creep compliance (Jnr) is reduced in both cases, especially on the second trial. While the low temperature performance stays almost unchanged (except for plant trial 1, where the low temperature limit is extended), the high temperature performance is increased in all cases.

The T-Sweep curves (Figure 10) show again an increase in the elasticity of the binder variants due to the additive. It can be stated that the modification in the laboratory is still more effective than the field modification. Secondly, the modification is dependent on the neat binder used.

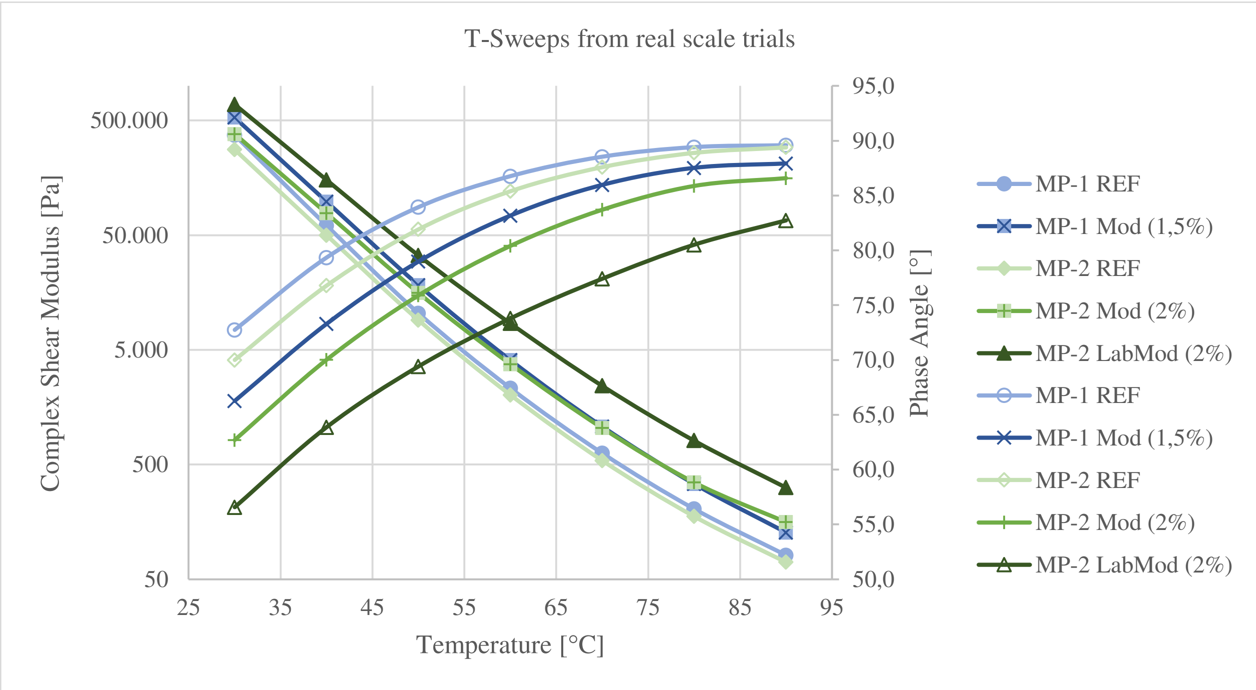

Figure 10 - T-Sweeps of the real scale trials

5.6 Real scale asphalt tests results

The test track is only used for a feasibility study but is not suited for evaluating asphalt under traffic conditions. After construction, asphalt specimens were drilled from the track. Considering that only 1,5% AS20 by mass of binder was added, the results show an improvement in the rutting performance compared to the unmodified REF variant seen in the sub-section 5.3 (Table 10). The break temperature is still lower than the PmB variant, while the fatigue behaviour of the surface layer is comparable to the REF and PmB variants.

It should be considered that no mix design was done prior to the production of the asphalt mixes. The recipe used were suited for a PmB. This has a big influence in the performance of asphalt layers. Ongoing studies show that the modification with AS20 leads to a lower increase in viscosity of the asphalt binder, than modification with SBS (see also chapter 5.2). Therefore, either pavements can be carried out at lower temperatures at comparable viscosity to PmB or an adjusted mix design is required to pave at standard temperatures as with PmB.

Table 10 - Summary of asphalt test results from specimens taken from the test track

Variant	**UCCT**		**UTST + TSRST**	**CITS**
	Inflexion Point [Cycles]	**Deformation Rate [‰]**	**Break Temperature [°C]**	**Loads to Failure [-] at 0,1 strain**
Surface Layer	1.424	9,07	-27,1	4.308
Binder Layer	1.542	2,37	-26,8	-

6 SUMMARY

According to the analysis presented, the following statements can be made:

- The rheological binder tests help to confirm the existence of a polymeric network among constitutive components (asphaltenes and aromatics) produced by the chemical modifier AS20.
- The degree of modification by AS20 is dependent on the chemical nature of the neat binder, i.e. different binders modified with the same amount of AS20 are modified to a different extent.
- AS20 modified asphalt shows an increased rutting and fatigue performance in asphalt samples produced in the laboratory. The performance at low temperatures is slightly affected but remains within an acceptable temperature range. Ongoing analysis on asphalt mixtures, where a softer binder was modified (e.g. PEN 70/100), show an improved low temperature behaviour and an excellent rutting performance at the same time, thus, expanding the usable elastoplastic temperature range.
- Asphalt binder modifications with AS20 were successfully and directly carried out in a commercial mixing plant. Swelling periods and a high shear mixing process as in case of polymer modification of binders are not necessary and asphalt mixtures containing AS20 modified binder are produced directly after AS20 dosage. Asphalt performance can be adjusted on demand by varying the concentration of AS20.
- The real scale asphalt tests confirmed binder and laboratory asphalt results. Current investigations show that even better results can be achieved when the mix design is adapted to the modified binder.
- Ongoing investigations show that AS20 modified asphalt requires less energy than SBS modified asphalt to achieve similar compaction levels at equal temperatures.

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Annex

1. Real Scale Trials

Since the publication of the paper in 2019, several real scale trials in trafficked pavement sections have been conducted, two of them in the United States and five in Germany. As an example, the construction of one of these trials will be presented in this annex. In August of 2020, a section with an extension of 2.5 km was paved using AS20 in Waldfischbach, Rhineland-Palatine, Germany. The paving trial consisted in a binder and surface layer, with 50% and 30% reclaimed asphalt, respectively. Before and after this section, the same mixtures but with a standard 25/55-55 polymer modified binder were paved. To test the recently discovered warm mix capabilities of AS20, the production and construction temperatures of the AS20 modified mixtures were 145°C and between 135°C-140°C, respectively. In the following pages, the experience and results of working with AS20 in the trial in Waldfischbach will be presented.

1.1. In-Line Modification

As mentioned in the main paper, being a low viscous fluid, AS20 requires less energy than standard polymers during modification. Therefore, the chemical additive can be dosed directly prior to mixing. In this trial, the additive was dosed directly to the binder weighing chamber, without influencing the normal mixing times. Once the additive comes in contact with the binder, it reacts with the functional groups of the binder. This reaction is not instantaneous; it keeps reacting during the mixing, storage, transport and construction. The functional groups that the neat binder develops due to the short-term oxidative aging experienced during these processes help the reaction. A similar effect is seen with reclaimed asphalt. During construction, good homogenization and workability have been seen in mixtures with high amounts of reclaimed asphalt. It is believed that this is due to the reaction of the additive with the functional groups of the binder in the reclaimed asphalt.

For the trial in Waldfischbach, a PEN 50/70 asphalt binder was modified with 2,5% by wt. of the additive referred to the total binder content (neat binder and the binder content of the reclaimed asphalt). The reference section was paved with a mixture produced with a polymer modified binder, the same neat 50/70 binder was used for the polymer modification.

1.2. Warm Mix

During the construction of a previous section in June 2019, where a binder layer with 50% reclaimed was being paved, a good workability was noticed during construction. This led to shortly study the temperature reduction capabilities of the additive in the laboratory, based on [1]. After obtaining satisfactory results, the additive was used to produce and pave a section with a warm-mix in Munich in late 2019, with successful results. Therefore, in Waldfischbach, the production and paving temperatures were also reduced. A temperature reduction is possible due the effect explained previously, the modification occurs during the different stages of the production and construction. The viscosity of the mixture is similar to the unmodified binder in the beginning, and it increases slowly as the different phases occur.

The temperature reduction comes with the added benefit of reducing the binder fumes and aerosols during construction, which at least in Germany, is of special interest, since the workplace exposure limit has been reduced from 10 mg/m^3 to 1.5 mg/m^3 [2]. This limit will come in effect in 2024.

2. Results

In the following section, the results of binder and asphalt test will be presented. The binder tests were performed on binder extracted from the asphalt mixture gathered during construction. The asphalt tests were performed on cores and beams drilled from roller compacted plates in the laboratory.

2.1. Binder Tests

Table 1 presents the results of the binder tests. To evaluate the behaviour in the high temperature range, and assess the rutting stability and the modification level achieved, following tests were performed: the softening point, the Binder Fast Characterization Test (BTSV) and the Multiple Stress Creep Recovery Tests (MSCR). First of all, it can be seen that all variants show a similar softening point. The only outliner is in the surface layer with AS20. The BTSV method delivers two values, the T_{BTSV} and the δ_{BTSV}, which represent the hardness and the modification of the binder, respectively [3]. The T_{BTSV} results show a similar trend than the softening point, where the AS20 surface layer sample strays slightly from the other three. This is supported by the δ_{BTSV}, where it can be seen that the modification level of this sample is lower than the other three. The lower the phase angle δ_{BTSV}, the higher the modification level. This analysis is also supported by the MSCR results. The recovery values (R%) are higher for the polymer modified variants, which can be expected due to the difference between the elastomeric polymers of SBS and the chemical crosslinking of AS20. Nevertheless, aside from the slight difference of the AS20 surface layer sample, the variants show a behaviour in a similar order of magnitude. To assess the behaviour of the binder at low temperatures, the bending beam rheometer (BBR) was used. In **Table 1**, the low temperature continuous grade calculated following the ASTM D7643-16 Standard are presented. It can be seen that the low temperature behaviour is dominated by the creep rate. In both cases, the continuous grade is very similar. AS20 shows a lower grade in case of the base layer, and a higher grade in the surface layer, although the difference in both cases is less than 1,5 °C.

Table 1. Binder tests results

Layer	Sample	Softening Point	BTSV		MSCR 3,2 kPa		BBR	
		[°C]	T_{BTSV} [°C]	δ_{BTSV} [°]	R [%]	Jnr [1/kPa]	$T_{m0.3}$	T_{S300}
Binder Layer	PmB	67.0	62.63	68.92	46.04	0.204	-21.7	-28.5
	AS20	67.2	64.26	69.59	32.84	0.195	-22.2	-25.9
Surface Layer	PmB	65.8	60.39	69.22	43.64	0.287	-23.5	-27.2
	AS20	62.8	58.91	72.55	13.96	0.606	-22.1	-26.3

2.2. Asphalt Tests

In **Table 2**, the results of several asphalt tests are presented. To assess the rutting stability, the wheel tracking (10.000 rollovers with a rubber wheel at 60°C) and cyclic compression tests (cyclic loading, 10.000 cycles at 50°C) were performed. Both tests show that the AS20 variant has a better performance against rutting than the reference variant. The rut depth (RD_{Air}) and the proportional rut depth (PRD_{Air}) are lower for AS20 sample in both cases. The similar effect can be seen with the strain and strain rate at the end of the test in the uniaxial cyclic compression test. The strain is lower in both cases, but the strain rate is not. The strain rate of the AS20 surface layer is slightly higher, which correlates with what was seen on a binder level. Regarding the low temperature behaviour, the results of the thermal stress restrained specimen test (TSRST) show that all variants should have a similar performance.

Table 2 - Asphalt test results

Layer	Sample	Wheel Tracking Test		Cyclic Compression		TSRST
		RD_{Air} [mm]	PRD_{Air} [%]	Strain [‰]	Strain rate [‰/n 10^4]	Break T° [°C]
Binder Layer	PmB	4.37	10.87%	61.80%	9.450	-27.9
	AS20	3.16	5.25%	54.30%	8.290	-25.4
Surface Layer	PmB	3.95	9.83%	35.90%	4.200	-24.3
	AS20	2.45	4.07%	26.45%	5.360	-26.0

3. Conclusions

From this short update, several conclusions can be drawn. First of all, it has been possible to pave several section in Germany and the US with this novel additive, some of them even at warm-mix temperatures. Lowering the production temperature, as can be seen in the binder and asphalt results, does not compromise asphalt performance. The findings presented in the main manuscript correlate with the experience and results from these real scale trials. Additionally, experience has been gained in the modification procedure. It has been possible to dose the additive in an in-line procedure, without affecting mixing times, thus allowing an on-demand production of modified asphalt mixture. Some of the sections paved with AS20 are being regularly monitored with profile measurements to evaluate their rutting stability over time. The additive AS20 is now commercially known as B2Last® and is commercialized by BASF.

4. REFERENCES

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