Warm Mix Asphalt / Low temperature asphalt

Optimizing Warm Mix concepts with combination products

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Abstract

When producing asphalt mixes at reduced production temperatures some material aspects have to be taken into account. The reduction in temperature of the final product is achieved by a reduced power to the burner in the heating drum. This could lead to parts of the moisture staying within the natural aggregates and the recycled asphalt pavement, because they cannot be completely evaporated due to the reduced heat energy. Consequently this could lead to insufficient coating of the aggregates or to moisture being captured. Possible effects may be deficiencies due to moisture or to reduced adhesion. Additionally it has to be taken into account that due to the reduction in mix temperature the timeframe for paving and compaction also gets significantly smaller. This has to be addressed at composition or equipment level. Within this investigation a combination product consisting of a Fischer-Tropsch-wax, a petroleum-based component and an adhesion promoter was added to the bitumen to solve the mentioned problems. This solid additive may be added at asphalt production level. To prove the modified properties compaction trials on a SMA 8 S have been conducted to quantify the influence on compactibility. Fatigue tests have been conducted on standard samples and samples produced at reduced temperatures. On the one hand a reference variant without additive and without temperature reduction was evaluated and on the other hand a modified variant with additive and temperature reduction. Both variants were stored in dry conditions after preparation. To simulate a possible moisture influence, the samples of both variants were additionally stored in water. The results allowed a solution with comparable technical properties at lowered production temperatures to be found.

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1. INTRODUCTION

Warm Mix Asphalt (WMA) is a designation for processes which can lower the production temperatures of asphalt to 100 to 150 °C compared to 140 to 190 °C for standard Hot Mix Asphalt (HMA) [1, 2]. It is regarded as being one of the key technologies for the future. It will make an important contribution to reducing binder aging in manufacturing, reducing emissions at the mixing plant and protecting the health of workers on the job site. When lowering the production temperatures, various technological problems can occur. Reduced performance in the drying drum of the fresh aggregates can result in moisture remaining in or on the aggregates which interferes with the further production process. Possible consequences are an incomplete coating of aggregates with bitumen or a difficult paving behaviour. With otherwise constant composition of the asphalt, a reduction in the temperature during paving additionally reduces the available compaction time span. Possible consequences of a reduction in production temperature can be the following:

- insufficient coating of minerals due to moisture residue
- water sensitivity of the asphalt mixes due to incomplete coating or insufficient affinity between binder and aggregate
- reduced compaction performance due to lowered paving temperature
- reduced layer performance due to reduced or insufficient compaction

Previous studies have shown different results regarding increased water sensitivity of the asphalt mixes due to residual moisture on the aggregates. Several researchers reported that residual moisture at the aggregates in WMA might result in a poor bond with the binder and therefore damage in the presence of water (e.g. [3, 4]). Goh and You [5] found similar Tensile Strength Ratio values (after/before water storage) for FT-wax modified warm mix and hot mix asphalts. In addition, another study [6] did not find differences between WMA and HMA regarding moisture damage in filed tests. This unclear situation triggered an extensive National Cooperative Highway Research Programme (NCHRP) research project in the USA [7]. The conclusions were that though the water sensitivity was not observed in the field, it was clearly proven by lab investigations, also with asphalt mix samples from mixing plants. The addition of hydrated lime or of chemical adhesion promoters successfully improved the water sensitivity. Therefore the addition of such additives was recommended for all WMA pavements.

2. CONCEPTION OF A COMBINATION PRODUCT

Conventional warm mix processes attempt to specifically address the possible consequences of a reduction in the production temperature, with the individual technical aspects sometimes being addressed differently [1]. Typical technologies are

- use of viscosity-reducing additives or viscosity-reduced binders (usually by using waxes)
- bitumen foaming technologies or zeolites
- chemical additives (mostly surfactants, also used as adhesion promoters)

The aim of the technical development in this case was the conception of a combination product that simultaneously addresses two main goals:

- significant improvement in the affinity between binder and aggregate in the presence of moisture and
- significant improvement in compactibility at reduced paving temperatures.

Basic components of the combination product are a Fischer-Tropsch wax modified with a petroleum-based component with the trade name Sasobit Redux [3] and a material that can be used as an adhesion promoter. Both products were combined on a laboratory scale to the combination product Sasobit Redux A (further on “modified FT wax”), so that a single component was available. The addition takes place directly to the heated bituminous binder. In this, the product is storage and heat stable. In contrast to previous procedures, this combination product avoids the challenges of selecting a compatible adhesion promoter, as well as storing, handling and correctly dosing additional materials at the asphalt mixing plant.

To prove the suitability of the product as a WMA additive, the following tests were carried out:

- Compaction tests at lowered temperatures to compensate for the reduced paving temperature
- Experiments to simulate the WMA manufacturing process in the laboratory to produce suitable specimens
- Water storage of the specimens to simulate a possible water sensitivity
- Modified fatigue tests before and after water storage for variants with and without WMA technology to address the performance characteristics

3. COMPACTION STUDIES

In order to determine the influence of the different additives on the compaction behaviour of the asphalt, compaction trials were carried out on a stone mastic asphalt SMA 8 S with three different binder types. The basis was a commercially available polymer modified bitumen PmB 25/55-55 A (further on “standard PmB”) according to TL Bitumen [9], which was the reference standard. In the second variant, the frequently used FT-wax Sasobit (further on “standard FT-Wax”) was stirred in at a dosage of 1.5 Wt.% by binder mass. The third variant consisted of the base binder and an addition of 1.5 Wt.% modified FT wax. From all variants, the stone mastic asphalt was produced by laboratory method. This was followed by the production of three Marshall specimens at compaction temperatures of 60, 80, 100, 120 and 145 °C following DIN EN 12697-30. On all specimens, the volume density was determined according to EN 12697-6 and TP Asphalt [10, 11], respectively, and an average was calculated from the three individual values. The results are shown in detail in Table 1 and graphically presented in Figure 1. The reference variant with the standard PmB shows the usual course of density increase with increasing compaction temperature. The variant with addition of the standard FT wax indicates a significant increase in the bulk density in the region of the compaction temperatures of 120 °C and 145 °C. Within this temperature range, the wax liquefies and produces a significantly improved compactibility of the asphalt mixture in laboratory compaction, which leads to a significant increase in bulk density, which leads in practice to an increase in the degree of compaction and is considered positive. At temperatures of 100 °C and 80 °C, however, compared to the reference variant lower bulk densities of the specimens are recorded. This is due to the temperature drop below the crystallization point of the standard FT wax used, which leads to a significant increase in viscosity of the binder. This confirms the finding that in FT wax-modified asphalts the compaction temperature in the laboratory has a lower limit. That the result of the bulk density at a production temperature of 60 °C is approximately identical to the result of the reference variant, must be regarded as insignificant, since the overall density at this temperature is to be classified as too low. In contrast, the compaction curve over the temperature in the third variant with the modified FT wax is clearly different. Here, over the entire temperature range, a significant increase in compaction occurred with unchanged compaction energy. At compaction temperatures of 120 °C and 145 °C, approximately the same results as in the variant with the standard FT wax are achieved.

As a result, it can be seen, that with the help of the modified FT wax a compaction temperature reduction of 25 K is possible. Instead of 145 °C as for the reference variant, here 120 °C lead to the same density state at the same compaction energy in the laboratory.

Table 1: Densities of Marshall specimens produced at different temperatures

Compaction Temperature	SMA 8 S with standard PmB (Reference)		SMA 8 S with PmB + 1.5 Wt % standard FT wax		SMA 8 S with PmB + 1.5 Wt % modified Wax	
	Density	Mean	Density	Mean	Density	Mean
[°C]	[g/cm³]	[g/cm³]	[g/cm³]	[g/cm³]	[g/cm³]	[g/cm³]
145	2.334	2.329	2.343	2.343	2.351	2.346
	2.328		2.346		2.341	
	2.324		2.339		2.345	
120	2.304	2.302	2.330	2.330	2.333	2.329
	2.302		2.326		2.335	
	2.299		2.335		2.318	
100	2.276	2.281	2.267	2.271	2.285	2.292
	2.282		2.267		2.288	
	2.286		2.279		2.303	
80	2.226	2.232	2.186	2.192	2.263	2.256
	2.237		2.193		2.255	
	2.234		2.197		2.250	
60	2.141	2.146	2.152	2.143	2.166	2.162
	2.153		2.146		2.155	
	2.144		2.132		2.166	

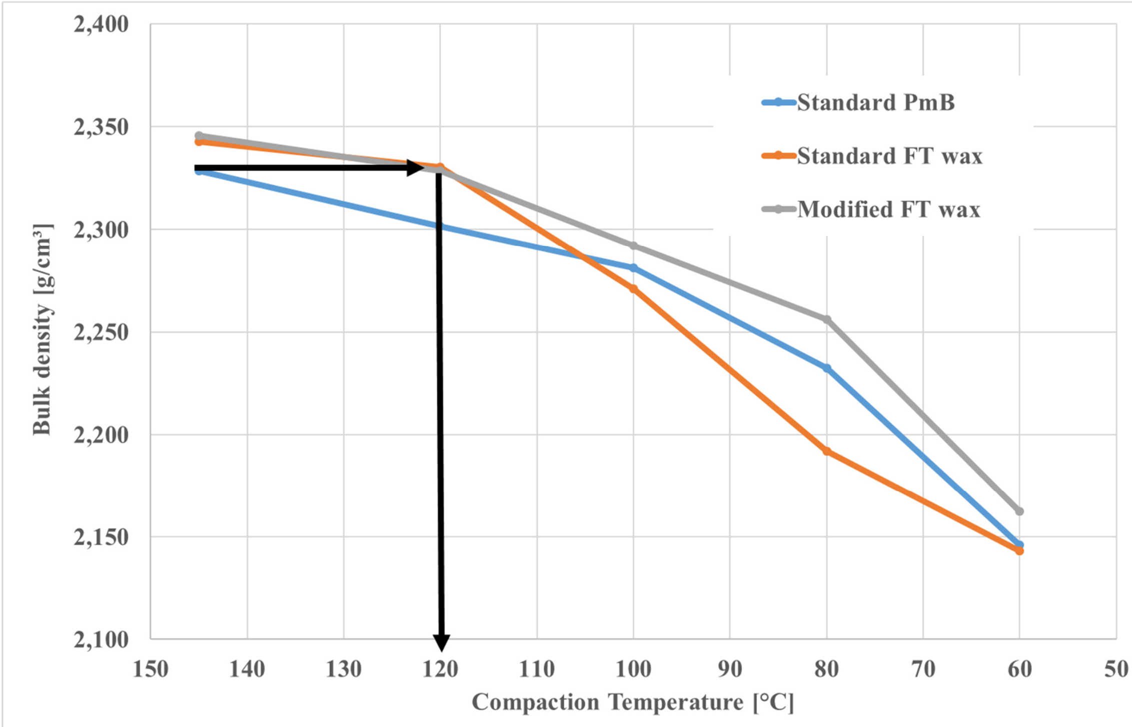

Figure 1: Change of marshall density over compaction temperature

4. WARM MIX LABORATORY SIMULATION

In order to prove the suitability of the combination product as a warm mix additive, further laboratory tests were carried out on the SMA 8 S with the reference binder and the reference binder with the addition of 1.5 Wt.% modified FT wax. Traditional warm mix processes aim to lower production temperatures by 10-30 °C [1]. Since in industrial production the temperature control of the end product is controllable only indirectly by the amount of heat of the aggregates and thus largely by the performance of the drying drum for the minerals, in the implementation of Warm Mix process, the burner power must be shut down or / and the transit time of the aggregates in the drum be reduced. Depending on how this process is adapted, it affects the moisture content of the minerals after leaving the drum. If the combination of temperature and transit time is too low, a higher moisture content will remain in the aggregates.
A variation of the drying drum process parameters cannot be simulated by directly transferring it to the laboratory, since the usual heating processes in the laboratory are different and a calibration on the real process is not possible. This is mainly since the setting of a realistic moisture content in the aggregates is not directly possible in the context of laboratory processes, as the dry weight is always weighed in order to work precisely. A targeted addition of moisture after drying appears unrealistic due to the much slower heating process in the laboratory, since the moisture is presumably evaporated before reaching the necessary compaction temperature.
For this reason, the laboratory production process for the asphalt is changed so that after the process steps

- drying,
- weigh in,
- heating the aggregates to a temperature 25 K below the temperature of the reference variant,
- premixing

a mass 3 Wt.% water is added to the mixer. This is done before adding the binder to the hot aggregate, where a part of the added water spontaneously evaporates due to steam formation. Subjectively, this affects about half of the added water. The residual moisture is obviously retained on the aggregate surfaces. This is followed immediately by the addition of the bitumen to the mixture and another mixing process. The mixing time is thereby not changed compared to the reference variant. The aim of this procedure is to simulate the influence of remaining moisture on the mixing process.
Two variants of the same stone mastic asphalt SMA 8 S as in the compaction trials were investigated. The following variants were tested:

- SMA 8 S with 25 / 55-55 (reference variant) in conventional laboratory production (145 °C compaction temperature, no addition of moisture) -> Variant 1
- SMA 8 S with 25 / 55-55 and 1.5% modified FT wax with WMA simulation of laboratory production (120 °C compaction temperature, 3% moisture addition) -> Variant 2

From both variants, sample plates were produced using the rolling sector compactor and the volumetric characteristics were determined. From these plates, cores were drilled which were used for the further tests.
The reference version 1 with conventional test specimen production achieved an average density of 2.414 g/cm³. For variant 2, a bulk density of 2.411 g/cm³ was obtained in WMA simulation and compaction at 120 °C, which must be considered equivalent to the reference variant. In this respect, the combination product is suitable to compensate for the effect of a 25 °C reduced manufacturing temperature without restrictions in terms of compaction degree.

5. WATER EXPOSITION

In order to determine a possible water sensitivity of the compacted asphalt, one half of the test samples is subjected to a water storage based on German technical rules [12, 13]. The specimens are stored for 72 hours at 40 °C under water in a desiccator under vacuum.

6. PERFORMANCE TESTS

To determine the performance of the different versions, modified fatigue tests following the German standard TP Asphalt-StB Part 24 [14] (Modified German version of Tensile Strength Ratio DIN EN 12697-24, annex E) were carried out. To determine the fatigue function, a sinusoidal pressure threshold load is imposed on a cylindrical test specimen via two load entry rails diametrically opposite one another on the lateral surface using the indirect tensile test. In this case, a biaxial stress state is formed in the test specimen. When the specimen is loaded, a horizontally oriented tensile stress is produced, which is almost constant in the middle region of the vertical specimen axis. This significantly affects the material fatigue and thus the damage of the sample. Furthermore, a vertically directed compressive stress is induced, which is variable over the vertical specimen axis. This compressive stress also influences the fatigue progress during the test, but to a much lesser extent compared to the tensile stress. When performing the indirect tensile test to determine the fatigue function of asphalt, the specimens are subjected to a load at a test temperature and a loading frequency until reaching the fatigue criterion.
Cylindrical specimens according to TP Asphalt-StB Part 27 [15, 16] were drilled out of asphalt sample plates, produced with the rolling sector compacting device according to the TP Asphalt-StB, Part 33. Their densities were measured by means of underwater weighing according to TP Asphalt-StB Part 6 [10, 11]. The specimens used have a height of 40 ± 3 mm and a diameter of 100 ± 3 mm. The investigated variants are shown in Table 2.

Table 2: Tested samples

	asphalt	binder	production	compaction temperature	storage
1.1	SMA 8 S	Standard PmB	Standard	145 °C	dry
1.2					wet
2.1		PmB + 1.5 Wt.% modified FT wax	WMA-simulation	120 °C	dry
2.2					wet

The test parameters are as follows:

- Test temperature: 20 °C
- Load frequency: 10 Hz
- Lower stress level: 0.035 MPa
- Nominal upper stress level for variant 1.1: 0.24 and 0.55 MPa
- Nominal upper stress level for variant 1.2: 0.24 and 0.55 MPa
- Nominal upper stress level for variant 2.1: 0.23 and 0.60 MPa
- Nominal upper stress level for variant 2.2: 0.23 and 0.60 MPa

Compared to the specification of the actual test standard, the selected upper stress levels have been reduced from three to two values, since due to the usually high precision of the method, in principle very high regression coefficients are obtained.

As a result of the fatigue tests, each of the four tested variants receives three individual results in the form of a number of load repetitions until the macro-crack occurs as defined in [14]. The results of the different variants are given in the tables. If one compares the two variants with dry storage (see Table 3 for standard PmB and Table 5 for modified FT wax) and the two variants with wet storage (see
Table **4** for standard PmB and

Table 6 for modified FT wax), it becomes clear that in each case only very slight differences exist in the fatigue functions obtained. However, the two WMA variants are - although not significantly - slightly better than the results of the variants with conventional production.

Table 3: Fatigue results for SMA 8 S with standard PmB after dry storage

Testing temperature [°C]	Poisson's ratio μ [-]	Upper stress level σ_0 [MPa]	Initial elastic horizontal strain $\varepsilon_{el,anf}$ [‰]	Repetition until fatigue damage N_{Makro} [-]
20	0.30	0.55	0.238	2040
			0.224	2572
			0.230	2610
		0.24	0.089	65870
			0.084	93000
			0.081	94800

Table 4: Fatigue results for SMA 8 S with standard PmB after water storage

Testing temperature [°C]	Poisson's ratio μ [-]	Upper stress level σ_0 [MPa]	Initial elastic horizontal strain $\varepsilon_{el,anf}$ [‰]	Repetition until fatigue damage N_{Makro} [-]
20	0.30	0.55	0.267	2104
			0.231	3188
			0.235	2806
		0.24	0.094	80000
			0.099	89655
			0.082	95150

Table 5: Fatigue results for SMA 8 S with modified FT wax after dry storage

Testing temperature [°C]	Poisson's ratio μ [-]	Upper stress level σ_0 [MPa]	Initial elastic horizontal strain $\varepsilon_{el,anf}$ [‰]	Repetition until fatigue damage N_{Makro} [-]
20	0.30	0.60	0.268	1952
			0.303	1441
			0.289	1545
		0.23	0.078	156000
			0.071	144000
			0.078	142600

Table 6: Fatigue results for SMA 8 S with modified FT wax after water storage

Testing temperature [°C]	Poisson's ratio μ [-]	Upper stress level σ_0 [MPa]	Initial elastic horizontal strain $\varepsilon_{el,anf}$ [‰]	Repetition until fatigue damage N_{Makro} [-]
20	0.30	0.60	0.250	2202
			0.271	2088
			0.301	1950
		0.23	0.101	110160
			0.086	171393
			0.091	133020

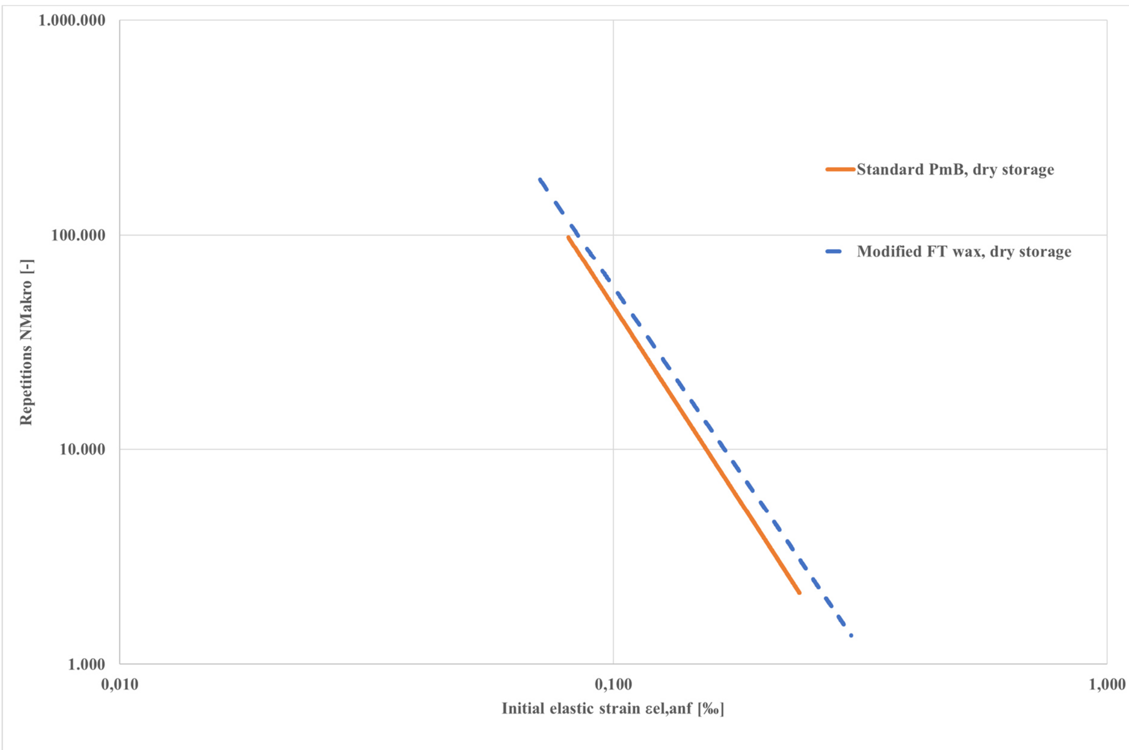

Figure 2: Comparison of fatigue results – dry storage

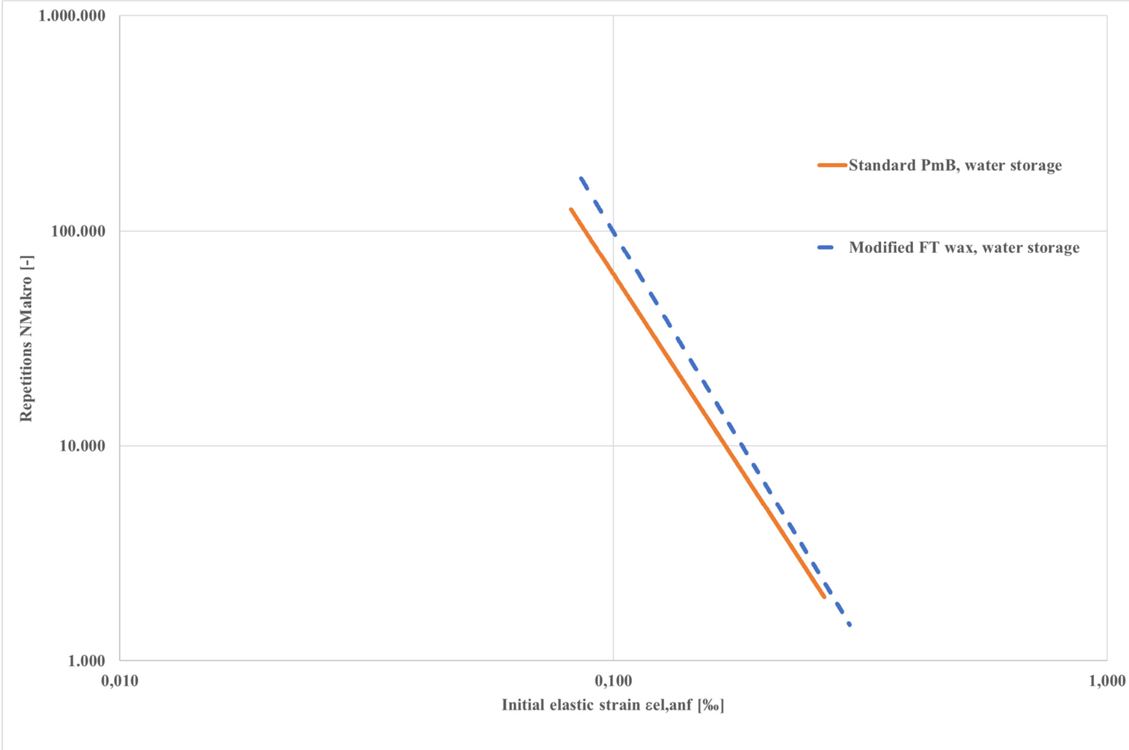

Figure 3: Comparison of fatigue results – water storage

7. SUMMARY

A warm mix additive was designed as a combination product of a modified FT wax and an adhesion promoter. The additive should address at the same time the effect of moisture retentions at the surface of the aggregates and a reduced compactibility due to a reduced compaction temperature and should enable easy usage

As part of the investigation, compaction tests were carried out. This resulted in a possible reduction of the compaction temperature from 145 °C to 120 °C at a constant compaction state when using the additive. The effect of possibly remaining moisture in the aggregate mixture was investigated using a laboratory WMA simulation. The specimens thus obtained were subjected to performance studies with and without water storage. As a result, for the variants with additive and 25 Kelvin of reduced compaction temperature, an equivalent to slightly improved performance compared to the reference variant is shown. The combination product is thus very well suited in relation to the investigations carried out to realize a lowering of the production temperature by ca. 25 Kelvin.

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REFERENCES

[1] European Asphalt Pavement Association: The use of Warm Mix Asphalt. EAPA-Position Paper. Published online on www.eapa.org. Brussels/Belgium, 2014. Last downloaded August 01th 2019

[2] Forschungsgesellschaft für Straßen- und Verkehrswesen: Zusätzliche Technische Vertragsbedingungen und Richtlinien für den Bau von Verkehrsflächenbefestigungen aus Asphalt, ZTV Asphalt-StB 07/13, edition 2007/version 2013. FGSV Verlag, Köln/Germany, 2014

[3] Hurley, G. C. and Prowell, B. D., Ecaluation fo Sasobit for use in warm mix asohalt, NCAT Report 05-06, Auburn, National Center for asphalt Technology, 2005

[4] Kvasnak, A. N. and West, R. C., Case study of warm mix asphalt moisture susceptibility in Birmingham, Alabama, Transport Research Boar 88th annual meeting, No. 09-3703, Washington DC, 2009

[5] Goh, S. W. and You, Z.; Evaluation of warm mix asphalt produced at various temperatures through dynamic modulus testing and four point beam fatigue testing. Proceedings of the GeoHunan international conference –

pavements and materials: Recent advances in design, testing and construction. Hunan, Geotechnical Special Publication, Vol. 212, China, 2011, 123-130
[6] Hurley, G., Prowell, B. and Kvasnak, A., Wisconsin field trial of warm mix asphalt technologies. Construction Summary (NCAT Report 10-04), Auburn, National Center for Asphalt Technology, 2010
[7] Epps, A. E: et al, Evaluation of the Moisture Susceptibility of WMA Technologies, NCHRP Report 763, Transport Research Board, Washington DC, 2014
[8] Sasol Performance Chemicals: Sasobit REDUX – Produktinformationen (product information). September 2016 Published online on www.sasobit.de. Last downloaded August 01th 2019
[9] Forschungsgesellschaft für Straßen- und Verkehrswesen: Technische Lieferbedingungen für Straßenbaubitumen und gebrauchsfertige Polymermodifizierte Bitumen, TL Bitumen-StB 07/13, edition 2007/version 2013. FGSV Verlag, Köln/Germany, 2013
[10] European Standard EN 12697-6: Bituminous mixtures - Test methods for hot mix asphalt - Part 6: Determination of bulk density of bituminous specimens; German version EN 12697-6:2012
[11] Forschungsgesellschaft für Straßen- und Verkehrswesen: Technische Prüfvorschriften für Asphalt, TP Asphalt-StB, Teil 6: Raumdichte von Asphalt-Probekörpern, edition 2016. FGSV Verlag, Köln/Germany, 2016.
[12] European Standard EN 12697-12: Bituminous mixtures - Test methods - Part 12: Determination of the water sensitivity of bituminous specimens; German version EN 12697-12:2018 (Method A), 2018
[13] Forschungsgesellschaft für Straßen- und Verkehrswesen: Technische Prüfvorschriften für Asphalt, TP Asphalt-StB, Teil 12: Wasserempfindlichkeit von Asphalt-Probekörpern, edition 2007. FGSV Verlag, Köln/Germany, 2008
[14] Forschungsgesellschaft für Straßen- und Verkehrswesen: Technische Prüfvorschriften für Asphalt, TP Asphalt-StB, Teil 24: Spaltzug-Schwellversuch – Beständigkeit gegen Ermüdung, edition 2018. FGSV Verlag, Köln/Germany, 2018
[15] European Standard EN 12697-27: Bituminous mixtures - Test methods - Part 27: Sampling; German version EN 12697-27:2017
[16] Forschungsgesellschaft für Straßen- und Verkehrswesen: Technische Prüfvorschriften für Asphalt, TP Asphalt-StB, Teil 27: Probenahme, edition 2016. FGSV Verlag, Köln/Germany, 2016