Studying the aging influences on the calculated pavement design life of surface course asphalt mixes

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Contribution theme

01. Asphalt mixture performance and testing

Executive summary

Road construction is facing new challenges in terms of economy and environment. The search for optimization potential in production, paving and reuse is being driven forward, with sustainability playing a central role. The German regulations on RDO Asphalt offer a procedure for predicting the service life of road structures. However, this set of rules focuses mainly on the asphalt base course in the verification and needs to be extended for application to asphalt surface courses. Particular issues with asphalt surface courses are influences from aging and from freeze-thaw cycles. In order to simulate these influences, laboratory tests were carried out on an AC 8 D S with 50/70 road bitumen. For aging, specimens were treated for 60 h at 60 °C with an ozone-air mixture. The effect of freeze-thaw cycles in combination with water and a sodium chloride solution were simulated by the CDF test. Based on fatigue, stiffness, and low temperature tests, associated material parameters were determined and further development of the material model continued. Calculations on service life predictions of a road structure could then be made. In the predictions, the combination of influences on stiffness, fatigue, and low-temperature behavior was considered in conjunction with temperature and traffic load. The calculations show that freeze-thaw loading has a negative influence on the fatigue behavior of the surface courses, while ozone treatment has a positive influence.

Keywords

asphalt surface courses, aging, ozonation, freeze-thaw cycle, performance

1. INTRODUCTION

In view of the latest developments in the economy and with regard to environmental concerns, road construction is facing further challenges. The search for optimization potential in manufacturing, paving and reuse is being strongly pursued, with the consensus being particularly reflected in the term sustainability. This term can be defined and viewed from various angles. In order to drive the development towards a more sustainable construction method, the conservation of resources and the reduction of CO_2 emissions are of particular importance throughout the industry. Perpetual pavements are the key to achieving this goal. In Germany, the RDO-Asphalt [1] is a regulation that provides a mathematical forecast of the service life of any road structure and thus offers a tool for the construction of sustainable traffic routes. The calculation is performed at the relevant point for the fatigue status in the structure, the bottom of the asphalt base course in the load axis. In terms of resource conservation and sustainable service life, the procedure needs to be additionally extended for application in the area of asphalt surface courses. The theoretical basis for the damage criterion "fatigue cracking in the asphalt surface" is available. Due to their exposed position on the road surface, asphalt surface courses in particular are exposed to influences that are not yet taken into account in the calculation procedure. In particular, this is the problem of asphalt aging. The integration of the effects of aging, such as the embrittlement of the bitumen and thus a significant decrease in the performance of the asphalts, have not been transferred from the scientific test procedures existing to date into realistic applications. In order to be able to take this influence into account with sufficient accuracy, further development of the material models used is required. The aging tests currently available (both thermal and oxidative) lead to an increase in viscosity and therefore to an increase in stiffness, usually accompanied by an improvement in the fatigue function. From a materials engineering point of view, this is also quite conceivable at the beginning of an incipient aging process. However, the "tipping point" of material behavior, which until now has been assumed to be characterized by a significant decrease in fatigue resistance, for example, has not yet been demonstrated experimentally. In addition to the susceptibility to aging, asphalt surface courses in particular are stressed in winter by freeze-thaw cycles in combination with the use of de-icing materials. These stresses are currently not covered by the dimensioning. The extent to which the influences of aging and freeze-thaw loading affect the primary material behavior cannot currently be assessed and is consequently applied and taken into account.

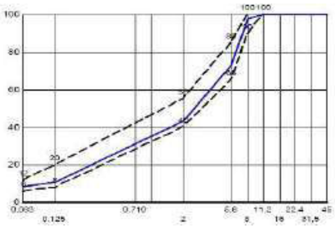
2. MATERIAL AND TREATMENT OF ASPHALT SPECIMENS IN THE LABORATORY

2.1 Asphalt mixture and sample preparation

The test material is an AC 8 D S with a road bitumen 50/70, which meets the requirements of German guidelines TL-Asphalt [2]. The material to be tested was produced in an asphalt mixing plant, filled into metal buckets and stored at room temperature until the test specimens were produced. The asphalt specimen plates were manufactured and compacted using a rolling sector compactor in accordance with Technical Test Specification for Asphalt Part 33 [3]. Thenafter the cylindrical specimens were obtained from these plates in accordance with Technical Test Specification for Asphalt Part 27 [3]. The prismatic specimens for the cooling tests were fabricated from the asphalt plates in accordance with Technical Test Specification for Asphalt Part 46A [3]. Due to the need for a realistic surface texture, the plates were manufactured with an exact height of 40 mm. To eliminate specimen-related bias in the results, the plane parallelism of the surfaces, as well as the perpendicularity to the shell surfaces, was checked. After the geometrical and physical boundary conditions were fulfilled and the surface structure resembled the condition of a road in situ, the determination of the density by dip weighing according to Part 6 [3] was carried out. After the immersion weighing, the specimens were dried until the mass was constant. The material parameters and grading curve determined in the laboratory are shown in Table 1.

Table 1: Conventional material parameters of the analyzed material and grading curve

Bitumen content	6,1	[M.-%]
Rock bulk density	2,744	[g/cm³]
Mix density	2,489	[g/cm³]
Bulk density	2,409	[g/cm³]
Voids content	3,2	[Vol.-%]



Before further stressing of the cylindrical test specimens by the aging process and the freeze-thaw cycles in the CDF test, a textured condition of the base surfaces similar to an asphalt surface in road traffic should be given. In order to produce a realistic surface condition, both cylinder base surfaces were pretreated by irradiation with corundum of grain fraction 0.5/1 mm. This allowed the top bitumen layer, which exists due to the manufacturing process, to be removed. This procedure was carried out in a blasting cabin in preparation for tests according to Part 49 [3], formerly the Wehner/Schultze method. In order to improve the removal of the bitumen, the specimens were previously stored in a freezer at -10 °C for one hour.

For the planned tests to determine the stiffness, fatigue and low-temperature behavior, the bulk densities of the specimens must be within a variance of 0.03 g/cm^3. This ensures that influences resulting from the variance of the void content are reduced. The influence is further accounted for by sorting the specimens in ascending order within this limit. In addition, one specimen each with a low, medium and high void density was selected for each loading condition. The specimens were stored lying on the cylinder base at an ambient temperature of about T = 20 °C, protected from direct sunlight and in a darkened room. As a reference to the test series with treated asphalt specimens, a complete series of unstressed material was tested. Furthermore, all materials were tested under the same test conditions.

2.2 Ozonation

Prior to the main investigations concerning the aging procedure by ozone, small-scale preliminary tests in the DSR were carried out on pure bitumen to assess test parameters. These served to ensure the functionality and repeatability of the process. The influence of ozone consumption (Figure 1) was also considered during the treatment. The difference is calculated from the ozone measurement prior to and behind the reactor. The decrease in consumption with time can be seen. The initially high consumption is due to the high reactivity of ozone with the surfaces of the bitumen samples. After 40 h, the consumption has decreased significantly and remains at a constant level.

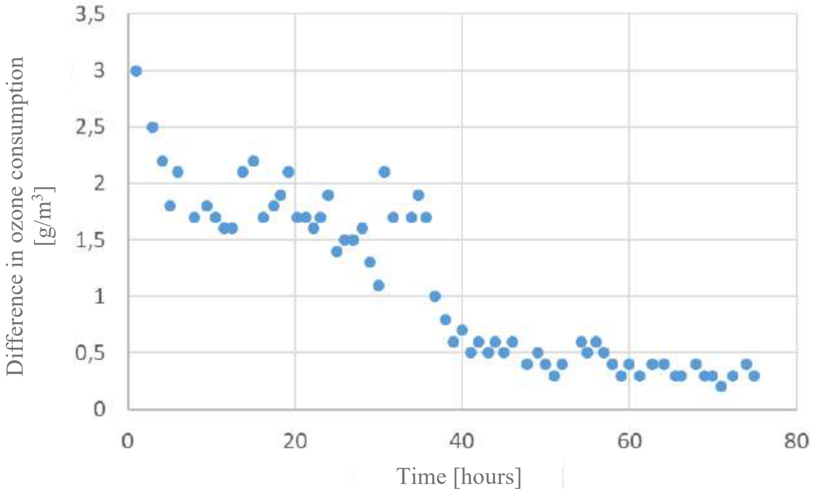


Figure 1: Difference in ozone consumption during bitumen ozonation at 60 °C

Figure 2 shows the scope of the preliminary tests over a total of 11 combinations between 0 h - 75 h ozonation duration and 30 °C – 60 °C ozonation temperature. It can be confirmed that the process at high temperatures has a larger effect in terms of increasing the complex shear modulus. The tendency to stiffen the material for the further process, is illustrated by the continuous increase of the complex shear modulus. When considering the evolution of the phase angle at 60 °C, it can be seen that it tends to decrease, corresponding to an improvement in the elastic potential. Based on ozone consumption and the comparative DSR studies of the complex shear modulus and phase angle on fresh bitumen and bitumen ozonated with different degrees, the parameters for ozonation for asphalt specimens were set to 60 hours at 60 °C.

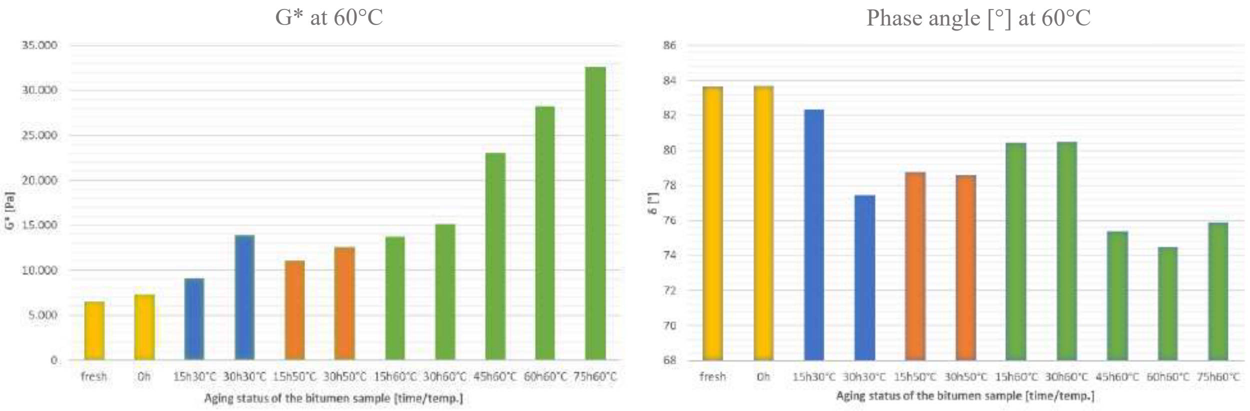


Figure 2: Evolution of the complex shear modulus (left) and phase angle (right) at 60 °C test temperature in DSR

Figure 3 shows the ozonation system. Compressed air is used for ozonation, which is first dried over two drying columns (silica gel, CaCl2) (1). Subsequently, the ozone is generated in the ozonizer (2) and passed through the glass reactor (3), which is located in a drying cabinet (4). A valve system (5) allows the ozone concentration in the air stream to be measured upstream and downstream of the reactor (6). Based on the input and output measurement of the ozone concentration, the real consumption during the gassing process in the test series can be determined. Based on this, it is possible to estimate the reactivity of the material and to narrow down the reaction areas. Ozonation was performed for 7 or 8 h per day. After that, the ozonator was switched off. It was waited until no more ozone was measured in the air stream behind the reactor, then the air stream was also turned off. Overnight, the reactor remained in the heated drying cabinet. The next day, ozonation was continued.

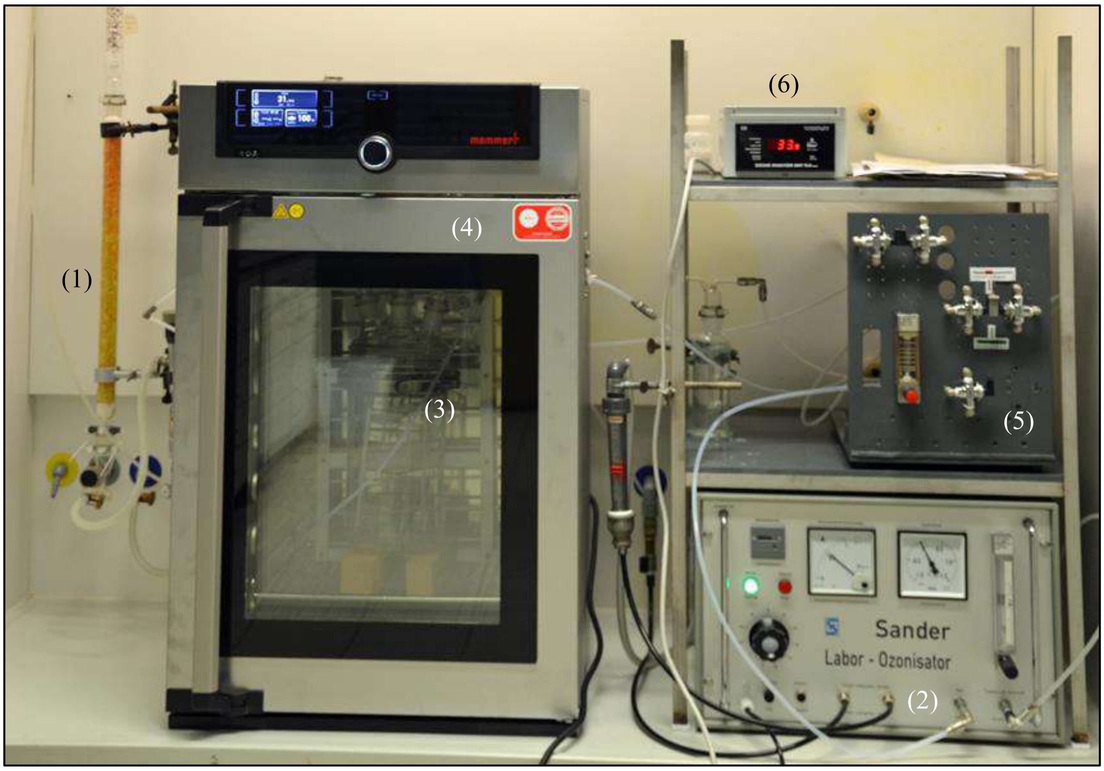


Figure 3: Ozonation device

5 cylindrical or 4 prismatic test specimens were placed in the glass reactor. Ozonation was carried out at 60 °C with air as the source gas. Before switching on the ozonizer, the samples were heated to 60 °C in the drying oven. A total of 20 cylindrical specimens were aged in 4 aging series under analogous conditions. One specimen at a time was chemically analyzed. Figure 4 shows the differences in ozone concentration before and after the glass reactor. The ozone consumption drops sharply within the first 6 hours and then levels off at a low value of approx. 0.5 mg/Nm^3. It can be assumed that within this time the reactions take place primarily at the surface. Reactions at deeper levels tend to occur more slowly, which is why consumption drops off sharply. This is mainly due to the available reactive surface and the size of the test specimens. At this point, no comparison of ozonation with other similar processes can be attempted, as they do not exist on this scale.

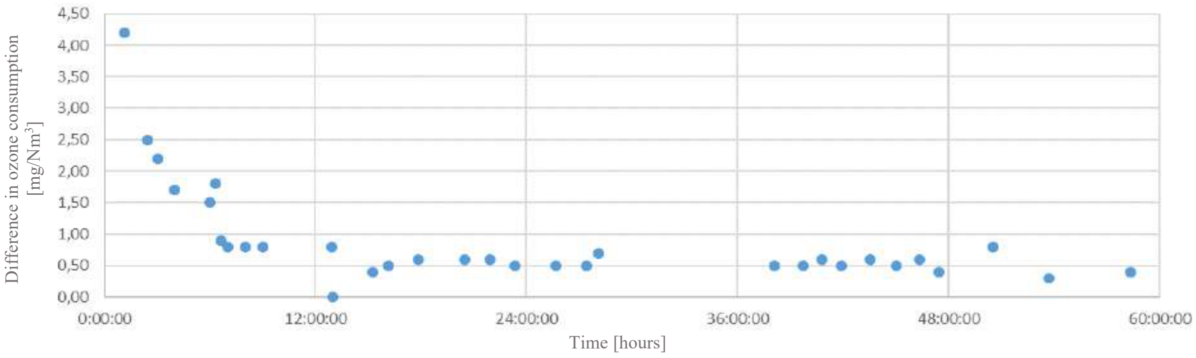


Figure 4: Difference of ozone concentration before and after glass reactor during specimen ozonation

2.3 Capillary Suction of De-icing chemicals and Freeze-Thaw Test (CDF-Test)

The CDF method is a test method developed for concrete, which is used to evaluate the frost resistance and the freeze-thaw resistance. The CDF value, which indicates the resistance of the concrete mix, is the quotient of the weathered mass and the test area for a stress of 28 freeze-thaw cycles.

A method for determining the resistance to freeze-thaw loading of asphalt specimens was developed by Wörner et al. [4]. In addition to the development of the method, only the weathering was investigated within the project, so no conclusion could be drawn on the performance properties (stiffness, fatigue, low-temperature behavior). However, the method developed (CDF method using NaCl solution) is very suitable for weathering test specimens that are subsequently tested in a cyclic indirect tensile test (IT-CY), thus providing information on changes in performance properties as a result of freeze-thaw exposure.

For the testing of asphalt specimens, 28 freeze-thaw cycles were applied following [4]. A freeze-thaw cycle (FTC) comprises 12 hours. At the beginning of the cycle, the test chamber is cooled from the starting temperature (20 °C) in 4 hours at a constant cooling rate of 10 K/hr. The temperature is then held constant at -20 °C for 3 hours and then raised back up to +20 °C in 4 hours at a heating rate of 10 K/hr. This is followed by holding the temperature constant at 20 °C for 1 hour. The temperature cycle is monitored at the reference point. The deviation of the temperature measured at the reference point must not exceed ± 0.5 K (for the minimum temperature) and ± 1 K for the other temperatures. A constant time difference between the individual test containers is permissible. The temperature tolerance may be exceeded for an interval not exceeding 10 minutes immediately after the first ice formation [5]. After 14 days, the specimens have undergone a total of 28 FTC and can be removed. To ensure mass constancy, the specimens were air dried for a minimum of 7 days, until they underwent the cyclic indirect tensile test to assess fatigue and stiffness.

The test specimens were divided into the test series "FTC with H2O" and "FTC with NaCl". In the test series with H2O, the FTC were carried out in a solution of pure demineralized tap water, while in the test series with NaCl a 3% sodium chloride solution of 97 wt.% demineralized water and 3 wt.% de-icing salt was used. The division between water and sodium chloride solution is justified by the fact that some municipalities in Germany do not use de-icing agents, but only rely on grit. All test specimens were subjected to the CDF procedure at the same time. Storage during FTC was in separate stainless steel containers, each containing 4 specimens. The containers were filled with the respective test liquid until the specimens were completely covered. This ensures complete capillary filling of the voids in the asphalt and exposure to the FTC on all sides.

3. LABORATORY TESTS FOR MATERIAL MODEL

For the determination of the performance properties of the asphalt mixes (stiffness and fatigue behavior), the cyclic indirect tensile test is used [6]. In the IT-CY, cylindrical specimens are subjected to sinusoidal compressive swell loading via two load application bars diametrically opposite each other on the lateral surface, resulting in a tensile swell stress in the horizontal direction in the specimen. During the test, the total horizontal deformation resulting from the vertical load is measured and recorded. Further investigations of the low-temperature behavior in the cryogenic range are carried out by means of the cooling test. In this test, a prismatic asphalt specimen is continuously subjected to thermal (cryogenic) stress at a cooling rate of -10 K/h, starting at a starting temperature of T=20 °C, as the specimen length is kept constant during the test.

3.1 Fatigue tests

The fatigue behavior is determined according to the Technical Test Specification for Asphalt – Part 24 Fatigue [3]. For this purpose, cylindrical asphalt specimens are loaded at a constant test temperature of T = 20 °C and at different strain levels until the specimen breaks. The material-specific fatigue properties of the asphalt mixes are characterized by the fatigue function. The set of values of initial elastic horizontal strain $\varepsilon_{el,anf}$ and the number of load cycles to failure of the specimen N_{Macro} from the fatigue function. The initial elastic strain $\varepsilon_{el,anf}$ is calculated for load cycles 98 to 102. In determining N_{Macro} based on the concept of dissipated energy ratio, the energy ratio ER_N is formed from product of load cycle number N and stiffness modulus $|E^*_N|$ calculated for that N. The fatigue function is derived from a minimum of nine individual tests. Equation 1 is used to determine the material-specific fatigue functions.

$$N_{Macro} = k * \varepsilon_{el,anf}{}^{n}$$ *Equation 1*

with:

N_{Macro}	[-]	number of load cycles to macro-cracking
$\varepsilon_{el,anf}$	[‰]	initial elastic strain in center of specimen
k,n	[-]	material-specific parameters of the fatigue function

3.2 Stiffness tests

The stiffness behavior is determined according to the Technical Test Specification for Asphalt – Part 26 Stiffness [3]. Due to the distinctive temperature and frequency dependence of the stiffness of asphalt mixes, the IT-CYs are performed at different test temperatures (-10 °C, 5 °C, 20 °C) and five test frequencies (0.1 Hz – 10 Hz). Knowing the master curve, the absolute Young's modulus (stiffness modulus) can be calculated using Equation 2. Furthermore, using Equation 3, the absolute Young's modulus can be determined for any combination of temperature and frequency.

$$|E| = E_{min} + \frac{E_{max} - E_{min}}{1 + e^{(z_1 \cdot x^* + z_0)}}$$ *Equation 2*

$$x^* = \log_{10}\left(\mathrm{e}^{\mathrm{M}\cdot\left(\frac{1}{\mathrm{T}+273,15} - \frac{1}{\mathrm{T_R}+273,15}\right)} \cdot f \right)$$ *Equation 3*

with:

|E|	[MPa]	absolute modulus of elasticity, corresponds to the magnitude of the complex modulus of elasticity
E_max	[MPa]	upper limit of the absolute modulus of elasticity
E_min	[MPa]	lower limit of the absolute modulus of elasticity (E_min = 0)
z1, z0	[-]	material specific parameters of the main curve
x*	[-]	any abscissa value determined by temperature-frequency equivalence
M	[-]	parameter for temperature shift
T, TR	[°C]	temperature, reference temperature (usually 20 °C)
f	[Hz]	frequency

3.3 Cool-down tests

The characterization of the cryogenic behavior of asphalt is performed according to the Technical Test Specification for Asphalt – Part 46 A [3]. As a result of the cooling test, the course of the cryogenic tension as a function of the specimen temperature, the fracture stress at failure of the specimen $\sigma_{cry,F}$ and the associated fracture temperature T_F are obtained. The fracture stress is the maximum cryogenic tension reached. The correlation between cryogenic tension and temperature is required as an input variable for the computational dimensioning according to the RDO Asphalt [1]. For this purpose, the cryogenic stress curves obtained from a minimum of three individual tests are approximated using Equation 4, employing a polynomial function (Figure 5). Thus, the cryogenic stress can be calculated for any given temperature.

$$\sigma_{cry} = c_1 \cdot T^4 + c_2 \cdot T^3 + c_3 \cdot T^2 + c_4 \cdot T + c_5$$ *Equation 4*

with:

σ_{cry}	[MPa]	cryogenic (thermal induced) tension
T	[°C]	temperature
c_1 - c_5	[-]	parameters of the regression function

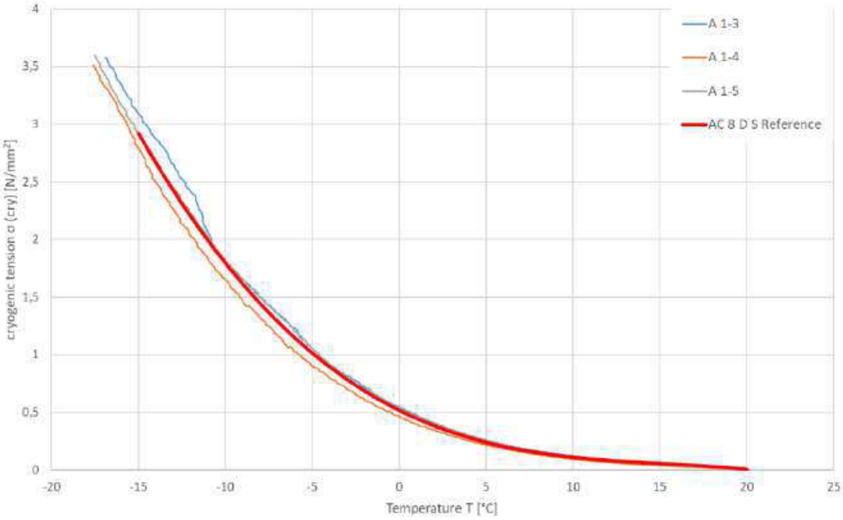


Figure 5: Illustration of the correlation between temperature and thermal induced (cryogenic) tension

4. TEST RESULTS

The material parameters determined by the described tests form the basic material model for calculating the fatigue status of an asphalt surface course. Based on the changes from treatment by ozone and exposure to freeze-thaw cycles, the model for asphalt mixes can be extended to include adjusted performance characteristics for aging. In the following section, the changes in fatigue, stiffness and low temperature behavior after weathering or aging are presented.

4.1 Fatigue performance

Ozonation

When comparing the fatigue functions of the reference asphalt specimen and the ozonated asphalt specimen (Figure 6), no noticeable differences can be identified.. After the aging procedure, the individual fatigue tests reflect almost exact material characteristics with regard to the reference. It is particularly striking that with respect to the tolerable load changes up to the macrocrack criteria, no deviations from the reference occur across all load ranges. When the fatigue function is plotted as a function of stress, however, a slight improvement can be seen in the aged variant. Basically, this behavior can be seen as an indication that the ozonation process only influences the stiffness, but did not change the fatigue behavior of the specimens tested.

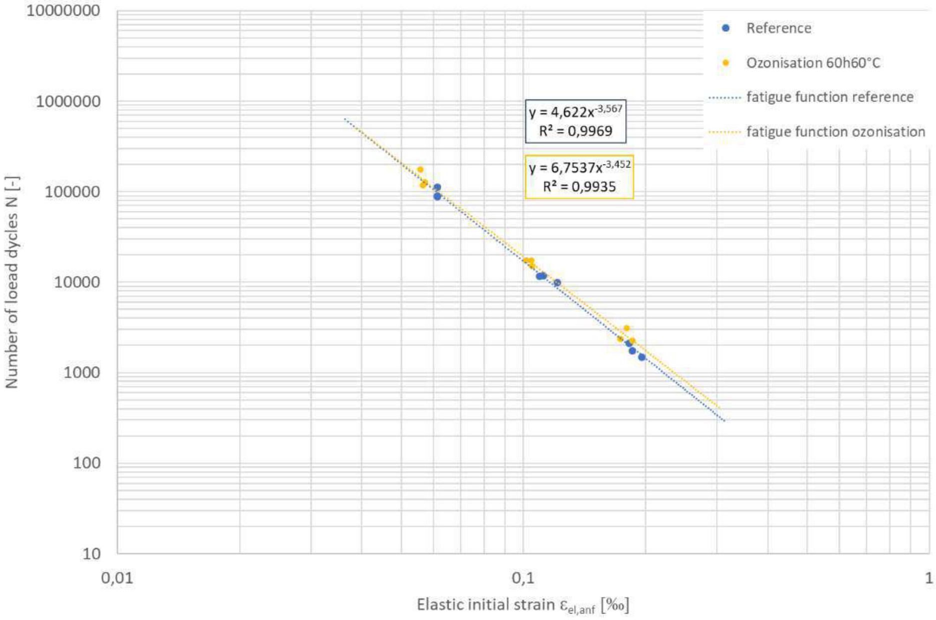


Figure 6: Fatigue function after ozonation for 60 h at 60° C

De-icing chemicals and Freeze-Thaw Test

The fatigue functions of the AC 8 D S after 28 freeze-thaw cycles in the respective solutions do not show any significant changes compared to the reference. Nevertheless, a closer comparison of the functions reveals a slight improvement in the fatigue characteristics because of exposure to the water or sodium chloride solution (Figure 7). These improvements become apparent when looking at the individual tests. Here, higher load cycles are achieved for all load groups until the macrocrack criterion is reached. There are no differences between the H2O and NaCl variants with respect to the fatigue function. Basically, this development is to be evaluated positively, since damage with a significant influence on the material characteristics can be ruled out. In order to make more precise statements regarding the influence of the FTC, the development of the main curve must also be evaluated. It was also checked whether changes in the fatigue function were caused by individually different top stresses. However, a stress-dependent plot of the fatigue functions showed congruent shifts between the reference variant and the variants after stressing by the FTC, so that this can be ruled out.

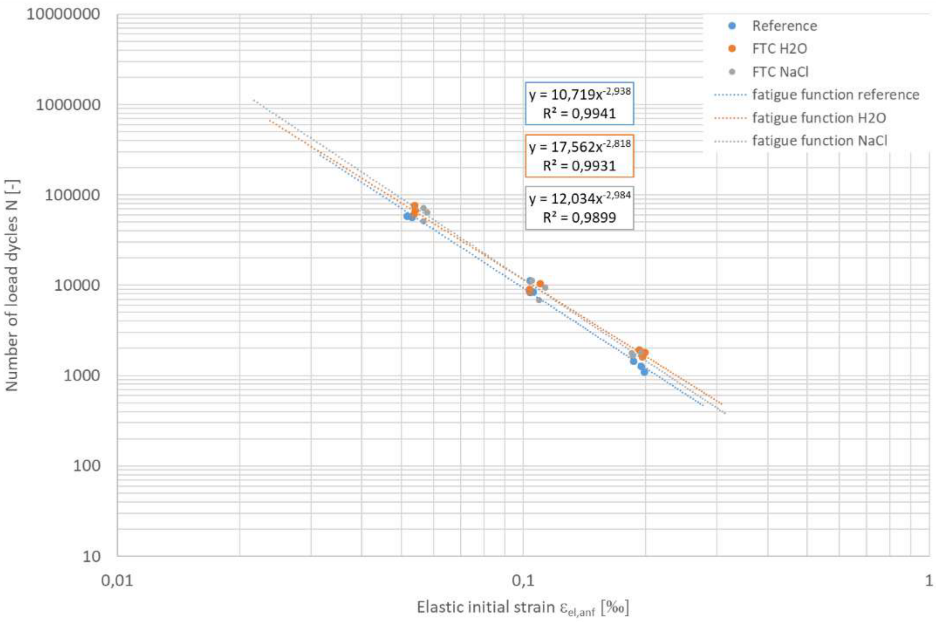


Figure 7: Fatigue functions of the AC 8 D S after freeze-thaw cycles

4.2 Stiffness performance

Ozonation

A direct comparison of the master curves (Figure 8) shows a decrease in stiffness for the aged series. This result contradicts previous observations on the behavior of asphalt mixes after various aging processes, in which stiffening/brittleness has tended to occur. During the gassing in connection with the effect of the temperature during the ozonisation process, the decrease in stiffness is due to the polymer degradation already described.

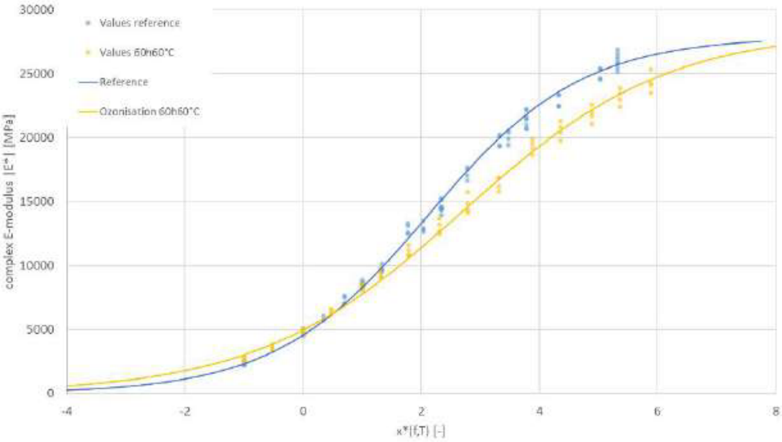


Figure 8: Master curves after ozonation over 60h at 60° C

De-icing chemicals and Freeze-Thaw Test

When looking at the master curves in Figure 9, a more pronounced change due to the influence of the FTC can be observed. While the reference shows the best stiffness properties, especially in the linear range, a flattening of the main curves and thus a loss of stiffness occurs in both treated variants. In a direct comparison, the variant stored in the pure water solution shows the greatest loss of stiffness. For further considerations, especially with regard to the development of the asphalt in contact with de-icing salt solution, additional test series are intended with higher concentrations of the sodium chloride solution. The intention is to cause an increasing deterioration of the main curve by raising the concentration.

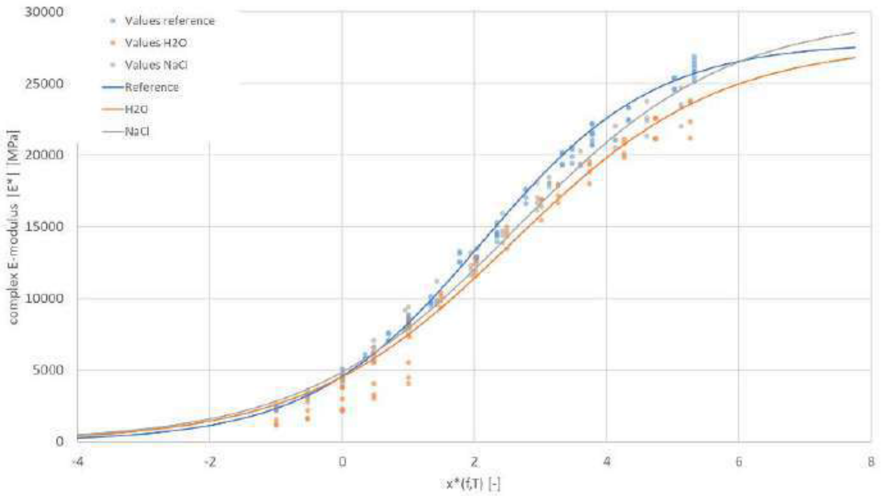


Figure 9: Main curves of the AC 8 D S after freeze-thaw cycles

4.3 Low Temperature performance

Ozonation

As shown in Figure 10, ozonation has an influence on the low-temperature behavior. During the cooling test, consistently higher cryogenic tensile stresses develop in the aged specimen than in the specimen of the reference material. As a result, the asphalt is more susceptible to low temperature cracking.

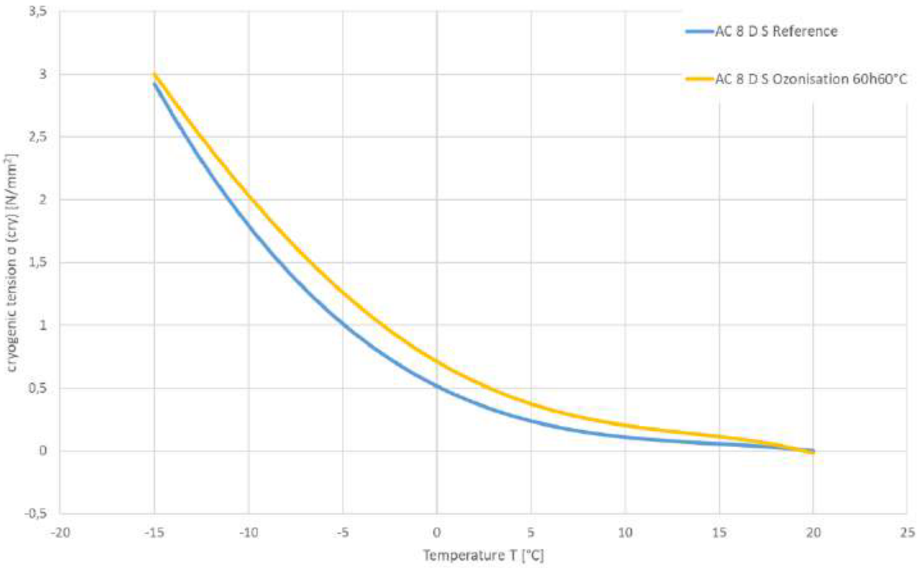


Figure 10: Low temperature behavior of the AC 8 D S after ozonation

De-icing chemicals and Freeze-Thaw Test

The behavior of the tested asphalt mixes in the low-temperature range is not affected after exposure to the demineralized or the sodium chloride solution in correlation with the freeze-thaw cycles. Despite the slight variations between the individual tests (see Figure 5), the averaged overall functions do not deviate from the reference. Figure 11 summarizes the results in the form of the approximated polynomials.

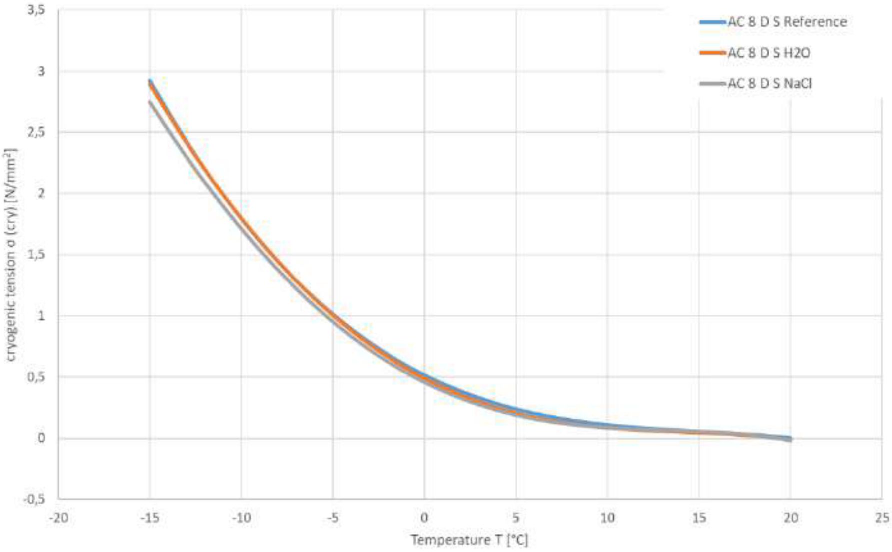


Figure 11: Low temperature behavior of the AC 8 D S after subjected to freeze-thaw cycles

5. PAVEMENT DESIGN LIFE CALCULATIONS

5.1 Calculation method and parameters

The basic principles of computational dimensioning and service life calculation are anchored in the RDO Asphalt [1]. Input variables for the procedure are laboratory-determined material parameters, the (local) climatic conditions and the traffic load. The procedure is intended to prevent structural damage during the planned service life. The maximum service life is reached when 100% of the fatigue status is reached at the verification point of the structure and a crack occurs. The verification procedure according to the RDO Asphalt is based on the damage hypothesis according to Miner [7]. This states that the partial damage in the material (due to the loads from climate and traffic) accumulates to a total damage (Equation 5). The calculations are based on a multi-layer model.

$$\Sigma_{MINER} = \sum_{i=1}^{n} \frac{vorh\ N_i}{zul\ N_i} \leq 1 \qquad \textit{Equation 5}$$

with:

Σ_{MINER}	[-]	MINER-Sum (Sum of all partial damages)
vorh N_i	[-]	the number of load cycles to be expected with the stress (σ or ε) in the loading condition
zul N_i	[-]	the number of load cycles associated with the stress (σ or ε) in the stress state
n	[-]	Number of stress conditions to be considered

As Zeißler [8] shows, computational verifications for asphalt surface courses can be performed using the principal stress state, since only elongation or compressions occur in the principal axis system. After determining the largest principal strain, the fatigue status can be calculated for the pavement cross section at any point in the asphalt pavement in accordance with the dimensioning procedure given in the RDO Asphalt. Compared to the verification point of the asphalt base course, for the asphalt surface course the area cannot be set to a precise point. The location and expression of the main strains next to the wheel contact area depends on the thickness of the asphalt layers and the differences in stiffness of the individual asphalt mixes. As a result, a holistic area must always be investigated. However, since the failure of the entire structure is defined when a crack develops, the fatigue of the asphalt base course is decisive in most cases. For the following calculations, primarily the fatigue status and service life of the asphalt surface course were considered and investigated.

For the calculations, a pavement structure commonly used in Germany (Bk 10 according to [9]) for a rural road was selected. The structure is shown in Figure 12. For the binder (AC 16 B S) and base course material (AC 32 T S), material parameters determined in the laboratory were used. The input parameters from traffic and climatic conditions were selected as constant for all calculations. Only the material properties of the surface courses determined by the laboratory tests were changed.

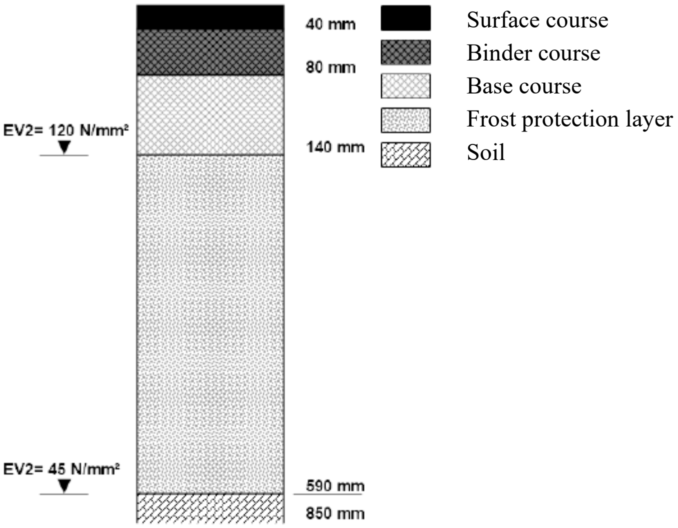


Figure 12: Layer arrangement of the construction for the pavement service life calculations

Table 2 shows the input parameters for the pavement service life calculations. With regard to the frequency distribution of the surface temperatures, normalized characteristic temperature profiles (ncT's) are applied [10]. A service life N of 30 years is targeted for the design. the axle factor f_A, lane factor f_1, lane width factor f_2 and gradient factor f_3 are additionally required to determine the traffic load. The average annual increase in heavy traffic p_z and adjustment factors for all asphalt layers were also specified. Based on these input data, the calculations could be performed using the software Ad2Pave [11].

Table 2: Parameters for determining the traffic load

$DTV^{(SV)}$	f_A	f_1	f_2	f_3	p_z	Adjustment coefficients	N	T-Zone
3200	3,3	1	1,4	1,02	0,01	1100	30	averaged

5.2 Calculation results

The following presents the calculations of service life for the various asphalt materials. In addition to the value of the fatigue status for the failure criterion, the coordinates of the decisive point in each layer are also determined. For this design, the fatigue in the base course area is relevant after 30 years of service life (red). The surface course material reaches a fatigue status of 75% during this time. Figure 13 shows the structure of the pavement (left) and the visualization of the calculations (multi-layer model). The points of the maximum fatigue status for each asphalt layer are marked (blue).

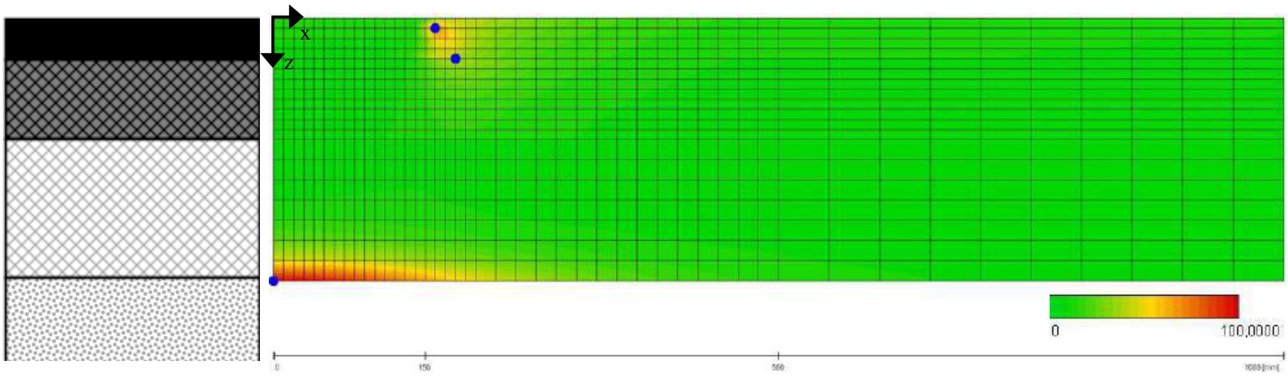


Figure 13: Visualization of the fatigue status and relevant point of each layer in the multilayer model (reference)

When comparing the fatigue status of the different variants (Figure 14), the different treatments of the surface course material are clearly visible. While in the calculations the values of the fatigue status for binder course and base course change only marginally, improvements and deteriorations were predicted in relation to the reference variant. The treatment of the asphalt specimens by the freeze-thaw cycles, both with water or with sodium chloride solution cause a deterioration of the material behavior. The fatigue crack in the surface course is predicted to be the decisive failure criterion of the structure even before the base course. This has different consequences for the damage development in the form of cracks. The influence from the combination suggests top-down cracking. This type of damage, as predicted in the model, is located beside the rolling lanes and can be a single crack or a crack with many branches parallel to the direction of travel. In the case of the reference and ozonized variant, bottom-up cracking is expected. This develops in the base course due to tensile strains at the bottom and forms towards the top of the structure. The corresponding results of the fatigue calculation are shown in Table 3. Figure 15 shows a relative comparison of the visualization of the calculations for the other materials.

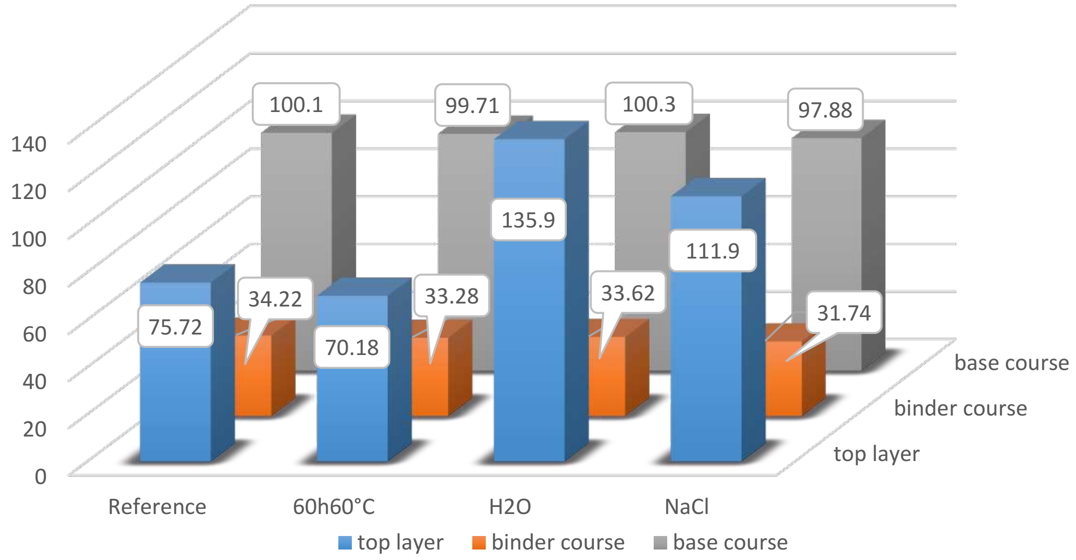


Figure 14: Fatigue status of all variants [%]

Table 3: Parameters of fatigue calculation (aging)

	Asphalt layer	Material	x-coord [mm]	z-coord [mm]	Fatigue status [%]
Reference	1	AC 8 D S	160	10	75,72
	2	AC 16 B S	180	40	34,22
	3	AC 32 T S	0	260	100,13
60h60°C	1	AC 8 D S 60h60°C	160	10	70,18
	2	AC 16 B S	180	40	33,28
	3	AC 32 T S	0	260	99,71
H2O	1	AC 8 D S H2O	160	10	135,9
	2	AC 16 B S	180	40	33,62
	3	AC 32 T S	0	260	100,39
NaCl	1	AC 8 D S NaCl	160	10	111,93
	2	AC 16 B S	180	40	31,74
	3	AC 32 T S	0	260	97,88

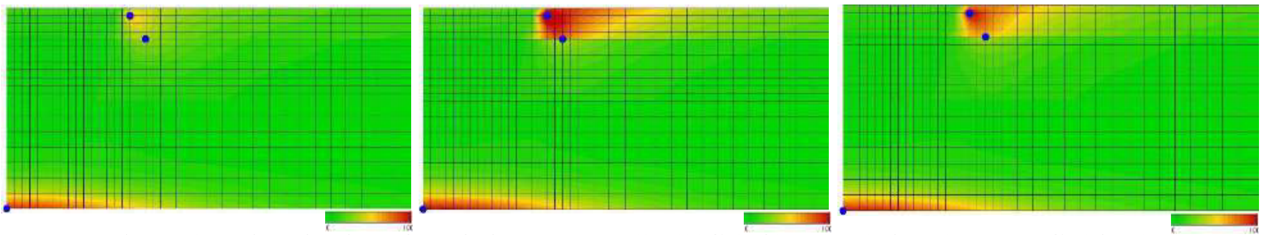


Figure 15: Visualization of the fatigue status: 60h60°C (left), H2O (middle) and NaCl (right)

6. DISCUSSION AND CONCLUSION

The investigations of the material after treated by ozonation or freeze-thaw cycles and the calculations for predicting the service life represent a further development of the fundamentals of the material model of asphalt surface courses. The combination of influences on the stiffness, fatigue and low temperature behavior is taken into account in the calculations and can be correlated with the influences from temperature and traffic load. The calculations further show that the treatment with freeze-thaw cycles has a large negative influence on the fatigue behavior of the surface courses. The influence from ozonation turns out to be positive in direct comparison. The improvement can possibly be attributed to a better interaction of the overall structure despite lower stiffness. In order to be able to better and more accurately represent the processes of aging in asphalt surface courses in the future, the focus will be on the layer-by-layer adjustment of the factors in the calculation. The potential of this method to contribute to more sustainable asphalt construction methods through material optimization and adaptation to local climatic and traffic-related conditions is enormous. In the future, the deformation properties of asphalt, especially in the surface courses for the prediction of rutting, will also be included in the material model. The combination of the calculation of the fatigue status and the rutting development can consequently be used to develop a targeted service life calculation for concepts to coordinate maintenance measures.

7. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support of Federal Highway Research Institute (BASt). The work on which this report is based was commissioned by the Federal Ministry for Digital and Transport under FE 04.0339/2021/MGB. Responsibility for the content lies solely with the author. Furthermore, the authors thank the project partner on chair of wood and plant chemistry at TUD Dresden University of Technology for their support.

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