Asphalt mixture performance and testing

Performance test method for evaluating the resistance to freezing and thawing of asphalt

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Abstract

In winter, asphalt roadways are exposed to extreme loads due to frost-thaw changes and the use of de-icing agents. These stresses can lead to severe damage of the surface. The currently applicable requirements for aggregates with regard to resistance to freezing and thawing with de-icing agents (salt) are empirically based. The changes in the road surface that occur in practice - above all due to the effects of freeze-thaw cycles in conjunction with de-icing agents - cannot be simulated in the laboratory due to the lack of a test procedure. The CDF method developed for concrete was adapted for testing asphalt surfaces in the laboratory. The freeze-thaw de-icing salt resistance is assessed by determining the mass of the material weathered from a sample after a certain number of freeze-thaw cycles. Based on the findings of the investigations, a draft "Test specification for the CDF Asphalt Test" was developed. Three different asphalts (AC, SMA, PA) with a total of six different aggregates were tested. The aggregates showed weathering values in the freeze-thaw test with de-icing agent (salt) between 0.3 wt.% and 45.1 wt.%. The test results obtained confirm the applicable requirements for the aggregates; aggregates with properties in accordance with requirements in the freeze-thaw salt test also lead to low surface weathering in the asphalt test. It has also been shown that asphalts with a high proportion of coarse aggregates (SMA, PA) react more strongly to the test than asphalt concretes; the same applies to water-saturated samples. The CDF Asphalt Test can also be used to evaluate asphalts that have already been used. For the CDF Asphalt Test, an orientation value for weathering of 200 g/m² can be assumed. The precision data of the test still have to be determined and an evaluation background has to be cre-ated.

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4. INTRODUCTION

In winter, asphalt roadways are subjected to extreme loads due to freezing and thawing and the use of de-icing agents, which are intensified by the number of freeze-thaw cycles, i.e. transitions to temperatures below 0°C. These stresses can lead to severe damage, especially to aggregates in the asphalt surface. The damage mechanisms responsible for this and the effect of the de-icing agents cannot yet be adequately described in the laboratory.

The requirements currently applicable for aggregate with regard to resistance to freezing and thawing in the presence of salt are empirically justified. The test values determined in the laboratory and the changes observed in practice in the road surfaces (aggregate particle break-outs, particle degradation) rarely correlate unambiguously. The requirements for road safety, above all for grip, apply throughout the service life of an asphalt surface course. These requirements must not be impaired by rolling traffic or the weather.

The changes in the road surface that occur in practice - above all due to the effects of freezing and thawing in conjunction with de-icing agents - cannot currently be simulated in the laboratory due to the absence of a test procedure. With regard to asphalt road construction, only the requirements for the aggregate are available. The following test methods are available for testing the resistance of aggregate to freezing and thawing.

- Determination of resistance to freezing and thawing in water (EN 1367-1),
- Determination of resistance to freezing and thawing in the presence of salt (NaCl) (EN 1367-6),
- Magnesium sulfate test (EN 1367-2).

The most common methods for assessing the behaviour of aggregates subjected to frost or freezing and thawing are crystallization methods (with magnesium or sodium sulfate solution) and frost tests with or without de-icing salt.

Exposure to freezing and thawing or freezing and thawing in the presence of salt leads on the one hand to precipitation and on the other hand to structural changes (damage to the inner structure). In the case of frost tests on the aggregate, the assessment is based exclusively on the percentage of loss of mass F. The internal damage remains unconsidered. One way of recording the structural changes is to determine the strength development in the event of freezing and thawing or freezing and thawing in the presence of salt in accordance with EN 1367-1, Appendix B. T In this case, the impact values according to EN 1097-2 before and after freezing and thawing or freezing and thawing in the presence of salt are determined and compared with each other for the test aggregate particle size 8/12.5 mm. The procedure usually results in a loss of strength.

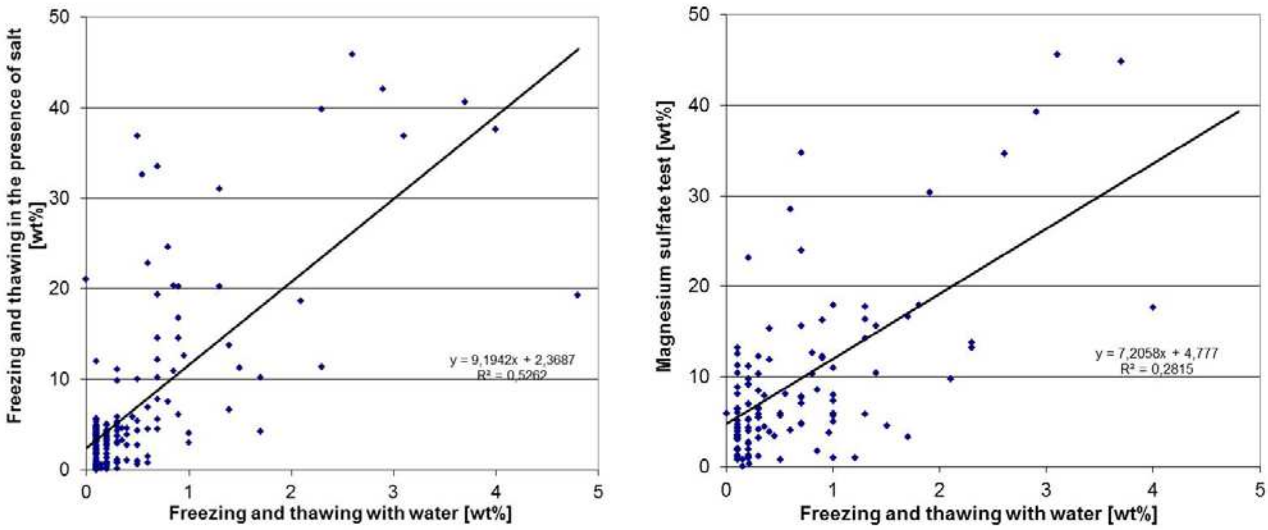
However, different authors have come to the conclusion that the freezing and thawing test with water yields only limited practice-oriented and representative results, e.g. [1, 2]. In addition, the process shows a relatively low spread and thus variation of the results with different qualities of the rocks. In the case of freezing and thawing in the presence of salt, the aggregate is exposed to an extreme load which, perhaps, never occurs in reality. Therefore freezing and thawing in the presence of salt provides better differentiation and agreement with practice behaviour than freezing and thawing with just water [1].

The results obtained with these test methods do not possess any reliable correlations with each other, so that the aggregate is assessed differently depending on the method. In addition, it must be taken into account that in these test standards a test particle size is always assessed which represents all aggregate particle classes for the particular deposit. Figure 1 shows the correlation of the results obtained from the three frost test methods for the evaluated test pairs. The diagrams clearly show that there are no correlations between the methods. The evaluation also shows that there are large ranges in the results of the frost tests in the individual stone groups/types.

5. TEST METHODS USED

The concrete industry was faced with a similar problem when freeze-thaw damage occurred on a large scale, e.g. in locks. As a result, the CDF method was developed so that, among other things, concrete samples could be examined in a practical manner at different cycle times [3, 4].

The CDF test is used to test the resistance to freeze-thaw stress with simultaneous de-icing agent loading. CDF means "Capillary suction of Deicing chemicals and Freeze-thaw test". The CDF test enables the simultaneous measurement of moisture absorption and internal structure damage by a number of freeze-thaw cycles with uniaxial heat and moisture transport in the presence of a defined test liquid. As a rule, a defined de-icing salt solution (3% NaCl solution) is used. With the CDF method, the sample is placed in the test device in such a way that it can absorb the test solution. The specimens are subjected to a temperature cycle regime in a temperature-controlled test cabinet according to Fig. 2. Tests [5] with the CDF method have shown that specimens which are exposed to a constant supply of moisture show a higher degree of scaling than specimens which can dry in the test cycle. In view of the limitation of the test duration, drying of the specimens should therefore be dispensed with. Road surfaces are also exposed to constant moisture penetration.



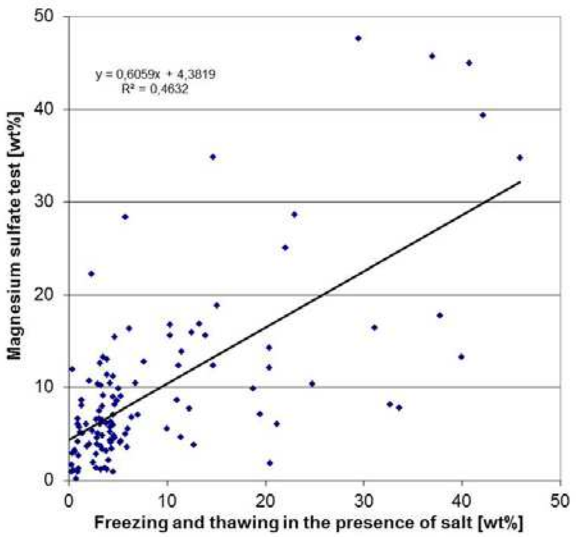


Figure 1: Relationship between the results of the different frost test methods

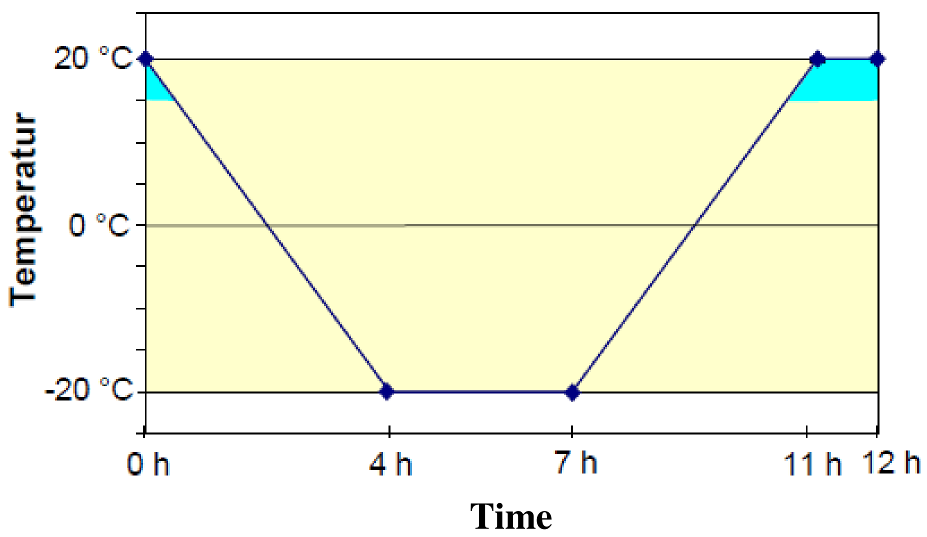


Figure 2: Freeze-thaw cycle according to BAW data sheet [3]

The freeze-thaw resistance in the presence of salt is assessed by determining the mass of material weathered from the specimen after 56 freeze-thaw cycles ([3] assumes that 28 freeze-thaw cycles are sufficient). The requirement value (acceptance criterion) is often 500 g/m². Figure 2 shows the cycle according to [3]. The determination of the weathering quantity takes place in the period marked in blue.

In the case of freezing and thawing in the presence of salt, the surface scaling is dominant and has priority for assessment. The internal damage is additionally measured [3]. For concrete, a surface scaling of max. 1500 g/m² and a reduction of the modulus of elasticity (internal damage) by a maximum of 25 % apply as acceptance criteria.

The damage mechanisms for concrete have been largely investigated with regard to frost attack. In the case of concrete, this results in extensive weathering, whereas in the case of asphalt the increased expulsion of individual aggregates is to be expected. The extent to which the integration of the aggregate into the mortar matrix affects freeze-thaw attack will be examined here. It should also be noted that the empirical values for concrete cannot be transferred to asphalt, since asphalt can be expected to have significantly less scaling.

In contrast to concrete, asphalt does not have a high absorbency, so it is not absolutely necessary to arrange the specimens in the same way as concrete specimens. It may also be possible to work with specimens that are exposed to test fluid from above. For this reason, the CDF slab test was also used in preliminary tests, in which the test liquid is applied to the sample from above during the freeze-thaw cycles. For this purpose, the outer surfaces of the samples were masked in such a way that the sealing material protrudes approx. 5 cm beyond the sample surface and the sample can be covered with test liquid. The procedure which proves to be more favourable in the course of these tests will be used for the subsequent tests.

6. METHODOLOGY OF THE PROCEDURE

Six aggregates with different freeze-thaw/deicing salt behaviour were included in the investigations. The tests with the previously selected test method were carried out on an asphalt concrete (AC 11 D S), a stone mastic asphalt (SMA 11 S) and, for orientation, a porous asphalt (PA 11). The surfaces of these asphalts have a different amount of aggregates, so that different results are expected. The effect of the test liquid, the degree of compaction, the type of binder, the proportion of mortar and the use of lime hydrate on the asphalts was investigated. Six test specimens were tested per test variation and asphalt type. Table 1 shows the test variations. The voids in the specimen (100 % compaction degree) were about 3.0 to 3.5 Vol.-% for the AC, 2.5 to 3.0 Vol.-% for the SMA and 25.0 to 28.0 for the PA

		GK 1	GK 3	GK 6	GK 5	GK 2	GK 7
TM 1	CD 100%						
	CD 97%						
	CD 97%, water saturated						
	CD 100%, heat stress						
	CD 100%, PmB						
	CD 100%, PmB, low content of mortar						
	CD 100%, hydrated lime						
TM 2	CD 97%						

TM1	NaCl		Tests for AC, SMA and PA
TM2	sodiumformate		Tests for AC and SMA
CD	Compaction degree		Tests for AC

Table 1: Test variations

7. SELECTION OF AGGREGATES, ASPHALT DESIGN AND PRODUCTION OF TEST SPECIMENS

The 8/11 mm aggregates were selected on the basis of the expected loss of mass F caused by freezing and thawing in the presence of salt. Table 2 lists the selected aggregates with the federal German state of origin and the expected and actual test value for the resistance to freezing and thawing in the presence of salt. In addition, the table contains the designations of the aggregates in this paper (GK 1 to GK 7).

In order to compare the direct effect of the aggregates, only the coarsest particle class (8/11 mm) according to Table 2 was varied. The other proportions of the aggregate mixture for the asphalt were kept constant. To ensure an unambiguous evaluation of the tests, the supplied 8/11 mm aggregate of undersized and oversized particles and the supplied 5/8 mm of oversized particles were removed.

	Aggregate	region of origin	expected F_{EC} [wt.%]	determined F_{EC} [wt.%]
GK 1	Granite	Bavaria	< 1	0.3
GK 2	Limestone	Bavaria	15	15.0
GK 3	Crushed gravel	Bavaria	8	1.9
GK 4 *	Diabase	Bavaria	5	1.5
GK 5	Diabase	Thuringia	20	10.4
GK 6	Greywacke	Thuringia	8	8.7
GK 7	Andesite	Thuringia		45.1

* not taken into account in the experiments

Table 2: Selected coarse aggregate 8/11 mm for asphalt tests

The basic initial tests were prepared for GK 1 and then adapted for the other aggregates in such a way that comparable volumetric ratios were obtained.

For the further freeze-thaw tests (CDF), test slabs according to EN 12697-33 were produced from the asphalt mix produced in the laboratory using the roller sector compactor. The surface of the test slabs was then sandblasted (at -20°C for 120 s for all specimens) to remove the binder film from the surface and provide the free surfaces of the aggregates in the freezing and thawing tests. Drilled cores with a diameter of 100 mm were taken from the test slabs for the freeze-thaw tests in the presence of salt.

8. COMPARATIVE FROST AND DE-ICING SALT EXPERIMENTS (CDF TEST, CDF SLAB TEST)

The comparative tests were used to determine the test method to be used for the main tests. The tests were carried out on both the AC 11 D S and the SMA 11 S using the CDF and CDF slab tests. The aggregates used were samples which showed a loss of mass F of 0.3 and 15.0 wt.%, respectively, in the freeze-thaw tests in the presence of salt.

In summary, it can be deduced from the results that the further tests will be carried out with the CDF test, i.e. with NaCl solution applied from below, since this type of test leads to a greater spread of the results so that the different aggregates can be better distinguished (Figure 3). Since the surface scaling is linear, it is possible to reduce the number of cycles - as in the concrete test - to 28 cycles for routine testing. The consideration of the internal damage as well as the water absorption does not lead to any further results, so that the presentation of these results is omitted.

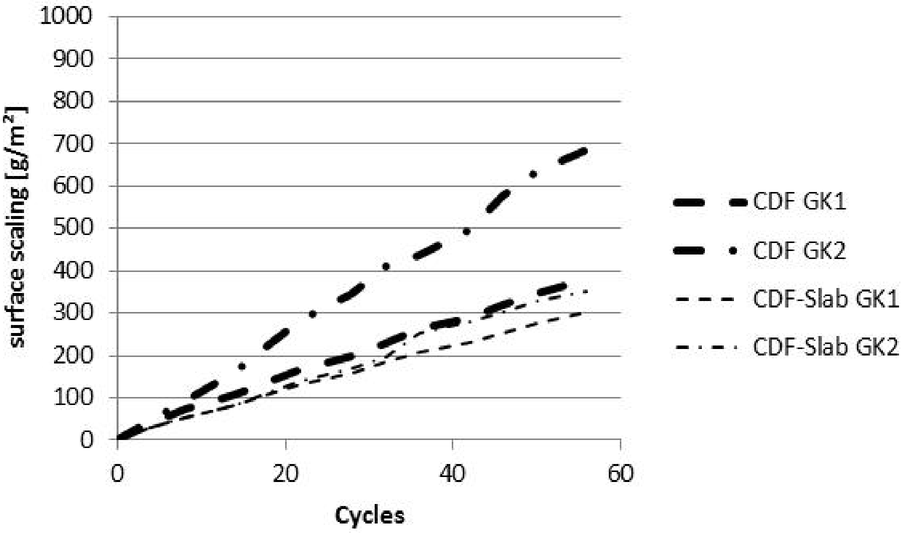


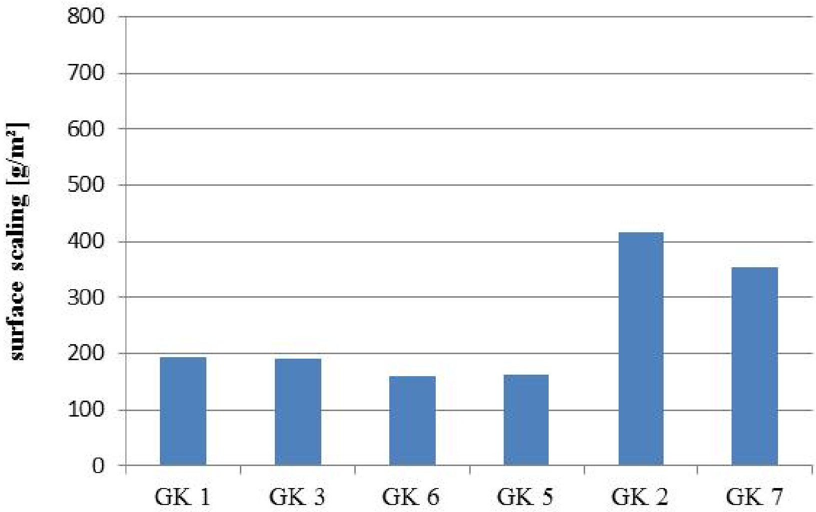
Figure 3: Results of the comparative trials on AC 11 D S

The evaluation of test series with a different number of tested specimens shows that for the later application of the test in practice a series of six specimens should be used. If necessary, a futher reduction can be possible after an interlaboratory comparison has been carried out. Of the total of 534 specimens tested during the main tests, only eight were found to be outliers.

9. FREEZING AND THAWING IN THE PRESENCE OF SALT (MAIN TESTS)

In the presentations of the test results, the aggregates are arranged according to ascending result in the freeze-thaw test in the presence of salt (GK 1 (0.3 wt.%) - GK 3 (1.9 wt.%) - GK 6 (8.7 wt.%) - GK 5 (10.4 wt.%) - GK 2 (15.0 wt.%) - GK 7 (45.1 wt.%)).

It can be seen from the results in Fig. 4 that the aggregates with splintering of less than 10 wt.% in the freeze-thaw test in the presence of salt achieve comparable results and that the differences between the individual samples are relatively small for the different asphalts (AC, SMA). In the case of GK 2 and GK 7 with splintering of 15.0 and 45.1 wt.% respectively, larger differences result between the individual values. The surface scaling of the more frost-resistant aggregates is below 250 g/m² for GK 2 and GK 7 above 250 g/m²; the differences are more pronounced for stone mastic asphalt because particles broke out of the surface. The difference is more obvious in the case of porous asphalt: if the surface weathering for GK 1 is around 380 g/m², the value for GK 7, which showed a splintering of 45 wt.%, in the freeze-thaw test in the presence of salt, rises to over 9000 g/m², i.e. a factor of over 10 compared with stone mastic asphalt. Figure 5 shows a specimen of the porous asphalt before and after testing. In addition to the mortar scaling, the loss of individual particles is clearly apparent and depends on the amount of aggregates on the surface (PA>SMA>AC). The individual test parameters (degree of compaction, test liquid, type of binder, ...) have independently of the asphalt no significant effect.



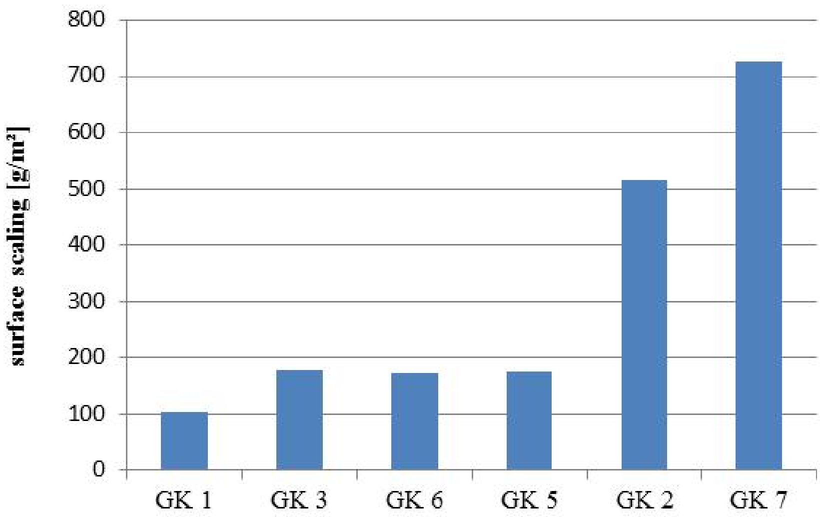


Figure 4: Results of the CDF tests for AC 11 D S (top) and SMA 11 S (bottom) at 100 % compaction degree and NaCl as test liquid

Figure 5: Test specimen of porous asphalt before and after CDF test

The surface scaling curves of the samples are shown for AC 11 D S and SMA 11 S for GK 1 and 7 in Figure 6. Basically, it can be stated that the scaling increases linearly with time. The curves clearly show that the scatter of the individual samples are lower for low surface scaling compared with high surface scaling, but the scatter as a percentage of the measured value is similar.

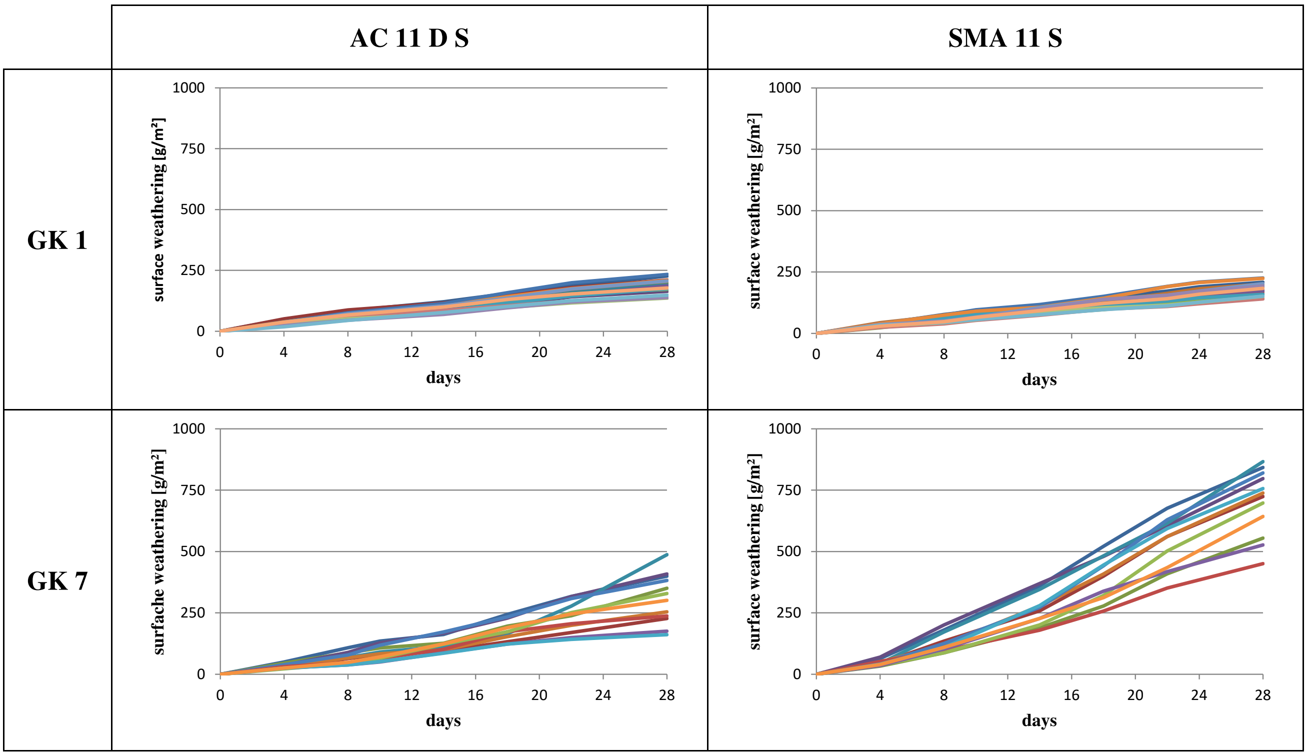


Figure 6: Surface scaling curves for AC 11 D S and SMA 11 S for GK 1 and GK 7

For a series of tests, it was also examined whether the stress in the CDF test leads to a change in the properties of the binder. Fig. 7 shows the results of the temperature sweep in the Dynamic Shear Rheometer (DSR). It is obvious that the stress does not affect the properties of the bitumen; no changes are visible, no differences occure, the lines are concurring.

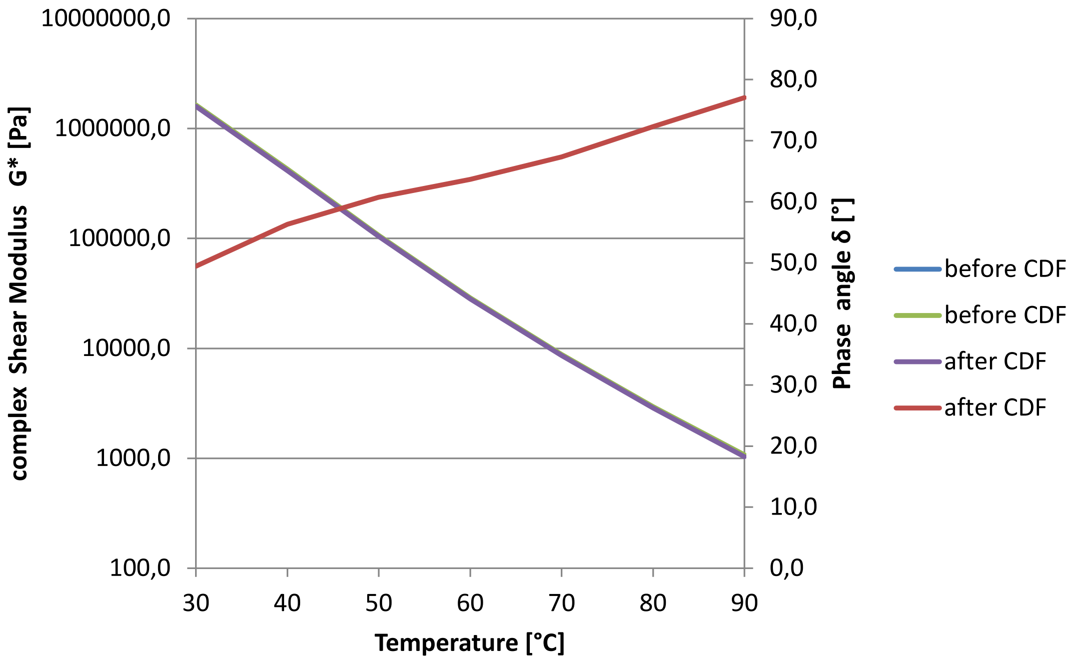


Figure 7: Temperature sweep in the DSR [6] with the recovered binder before and after the CDF test

10. SUMMARY

Regarding the effect of freezing and thawing on asphalt road constructions, only the specified requirements for the aggregate are available. Up to now there is no test for the asphalt surface available. After comparative tests (CDF test and CDF slab test) it is concluded that future tests will be carried out with the CDF test, i.e. with NaCl solution applied from below, since this type of test leads to a greater spread of the results so that different aggregates can be better distinguished. Since the surface scaling is linear with time, it is possible to reduce the number of cycles - as in the concrete test - to 28 cycles for routine testing.

For the main tests on asphalt (AC, SMA, PA) with the CDF method only the 8/11 mm aggregate size fraction changed on the basis of the expected loss of mass F in the freeze-thaw test in presence of salt. The six selected aggregates had values for loss of mass F of 0.3 wt.%, 1.9 wt.%, 8.7 wt.%, 10.4 wt.%, 15.0 wt.% and 45.1 wt.%.

In summary, it can be stated that the frost sensitivity of the tested asphalt samples - expressed by the surface scaling - essentially depends on the aggregates used in the asphalt and not on the boundary conditions during the test or initial treatment of the samples.

The specific findings are as follows:

- Aggregates with a loss of mass F of less than 10 wt.% in the freeze-thaw test in the presence of salt also result in similar surface scaling during the CDF test for asphalt concrete and stone mastic asphalt.
- Aggregates with loss of mass F of more than 15 wt.% in the freeze-thaw test in the presence of salt also show high surface scaling during the CDF test for asphalt concrete, stone mastic asphalt and porous asphalt.
- Stone mastic asphalt and porous asphalt react more strongly to the CDF test than asphalt concrete.
- A reduction in the degree of compaction from 100 % to 97 % does not lead to an increase of the surface scaling.
- Water saturation of the specimens before the start of the CDF test leads to a partial increase in surface scaling compared with the test specimens without water saturation. The increase is particularly noticeable for the stone mastic asphalt and the aggregates with high splittering in the freeze-thaw test in the presence of salt.
- Heat-stressing of the aggregate before asphalt production resulted in unfavourable values only for the stone mastic asphalt test with the aggregates with the highest loss of mass F in the freeze-thaw test in the presence of salt than for the test specimens with "virgin" aggregates.
- Lime hydrate has no effect on surface weathering.
- The binder properties are not affected by the CDF asphalt test.
- The use of a different thawing agent (sodium formate solution instead of NaCl solution) - as used on airfields - does not affect the assessment. Only the limestone reacts more strongly to the second thawing agent.

- The estimated values for repeatability are at the level of the values in the BAW data sheet.

The CDF asphalt test was considered as background for assessment in which the values obtained from the freeze-thaw test of the aggregates in the presence of salt must also be included. Only in this way is it possible to distinguish precisely between individual aggregates. The results also confirm the present applicable requirements for aggregates.

For future test series it is of interest to investigate the range of loss of mass F in the freeze-thaw test in presence of salt between 10 and 15 wt.% in more detail, since in this range there is a pronounced jump in the surface scaling in the CDF asphalt test.

The CDF asphalt test can also be used to assess trafficked areas that have already been used in order to estimate any damage that may still be expected.

11. ACKNOWLEDGEMENTS

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The author is solely responsible for the content.

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