# ASSESSMENT OF SPECIFIC PAVEMENT CONCRETE MIXTURES BY USING AN ASR PERFORMANCE-TEST

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**Abstract**

In Europe, the commonly used ways to achieve a sufficient durability of concrete for outdoor elements are based on the description-principle. But in case of ASR these description principals are not always successful. In the last decade, the issue of external alkalis and their influence on ASR in concrete has become more important since airfield concrete pavements showed worldwide ASR-distress related to the use of alkali-containing runway deicers based on acetates and formats. Also, several highway concrete pavements in Germany showed ASR distress after a short period of service life. The influence of deicers on ASR was investigated in the last years by using the FIB (=Finger-Institute for Building Materials Science) cyclic climate storage as ASR performance-test for the assessment of specific concrete mixtures. The deleterious influence of alkali-containing deicers on concretes with reactive aggregates, especially slow/late reacting aggregates, was clearly confirmed. Deicers based on acetates and formates turned out to be extremely deleterious.

**Keywords**: ASR performance-test, external alkalis, pavement concrete, deicers, slow/late aggregates

## 1 INTRODUCTION

According to the European standard EN 206-1 [1] and DIN 1045/1-4 [2], sufficient concrete and unit durability is guaranteed when the corresponding requirements are met as to:

- Examination and supervision of the concrete components
- Usage of the description-principle (EN 206-1) with examination and supervision of the concrete and unit properties and compliance of several limits e.g. for thickness of concrete cover as well as concrete composition like w/c, kind and content of cement, content of artificial air voids, etc.

Sufficient results by avoidance of e.g. corrosion of reinforcement, insufficient frost- and frost/de-icing salt resistance and concrete corrosion as a consequence of chemical attack were achieved by usage of the description-principle. For the most durability problems ample long-term experience exists and appropriate recommendations are part of the European standards. But the cases of ASR damage which have occurred with increasing frequency to pavement concretes for motorways and airports in Germany [3,4,5,6] and the USA [7,8] in the last decade shows, that the presently standardized ways and the several used test procedures to characterise the reactivity of aggregates and evaluate the durability of concrete were insufficient to avoid ASR-damage. Especially the deleterious influence of alkali-containing deicers on concretes with reactive aggregates is not well integrated in present ASR-test procedures. It has been suspected for some time now, that the action of alkali-containing deicers is capable of favoring an alkali-silica reaction (ASR) in concretes with reactive aggregates. The current situation with increasing numbers of ASR-damage worldwide shows clearly the necessity of an ASR performance-test for the assessment of pavement concrete mixtures which will be subjected to externally supplied alkalis.

## 2 MATERIALS AND METHODS

### 2.1 General

It is very common to assess the reactivity of aggregates by using a mortar bar test. Most of them are derived from the South-African NBRI-test, developed by Oberholster and Davies. The 2007 revised German Alkali-Guideline [9] contains two mortar bar tests (reference method similar to NBRI-test [10], alternative method as described in [9,11]) to assess the reactivity of slow/late reacting aggregates. Mortar bar tests are capable for a short-term assessment of the reactivity potential, but in some cases they do not correlate with field-performance or the concrete prism test [12].

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Various long-term concrete prism tests at different temperatures (38, 40 or 60 °C) are used to assess the reactivity of aggregates to predict the durability of concretes that may suffer from ASR. They are considered as reliable, but investigations with comparative field tests have shown, that there is not always a correlation between different test methods and the behavior in the field by some slow/late reacting aggregates [12]. Attempts have been made to develop performance-test methods for concretes on the basis of the concrete prism test, which is in fact an aggregate reactivity test. But a real performance-test should be able to assess the durability of real concrete mixtures having regard to the planned in-service conditions of the eventual structure, especially in the case of external alkali supply.

Two presently not standardized performance-tests are used in Germany. The modified French AFNOR P18-454 is used as performance-test at the VDZ (German Cement Works Association, Düsseldorf), where the concrete prisms are stored in a small steel vessel at 60 °C and 100 % RH over water. To consider the case of an external alkali supply, the concrete prisms are periodically dried for 5 days at 60 °C prior to an immersion in the deicer solution at 20 °C for 2 days. Freeze-thaw-cycles, which are typical for climate conditions in Middle Europe, are not considered and the concentration of the applied deicing solution is not clearly defined yet. Until now, predominantly results with test cement ($Na_2O_{eq}$ = 1.3 wt %) and NaCl-based deicers were published [13,14].

Since 2001, an alternating climate test method (cyclic climate storage) is used at the FIB for accelerated simulation of Central European climatic conditions, in order to assess the durability of specific concretes for outdoor structures [4,6,15,16]. Significant factors from environmental effects (drying, moistening, freezing and thawing, exposure to deicers) are simulated for this purpose by alternating temperature and moisture conditions in a climate simulation chamber. An alternating climate test program has been especially developed for investigations into ASR for pavement concretes. One complete cycle lasts 21 days and consists of a drying phase, a moistening phase and a freeze-thaw phase. At least 6-8 cycles (5-6 months) are necessary to permit reliable assessment of a concretes durability regarding ASR [15,16]. The test was calibrated on ASR-damaged pavements and structures by testing these mixtures after the damage occurred in field. Results of base-line investigations the influence of deicing chemicals on ASR in concrete are presented in [17,18].

## 2.2 Cyclic climate storage used for ASR performance-testing

In cooperation with a manufacturer of special climate simulation devices from Thuringia[1], preliminary investigations were carried out for several years on a specially developed prototype that resulted in a new multifunctional climate simulation chamber. Since 2001, cyclical climate simulations can be carried out with greater ability to investigate a wide range of climate conditions than before and with high reproducibility. In the climate simulation chamber[2], temperatures between -40 °C to +90 °C with a changing rate of up to 5 °C/min are selectable. To realize a realistic velocity of the temperature changes, the rate of change can be adjusted to ≥ 0.01 °C/min (e.g. in the case of freeze-thaw cycles according to the CDF/CIF-Test 0.17 °C/min). Extreme moisture gradients in the concrete specimens at freely selectable temperatures are achieved by

(1) Intensive drying at < 10 % RH

and

(2) Moistening

with considerably reduced leaching due to fog arising from a temperature-controlled water quench at the chamber bottom in comparison to common spray systems in German fog cambers.

Unique to ASR-related deterioration, a special cycle (Figure 1) was developed, based on European conditions. A complete cycle lasts 21 days and consists of:

- 4 days intensive drying (60 °C, < 10 % RH)
- 14 days fog (45 °C, 100 % RH)
- 3 days of freeze-thaw-cycling (+20…-20 °C).

After 7 days of curing (20°C, > 95 % RH), the upper edges of the concrete prisms will be surrounded with a foamed rubber tape similar to the Swedish slab-test (Figure 3). At the start of the first fog phase, the deicing solution (0.6 mol/l) is applied directly onto the upper surface of the concrete prisms until the end of the cycle. During the following drying phase, the deicing solution evaporates on the upper surface of the prisms with the objective to avoid leaching and to ensure a constant and reproducible supply of alkalis. Due to the drying phase, the desiccated prisms absorb intensively the deicing solution and during the freeze-thaw-phase, the absorption of deicing solution is further

[1] Feutron Klimasimulation GmbH, Greiz

[2] Internal dimensions: 1.6×2.0×1.5 m, 750 kg sample material possible

increased due to the micro-ice-lens-pump mechanism [19]. Prior to every cycle, expansion, mass and resonance frequency measurements are carried out. Expansion is measured on embedded steel studs at either end of the prisms for an axial expansion measurement. The concrete prisms are always measured at 20 °C to avoid temperature influences on the results, especially caused by thermal expansion. A deterioration of the concrete can be assumed, when expansion exceeds 0.4 mm/m (without application of deicer) and 0.5 mm/m (with application of deicer), which was defined after performing many preliminary investigations and considering the expansion caused by moisture. By means of mass determination, differences in the moisture content are detected. To determine deterioration and formation of harmful, damage-related phases, microscopic investigations on thin sections by means of polarization microscope on polished sections and fractured surfaces by means of electron microscope (SEM/ESEM/EDS) are carried out [4,5,6,16].

The cyclic climate storage as an ASR performance-test was used already for more than 20 building projects and the assessment of more than 100 job mixtures [4,6,11,15-18].

### 2.3 Materials

A selection of 4 performance-tests, done on specific concrete mixtures for road and airfield pavements with unexpected results according to the standardized mortar bar test (alternative method [9]) results will be presented. The concretes were made with ordinary Portland cements (Table 1) which meet the special requirements (e.g. $Na_2O_{eq} \leq 0.80$ wt%) for use in pavement concretes according to the German guideline for pavements (ZTV Beton StB-01) and the regulation of the German Road Administration (BMVBS) [20]. Each concrete was made with a different coarse aggregate. A greywacke, an andesite, a rhyolite and a granodiorite were used. The fine aggregate was non-reactive, based on field experiences for all concretes tested. The concretes were made with air entraining agents and w/c of 0.42 (mixture details: Figure 4 - Figure 7). The concrete was mixed for 120 s in a compulsory mixer.

For the performance-test with deicer application, the 0.6 mol/l NaCl-solution was made from pure NaCl and distilled water. The commercial runway deicers were the same products that are used at the airports, the pavement concretes were tested for. The deicer solutions (depending on project e.g. potassium acetate or potassium formate) were always diluted to 0.6 mol/l regarding the active component prior to application on the concrete prisms. The amount of deicing salts applied in the field during one winter period in Germany, is approximately as much as applied within 8 cycles (NaCl - highway pavements) or one cycle (runway deicers - airfield pavements).

## 3 RESULTS

The 4 coarse aggregates were tested before the performance-test by using a standardised mortar bar test (Figure 2). The granodiorite was classified as non-reactive and the andesite as potentially reactive. The rhyolite and the greywacke were classified as reactive.

For the concrete with the reactive greywacke, the cyclic climate storage shows that the expansion exceeds the limit after 5 cycles when deicer solutions are applied but did not when only water is used (Figure 4). The concrete with the potentially reactive andesite shows no deleterious expansion, no matter if deicer solution or water is applied (Figure 5). The concrete with the reactive rhyolite, as identified by the mortar bat test also shows no deleterious expansion, no matter if deicer solution or water is applied (Figure 6). For the concrete with the granodiorite, classified as non-reactive with the mortar bar test, the expansion exceeds the limit after 6-8 cycles when the deicer solutions are applied but did not when water is used (Figure 7).

Microscopic examinations (thin sections, SEM) were carried out and ASR was confirmed for both concretes that exceeded the expansion limit. ASR-gel was found especially when acetate/formate based deicers were tested (Figure 8 - Figure 10).

## 4 DISCUSSION

The performance-tests should clarify, if pavement concretes with the 4 selected aggregates will be affected by ASR in the field or not. The greywacke was classified as reactive with the mortar bar test. The performance-test showed, if only water is applied, no deleterious ASR occurred, because the alkali content in concrete is low enough to prevent deleterious ASR. When deicing solutions were applied, deleterious expansions occurred, despite of the considerably low $Na_2O_{eq}$ (0.72 wt%) of the used cement. The greywacke was classified correctly by the mortar bar test for pavement concretes, but by using an appropriate binder with low-alkali content, a deleterious ASR might be avoided in the field for structures where no external alkalis will be supplied.

The andesite was classified as potentially reactive with the mortar bar test. The cyclic climate storage showed that also under attack of alkali-containing deicers no deleterious expansion occurred. In that case, the same cement ($Na_2O_{eq}$ = 0.72wt %) as that for the greywacke-concrete was used. Without the results from the cyclic climate storage, the andesite would have to be rejected for pavement concretes, but the andesite was revealed as sufficiently non-reactive in this testing regime. No ASR-damages in the field are known with that specific andesite.

The rhyolite was clearly classified as reactive with the mortar bar test. The cyclic climate storage showed that even under attack of alkali-containing deicers no deleterious expansion occurred. Again, the same cement ($Na_2O_{eq}$ = 0.72 wt %) as that for the greywacke-concrete was used. Without the results from the cyclic climate storage, the rhyolite would have to be rejected for pavement concretes and most structural concretes as well, but the rhyolite performed quite well during the performance-test. Water absorption tests and mercury intrusion measurements (MIP) showed that this specific rhyolite has an unusual dense structure. Obviously, the rhyolite was tested as reactive by the mortar bar test due to crushing the aggregates to fine (0.5-2 mm) particles that provide an increased surface which accelerates the ASR in the mortar bars. However, in concrete no ASR occurred because the ingress of pore solution into the coarse rhyolite grains is reduced due to the dense structure.

The granodiorite was classified as non-reactive with the mortar bar test, but the expansion was close to the limit for potentially reactive aggregates. However, severe and deleterious expansions occurred after 6-8 cycles, when deicing solutions were applied. ASR-gel was found by microscopic examinations (SEM, Figure 9). Again, no deleterious ASR occurred if only water was applied. The cement ($Na_2O_{eq}$ = 0.76wt %) was comparable to the one used in the other concretes. Examinations on thin-sections showed, that granodiorite grains were affected by ASR, especially in case of the applied potassium formate deicer (Figure 10). Coincidentally, ASR-distress in a highway concrete pavement with this granodiorite was found contemporaneous and so the result of the ASR-performance-test was additionally confirmed.

These examples are not the normal cases, but are rather individual. In many cases there is an acceptable correlation between mortar bar test and performance-test. However, the performance-tests showed clearly, that ASR in concrete is different from ASR in mortar bars. Field-reliable results only can be expected, if significant field conditions (drying, moistening, freezing and thawing, external alkalis) are considered properly in a concrete performance-test.

## 5 CONCLUSIONS

For more than a decade basic research has been carried out on very different aspects, in order to clarify the damage mechanisms and reasons for deterioration and harmful formation of phases in the hardened concrete. The developed ASR performance-test method has proved as suitable for assessing the durability of concretes regarding ASR under consideration of external alkali sources.

After testing more than 100 concretes, mostly job mixtures, with different cements and aggregates with the cyclic climate storage it was found that a deleterious ASR is initiated and accelerated highly in concretes with reactive aggregates, if exposed to alkali-containing deicers, especially based on acetates and formates [4,6,11,15-18]. The use of SCMs is beneficial in reducing the penetration of alkalis into the concrete, but in Germany the usage of portland cement for pavement concrete is the normal case, owed to other occurred durability problems (e. g. poor frost resistance). The influence of externally applied alkalis exceeds the influence of the cement alkali content sooner or later. Low-alkali cements delay considerably the ASR, but are not capable of permanently preventing a deleterious ASR, if external alkalis are supplied (Figure 11). Hence, using low-alkali cements is not a reliable method to avoid deleterious ASR if reactive aggregates are used and external alkalis are applied. Therefore, especially for pavement concretes (highways, airfields), the selection of sufficiently non-reactive aggregates is most important for avoiding a deleterious ASR, if alkalis from external sources are able to penetrate into the concrete. But the results showed that mortar bar tests are only suitable for a first short-term assessment of the reactivity of aggregates. Some aggregates may be classified incorrectly by mortar bar tests, especially when it is intended to use them in concrete pavements. It was found that the assessment of specific pavement concretes, i.e. the specific binder-aggregate combination used in the field, with a concrete performance-test like the cyclic climate storage is much more reliable in predicting the ASR-field behaviour for the concrete.

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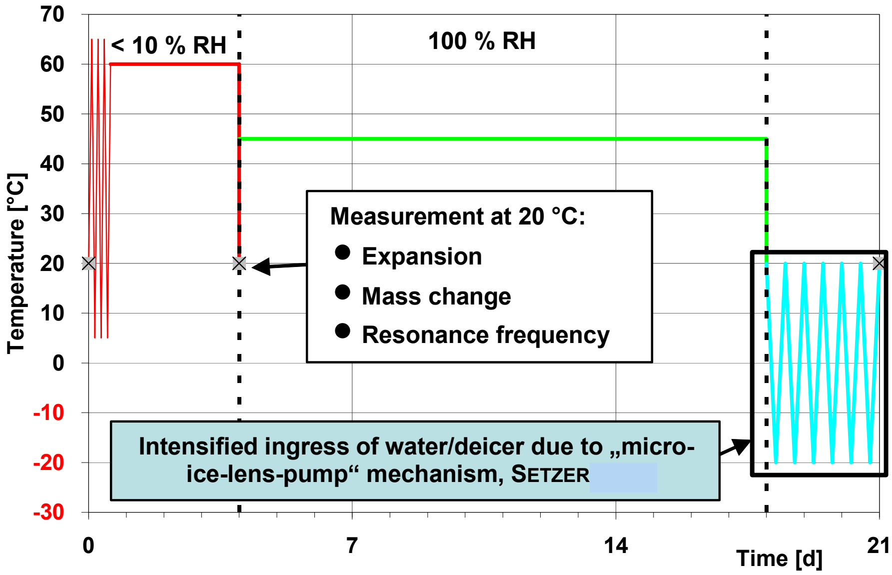


Figure 1: Scheme of cyclic climate storage (one cycle)

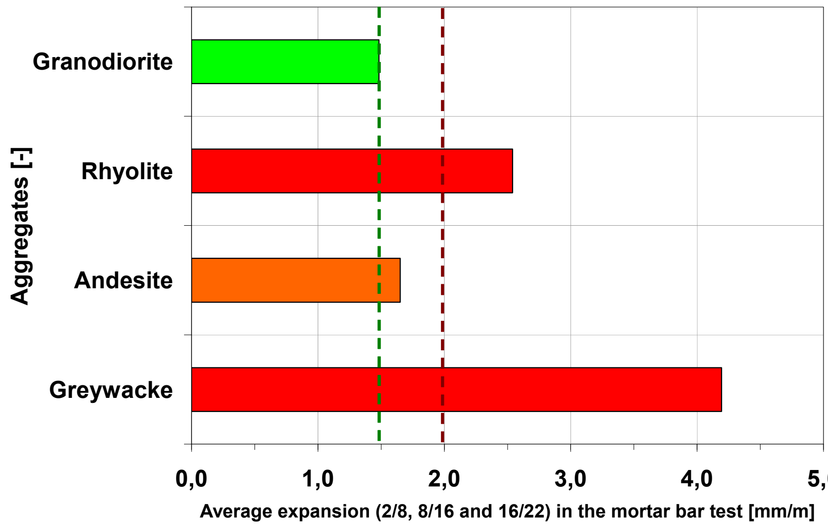


Figure 2: Results of mortar bar tests

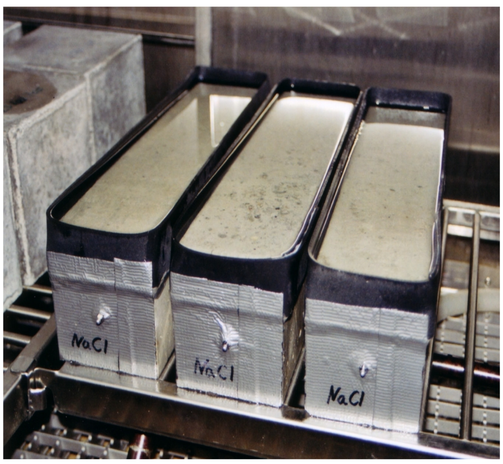


Figure 3: Concrete prisms with foamed rubber tape and applied deicing solution at the upper surface in the special climate simulation chamber

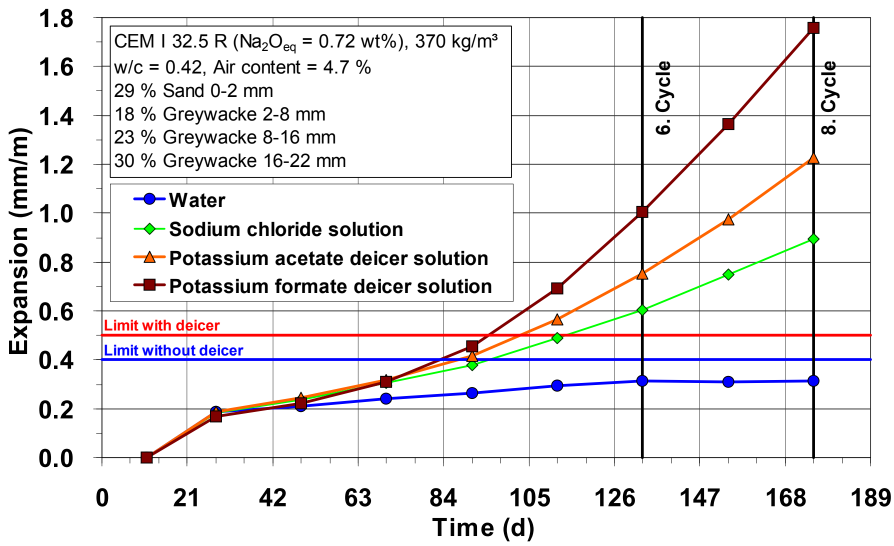


Figure 4: Expansion during the cyclic climate storage for a tested pavement concrete with reactive greywacke

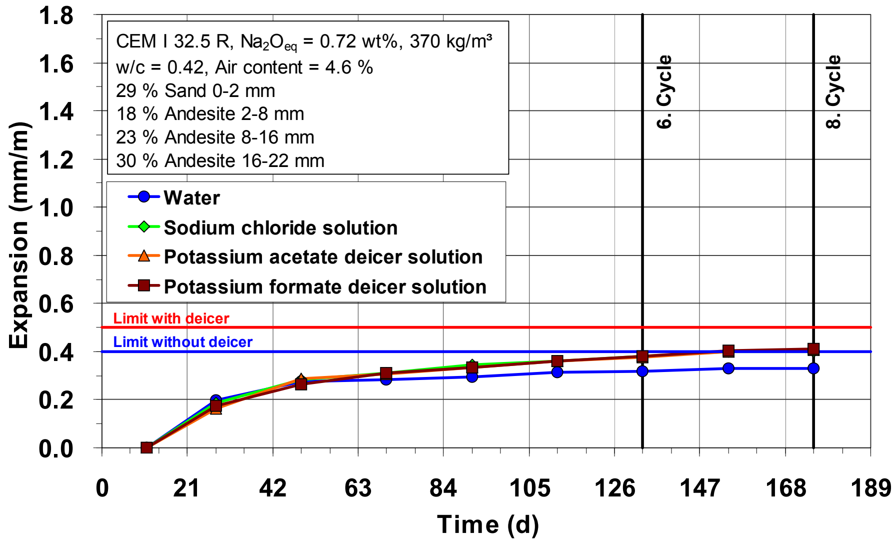


Figure 5: Expansion during the cyclic climate storage for a tested pavement concrete with potentially reactive andesite

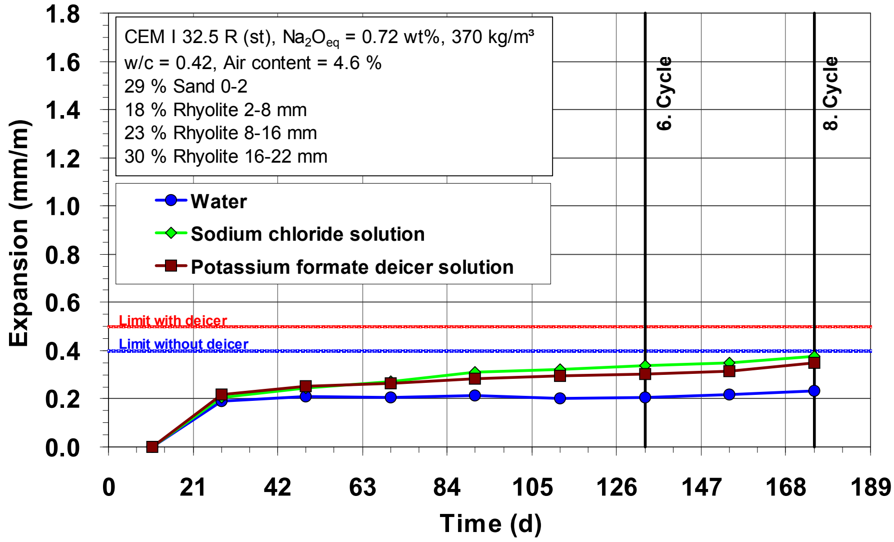


Figure 6: Expansion during the cyclic climate storage for a tested pavement concrete with potentially reactive rhyolite

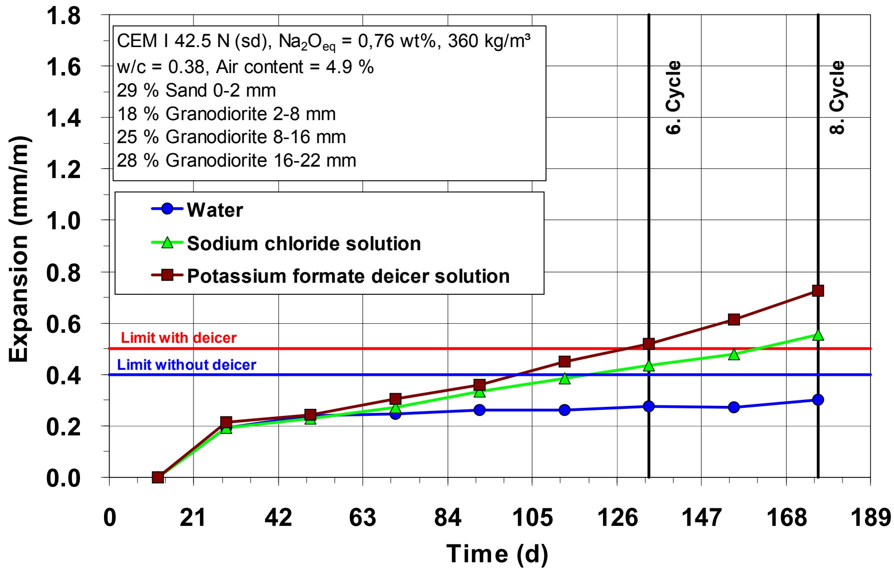


Figure 7: Expansion during the cyclic climate storage for a tested pavement concrete with potentially reactive granodiorite

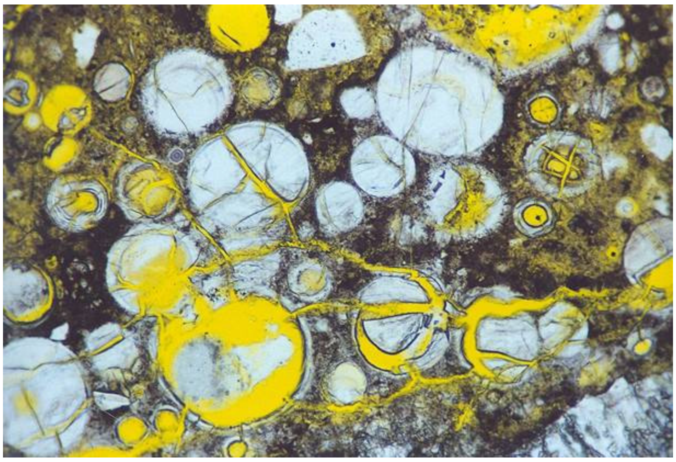

Figure 8: Thin section image, ASR-gel in artificial air voids

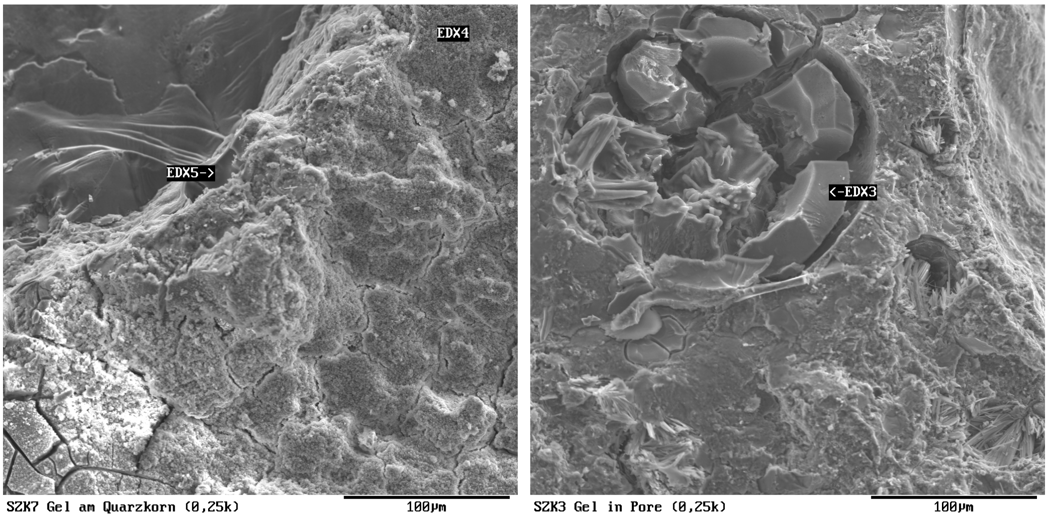


Figure 9: ESEM/REM images of ASR-gel in tested pavement concrete samples with deicer solution

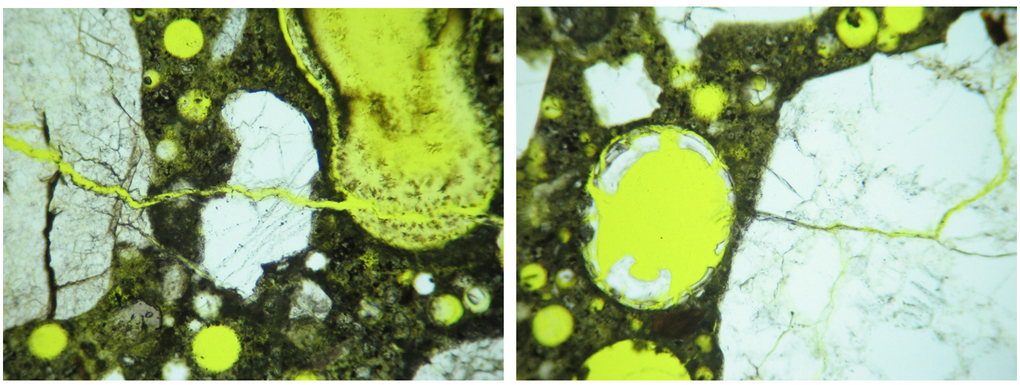

Figure 10: Thin section images after 8 cycles of performance-testing, cracks in granodiorite grains and ASR-gel in air voids

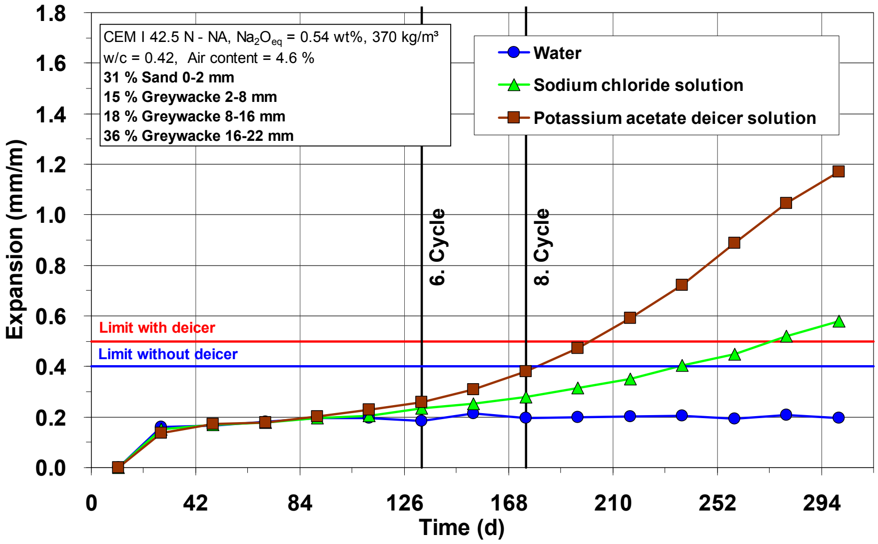


Figure 11: Expansion during the cyclic climate storage for a tested pavement concrete with reactive greywacke and low-alkali cement

Table 1: Cement composition

| Pavement cement ($Na_2O_{eq}$ according ARS 12/2006 [20]) | | | | |
|---|---|---|---|---|
| | | unit | | |
| $SiO_2$ | | (%) | 20.3 | |
| $Al_2O_3$ | | (%) | 3.94 | |
| $Fe_2O_3$ | | (%) | 3.90 | |
| CaO | | (%) | 63.2 | |
| MgO | | (%) | 1.20 | |
| MnO | | (%) | 0.04 | |
| $TiO_2$ | | (%) | 0.18 | |
| $K_2O$ | | (%) | 0.96 | water soluble 0.80 |
| $Na_2O$ | | (%) | 0.09 | water soluble 0.07 |
| $SO_3$ | | (%) | 3.1 | |
| Cl | | (%) | 0.116 | |
| $CaO_{free}$ | | (%) | 1.3 | |
| | | | | |
| Lime Standard | KST I | | 96 | |
| Silicate modulus | SM | | 2.6 | (correction $CaO_{free}$) |
| Alumina iron modulus | TM | | 1.0 | |
| Equivalent $Na_2O$ | $Na_2O_{eq}$ | (%) | 0.72 | water soluble 0.60 |
| | | | | |
| calculated | | | Bogue | |
| $C_3S$ | | (%) | 56.8 | |
| $C_2S$ | | (%) | 15.4 | |
| $C_3A$ | | (%) | 3.8 | |
| $C_2(A, F)$ | | (%) | 11.9 | |