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SUMMARY

The alkali reactivity of concretes for road pavements in the WS moisture class can be evaluated with ASR (alkali-silica reaction) performance tests. This article presents the background to the evaluation of the "60 °C concrete test with external supply of alkalis". Concrete road pavements that had been damaged to differing extents were classified into damage categories. Drill cores were then taken from them and tested with the 60 °C concrete test with external supply of alkalis. The tests were carried out with 3 % and 10 % sodium chloride (NaCl) solutions. Evaluation criteria were derived for both cases. The evaluation criteria were also derived by comparing the depth-dependent levels of water-soluble chlorides in concrete road pavements and in laboratory test specimens after conclusion of the ASR performance tests. The results of comparison trials of the 60 °C concrete test with the cyclic climate storage – in each case with external addition of alkalis – were also used. The evaluation criteria can be applied equally for ASR performance testing (evaluation of a concrete mixture) and for aggregate testing (evaluation of an aggregate).

ZUSAMMENFASSUNG

Mit AKR-Performance-Prüfungen kann die Alkaliempfindlichkeit von Betonen für Fahrbahndecken der Feuchtigkeitsklasse WS bewertet werden. Im vorliegenden Beitrag wird der Bewertungshintergrund für den „60 °C-Betonversuch mit Alkalizufuhr von außen" vorgestellt. Es wurden verschieden stark geschädigte Betonfahrbahndecken in Schadenskategorien eingestuft, daraus Bohrkerne entnommen und mit dem 60 °C-Betonversuch mit Alkalizufuhr von außen geprüft. Die Prüfungen wurden mit einer 3%igen und mit einer 10%igen Natriumchlorid-Lösung (NaCl) durchgeführt. Für beide Fälle werden Bewertungskriterien hergeleitet. Zur Herleitung der Bewertungskriterien wurden außerdem die tiefenabhängigen Gehalte wasserlöslicher Chloride in Fahrbahndeckenbetonen und in Laborprüfkörpern nach Abschluss von AKR-Performance-Prüfungen verglichen. Zusätzlich wurden die Ergebnisse von Vergleichsversuchen des 60 °C-Betonversuchs mit der Klimawechsellagerung jeweils mit Alkalizufuhr von außen herangezogen. Die Bewertungskriterien können gleichermaßen für AKR-Performance-Prüfungen (Bewertung eines Betons) wie für WS-Grundprüfungen (Bewertung einer Gesteinskörnung) angewendet werden.

(Translation by Robin B. C. Baker)

Experience with ASR test methods: advice on obtaining practical evaluation criteria for performance testing and aggregate testing

Erfahrungen mit AKR-Prüfverfahren: Hinweise zur Ableitung praxisgerechter Bewertungskriterien für Performance- und WS-Grundprüfungen

1 Introduction

Initial cases of damage due to alkali-silica reactions (ASR) appeared in Germany at the end of the 1960s in Schleswig-Holstein in industrial plants, quay walls and bridges [1]. The body of rules for avoiding damage in concrete structures caused by ASR, the Alkali Guidelines issued by the DAfStb (German Committee for Structural Concrete), have been consistently revised since then. Descriptive rules with which it is safe to build in all areas of building construction and civil engineering (moisture classes WO, WF, WA) are available in the form of the 2012 Alkali Guidelines, including the 1st and 2nd revisions (April 2010 and April 2011). The first version of the Alkali Guidelines of 1974 [2] has been extended several times with the result that with time they became difficult to understand. The Guidelines are currently being re-edited so that they correspond to the structure of European standards and will be easier to understand in practice.

The first cases of damage due to ASR in concrete road pavements appeared from 1996 in federal motorways in south-west Germany. The development of ASR performance test methods began when further cases of damage in motorways appeared in central Germany. The development of the methods followed the finding that the following concrete structural elements were subject to particularly severe stresses due to the effects of de-icing salt/de-icing chemicals and heavy dynamic traffic loads and were no longer dealt with appropriately by the current descriptive rules [3]:

- concrete roads of the SV and I to III construction classes as specified in the RStO
- airfields made of concrete.

The Bauhaus University Weimar (FIB) and the Research Institute in Duesseldorf (FIZ) each developed a method for investigating the alkali reactivity of concretes for these structural elements, namely the concrete test with "cyclic climatic storage" [4] and the "60 °C concrete test with external supply of alkalis" [5, 6]. The two methods lead to comparable evaluation of identical concretes and are recognized by the BMVBS (Federal Ministry of Transport, Building and Urban Development) [7, 8].

Regardless of the test method used the establishment of the evaluation criteria must satisfy two important criteria:

- avoidance of ASR damage
- retention of the competitiveness of concrete construction.

In order to satisfy the latter aspect it is necessary not just to account for and in future exclude the cases that have demonstrably led to damage. It must also continue to be possible to build with the concrete mixture and aggregates that have proved successful in practice.

Initially, a limit of 0.5 mm/m after ten cycles of the cyclic storage was set for the "60 °C concrete test with external supply of alkalis" when testing with a 10 % NaCl solution [5, 6]. By using this limit it should be possible to differentiate between those concretes for which damage due to an ASR is to be expected during the working life of the concrete road pavements and those for which no damage is expected. The BMVBS is introducing a WS aggregate test in 2013 through a new General Road Construction Circular. This test is intended to assess the suitability of coarse aggregates for road pavements made with concrete of the WS moisture class. One important component is the "WS concrete test" with which a coarse aggregate is to be investigated in an unfavourable concrete composition either with the "60 °C concrete test with external supply of alkalis" or with cyclic climate storage. Evaluation criteria that meet practical requirements are also needed for this application of the concrete tests.

2 Purpose of the investigation

The purpose of the investigation was to derive practical criteria for the "60 °C concrete test with external supply of alkalis" for evaluating the alkali reactivity of concretes and aggregates for use in the WS moisture class. Drill cores taken from concrete road pavements that had been damaged to differing extents were examined. The drill cores and additional laboratory concretes were each tested with 3 % and 10 % sodium chloride solutions (NaCl) in order to derive a relationship between the use of the two NaCl concentrations. Moreover, the relation between the test results and the damage categories, which describe the condition of the road pavements, should be established. The concretes from two road pavements were also simulated by laboratory concretes and tested. The laboratory concretes were produced with current charges of concrete constituents for the road pavements. Finally, the results of the 60 °C concrete test with 3 % and 10 % NaCl solutions were compared with the results of the cyclic climate storage for concretes with identical compositions. Additional information was provided by comparison of the chloride profiles in the test specimens made from a concrete after conclusion of the ASR performance tests with the chloride profiles of drill cores from road pavements and from a laboratory concrete after cyclic climate storage.

3 Investigations

3.1 Description of the condition of road pavements by damage category

The condition of road pavements damaged by ASR can be described by three damage categories as shown in ❱ Table 1 [9]. They were established in order to be able to specify appropriate repair measures for structural maintenance of concrete road pavements damaged by ASR. When alkali hydroxides react with alkali-reactive aggregates in a road pavement the first sign is usually discolouration of the trans-

vdz.

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Table 1: Allocation of the features to damage categories as defined in [9]

Damage category	Damage features
I	– discolouration in the area of the transverse joints / joint intersections (generally starting at the joint intersection) – no cracking beyond shrinkage cracks
II	– marked discolouration in joint areas – cracking in the joint intersection areas – incipient to marked cracking – possible longitudinal and transverse cracks at the transverse joints – possible additional longitudinal cracking in vibration channels, but still no loss of substance
III	– marked discolouration in the joint areas – very marked cracking (often with discolouration) – possible edge damage and/or broken corners – possible loss of substance, e.g. crumbling

verse joint and joint intersection areas. In this condition the road pavement may possibly exhibit shrinkage cracks but no ASR-induced cracks. Road pavements with these features are assigned to damage category I. If the ASR progresses then cracks are formed. Damage category II is characterized by incipient to marked cracking and marked discolouration in the joint areas. The cracks weaken the concrete microstructure, and the edges of the transverse joints are broken by the mechanical stresses from vehicles. This condition is described by damage category III in which loss of substance occurs together with crumbling of the transverse joints.

3.2 Drill cores from road pavements

Drill cores (15 cm diameter x approx. 30 cm) were taken from the road pavements of several concrete motorways in Germany. The road pavements were assessed visually and allocated to a damage category during visits to the sections. Essential information about the drill cores, the road pavement and their damage categories is listed in ❱ Table 2. All the data on drill cores 1 to 4, 6 and 9 to 11 were taken from [10]. Each of the drill cores was taken from the first traffic lane, which is the lane most heavily stressed by the lorry traffic. An exception to this was drill core 5, which was taken from the hard shoulder.

The drill cores were sawn in half lengthwise. Measuring studs for the longitudinal measurements were attached to the two ends for subsequent testing with the “60 °C concrete test with external supply of alkalis” in accordance with the storage plan in ❱ Table 3. The trials were carried out with a 3 % NaCl solution. The trials were intended to indicate the relationship between the damage category of a road pavement observed in practice and the residual expansion potential of the concrete in the “60 °C concrete test with external supply of alkalis”. On the basis of this relationship it should be possible to derive an assessment criterion for the concrete tests with external supply of alkalis in the 60 °C concrete test.

3.3 Influence of the sodium chloride concentration

The 60 °C concrete tests were carried out on different laboratory concretes and half drill cores in parallel with 3 % and 10 % NaCl solutions. These tests were intended to indicate the relationship between the results when using the two NaCl concentrations. Knowledge of this relationship might make it possible to apply results from tests with 3 % NaCl solution to tests that were carried out with 10 % NaCl solution. This also made it possible to compare the assessment criteria with one another.

Table 2: Information on the sections of motorway investigated and classification in damage categories as defined in [9]

Motorway section	Age on sampling in years	Sampling point	Damage category acc. to [9]	Discolouration of the joints	Cracking	Longitudinal and transverse cracks	Substance damage
1	9	1st TL	III	n.r.	yes	Longitudinal cracks, transverse cracks	yes
2	15	1st TL		n.r.	yes		yes, occasional
3	9	1st TL		n.r.	yes		yes
4	12	1st TL		yes	yes	yes	yes
5	12	HS	II	yes	yes, severe cracking	no	no
6	14	1st TL		n.r.	yes	longitudinal cracks	no
7	12	1st TL		no	yes	small longitudinal cracks	no
8	18	1st TL	I	no	yes, slight cracking	no	no
9	10	1st TL		no	shrinkage cracks	no	no
10	12	1st TL		no		no	no
11	16	1st TL	no damage	no	very fine shrinkage cracks	no	no

1st TL = first traffic lane; HS = hard shoulder
n.r.: not recorded

3.4 Simulated road pavement concretes

The concretes from damaged road pavement (motorway sections 1 and 3 with the same concrete composition, see Table 2) and an undamaged road pavement (motorway section 9, see Table 2) were simulated in the laboratory. The concretes are designated below as laboratory concrete 1 and laboratory concrete 9 respectively. These concretes were investigated with the "60 °C concrete test with external supply of alkalis" using 3 % and 10 % NaCl solutions. The concrete mix formulations, which were taken from [10], are listed in Tables 4 and 5. Current samples of the aggregate from the corresponding supply plants were used together with cement from a plant where the Portland cement had a comparable Na_2O equivalent. These tests were intended to confirm the evaluation criteria that were derived from the trials described in Sections 3.2 and 3.3.

3.5 Comparison of the 60 °C concrete test with the cyclic climate storage

Comparative investigations of ASR performance testing have been carried out during the past few years at the Research Institute (60 °C concrete test with and without external supply of alkalis) and at the Bauhaus University Weimar (cyclic climate storage) on a total of 18 concretes [7, 8, 11]. The concretes were made up as follows from the same starting materials:

- w/c = 0.42, c = 370 kg/m^3, air void content: 4.5 ± 0.5 vol. % and
- w/c = 0.42, c = 430 kg/m^3, air void content: ≥ 5.5 vol. %.

Different aggregates and Portland cements (Na_2O equivalents between 0.56 and 0.89 mass %) were used. The 60 °C

Table 3: Storage plan in the 60 °C concrete test with external addition of alkalis

Storage phase	Storage time	Measurement at end of storage	Climate
Sample preparation, attachment of measuring studs	–	–	20 °C and 65 % r.h.
Preliminary storage 7 d	6 d	–	60 °C and ≥ 98 % r.h
	1 d	zero measurement	20 °C and ≥ 98 % r.h.
Alternating storage every 14 d	5 d	–	60 °C in drying cabinet
	2 d	–	20 °C in NaCl test solution
	6 d	–	60 °C and ≥ 98 % r.h.
	1 d	measurement	20 °C and ≥ 98 % r.h.

Table 4: Laboratory concrete 1 = replicated concrete from motorway section A10-8, corresponds to motorway sections 1 and 3 in Table 2; data taken from [10]

Starting material	Size range [mm]	Proportion [vol. %]	Content[3] [kg/m^3]
Sand	0/2	30 [1]	543
Gravel	2/8	20 [1]	359
Gravel	8/16	10 [1]	180
Crushed Grandiorite	16/22	40 [1]	726
CEM I 42,5 N[2] cement	–	–	340
Mixing water (w/c = 0.46)	–	–	156
Air content	–	5.0 [3]	–

[1] W.r.t.: aggregate
[2] Na_2O equivalent = 0.85 mass % (0.81 mass % of Cement + 0.04 mass % by addition of K_2So_4)
[3] W.r.t.: concrete

Table 5: Laboratory concrete 9 = replicated concrete from motorway section A40-7, motorway section 9 in Table 2; data taken from [10]

Starting material	Size range [mm]	Proportion [vol. %]	Content[3] [kg/m^3]
Sand	0/2	28.2 [1]	512
Gravel	2/8	34.2 [1]	623
Crushed Greywacke	8/11	27.3 [1]	510
Crushed Greywacke	11/16	10.2 [1]	191
CEM I 42,5 N[2] cement	–	–	351
Mixing water (w/c = 0.42)	–	–	147
Air content	–	5.0 [3]	–

[1] W.r.t.: aggregate
[2] Na_2O equivalent = 0.81 mass % instead of 0.78 mass % in the original cement
[3] W.r.t.: concrete

concrete tests were carried out with 3 % and 10 % NaCl solutions and the cyclic climate storage was carried out with a 0.6 molar NaCl solution.

3.6 Chloride profile in concrete with external supply of alkalis

The levels of chloride in two concrete beams made with laboratory concrete 9 (see Section 3.4) after eleven cycles of alternating storage were determined over the cross-section to assess the penetration behaviour of sodium chloride in concrete during the 60 °C concrete test. 10 mm thick slices were sawn from all sides of the concrete beams for this purpose. The slices were ground to analysis fineness and the levels of water-soluble chloride were determined as specified in DIN EN 196-2 and related to the content of hardened cement paste. The results were compared with the results of the investigations of IGF Project 15977 N [12]. The levels of chloride in concrete drill cores from 20-year-old road pavements and in laboratory test pieces from the 60 °C concrete test and the cyclic climate storage had been determined in [12].

4 Results

4.1 Drill cores from road pavements

The expansions of the half drill cores in the 60 °C concrete test with external supply of alkalis in the form of 3 % NaCl solution are shown in ❱ Fig. 1 and in an extract in ❱ Fig. 2. The markers have been coloured to correspond to the damage categories of the road pavements. After ten cycles (140 days) the half drill cores from road pavements in damage category III exhibited expansions between 0.5 and 1.8 mm/m. The half drill cores from two road pavements in damage category II expanded between 0.4 mm/m and 0.6 mm/m. The expansions of the half drill cores from road pavements in damage category I lay between 0.1 mm/m and 0.3 mm/m (see Fig. 2). The half drill cores from one road pavement that after 16 years exhibited no damage (BK11) expanded by about 0.3 mm/m. Using an expansion of 0.3 mm/m after ten cycles (140 days) as the assessment criterion it was possible to differentiate between the concretes as follows:

Concretes from road pavements in the first traffic lanes of federal motorways that after ten to 18 years of intensive use exhibited no signs of a harmful ASR or slight cracking that was not attributable to an ASR or discolouration (no damage or damage category I).

Concretes from road pavements in the first traffic lanes of federal motorways that after nine to 15 years exhibited longitudinal and transverse cracks and in which loss of substance had occurred in some cases (damage categories II and III).

4.2 Influence of the sodium chloride concentration

In order to be able to compare the influence of external supply of alkalis with 3 % and 10 % NaCl solutions some half drill cores and laboratory concretes were tested in the 60 °C concrete test with both NaCl concentrations (❱ Fig. 3). The expansions with 10 % NaCl solution were on average about twice as high as the expansions with 3 % NaCl solution. The evaluation with an expansion of 0.3 mm/m as the criterion with 3 % NaCl solution corresponded approximately to the evaluation with an expansion of 0.6 mm/m as the criterion with 10 % NaCl solution. In both cases the evaluation was carried out after ten cycles (140 days after the end of preliminary storage). The results in Fig. 3 deviate from this relationship for three concretes. At present it is not possible to give the reasons for this deviant behaviour. For two laboratory concretes this would lead to a different evaluation (marked by a grey circle). Both concretes were produced with the same Precambrian greywacke.

In accordance with Section 4.1 this means that no indications of a harmful ASR or only slight cracking or discolouration should occur in practice after ten to 18 years use for all the concretes that lie in the blue region in Fig. 3.

4.3 Simulated road pavements concretes

The expansions of laboratory concretes 1 and 9 in the 60 °C concrete test with external supply of alkalis are shown in ❱ Fig. 4. The expansions with 3 % NaCl solution when using an evaluation criterion for the expansion of 0.3 mm/m are

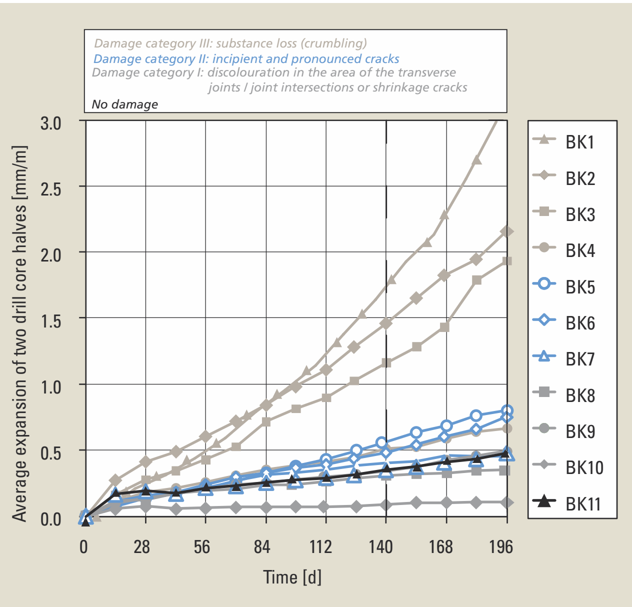

Figure 1: Expansion of drill core halves (average from two drill core halves) taken from road pavements that had been damaged to differing extents and tested in the 60 °C concrete test with external supply of alkalis by a 3 % NaCl solution; some data are taken from [10]

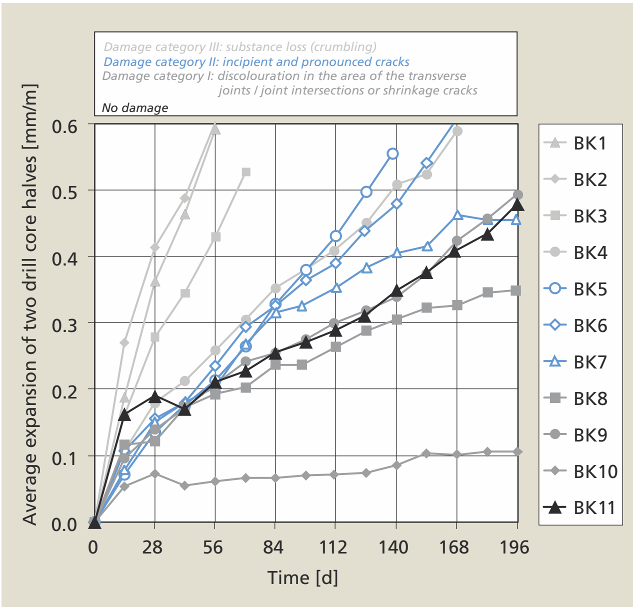

Figure 2: Expansion of drill core halves (average from two drill core halves) taken from road pavements that had been damaged to differing extents and tested in the 60 °C concrete test with external supply of alkalis by a 3 % NaCl solution (detail from Fig. 1); some data are taken from [10]

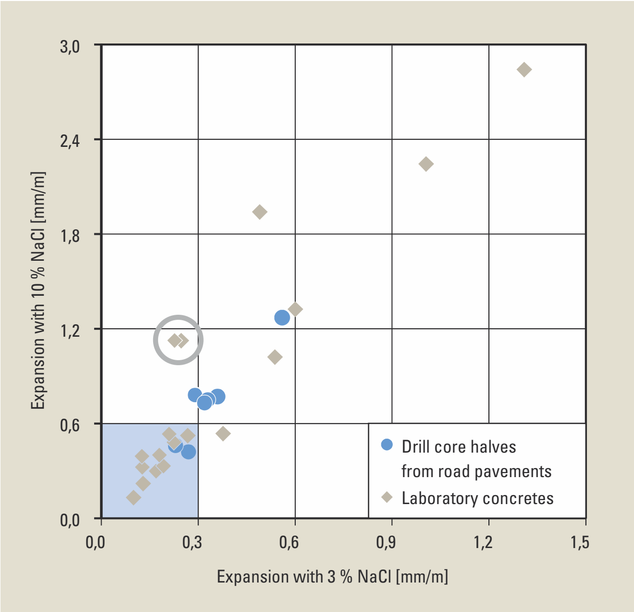

Figure 3: Expansion of drill core halves (average from two drill core halves) taken from road pavements and laboratory concretes after ten cycles (140 days after the end of preliminary storage) and tested in the 60 °C concrete test with external supply of alkalis by 3 % and 10 % NaCl solutions

shown in the left side; on the right are the expansions with 10 % NaCl solution when using an evaluation criterion for the expansion of 0.5 mm. After ten cycles (168 days) with 10 % NaCl solution both concretes exhibited expansions significantly above the limit of 0.5 mm/m that had been used previously in accordance with [5, 6]. The same would have applied if an evaluation criterion for the expansion of 0.6 mm/m had been used. In practice ASR damage had actually occurred (see motorway sections 1 and 3 in Table 2) with a concrete comparable with laboratory concrete 1. On the other hand, after ten years the road pavement with laboratory concrete 9 had been allocated to damage category I (see motorway section 9 in Table 2). In the test with 3 % NaCl solution and an evaluation criterion of 0.3 mm/m the laboratory concrete 9 would have passed the test. After ten cycles the laboratory concrete 1, for which the "associated" road pavement had been damaged (damage category III), exhibited expansions above the evaluation criterion of 0.3 mm/m. In this case the behaviour in practice was better simulated by the test with 3 % NaCl solution and an evaluation criterion of 0.3 mm/m than with 10 % NaCl solution.

4.4 Comparison of cyclic climate storage with the 60 °C concrete test with external supply of alkalis

The expansions with the two methods at the time of assessment are compared in ❱ Fig. 5, left, for 18 concretes. Six results come from FE Project 89.214/2008/AP "ASR in concrete road pavements" [11] that was commissioned by the BASt (Federal Highway Research Institute). A comparative evaluation using both methods was carried out on 17 concretes by using the evaluation criterion of 0.5 mm/m after eight cycles of cyclic climate storage with 0.6 molar NaCl solution and the evaluation criterion 0.5 mm/m after ten cycles in the 60 °C concrete test with external supply of alkalis using 10 % NaCl solution. In this case a different evaluation (light blue marker) would have been obtained for one concrete. This would have been four concretes if the evaluation criterion of 0.6 mm/m after ten cycles had been used in the 60 °C concrete test with 10 % NaCl solution.

❱ Fig. 5, right, compares the results from the 60 °C concrete test with external supply of alkalis with the cyclic climate storage when the 60 °C concrete test was carried out with 3 % NaCl solution and 0.3 mm/m was applied as the evaluation criterion. Four of the 16 concretes would have been evaluated differently as four concretes passed the 60 °C concrete test but exhibited expansions above the limit in the cyclic climate storage.

4.5 Chloride profile in the concrete with external supply of alkalis

❱ Fig. 6 shows the water-soluble chloride content in the concrete relative to the content of hardened cement paste in relation to the distance from the surface. The chloride con-

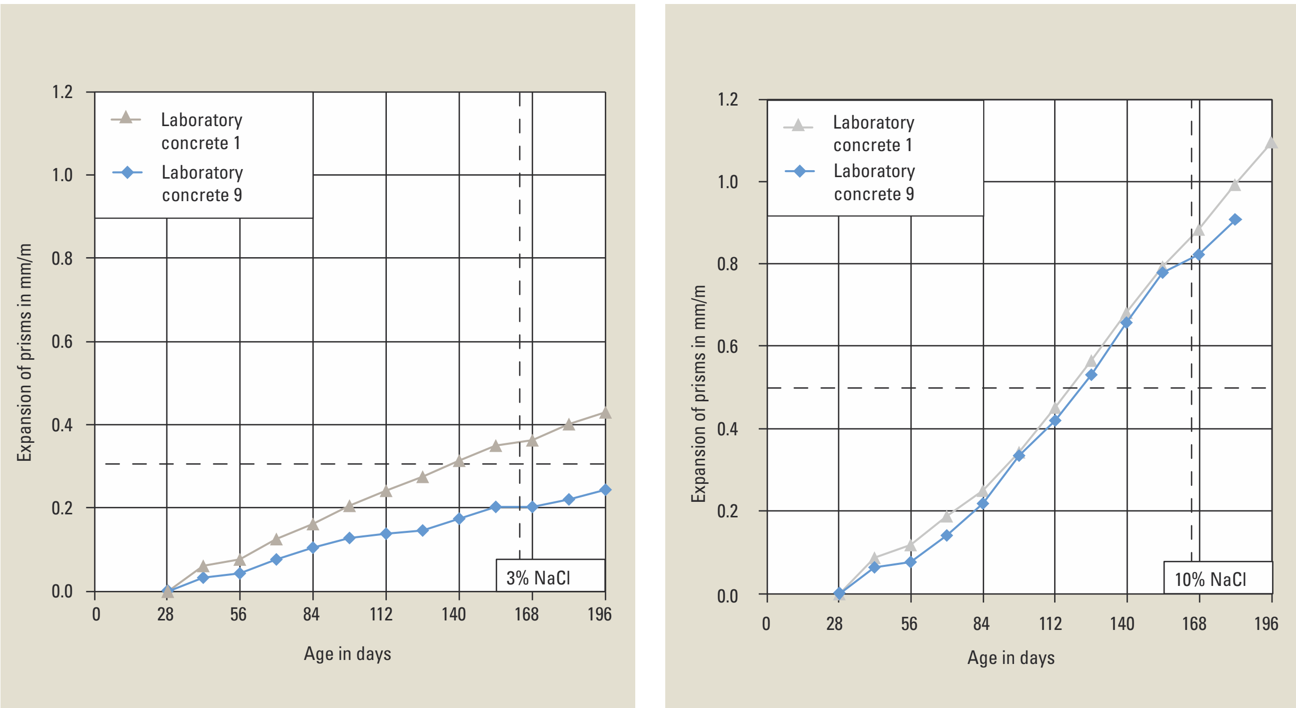

Figure 4: Expansion of concrete prisms in the 60 °C concrete test with external supply of alkalis; left: 3 % NaCl solution, right: 10 % NaCl solution

tent was examined in drill cores from concrete road pavements and in test specimens after conclusion of the cyclic climate storage (test specimens provided by the F.A. Finger Institute for Building Materials Science – Bauhaus University Weimar) and after the conclusion of the 60 °C concrete test with external supply of alkalis [12]. In concrete road pavements that were up to 20 years old the soluble chloride content in the hardened cement paste in the first centimetre of the concrete was up to 2 mass % and fell continuously to a depth of about 5 cm. With the cyclic climate storage and with the 60 °C concrete test with 10 % NaCl solution the levels of chloride in the area close to the surface lay between about 3 mass % and 4 mass %. In the 60 °C concrete test with 3 % NaCl solution the chloride content corresponded approximately to the levels that had been measured in the surface of the road pavements, so the 60 °C concrete test with 3 % NaCl solution simulated the conditions in the concrete road pavements that had been investigated. These results are in agreement with observations by Hamburg-Harburg Technical University [13]. Adjusting the test and the evaluation criteria in the 60 °C concrete test would possibly therefore improve their transferability to practical conditions.

5 Final Remarks

The alkali reactivity of concretes (ASR performance testing) and of aggregates (WS concrete road testing) for road pavements in the WS moisture class can be evaluated in concrete tests with external supply of alkalis.

The alkali reactivity of concretes (ASR performance testing) and of aggregates (concrete roads WS testing) for initial in the WS moisture class can be evaluated in concrete tests with alkali supply from outside. The Bauhaus University in Weimar (FIB) and the Research Institute in Duesseldorf (FIZ) each developed a procedure for this purpose, namely concrete tests with "cyclic climate storage" and the "60 °C concrete test with external supply of alkalis". The intention is that in the future it will be possible to avoid ASR damage by applying these procedures. The cases that have verifiably led to damage must therefore be identified and then excluded in future by stipulating evaluation criteria. However, it must also continue to be possible to build with concrete mixes and aggregates that have proved successful in practice.

In order to fulfil both requirements it must be possible to transfer the laboratory results to practical conditions. The transferability was assessed by investigating drill cores from concrete road pavements and laboratory concretes with the "60 °C concrete test with external supply of alkalis". The results can be summarized as follows:

Concretes that exhibited a maximum expansion of 0.3 mm/m after ten cycles in the 60 °C concrete test with 3 % NaCl solution showed no signs of a harmful ASR after ten to 18 years of intensive use in concrete road pavements in the first traffic lane of federal motorways or only showed slight cracking that was not attributable to an ASR. Discolouration occurred in some cases in the area of transverse joints or joint intersections (no damage or damage category I). With larger expansions it has to be assumed that damage in damage categories II or III will occur in concrete road pavements in the WS moisture class after nine to 15 years.

Comparison testing with 10 % NaCl solution in the 60 °C concrete test showed that in most cases the same evaluation as with 3 % NaCl solution is obtained if an evaluation criterion of 0.6 mm/m after ten cycles is applied. With 3 % NaCl solution and an evaluation criterion for the expansion of 0.3 mm/m the transferability to practical conditions seems possibly better than the test with 10 % NaCl solution and an evaluation criterion of 0.5 mm/m after ten cycles (current practice). One precondition is that the client is prepared to accept that damage category I may occur in individual cases after ten years in use.

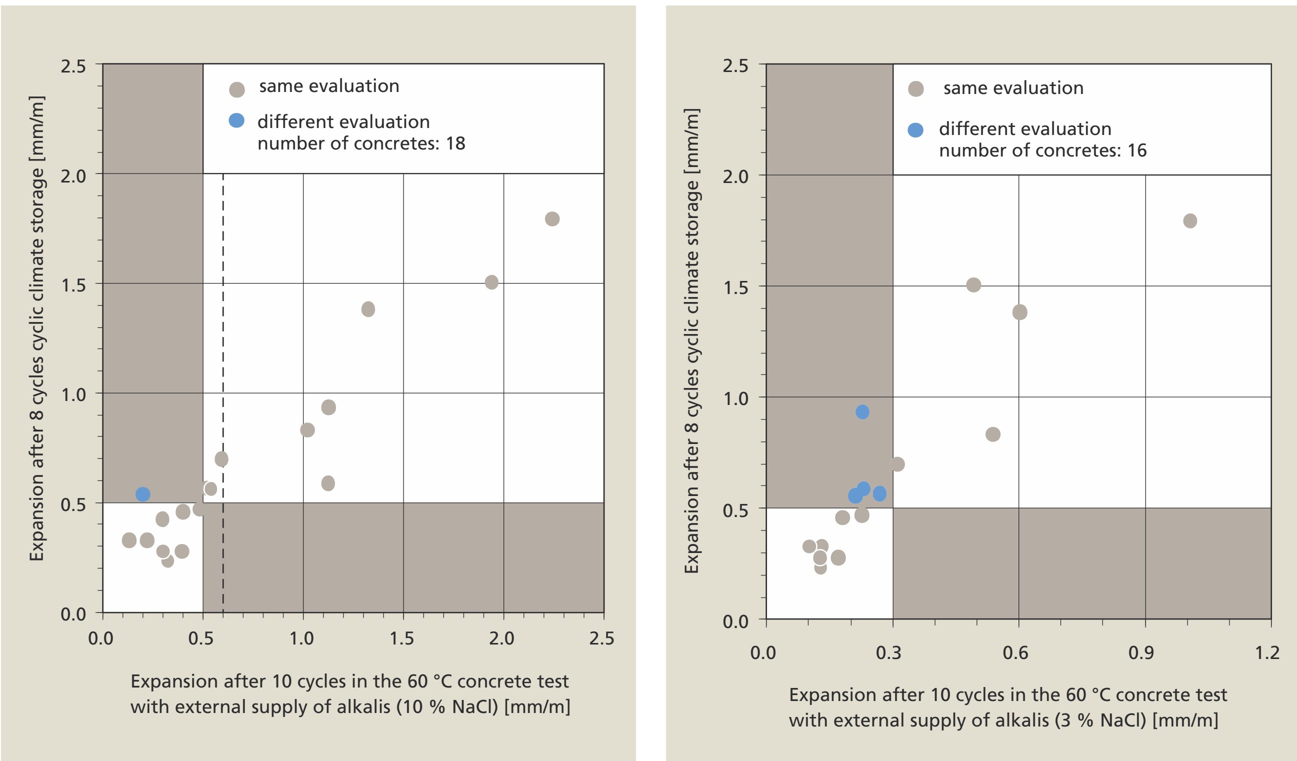

Figure 5: Expansion of different concretes for the WS moisture class after eight cycles of cyclic climate storage with 0.6 molar NaCl solution (evaluation criterion 0.5 mm/m) and expansion after ten cycles in the 60 °C concrete test with supply of alkalis; left: 60 °C concrete test with 10 % NaCl solution (evaluation criterion 0.5 mm/m or 0.60 mm/m), right: 60 °C concrete test with 3 % NaCl solution (evaluation criterion 0.3 mm/m)

With the "60 °C concrete test with external suply of alkalis" and the cyclic climate storage the evaluation of the concretes was almost universally comparable when the 60 °C concrete test was carried out with 10 % NaCl solution and 0.5 mm/m was applied as the evaluation criterion. If the 60 °C concrete test with 3 % NaCl solution with an expansion of 0.3 mm/m after ten cycles as the evaluation criterion was used then agreement of the evaluation with the cyclic climate storage was reduced.

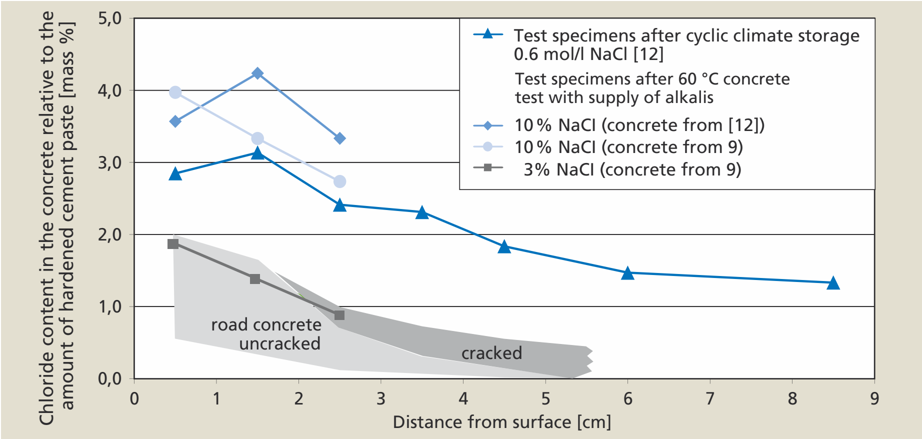

Figure 6: Content of water-soluble chloride in drill cores from concrete road pavements and in laboratory test specimens after conclusion of the ASR performance tests (cyclic climate storage and 60 °C concrete test with external supply of alkalis), relative to the content of hardened cement paste [12]

With the 60 °C concrete test with 3 % NaCl solution the chloride content that was determined at the end of the test corresponded approximately to the levels that were measured in the concrete road pavements. Adaptation of the 60 °C concrete test would therefore possibly also have a beneficial effect in this respect on the transferability of the laboratory tests to practical conditions.

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