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Dok-Nr. 93298

SUMMARY

Damage caused by an alkali-silica reaction (ASR) in concrete structures can be avoided by using concrete composition with a low alkali reactivity. The German Cement Works Association (VDZ) has developed criteria for ASR performance tests in order to make a practical evaluation of the alkali reactivity of concrete composition for elements of the WF (moist) and WA (moist + external supply of alkalis) moisture classes. Investigations were carried out to find the conditions under which the 60 °C concrete test with and without external supply of alkalis reproduces the requirements concerning measures in the Alkali Guidelines for the WF and WA moisture classes.

ZUSAMMENFASSUNG

Schäden infolge einer Alkali-Kieselsäure-Reaktion (AKR) an Betonbauwerken können vermieden werden, indem Betone eingesetzt werden, deren Alkaliempfindlichkeit gering ist. Um die Alkaliempfindlichkeit von Betonen für Bauteile der Feuchtigkeitsklassen WF (feucht) und WA (feucht + Alkalizufuhr von außen) praxisgerecht bewerten zu können, hat der Verein Deutscher Zementwerke (VDZ) nun Kriterien für AKR-Performance-Prüfungen entwickelt. Dazu wurde untersucht, unter welchen Bedingungen der 60 °C-Betonversuch mit und ohne Alkalizufuhr von außen die Festlegungen zu Maßnahmen der Alkali-Richtlinie in den Feuchtigkeitsklassen WF und WA abbildet.

CONCRETE TECHNOLOGY REPORTS

(Translation by Robin B. C. Baker)

Practical testing of the alkali reactivity of concrete compositions of the WF and WA moisture classes in ASR performance tests

Praxisgerechte Prüfung der Alkaliempfindlichkeit von Betonen für die Feuchtigkeitsklassen WF und WA in AKR-Performance-Prüfungen

1 Introduction and research objective

An alkali silica reaction (ASR) can damage concrete and reduce the intended service life of concrete structures. In this situation the serviceability can sometimes only be retained by expensive repairs. Damaging ASR will not occur if the aggregate is sufficiently non-reactive to alkalis, the concrete is sufficiently dry or the effective alkali content in the pore solution of the concrete is appropriately low. The alkalis come from the constituents of the concrete composition, predominantly the cement, and in some cases from de-icing agents that can penetrate into the concrete from outside. The Alkali Guidelines of the DAfStb (German Committee for Structural Concrete) [1] specify measures that have to be applied in Germany for concrete compositions complying with DIN EN 206/DIN 1045-2 in order to avoid ASR damage. The measures are specified in relation to the following parameters:

- alkali reactivity class of the aggregate
- moisture class of the concrete element
- cement content of the concrete composition.

In certain cases it is only permissible to use alkali-reactive aggregates of the E III-S alkali reactivity class in combination with low-alkali cement as specified in DIN 1164-10 or other aggregates that are not reactive to alkalis (alkali reactivity class: E I, E I-O – E I-OF or E I-S) in order to avoid ASR damage. These requirements take all the potentially possible material combinations into account ("worst-case scenario"). This means that there are concrete compositions that do not fulfil the above-mentioned requirements but which, in spite of this, would not lead to any ASR damage in practice. In order to be able to use such concrete compositions the Alkali Guidelines have, since the 2007 edition, allowed their use if the lack of reactivity to alkalis is verified by an expert report. As a rule, such an expert report is based on an ASR performance test. The ASR performance test should provide information about whether a concrete composition is sufficiently non-reactive to alkalis in the appropriate moisture class so that it will not be damaged by an ASR during the planned service life. The ASR performance test methods and the conditions for attestation of conformity have not yet been described in the Alkali Guidelines. CEN/TR 16349 allows, in principle, for the possibility of assessing the alkali reactivity with the aid of ASR performance tests [2] but contains no further details. The 60 °C concrete test (without alkali supply) has, since 2004, been included in the AFNOR P 18-454 standard [3] and is used in France and Switzerland for evaluating the alkali reactivity of concrete compositions [4, 5].

Before the ASR performance tests can also find their way into the Alkali Guidelines in Germany it must be proved that concrete compositions that are composed, and can be used, in accordance with the rules in the Alkali Guidelines can also be evaluated appropriately. The requirements in the Alkali Guidelines reflect the experience in Germany with concrete compositions that either exhibit no ASR damage or with which ASR damage has been shown to occur. Using the Alkali Guidelines it is possible to construct buildings and civil engineering works safely with regionally available concrete constituents.

The following tests were used in the IGF project 16569 N:

- "the 60 °C concrete test without alkali supply" for evaluating the alkali reactivity of concrete compositions of the WF moisture class (environment: concrete element is exposed to extraneous moisture, complies with E2 of CEN/TR 16349 [2])" and
- "the 60 °C concrete test with alkali supply" for evaluating the alkali reactivity of concrete compositions of the WA moisture class (environment: concrete element is exposed to extraneous moisture and to external supply of alkalis, complies with E3 of CEN/TR 16349 [2])".

In order to establish the conditions under which the test methods reproduce the lack of reactivity to alkalis of concrete compositions of the WF and WA moisture classes in agreement with the requirements of the Alkali Guidelines, concretes were made up in accordance with the requirements of the Alkali Guidelines and examined under varying test conditions (preliminary storage and sodium chloride concentration).

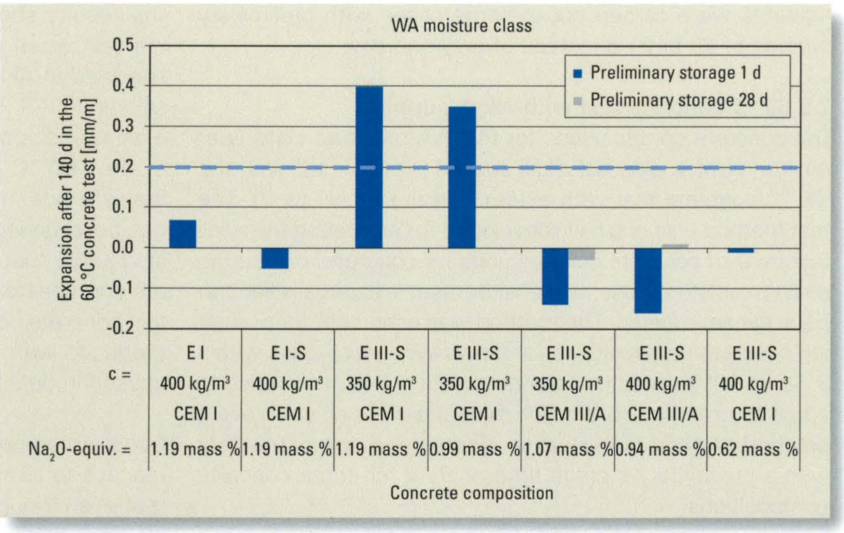

Figure 1: Expansion of various concrete compositions after 140 d in the 60 °C concrete test without external alkali supply, 1 d preliminary storage at 20 °C/100 % r.h. (blue) and 28 d preliminary storage at 20 °C/100 % r.h. (grey), limit based on AFNOR FD P 18-456 [4]

Table 1: Aggregates and expansions in mm/m (‰) in the 60 °C concrete test as specified in the Alkali Guidelines

Aggregate	Alkali reactivity class	Expansion in the 60 °C concrete test
Rhine gravel	E I	0.24
Crushed rhyolite	E I-S	0.07
Crushed gravel from the Upper Rhine Graben	E III-S	1.22
Crushed greywacke	E III-S	2.04
Natural sand	E I	–

Table 2: Cements, composition and Na_2O-equivalent

Cement		Proportion[1)]/ constituent [mass %]	Na_2O-equivalent [mass %]		
			Cement without S	S, FA	Total cement
1	CEM I 42,5 R	–	–	–	1.19
2	CEM I 42,5 R	–	–	–	1.01
3	CEM I 42,5 R	–	–	–	0.99
4	CEM I 42,5 N	–	–	–	0.81
5	CEM I 42,5 N	–	–	–	0.62
6	CEM III/A [42,5 R]	44 S	1.19	0.61	0.94
7	CEM III/A [42,5 N]	44 S		0.92	1.07
8	CEM I 32,5 R	–	–	–	0.89
9	CEM I 42,5 N (st)	–	–	–	0.67
10	CEM I 42,5 N-NA	–	–	–	0.56
11	CEM I 42,5 R (1) + 20 mass % FA		–	2.47	1.19
12	CEM I 42,5 R (1) + 30 mass % FA		–		

S: granulated blastfurnace slag, FA: fly ash
[ ]: strength class of the laboratory cement
1) Proportion relative to the cement without sulfate agent

2 Investigations

2.1 Initial constituents and concrete compositions

Concrete compositions were produced with coarse 2/16 mm aggregates of different alkali reactivity classes (➧ Table 1) in combination with various cements (➧ Table 2). The cement content was 300, 350, 370, 400 or 430 kg/m^3 and the water/cement ratio was 0.42 or 0.45. Sand was used in all the concrete compositions at about 30 vol. %. As a rule the coarse aggregate contained 40 vol. % of the 2/8 particle size group and 30 vol. % of the 8/16 particle size group. Table 1 shows the expansion of the coarse aggregates in the 60 °C concrete test as specified in the Alkali Guidelines. After 140 d the expansion of the reactive greywacke (E III-S) and of the reactive crushed gravel from the Upper Rhine Graben (E III-S) lay significantly above the limit value of 0.30 mm/m. The non-reactive Rhine gravel (E I) and the non-reactive rhyolite (E I-S) exhibited expansions below the limit value.

2.2 60 °C concrete test without alkali supply

The concrete compositions for the WF moisture class (wet environment) were tested with the "60 °C concrete test without alkali supply". The test procedure corresponded to the 60 °C concrete test as specified in the Alkali Guidelines, Appendix C [1] that is based on AFNOR P 18-454 standard [3]. The tests were evaluated as passed if the expansions after 140 d were ≤ 0.20 mm/m. This limit value was chosen on the basis of AFNOR FD P 18-456 [4]. For concrete compositions containing fly ash the expansion based on AFNOR FD P 18-456 was compared with the limit values of 0.20 mm/m after 140 d and 0.30 mm/m after 52 weeks. Additional investigations were carried out in some cases with preliminary storage of 28 or 91 d instead of only one day.

2.3 60 °C concrete test with alkali supply

The concrete compositions for the WA moisture class (wet environment + external alkali supply) were tested with the "60 °C concrete test with external alkali supply" [6, 7]. The test method was originally developed for evaluating the alkali reactivity of concrete compositions for concrete road surfaces (WS moisture class: wet environment + external alkali supply + dynamic loads). The method was used here for evaluating concrete compositions for the WA moisture class with a 3 % or 10 % sodium chloride solution (NaCl) in order to adapt the method to the WA moisture class and achieve a practical method of evaluation. Tests were also carried out with a preliminary storage time of 91 d for some concrete compositions.

2.4 Storage in the outdoor exposure site

Some concrete compositions were also stored in the outdoor exposure site in order to compare the results of the laboratory investigations with the behaviour of the concrete compositions under practical conditions. The testing has been carried out in this way since the 1970s [8].

3 Results

3.1 WF moisture class

Concrete compositions were made up in accordance with the requirements of the Alkali Guidelines. According to the Alkali Guidelines these concretes are not expected to exhibit any ASR damage in structures that are exposed to a moist environment during a service life of at least 50 years. The expansions after 140 d in the 60 °C concrete test are summarized in ➧ Fig. 1. In some cases the concrete compositions containing blastfurnace cements were stored for 28 d at 20 °C and 100 RH (grey values) before the start of the test.

The results show that five concrete compositions passed the test when employing the limit value of 0.20 mm/m as specified in AFNOR FD P 18-456 [4]. Two concrete compositions (E III-S, c = 350 kg/m^3, and CEM I cement) exhibited expansions above the limit value. In these cases the results of the "60 °C concrete test without alkali supply" lay on the safe side. It is recommended that the limit value should not be changed initially because investigations in Switzerland show that with this method it is possible to differentiate appropriately between non-reactive and potentially reactive concrete compositions if the concrete compositions are produced with Portland cement [9, 10]. The results are discussed in detail below.

Concrete compositions containing aggregates that are non-reactive to alkalis (E I and E I-S) passed the 60 °C concrete test even though the cement content of 400 kg/m^3 and the Na_2O-equivalent of the cement of 1.19 mass % were high. In both cases the test method correctly reproduces the requirements of the Alkali Guidelines that do not lay down any requirements for the alkali content of the cement or for the

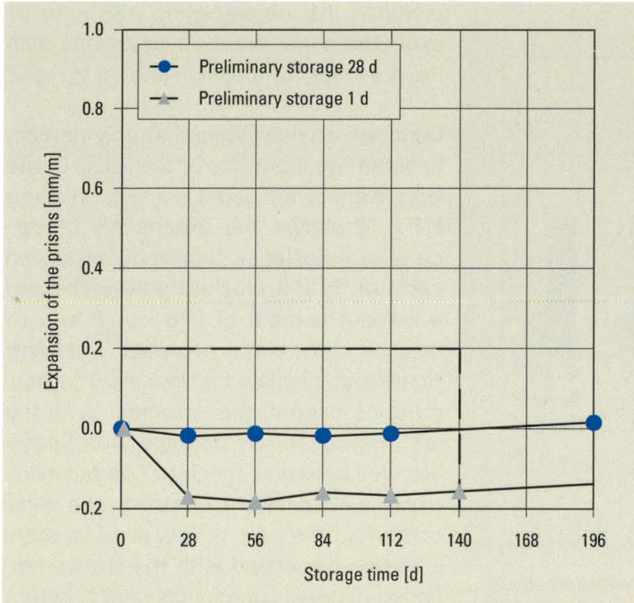

Figure 2: Expansion of a concrete composition made with crushed greywacke of the E III-S alkali reactivity class and CEM III/A 42,5 R (laboratory cement) in the 60 °C concrete test without alkali supply. Concrete with different preliminary storage times. CEM III/A 42,5 R cement, Na_2O-equiv. = 0.94 mass %, c = 400 kg/m^3, w/c ratio = 0.45, 30 vol. % sand 0/2, 70 vol. % greywacke E III-S 2/16

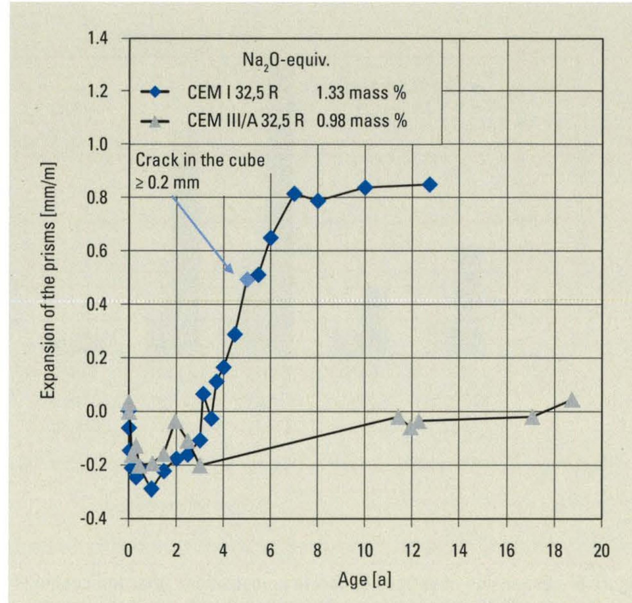

Figure 3: Expansion of a concrete composition made with crushed precambrian greywacke of the E III-S alkali reactivity class and various cements, stored in the outdoor exposure site. c = 500 kg/m^3, w/c = 0.45, 30 vol. % sand 0/2, 70 vol. % crushed precambrian greywacke E III-S 2/16

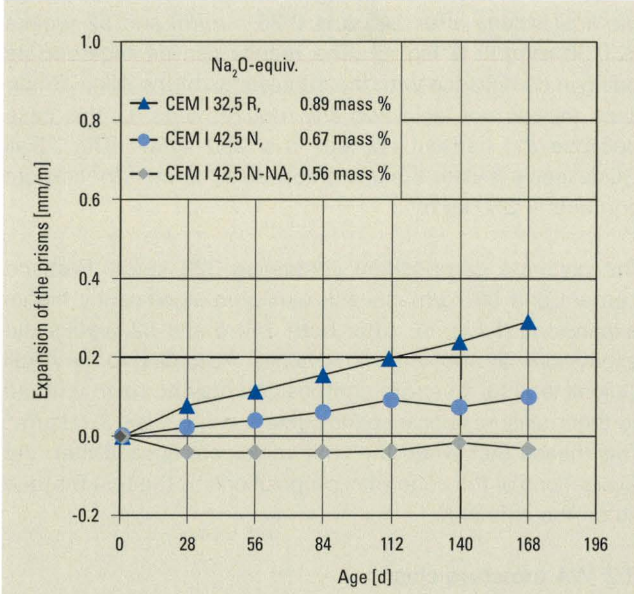

Figure 4: Expansion of various concrete compositions made with crushed greywacke of the E III-S alkali reactivity class and various Portland cements in the 60 °C concrete test without alkali supply. c = 370 kg/m^3, w/c ratio = 0.42, air voids = 4.5 ± 0.5 vol. %, 31 vol. % sand 0/2, 69 vol. % crushed greywacke E III-S 2/22

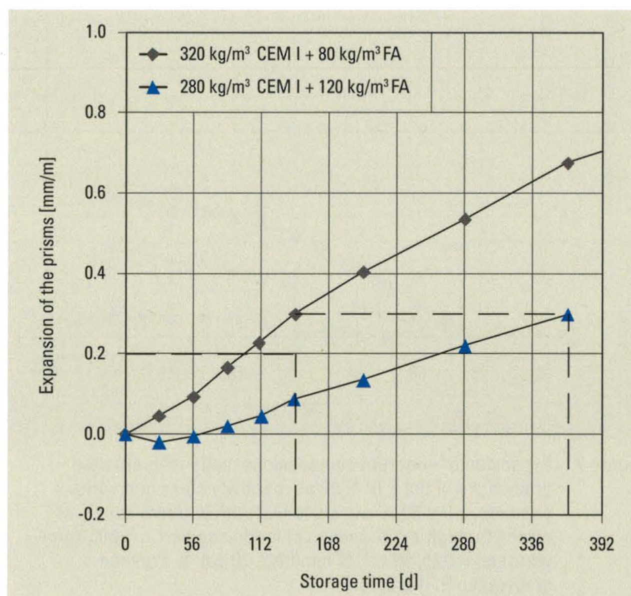

Figure 5: Expansion of a concrete composition made with crushed greywacke of the E III-S alkali reactivity class, Portland cement and fly ash (FA) in the 60 °C concrete test without alkali supply, with a preliminary storage time of 28 d. CEM I 42,5 cement, c + f = 400 kg/m^3, Na_2O-equiv. CEM I = 1.19 mass %, w/(c + f) = 0.45 (k = 1.0), 30 vol. % sand 0/2, 70 vol. % greywacke E III-S 2/16

cement content for the E I and E I-S alkali reactivity classes (non-reactive aggregates).

According to the Alkali Guidelines, low-alkali cement must be used for concrete compositions in the WF moisture class with a cement content of 400 kg/m^3 and reactive aggregates in the E III-S alkali reactivity class. An investigation was therefore carried out on a concrete composition containing crushed greywacke (E III-S) and Portland cement with Na_2O-equivalent of 0.62 mass %. The Na_2O-equivalent lies only slightly above the limit of 0.60 mass % that, according to DIN 1164-10, applies to Portland cement with low-alkali content. The concrete composition exhibited no expansions. The 60 °C concrete test therefore correctly reproduces the requirements of the Alkali Guidelines.

A concrete composition made with laboratory cement containing granulated blastfurnace slag that fulfils the requirements for low-alkali cements as specified in DIN 1164-10 also passed the test and the evaluation corresponded to the Alkali Guidelines (➧ Fig. 2). With cements containing granulated blastfurnace slag the concrete initially exhibited shrink-

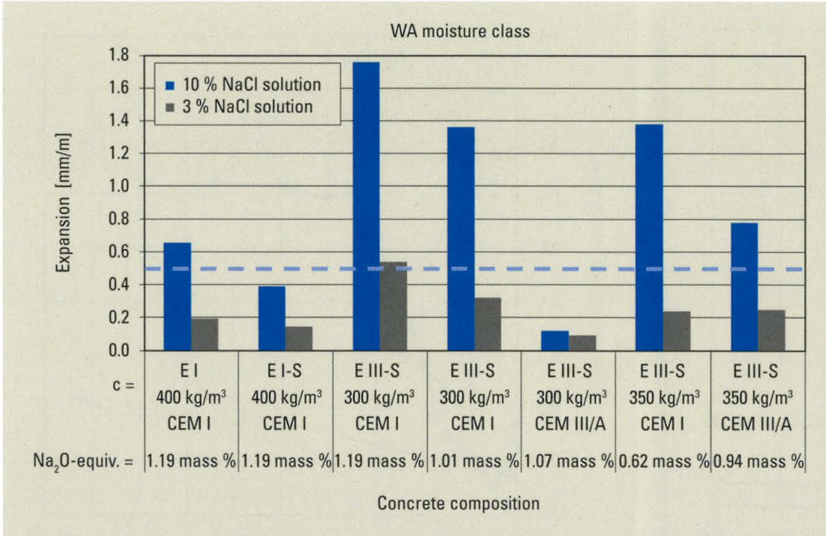

Figure 6: Expansion of various concrete compositions after ten cycles of alternating storage in the 60 °C concrete test with external supply of alkalis through a 3 % (grey) and a 10 % (blue) sodium chloride solution

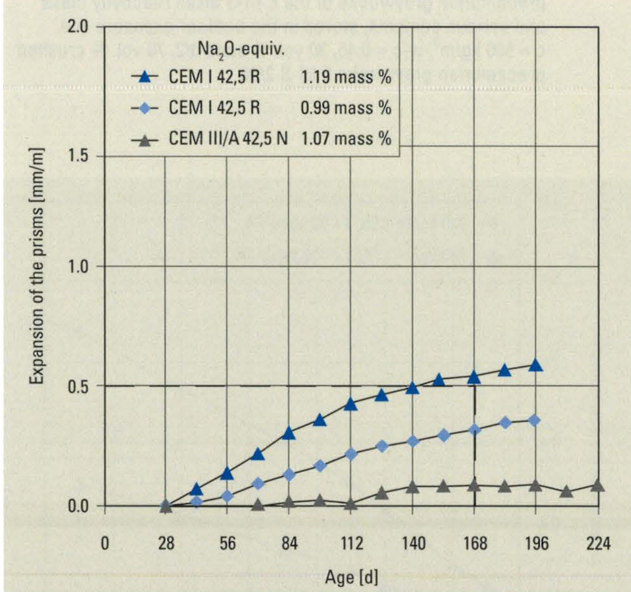

Figure 7: Expansion of concrete compositions made with crushed greywacke of the E III-S alkali reactivity class and various cements in the 60 °C concrete test with external supply of alkalis through a 3 % sodium chloride solution. c = 300 kg/m^3, w/c ratio = 0.45, 30 vol. % sand 0/2, 70 vol. % crushed greywacke E III-S 2/16

age deformation within the first 28 d when it was stored above water at 60 °C in the test reactor at the age of one day. If expansion due to an ASR occurred in the first 28 d it would not be possible to differentiate between the shrinkage and the ASR expansion. The shrinkage during the test is significantly reduced if the concrete is exposed to hydration through preliminary storage at 20 °C for 28 d. Preliminary storage for 28 d is therefore to be recommended for concrete compositions made with cements containing granulated blastfurnace slag and fly ash.

❱ Fig. 3 shows, among other things, the expansion of a concrete in the outdoor exposure site that was produced with a Precambrian greywacke of the E III-S alkali reactivity class and CEM III/A cement. Neither cracks nor expansion had occurred after 19 years. In contrast to this, expansion and cracks occurred when a CEM I cement with high alkali content was used instead of the CEM III/A cement. This result confirms that no damaging ASR is to be expected under practical conditions with the concrete composition shown in Fig. 2.

Concrete compositions that only partially fulfil the requirements of the Alkali Guidelines were investigated in a second stage. ❱ Fig. 4 shows the expansions of concrete compositions that were produced with the E III-S crushed greywacke and a cement content of 370 kg/m^3 in combination with various cements. The Alkali Guidelines stipulate that low-alkali cement must be used in this situation. With the test method it was possible to differentiate well between concrete compositions made with different cements and alkali contents. The use of low-alkali cement could be dispensed with the above-mentioned material combination and concrete composition. However, an alkali content of the Portland cement (Na_2O-equivalent of 0.90 mass %) would be too high.

Concrete compositions containing fly ash and an alkali-reactive aggregate (E III-S) were investigated in a third stage. The expansions of the concrete composition made with 280 kg/m^3 Portland cement and 120 kg/m^3 fly ash did not exceed the limit values after 140 d (≤ 0.20 mm/m) and 52 weeks (≤ 0.30 mm/m) (❱ Fig. 5). The results can be regarded as being in compliance with the stipulations of the Alkali Guidelines that do not lay down any requirements for this case because the cement content is ≤ 350 kg/m^3. The Alkali Guidelines stipulate the use of low-alkali cement for cement contents > 350 kg/m^3.

The concrete composition containing 320 kg/m^3 Portland cement and 80 kg/m^3 fly ash exhibited significantly higher expansions (❱ Fig. 5). After both 140 d and 52 weeks the expansions lay above the limit values. According to the Alkali Guidelines this concrete composition may be used without further measures because the cement content is ≤ 350 kg/m^3. This means that when the limit values are applied then the evaluations of the concrete compositions by the test method lie on the safe side.

3.2 WA moisture class

The expansions after ten cycles of alternating storage are shown in ❱ Fig. 6 for various concrete compositions with supply of alkalis through a 3 % and a 10 % sodium chloride solution. The concrete compositions correspond to the requirements of the Alkali Guidelines. ASR damage is not to be expected. With a 10 % NaCl solution four of the seven concrete compositions exhibited expansions after 10 cycles of alternating storage that lay above the limit of 0.50 mm/m. In this case the concrete compositions would be debarred from use although, according to the Alkali Guidelines, their use would be permitted. Testing with a 10 % NaCl solution does not therefore appear to be appropriate.

If the concrete compositions are tested with a 3 % sodium chloride solution the expansions lie under the limit value for six of the seven concretes. One concrete exhibits expansions that lie just over the limit value. On the basis of these results the evaluation of concrete compositions using a 3 % sodium chloride solution is in line with practical experience.

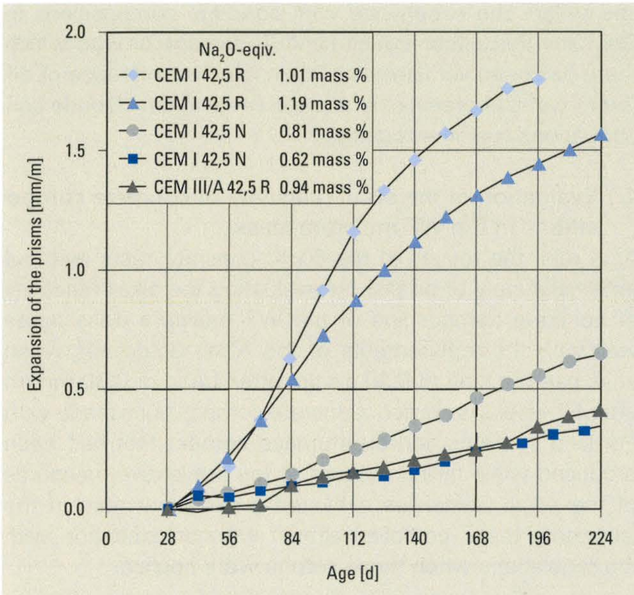

Figure 8: Expansion of concrete compositions made with crushed greywacke of the E III-S alkali reactivity class and various cements in the 60 °C concrete test with external supply of alkalis through a 3 % sodium chloride solution. c = 350 kg/m^3, w/c ratio = 0.45, 30 vol. % sand 0/2, 70 vol. % crushed greywacke E III-S 2/16

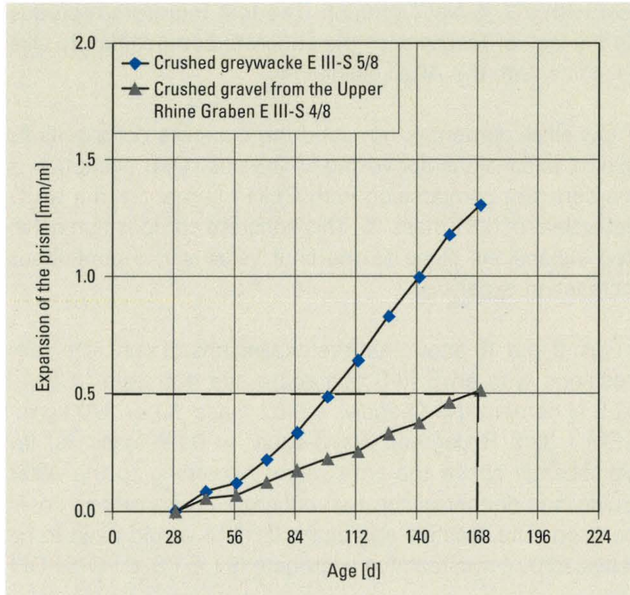

Figure 9: Expansion of concrete compositions made various aggregates of the E III-S alkali reactivity class in the 60 °C concrete test with external supply of alkalis through a 3 % sodium chloride solution. CEM I 42,5 N cement, Na_2O-equivalent = 0.62 mass %, c = 430 kg/m^3, w/c ratio = 0.42, air voids = 5.5 ± 0.5 vol. %, 30 vol. % sand 0/2, 70 vol. % crushed greywacke E III-S 5/8 or crushed gravel from the Upper Rhine Graben E III-S 4/8

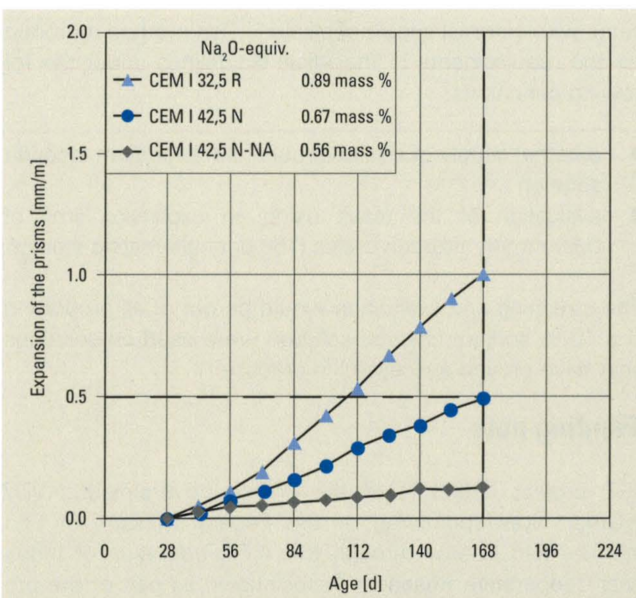

Figure 10: Expansion of concrete compositions made with crushed greywacke of the E III-S alkali reactivity class and various cements in the 60 °C concrete test with external supply of alkalis through a 3 % sodium chloride solution. c = 370 kg/m^3, w/c ratio = 0.42, air voids = 4.5 ± 0.5 vol. %, 31 vol. % sand 0/2, 69 vol. % crushed greywacke E III-S 2/22

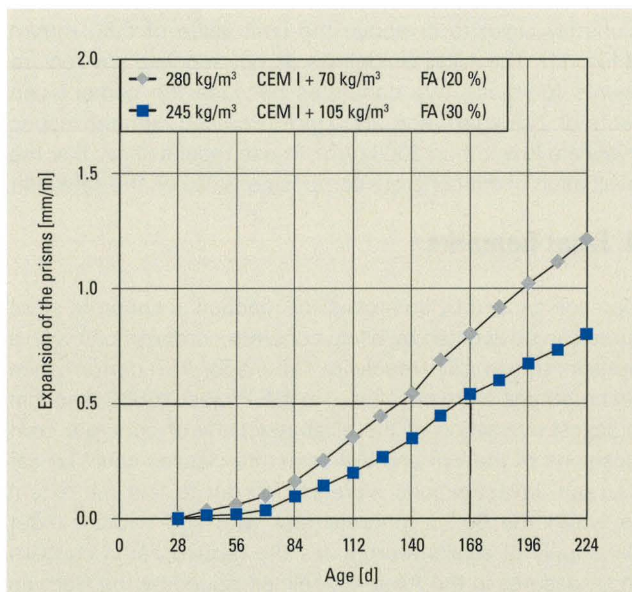

Figure 11: Expansion of concrete compositions made with crushed greywacke of the E III-S alkali reactivity class, Portland cement and fly ash in the 60 °C concrete test with external supply of alkalis through a 3 % sodium chloride solution. CEM I 42,5 cement, Na_2O-equiv. = 1.19 mass %, c + f = 350 kg/m^3, w/(c + f) = 0.45 (k = 1.0), 30 vol. % sand 0/2, 70 vol. % greywacke E III-S 2/16

The results of the concrete tests with a 3 % sodium chloride solution are presented and discussed below.

According to the Alkali Guidelines it is not necessary to apply any measures for a concrete composition with crushed greywacke of the E III-S alkali reactivity class and a cement content of 300 kg/m^3. ❱ Fig. 7 shows the expansions of concrete compositions produced with various cements. As already described above, the expansion exceeds the limit value slightly with a high Na_2O-equivalent of 1.19 mass %. This result shows that the requirements of the Alkali Guidelines are reproduced on the safe side by the 60 °C concrete test with alkali supply. However, not all the concrete compositions that meet the requirements of the Alkali Guidelines would pass the test.

❱ Fig. 8 shows the expansions of concrete compositions that, according to the Alkali Guidelines, may only be used with low-alkali cements because of the cement content of 350 kg/m^3. One of the CEM I Portland cements used had a Na_2O-equivalent of 0.62 mass % and therefore lay at the limit for low-alkali cement. The CEM III/A (laboratory) cement with a Na_2O-equivalent of 0.94 % also fulfilled the requirements for low-alkali cement. Both concrete compositions passed the test with a 3 % NaCl solution. The test therefore reproduces the lack of reactivity of the concrete composition to alkalis in line with the Alkali Guidelines.

If low-alkali cement is not used the concrete compositions exhibit expansions above the limit value. One exception is the concrete composition with CEM I cement and a Na_2O-equivalent of 0.81 mass %. This concrete composition exhibited expansions close to the limit value and a continuous increase in expansion.

› Figs. 9 and 10 show that the expansions of concrete compositions with an E III-S aggregate and 430 kg/m^3 CEM I 42,5 N cement (Na_2O-equiv. = 0.62 mass %) or 370 kg/m^3 CEM I 32,5 R cement (Na_2O-equiv. = 0.89 mass %) lay significantly above the limit value. According to the Alkali Guidelines neither of the two concrete compositions could be used. The reactive aggregate (E III-S) would have to be replaced by a non-reactive aggregate (E I, E I-S, E I-O-E I-OF).

In individual cases the test can be passed by using low-alkali cement but this is not generally the case. The concrete composition with 370 kg/m^3 low-alkali cement (Na_2O-equivalent = 0.56 mass %) passed the test. The concrete with 430 kg/m^3 low-alkali cement and the reactive crushed greywacke (E III-S) did not pass it (Fig. 9).

With two concrete compositions containing fly ash the expansions lay close to or above the limit value of 0.50 mm/m (› Fig. 11). The Alkali Guidelines do not stipulate any requirements for these two concretes because the cement contents of 245 kg/m^3 and 280 kg/m^3 Portland cement respectively are lower than 300 kg/m^3. These results show that the evaluation of the concrete compositions lies on the safe side.

4 Final Remarks

Damage caused by an alkali-silica reaction in concrete structures can be avoided by using concrete compositions with a sufficiently low alkali reactivity. Criteria for ASR performance test methods were developed in IGF Project 16569 N so that practical evaluation of the alkali reactivity of concrete compositions of the WF and WA moisture classes could be carried out. Investigations were carried out to find the extent to which the 60 °C concrete test with and without external supply of alkalis reproduces the requirements concerning measures in the Alkali Guidelines issued by the German Committee for Structural Concrete (DAfStb) for the WF and WA moisture classes. The requirements in the Alkali Guideline reflect the experience with concrete compositions in Germany that either exhibit no ASR damage or with which there has been verifiable ASR damage. The influence of different types of preliminary storage and sodium chloride concentrations was investigated.

4.1 Evaluation of the alkali reactivity of concrete compositions in the WF moisture class

As a rule, the results of the 60 °C concrete tests (without external supply of alkalis) for evaluating the alkali reactivity of concrete composition of the WF moisture class agree well with the requirements of the Alkali Guidelines when an expansion limit of 0.20 mm/m after 140 d or 0.30 mm/m after 52 weeks is applied. Concrete compositions made with Portland cements and blastfurnace cement that had been produced while taking account of the preventive measures of the Alkali Guidelines exhibited a behaviour that, in the laboratory tests, complied almost without exception with the regulations when these criteria were applied.

Preliminary storage for 28 d at 20 °C is recommended both with cements containing granulated blastfurnace cement and when fly ash is used.

4.2 Evaluation of the alkali reactivity of concrete compositions of the WA moisture class

The alkali reactivity of concrete compositions of the WA moisture class was investigated using the "60 °C concrete tests with external supply of alkalis". This method reproduces the requirements of the Alkali Guidelines under the following conditions:

- external supply of alkalis through a 3 % sodium chloride solution
- evaluation of the result using an expansion limit of 0.50 mm/m after ten cycles (168 d) of alternating storage.

The stressing and evaluation would be out of all proportion if a 10 % sodium chloride solution were used on solutions that have proved successful in practice.

Funding note

IGF project 16569 N of the Forschungsvereinigung VDZ gGmbH was sponsored by the Federal Ministry of Economics and Energy through the AiF (Federation of Industrial Cooperative Research Associations) as part of the programme to promote Joint Industrial Research (IGF) based on a decision by the Germany Federal Parliament. ◂

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