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SUMMARY

Some cases of damage to concrete pavements have occurred in Germany in recent years that were attributable to reactive aggregates that had not yet been included in the German Alkali Guidelines. For some crushed aggregates and concrete compositions that are to be used in concrete pavements the Circulars "Allgemeines Rundschreiben Straßenbau" No. 15/2005 and No. 12/2006, published by the Federal Minister for Traffic, Construction and Housing at the instigation of the industry, therefore require an expert report on the danger of a harmful alkali silica reaction by testing agencies that are approved for this purpose. Further restrictions are also placed on the alkali content of the cements used for concrete roads. These requirements of the Circulars have been adopted in the draft of the Alkali Guidelines [1]. The testing and monitoring of the aggregates form an important element of the Alkali Guidelines. Accelerated test methods have been included for the first time in the present draft. Furthermore, it is permissible for the suitability of specific concrete compositions to be assessed by an expert on the basis of performance tests. Extensive investigations of the individual test methods for determining the alkali reactivity of aggregates and for evaluating concrete compositions in "performance tests" have been carried out at the Research Institute of the Cement Industry. The results have been compared with the experience gained from exposure tests and from practice. The investigations will have to be continued to enable better assessments to be made of the suitability of aggregates and concretes for specific structural elements. This will ensure that they are not excluded unnecessarily from application but will still guarantee the safety of the concrete construction.

ZUSAMMENFASSUNG

In den vergangenen Jahren sind einige Schäden an Betonfahrbahndecken aufgetreten, die auf reaktive Gesteinskörnungen, die bisher in der Alkali-Richtlinie nicht enthalten waren, zurückgeführt werden konnten. Die auf Veranlassung der Industrie vom Bundesminister für Verkehr, Bau und Stadtentwicklung (BMVBS) herausgegebenen Allgemeinen Rundschreiben Straßenbau Nr. 15/2005 und Nr. 12/2006 fordern deshalb für einige gebrochene Gesteinskörnungen und Betonzusammensetzungen, die in Betonfahrbahndecken eingesetzt werden sollen, ein Gutachten hinsichtlich der Gefahr einer schädigenden AKR von hierfür anerkannten Prüfstellen. Weiterhin wurde der Alkaligehalt der Straßenbauzemente weiter begrenzt. In den Entwurf der Alkali-Richtlinie [1] wurden diese Forderungen des Rundschreibens übernommen. Ein wesentlicher Bestandteil der Alkali-Richtlinie ist die Prüfung und Überwachung der Gesteinskörnungen. In dem vorliegenden Entwurf wurden erstmals Schnellprüfverfahren aufgenommen. Darüber hinaus wird die Möglichkeit geschaffen, dass die Eignung spezieller Betonzusammensetzungen durch einen Gutachter anhand von Performance-Prüfungen beurteilt werden kann. Im Forschungsinstitut der Zementindustrie wurden umfangreiche Untersuchungen zu den einzelnen Prüfverfahren zur Feststellung der Alkalireaktivität von Gesteinskörnungen und zur Bewertung von Betonzusammensetzungen in so genannten Performance-Prüfungen durchgeführt und die Ergebnisse mit den Erfahrungen aus Auslagerungsversuchen und aus der Praxis verglichen. Die Untersuchungen müssen fortgesetzt werden, um die Eignung von Gesteinskörnungen und Betonen für bestimmte Bauteile besser beurteilen zu können und sie einerseits nicht unnötig von der Verwendung auszuschließen sowie andererseits die Sicherheit der Betonbauweise zu gewährleisten.

(Translation by Mr Robin B. C. Baker)

ASR test methods – comparability and practical relevance*)

AKR-Prüfverfahren – Vergleichbarkeit und Praxis-Relevanz*)

CONCRETE TECHNOLOGY REPORTS

1 Introduction

In practice a deleterious alkali silica reaction (ASR) can occur relatively rapidly. In fact it can occur within one to three years with very reactive aggregates (in Germany these are generally gravels that contain porous opaline sandstone and flint), high alkali content in the concrete and moist ambient conditions – possibly with external supply of alkalis. However, with dense, slow-reacting, aggregates without pessimal behaviour (in Germany, for example, these are rhyolites, greywackes and crushed Upper Rhine gravel) it may only lead to visible damage after 10 to 30 years. Laboratory tests for a deleterious ASR are therefore particularly difficult. The tests should provide information within two to six months as to whether any damage will occur in practice after 10 to 30 years. The development of a test method is therefore only possible if there have been long-term investigations with test specimens stored outdoor at an exposure site and if investigations on structures with known concrete composition can be used for comparison.

2 Test methods

2.1 General

Numerous test methods have been developed for assessing the reactivity of aggregates on the one hand and for assessing concrete with respect to the risk of the occurrence of a deleterious alkali silica reaction on the other. Accurate modelling of the conditions actually present in an individual instance is not possible with a single test method. However, a suitable model should reflect the practical behaviour. It should also lead to the smallest possible variance. In principle, any such test method is a convention. Test methods for aggregates should make it possible to classify an aggregate as non-reactive, potentially reactive or very reactive. The tests for characterizing the reactivity of an aggregate are divided into accelerated mortar bar test methods and concrete prism tests. Performance test methods should make it possible to assess whether or not the concrete to be used in a particular instance would in practice exhibit any deleterious ASR, even in the long term.

2.2 Aggregate assessment

During the testing of the alkali reactivity of an aggregate it is necessary to differentiate between porous aggregates, possibly with pessimal behaviour, and dense aggregates. The test methods described below can only be used for dense aggregates without pessimal behaviour. Special framework conditions must be considered for porous aggregates.

2.2.1 Accelerated mortar bar tests

On the one hand, accelerated test methods have the advantage that they can assess aggregates within a short period but, on the other hand, they have the disadvantage that some aggregates are assessed too severely and then may be incorrectly excluded from use. In particular, accelerated test methods can lead to incorrect assessment of the alkali reactivity of gravels. The comminution of the grains of gravel that is necessary for these test methods means that the tests indicate a reactivity that is different from that of uncrushed gravel. This was established by J. Stark [2] for Upper Rhine gravel. The processed, i.e. crushed, Upper Rhine gravel did not pass the test but the uncrushed gravel was classified as far less reactive. However, comparison investigations with crushed and uncrushed gravel from Central Germany showed that the tests on crushed and uncrushed gravel gave identical results [3]. More precise clarification of the causes is needed.

Two methods are used in Germany – the DAfStb accelerated mortar bar test [4], which originated from Oberholster and Davies [5] as well as from RILEM [6], and the LMPA accelerated mortar bar test that was developed by Philipp [7]. Both have been adopted in slightly modified form in the current draft of the German Alkali Guidelines [1].

a) DAfStb accelerated mortar bar test

The aggregate is ground down to 0.125 mm to 4 mm and the comminuted material is used to produce a mortar (three 4 cm x 4 cm x 16 cm mortar prisms). The expansion of the prisms is measured after storage for 13 days (formerly 14 days) in 1 molar NaOH solution at 80 °C. The limit value for the expansion of the mortar bars is 1.0 mm/m. The lengths of the bars are measured at 80 °C [1].

b) LMPA accelerated mortar bar test

The aggregate is ground down to 0.5 mm to 2 mm. For production of the mortar the alkali content is raised to an Na_2O equivalent of 2.5 wt.% relative to the cement by addition of NaOH solution. The test is carried out on three mortar bars (4 cm x 4 cm x 16 cm) that are stored for 28 days at 70 °C over water in closed containers. The limit value for the expansion after 28 days is 1.5 mm/m. The lengths of the bars are measured at 20 °C [1]. The measurements were previously carried out at 70 °C, and the limit value then was 2.0 mm/m after 21 days [7].

2.2.2 Long-term test methods (concrete prism tests)

Comprehensive investigations have been carried out over the past few years in Germany with the 40 °C fog chamber method. This method was included in the German Alkali Guidelines [8] and corresponds approximately to the RILEM AAR-3 method [9]. The disadvantage of this method is its long duration of nine months. The 60 °C concrete prism test that is frequently used internationally and that can assess the aggregate after only three months is now also being used. With both methods it is possible to use the aggregate as delivered.

*) Expanded version of a lecture given at the 6th ibausil International Construction Materials Conference in Weimar on 22.09.2006

Table 1: Storage during the performance test with external supply of alkalis

	Duration of storage	Climatic conditions
Preliminary storage:	1 d	in the mould
28 d	6 d	20 °C and 100 % r.h.
	14 d	20 °C and 65 % r.h.
	6 d	60 °C and 100 % r.h.
	1 d	20 °C and 100 % r.h.
Alternating storage:	5 d	60 °C in drying cabinet
14 d rotation	2 d	20 °C immersed in test solution
	6 d	60 °C and 100 % r.h.
10 repetitions	1 d	20 °C and 100 % r.h.

a) 40 °C fog chamber storage

The 2/16 mm or 2/22 mm fraction is tested using three concrete prisms (10 cm x 10 cm x 50 cm) and one cube (30 cm), which are stored in a fog chamber for nine months at 40 °C and about 100 % r.h. The aggregate can be classified as non-reactive if the expansion of the prisms does not exceed 0.6 mm/m and the maximum crack width in the cube is less than 0.2 mm. It should be borne in mind that the expansion includes the temperature expansion and the moisture expansion.

b) 60 °C concrete prism test

The 60 °C concrete prism test was defined on the basis of the procedures in the French standard NF P 18-454 [10] and the RILEM AAR-4 method [11]. The 2/16 mm or 2/22 mm coarse fraction of the aggregate is used to produce three 7.5 cm x 7.5 cm x 28 cm prisms, which, after removal from the mould, are stored at 60 °C over water in tightly sealed containers in a test reactor. The expansion is determined by measuring the lengths of the prisms at 20 °C at 0, 4, 8, 12, 16 and 20 weeks after production of the test specimens. Based on the RILEM method the limit value is provisionally set at 0.3 mm/m after twelve weeks.

2.3 Performance testing

If an aggregate is classified as reactive (E III) in accordance with the German Alkali Guidelines then, depending on the moisture class of the structural component and the cement content of the concrete, the aggregate has to be replaced or cements with a low effective alkali content (low-alkali cements) have to be used. Performance tests are essential if aggregates or cements are not to be unnecessarily excluded from use and also, if necessary, for simulating an external supply of alkalis. The performance method should provide information about whether an intended concrete composition with a particular aggregate and particular cement can be used for a specific moisture class. The 60 °C concrete prism test and the cyclic climate storage [3] are currently being refined in Germany for this purpose. These methods are to be included in a future Part 4 of the German Alkali Guidelines.

2.3.1 60 °C concrete prism test without alkali supply

The 60 °C concrete prism test (see Section 2.2.2) can also be used as a performance test. In this case a limit value of 0.2 mm/m after twelve weeks based on [12] applies at present.

2.3.2 60 °C concrete prism test with alkali supply

Using the 60 °C concrete prism test as the basis it is also possible to test concretes for pavements using the storage system shown in ❯ Table 1 with external supply of alkalis (3 % or 10 % NaCl solution). In this test the amount of expansion is affected not only by the external supply of alkalis but also by the modified preliminary storage and the drying phase that differ from the original 60 °C concrete prism test described in Section 2.2.2 b). If concretes for airfields are being investigated then a solution based on potassium acetate or formate is used instead of an NaCl solution. With this method it is important that the concrete has sufficient time to form a dense microstructure (at least seven days under moist conditions and 14 days at 20 °C/ 65 % r.h.) before it is exposed to attack by a de-icing agent.

2.3.3 Cyclic climate storage

After sealed storage up to the 7th day, three prisms (10 cm x 10 cm x 40 cm) are exposed to at least six cycles in the climate simulation chamber. One cycle of the cyclic climate storage consists of a 4-day drying phase at 60 °C and < 10 % r.h., a 14-day moistening phase by fog at 45 °C and a 3-day alternating freeze-thaw phase with temperatures between -20 °C and +20 °C while immersed in a de-icing agent solution. The limit value has been set at 0.5 mm/m after at least six storage cycles (18 weeks) with exposure to de-icing agents. The limit value is 0.4 mm/m if water is used [3].

2.4 Outdoor storage

Long-term outdoor storage is essential in order to establish the limit values for ASR test methods. Outdoor storage tests have been carried out on the roof of the Research Institute for over 30 years. This outdoor storage provides a good indication of the suitability of a test method. By using the outdoor storage it was established that aggregates that in practice lead to damage can be detected with the 40 °C fog chamber storage (as an aggregate test) but that the 40 °C fog chamber storage is not suitable as a performance test [13, 15]. Two prisms (10 cm x 10 cm x 50 cm) and one cube (30 cm) are used for the outdoor storage (❯ Fig. 1).

2.5 Examination of structures

In addition to the carefully controlled outdoor storage, which provides dependable, detailed findings because the starting materials and the concrete composition are accurately known, the behaviour of structures is also an important

Figure 1: Prisms and cubes at the outdoor exposure site at the Research Institute in Düsseldorf

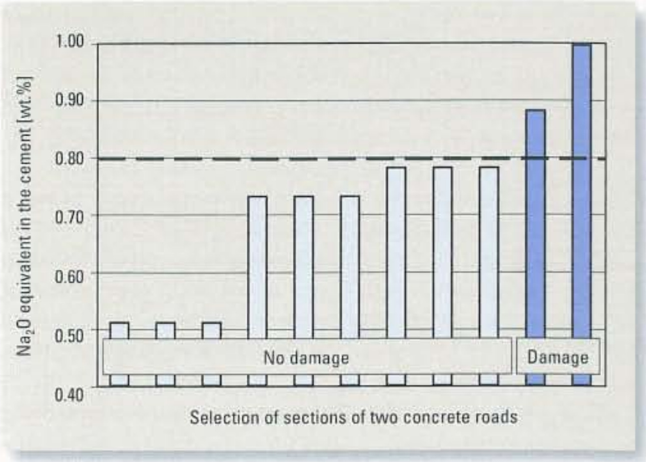

Figure 2: Various 10- to 14-year-old sections of two concrete roads with and without ASR damage. The damage started after ten years.

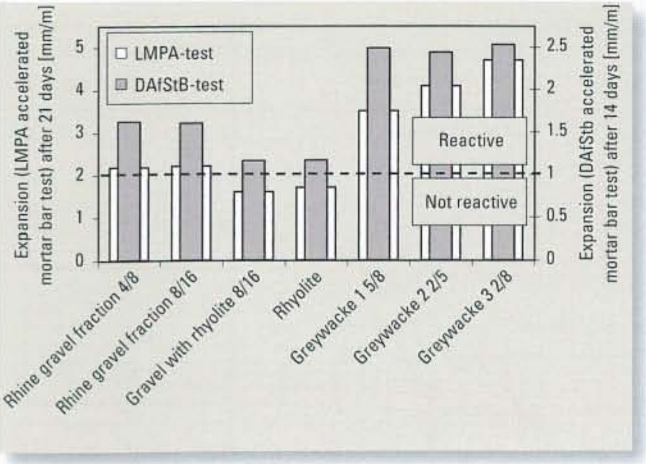

Figure 4: Expansion of mortar bars made with a selection of aggregates at the time of testing in the LMPA and DAfStb accelerated mortar bar tests

source of information for assessing a test method. As an example, ❯ Fig. 2 shows different sections (ages between 10 and 14 years – the damaged sections were 10 years old when the damage was detected) from two concrete roads that were all produced with a reactive aggregate (greywacke from the Sauerland) but with different cements. The diagram shows the alkali contents (Na_2O equivalents) of the different cements used. It confirms that the alkali content stipulated in Germany for pavement cements of, for example, Na_2O equivalent ≤ 0.80 wt.% for Portland cements (CEM I) would not lead to damage with this reactive aggregate.

3 Investigations

Different starting materials and concrete compositions were used for comparing different test methods and for the comparison between test methods and outdoor storage or the behaviour of structures. The following coarse aggregates, among others, were used:

- crushed Upper Rhine gravel
- greywacke
- rhyolite
- gravel with rhyolite
- Rhine gravel (Düsseldorf)

A Rhine sand (Düsseldorf) was used as the fine aggregate. The cements used were:

- Portland cements with alkali contents between 0.6 and 1.3 wt.% (Na_2O equivalent)
- CEM II/B-S and CEM II/B-M (S-LL) Portland composite cements

The cement content of the concrete lay between 300 kg/m^3 and 500 kg/m^3.

The test methods used are described in Section 2.

4 Results

4.1 Aggregate assessment

4.1.1 Accelerated mortar bar test

Various fractions of 16 different aggregates were investigated with the LMPA accelerated mortar bar test (measurement at 70 °C) and the DAfStb accelerated mortar bar test. The expansions of the mortar bars at the assessment times of the respective methods are summarized in ❯ Figs. 3 and 4. It is not in fact possible to derive any strict correlation from the investigations but, with the exception of three cases (see Fig. 3), the two test methods led to the same classifica-

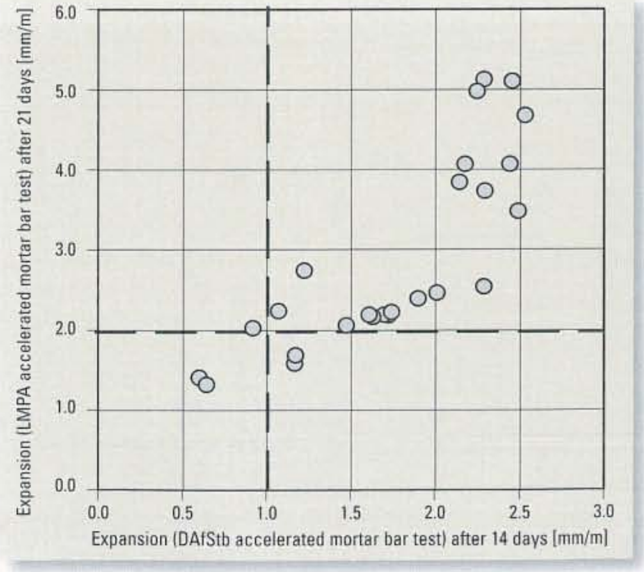

Figure 3: Expansion of mortar bars made with various aggregates in the LMPA and DAfStb accelerated mortar bar tests

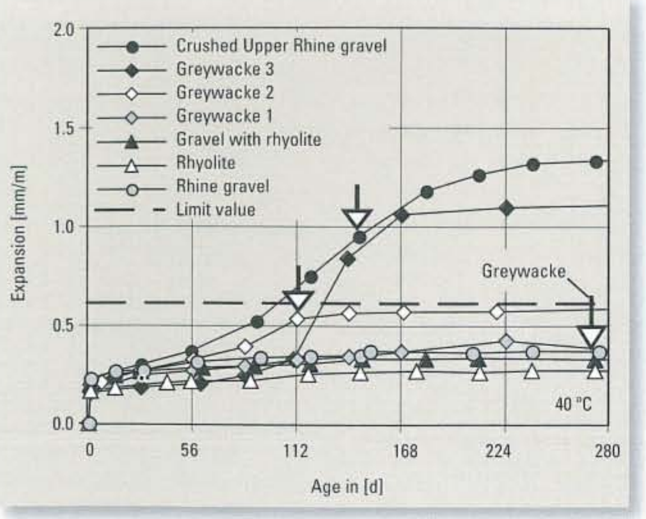

Figure 5: Expansion and crack development ≥ 0.2 mm (see arrows) of concretes made with various aggregates in the 40 °C fog chamber, c = 400 kg/m^3, w/c ratio = 0.45, CEM I 32,5 R cement with Na_2O equiv. = 1.3 wt.%

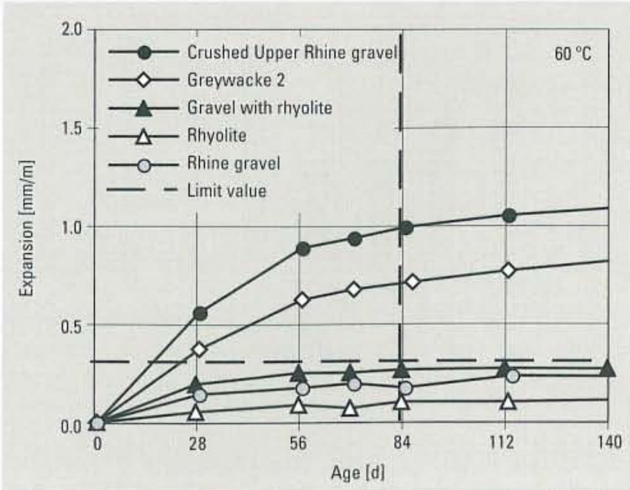

Figure 6: Expansion of concretes made with various aggregates (without greywacke 1 and 3) in the 60 °C concrete prism test, c = 400 kg/m, w/c ratio = 0.45, CEM I 32,5 R cement with Na_2O equiv. = 1.3 wt.%

tion with respect to the alkali reactivity of the aggregate. The DAfStb accelerated mortar bar test tended to be somewhat more severe than the LMPA accelerated mortar bar test.

4.1.2 Long-term testing (concrete testing)

The expansion and crack development of concretes made with seven different aggregates that had been tested in the 40 °C fog chamber in accordance with Part 3 of the Alkali Guidelines are shown in ▸ Fig. 5. Three aggregates are classified as reactive because the limit values for the expansion and/or the crack width were exceeded. The arrows in the diagram show the times at which cracks with widths ≥ 0.2 mm appeared in a cube.

Five of the seven aggregates (greywackes 1 and 3 were not investigated) were also tested with the 60 °C concrete test using the same concrete composition (▸ Fig. 6). After three months it provided the same information with respect to alkali reactivity as the 40 °C fog chamber storage did after nine months.

A comparison of the results of the DAfStb accelerated mortar bar test (Fig. 4) with those of the investigations in the 40 °C fog chamber (Fig. 5) shows that aggregates which have expansions between 1.0 mm/m and 2.0 mm/m in the accelerated mortar bar test can still pass the concrete prism test. The DAfStb accelerated mortar bar test, which is carried out with comminuted aggregates, is more severe than the test on the aggregate in its original state in a concrete test.

▸ Figs. 7 and 8 show the results of investigations that were carried out as part of the European PARTNER project [14] with six different European aggregates. The aggregates were tested in accordance with Part 3 of the Alkali Guidelines [8], with the exception of the cement (CEM I 42,5 R instead of CEM I 32,5 R), and by the RILEM AAR-4 [11] method, which formed the basis for the development of the 60 °C concrete test in Germany. Although the compositions differ slightly between RILEM AAR-4 (cement content 440 kg/m^3, w/c = 0.50) and the German Alkali Guidelines (cement content 400 kg/m^3, w/c = 0.45) the two methods agree in their assessments of the alkali reactivity of the aggregates. In the test with the 40 °C fog chamber storage the result for aggregate N5 is borderline, but with the RILEM AAR-4 method it is clearly identified as reactive.

4.1.3 Outdoor storage

The testing of the aggregate in the 40 °C fog chamber as described in Section 3 (▸ Fig. 9a) was checked at the Research Institute of the Cement Industry by outdoor storage (▸ Fig. 9b) of the test specimens on the roof of the Institute [15]. With the exception of one the aggregates were correctly classified by the 40 °C fog chamber test. Only with one aggregate – not shown in Fig. 9 – just three cracks ≥ 0.2 mm were found in the cube with outdoor storage that did not occur in the fog chamber. Thin sections will have to be used to determine whether these cracks have occurred as the result of a deleterious ASR. No damage has occurred in structures that contain concretes made with this aggregate.

4.2 Performance testing

4.2.1 Performance testing without external supply of alkalis

The 60 °C concrete prism test is used in France [10] and Switzerland [16] as a performance test method. Extensive investigations into this performance test method for assessing concrete compositions have been carried out in Germany as part of an AiF research project. So far a limit value of 0.2 mm/m

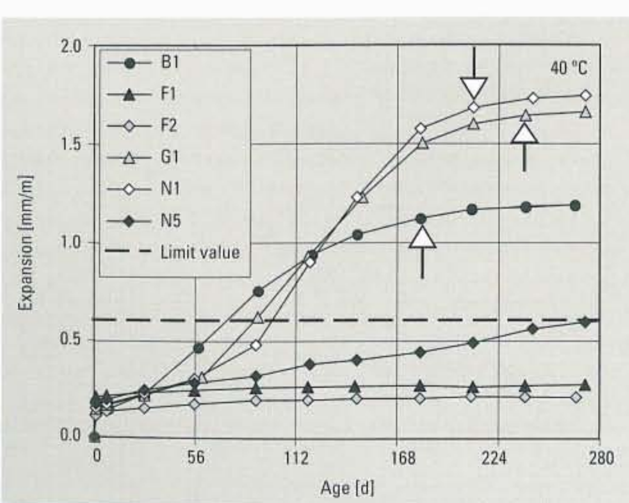

Figure 7: Expansion (limit value 0.6 mm/m) and crack development ≥ 0.2 mm (see arrows) of concretes made with various European aggregates in the 40 °C fog chamber, c = 400 kg/m^3, w/c ratio = 0.45, CEM I 42,5 R cement with Na_2O equiv. = 1.3 wt.%

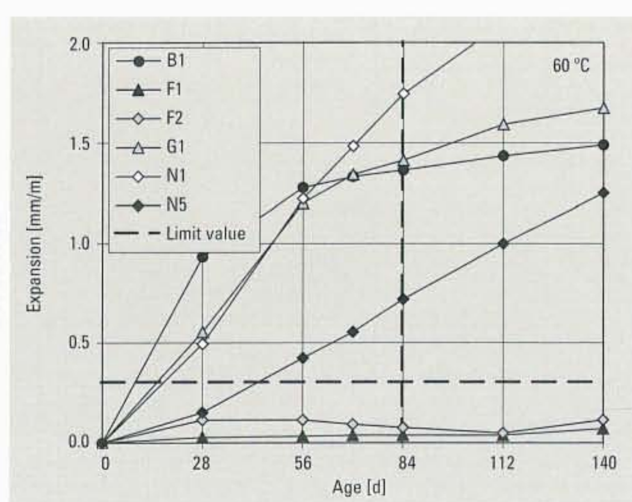

Figure 8: Expansion (limit value 0.6 mm/m) of concretes made with various European aggregates in the RILEM AAR-4 60 °C concrete test with c = 440 kg/m^3, w/c ratio = 0.50, CEM I 42,5 R cement with Na_2O equiv. = 1.3 wt.%

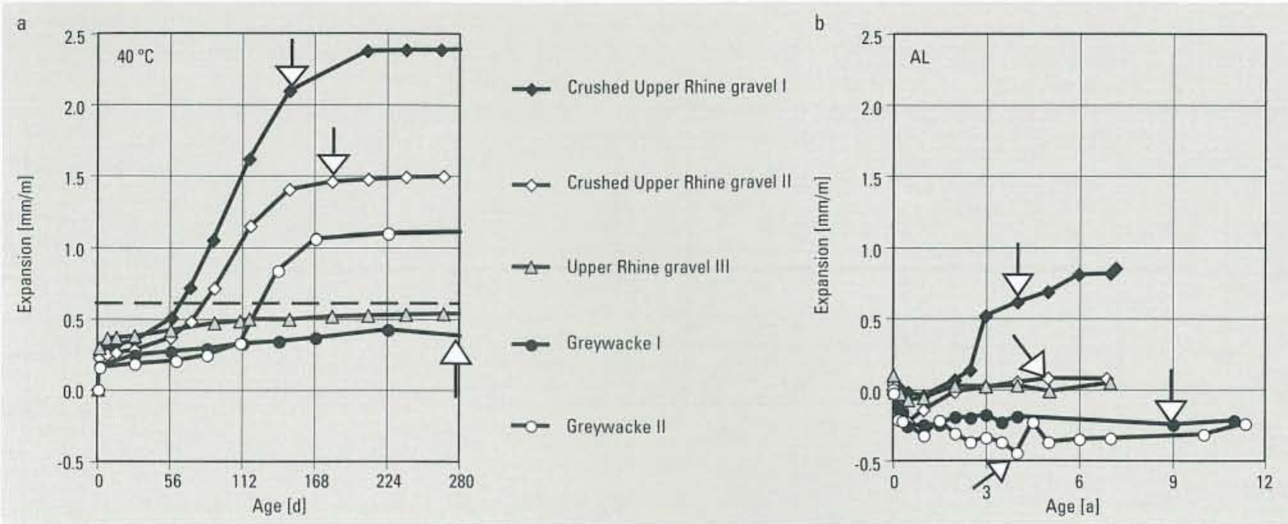

Figure 9: Expansion (limit value 0.6 mm/m) and crack development ≥ 0.2 mm (see arrows) of concretes made with various aggregates in the 40 °C fog chamber (Fig. 9a) and in the outdoor storage (AL) (Fig. 9b), c = 400 kg/m^3, w/c ratio = 0.45, CEM I 32,5 R cement with Na_2O equiv. = 1.3 wt.%

has been recommended (compared with 0.3 mm/m for the aggregate test). ❱ Fig. 10 shows how the expansion of concrete made with a reactive aggregate depends on the cement content.

The influence of the effective alkali content of the cement used can be deduced clearly from the results of the test method. With a low-alkali cement the expansion of concrete made with reactive aggregates remains below the limit value of 0.2 mm/m (❱ Fig. 11), even for a cement content of 400 kg/m^3.

The use of a CEM II/B-S or a CEM II/B-M (S-LL) cement led to results that were equally as good as those with the low-alkali Portland cement (❱ Fig. 12). The reactive aggregate used – crushed Upper Rhine gravel – can be used with a CEM I-NA (low alkali) cement or with CEM II/B-S or CEM II/B-M (S-LL) cement, e.g. for concrete in a moist environment, without causing any damage. This is supported by the results with a comparable concrete that had been produced with a CEM II/B-S cement and has been stored at the outdoor exposure site for seven years (❱ Fig. 13). So far no major expansion or cracking has occurred. As expected, the reference concrete, which was also produced with reactive, double-crushed, Upper Rhine gravel but with 500 kg/m^3 of the test cement (Na_2O equivalent of 1.29 wt.%), exhibited serious expansion and cracks ≥ 0.2 mm in the outdoor exposure site.

The influence of the w/c ratio is also reflected by the 60 °C concrete test (❱ Fig. 14). The alkali concentration in the pore solution increases with decreasing w/c ratio, while at the same time there is an increase in the density of the cement mortar. These two opposing tendencies produce the worst situation at a w/c ratio of 0.45.

The extent to which concretes that contain pozzolanic additions, or cements with pozzolanic main constituents, can be tested by this method has not yet been adequately clarified. To deal with this situation in Switzerland the test has been extended to a year with a simultaneous increase in the limit value to 0.3 mm/m [16]. The increase in the limit value is necessary because of the longer test duration and the associated higher moisture expansion. ❱ Fig. 15 shows investi-

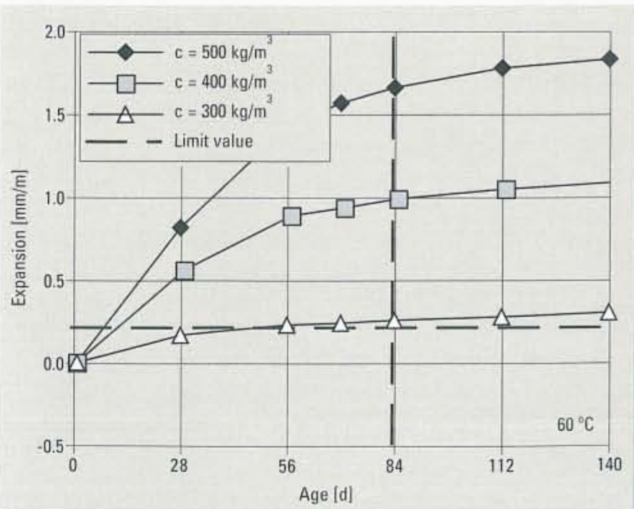

Figure 10: Expansion of concretes with different cement contents in the 60 °C concrete prism test with 70 % crushed Upper Rhine gravel, CEM I 32,5 R cement with Na_2O equiv. = 1.3 wt.%, w/c ratio = 0.45

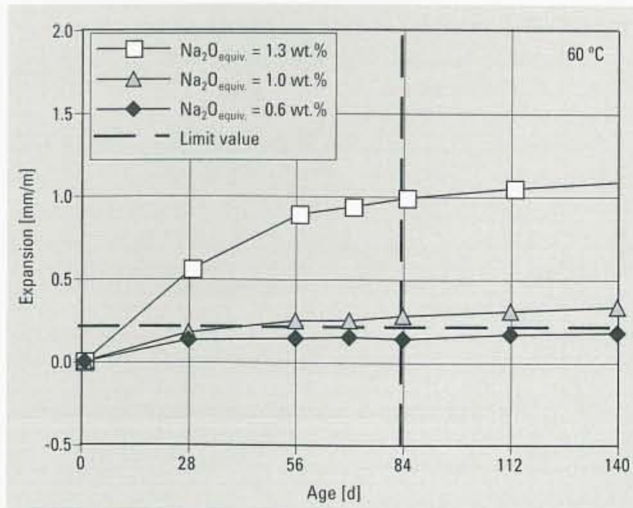

Figure 11: Expansion of concretes with different alkali contents (Na_2O equiv.) of the Portland cements in the 60 °C concrete prism test with 70% crushed Upper Rhine gravel, c = 400 kg/m^3, w/c ratio = 0.45

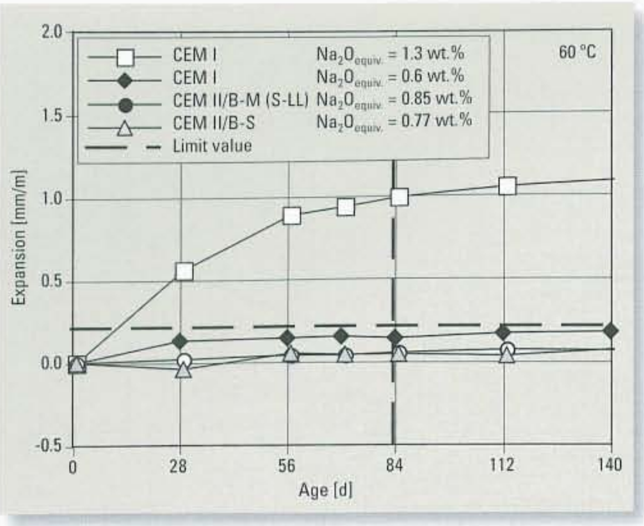

Figure 12: Expansion of concretes made with different cements and with different total alkali contents (Na_2O equiv.) in the 60 °C concrete prism test with 70% crushed Upper Rhine gravel, c = 400 kg/m^3, w/c ratio = 0.45

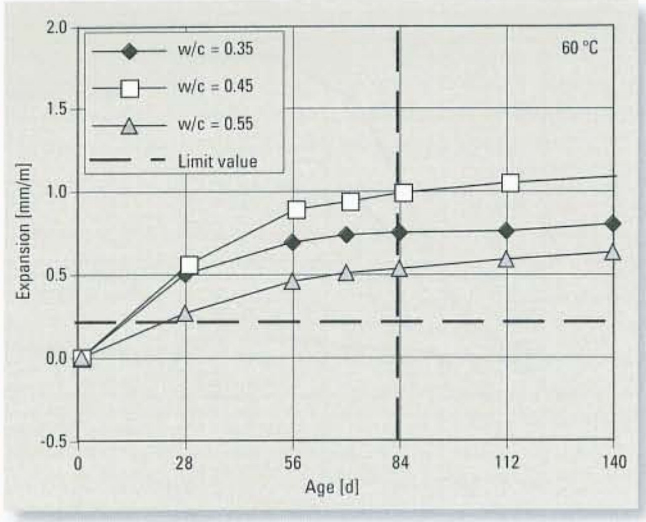

Figure 14: Expansion of concretes with different w/c ratios in the 60 °C concrete prism test with 70% crushed Upper Rhine gravel, c = 400 kg/m^3, CEM I 32,5 R cement with Na_2O equiv. = 1.3 wt.%

gations with 20 wt.% of fly ash FA1 or fly ash FA2. Fly ash FA1 has an alkali content of 3.1 wt.% Na_2O equivalent and fly ash FA2 has a value of 1.6 wt.% Na_2O equivalent. Both fly ashes significantly reduced the expansion caused by ASR – fly ash FA2 by somewhat more than fly ash FA1. Further investigations will show whether the 60 °C concrete test is suitable for testing concrete made with fly ash.

After one year the expansion of the concrete that contained fly ash FA2 was below the limit value of 0.3 mm/m and was rated as innocuous. The concrete that contained fly ash FA1, however, exceeded the limit value within the test period and was rated as critical. Interim results from tests in the outdoor exposure site with two concretes with comparable compositions confirm the expansion reducing effect of fly ash (› Fig. 16). It is not yet known whether the substitution of 20 wt.% of cement by fly ash is sufficient to prevent a deleterious ASR in concrete made with reactive, dense, aggregates and cement with a high alkali content. After six years of outdoor storage the development of a deleterious ASR is indicated by a slight increase in expansion since the 4th year. The chosen dosage for the fly ash has possibly only delayed a deleterious ASR, and not prevented it. The investigations are being continued.

4.2.2 Performance testing with external supply of alkalis

Some cases of ASR damage in concrete pavements that have occurred recently in Germany indicate that external supply of alkalis may intensify a deleterious ASR. This is particularly true of the potassium and sodium acetates and formates that are used as de-icing agents on airfields, but sodium chloride, which is used on concrete pavements, also intensifies the deleterious ASR. The extent to which this occurs is not yet sufficiently understood and is currently being investigated.

The limit value for the performance test with external supply of alkalis was initially set at 0.5 mm/m on the basis of practical experience. › Fig. 17 shows results from 60 °C concrete prism test with and without external supply of alkalis (NaCl). The prisms in the 60 °C concrete prism with external supply of alkalis (see Table 1) exhibited significantly greater expan-

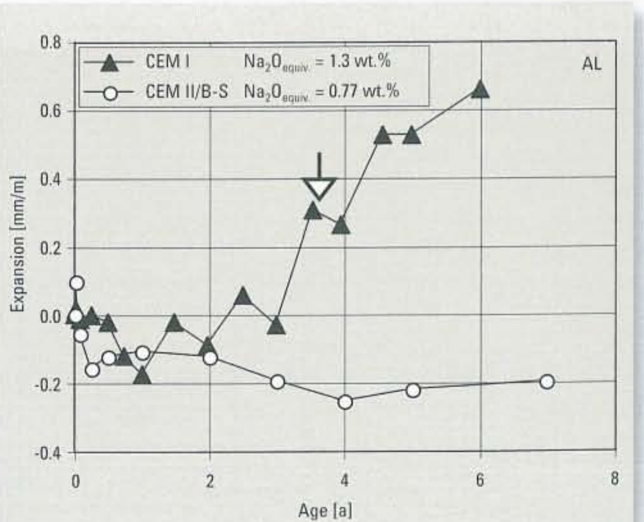

Figure 13: Expansion of concretes made with different cements in the outdoor store with 70% crushed Upper Rhine gravel. CEM II/B-S 32,5 R cement: c = 400 kg/m^3, w/c ratio = 0.45. CEM I 32,5 R cement: c = 500 kg/m^3, w/c ratio = 0.45

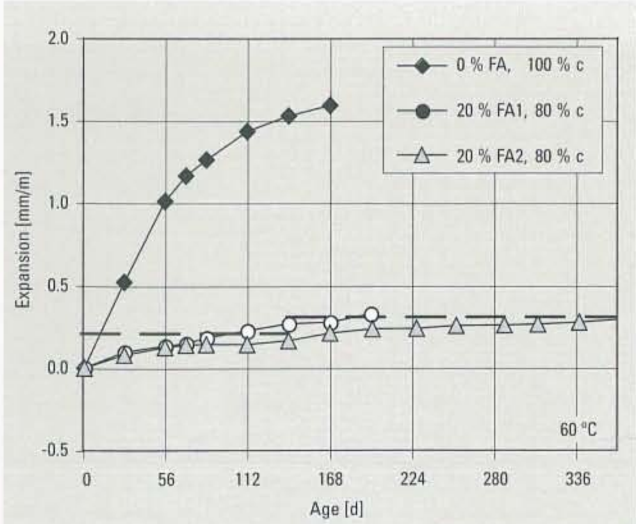

Figure 15: Expansion of concretes with and without fly ash in the 60 °C concrete prism test with 70% crushed Upper Rhine gravel, CEM I 32,5 R cement with Na_2O equiv. = 1.3 wt.%, w/(c+f) = 0.55, c + f = 500 kg/m^3

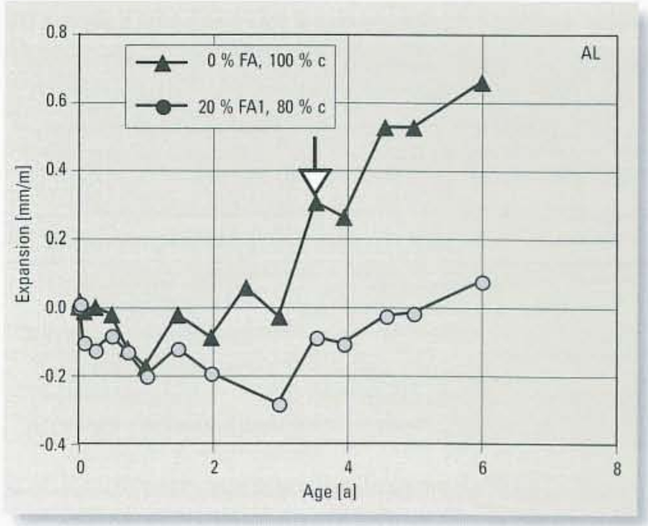

Figure 16: Expansion of concretes with and without fly ash in the outdoor store test with 70% crushed Upper Rhine gravel, CEM I 32,5 R cement with Na_2O equiv. = 1.3 wt.%, w/(c+f) = 0.45, c + f = 500 kg/m³

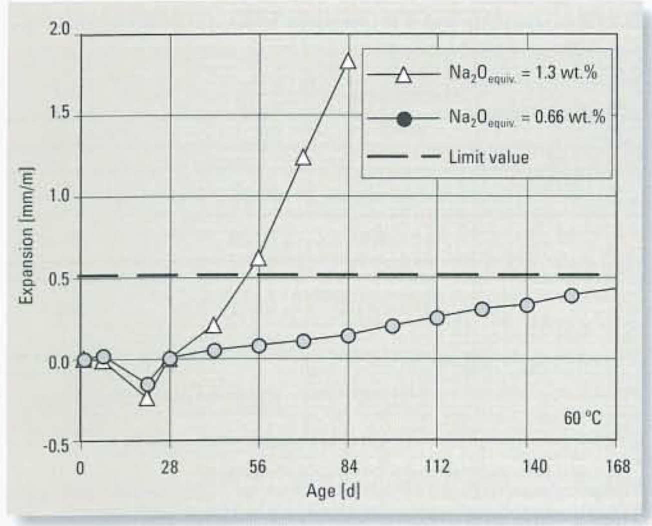

Figure 18: Expansion of concretes made with different cements in the 60 °C concrete prism test (performance test) with external supply of alkalis (10% NaCl solution), 70% crushed Upper Rhine gravel. Na_2O equiv. = 1.3 wt.%, c = 400 kg/m³, w/c ratio = 0.45. Na_2O equiv. = 0.66 wt.%, c = 385 kg/m³, w/c ratio = 0.42

sions than the conventionelly stored prisms at 60 °C. The tests also showed that this combination of a reactive aggregate (reactivity in the middle range) and a cement for road paving can be used for concrete pavements (➧ Fig. 18). However, these investigations are not applicable to concretes for airfields that are treated with different de-icing agents (sodium and potassium acetates or formates).

5 Testing strategy

5.1 Aggregate assessment

➧ Fig. 19 shows the strategy for aggregate testing as described in Part 3 of the draft of the German Alkali Guidelines [1]. The specific points that should be taken into account are described below.

After the petrographic investigation of the aggregate an accelerated mortar bar test is carried out as part of an initial test on three samples per aggregate. For crushed rock it is sufficient to test the 8/16 mm fraction. For crushed gravel the 2/8 and 8/16 fractions are tested together by crushing a mixture of the two fractions. The samples have to be taken by the testing institute or by the third-party inspector at intervals of about four weeks.

If the accelerated mortar bar test is passed then no further tests or measures are necessary. If the accelerated mortar bar test is not passed then a concrete test should be carried out. If this concrete test leads to a positive result then again no further tests or measures are necessary, not even if there is external supply of alkalis. If the concrete test is not passed then it is necessary to take the measures described below (➧ Table 2).

If no expert is engaged and no performance test is carried out then the following general rule applies: for concretes that are exposed to a moist environment with external supply of alkalis the aggregate must be replaced. If the concrete is exposed to a moist environment without external supply of alkalis then the aggregate can be used in the concrete in combination with a low-alkali cement. These measures mean

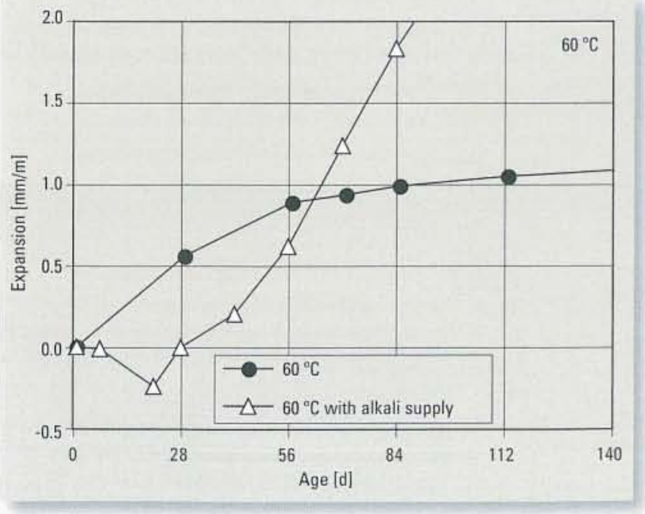

Figure 17: Expansion of a concrete in the 60 °C concrete prism test (aggregate test) and the performance test at 60 °C with external supply of alkalis (10% NaCl solution), 70% crushed Upper Rhine gravel, c = 400 kg/m³, w/c ratio = 0.45, CEM I 32,5 R cement with Na_2O equiv. = 1.3 wt.%

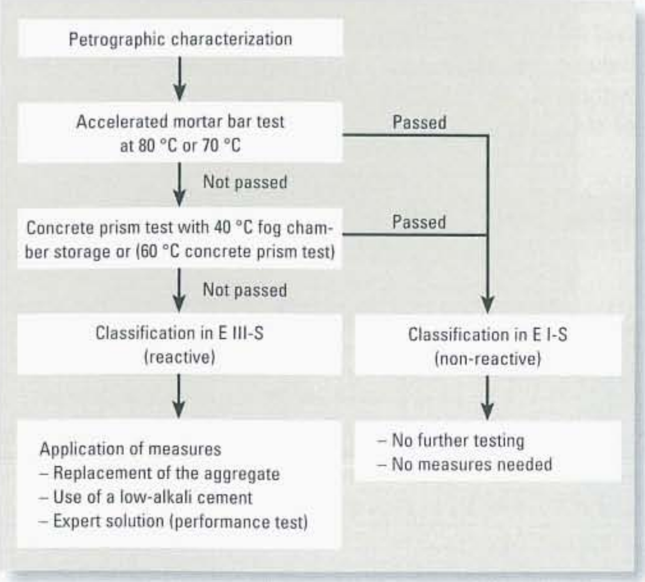

Figure 19: Flow chart for the aggregate test described in Part 3 of the draft of the German Alkali Guidelines [1]

Table 2: Measures to prevent deleterious ASR in concrete when using aggregates described in Part 3 of the draft of the German Alkali Guidelines [1]

Reactivity class	Cement content [kg/m³]	Measures required for moisture class			
		WO (Dry)	WF (Humid)	WA (Humid with external supply of alkalis)	WS (Humid with external supply of alkalis and dynamic loads)
E I-S	Not stipulated	None	None	None	Cements for road paving[4]
E III-S[1]	c ≤ 300	None	None	None	Cements for road paving[4]
	300 < c ≤ 350	None	None	Performance test[2] or low-alkali cement according to DIN 1164	Cements for road paving[4] and replacement of aggregate or expert report[3]
	c > 350	None	Performance test[2] or low-alkali cement according to DIN 1164	Performance test[2] or replacement of aggregate	Cements for road paving[4] and replacement of aggregate or expert report[3]

[1] Also applies for aggregates that have not been assessed.
[2] The performance testing will be described in a future part 4 of the German Alkali Guidelines. Until further notice the stipulation of preventive measures will be based on an expert report.
[3] Experienced technical experts must be called in for issuing expert reports.
[4] See [1]

that a number of aggregates or cements cannot be used in specific areas so it is advisable to have the concrete composition to be used specially assessed by an expert report using a performance test.

5.2 Performance test

The performance test should be carried out with the concrete intended for the structure. For safety the cement content should be increased by 5 % to 10 % for the performance test. The performance test is relatively expensive so it can be advisable to use the accelerated test method to monitor the aggregate. If the results of the accelerated test method and the composition of the aggregate do not change substantially and if a cement is used with an alkali content that corresponds approximately to that used in the performance test (i.e. its Na_2O equivalent is not more than 0.05 wt.% higher) then the concrete can be used.

6 Conclusion

ASR test methods must provide information within two to six months as to whether any deleterious ASR will occur in a concrete, including in the long term. In some cases this damage only appears after 10 to 30 years so it is absolutely essential that the limit values for the test methods are calibrated against outdoor exposure tests and investigations carried out on structures. The Research Institute of the Cement Industry has results from long-term outdoor exposure tests without external supply of alkalis and from the examination of structures.

The investigations are subdivided into tests on aggregates, in which the reactivity of the aggregates is determined, and performance tests that assess the suitability of the concrete for a specific application.

The 40 °C fog chamber method, with which the aggregate can be classified reliably, is available in Germany for dense aggregates. However, the method takes a long time and is therefore to be replaced in the next years by the 60 °C concrete prism test.

Accelerated test methods already enable a short-term classification of aggregates. The methods are very severe and lie significantly on the safe side. If the aggregate passes the test it can be classified as non-reactive to alkalis. If the test is not passed then it can be followed by concrete tests to clarify the reactivity of the aggregate. The accelerated test methods can also be used for monitoring aggregates.

With the 60 °C concrete test it is possible to carry out performance tests with and without external supply of alkalis. Limit values are stipulated on the basis of the practical experience available at the Research Institute of the Cement Industry.

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