THE EU "PARTNER" PROJECT- EUROPEAN STANDARD TESTS TO PREVENT ALKALI REACTIONS IN AGGREGATES FINAL RESULTS AND RECOMMENDATIONS

Philip J. Nixon[1] *, Jan Lindgård[2], Ingmar Borchers[3],
Børge Johannes Wigum[4] & Björn Schouenborg[5]

[1]Associate, Building Research Establishment, WATFORD, WD25 9XX, UK

[2] SINTEF Building and Infrastructure, NO-7465 TRONDHEIM, Norway

[3] Verein Deutscher Zementwerke e.V., DÜSSELDORF, Germany

[4] Mannvit Engineering, Grensásvegur 1, IS-108 REYKJAVIK, Iceland

[5] SP Technical Research Institute of Sweden, BORAS, Sweden

Abstract

This paper describes the EU PARTNER Project providing the basis for a unified European test procedure for evaluating the alkali reactivity of aggregates. The project evaluated the tests developed by RILEM and some regional tests, for their suitability for use with the wide variety of aggregates and geological types found across Europe. The project had 24 partners from 14 countries, covering most of Europe, from Iceland to Greece and 22 different types of aggregates from 10 different European countries were evaluated.

It was found that in most cases the RILEM tests could successfully identify the reactivity of the aggregates tested. They were most successful with normally reactive and non-reactive aggregates, but with aggregates that react very slowly an extended test period may be necessary for some of the RILEM methods. Overall, the accelerated mortar bar test and the accelerated concrete tests seemed most effective, and to have the best precision.

Keywords: Alkali-Silica Reaction, petrographic evaluation, test-methods, field tests, standardization.

1 INTRODUCTION

This paper describes the results of PARTNER, a project partly funded by the European Community, which had the overall objective of establishing a unified test procedure for evaluating the alkali reactivity of aggregates across the different European economic and geological regions. It is intended that the results of the project will be implemented by CEN in the form of new standard methods of test and specifications.

In the project the tests developed by RILEM, and some established regional tests, were evaluated for their suitability for use with the wide variety of aggregate and geological types found across Europe. The results of the accelerated laboratory tests were calibrated against the behaviour of these aggregates in real concrete structures and in field test sites. The precision of the tests was then determined by inter-comparison trials using a common set of materials. Additionally, a petrographical atlas of the potentially alkali-reactive rocks in Europe was produced and published, an education programme undertaken and recommendations made to the relevant technical committees of CEN.

The project had 24 Partners from 14 countries, covering most of Europe, from Iceland to Greece.

2 THE TEST PROGRAMME

2.1 General

Details of the test programme, the aggregates, the methods of test and the results are given in a series of technical reports published by the Norwegian research institute SINTEF [1], [2], [3], [4], [5]. These reports may be freely downloaded (*www.partner.eu.com*). Several papers covering parts of the project in more detail have also been submitted to the ICAAR 2008 conference.

A brief outline of the test programme is given in the following sub-chapters.

* Correspondence to: nixonp@bre.co.uk

2.2 The methods of test

The main candidate methods of test were those developed by the RILEM committees TC106 and TC191-ARP. Additionally, several methods of test that were already established in particular European regions were included in order to see if these could be replaced by the RILEM methods for the particular geological types of aggregate for which they had been developed.

The field site tests were included to provide a means of calibrating the accelerated tests against behaviour in conditions closer to those experienced by actual structures.

The full list of methods, with brief descriptions, and references to the original published methods [6-13] are given in Table 1. The tests were performed according to these methods, amplified by detailed notes prepared for each method.

2.3 The aggregates

The aggregates to be used for testing were chosen on the basis of a questionnaire completed by each partner regarding local potentially reactive materials. The final list contained 22 different types of aggregates from 10 different countries. The aggregates were selected with the purpose of covering most types of reactive aggregates throughout Europe. Additionally, non-reactive reference aggregates were tested.

2.4 The test programme for testing the aggregates with the different methods

Laboratory methods

The test programme took into account the need for a sufficient number of tests on each aggregate type using each of the main (RILEM) methods and the experience and budgets of the participating laboratories. For the regional (i.e. Danish-, German- and Norwegian), methods a reduced programme was undertaken in a few laboratories experienced with these methods. The numbers of laboratories who participated in the evaluation of each method, the numbers of aggregate types tested according to the different methods and the total numbers of single tests performed were as follows:

AAR-1	13[1] laboratories;	22 aggregate types;	in total 123 single analyses.
AAR-2	16[2] laboratories;	22[3] aggregate types;	in total 75 single tests.
AAR-3	10 laboratories;	19 aggregate combinations;	in total 48 single tests.
AAR-4	6 laboratories;	18 aggregate combinations;	in total 59 single tests.
AAR-4 (Alt.)	3 laboratories;	14 aggregate combinations;	in total 22 single tests.
Norwegian	2 laboratories;	10 aggregate combinations;	in total 13 single tests.
German	1 laboratory;	10 aggregate combinations;	in total 10 single tests.
Danish mortar bar	3 laboratories;	25[4] aggregate types;	in total 37 single tests.
Chatterji test	3 laboratories;	14 aggregate types;	in total 26 single tests.

In total 413 tests were performed within the PARTNER project. The total amount of aggregate needed by the laboratories were calculated, collected by a partner in the particular country, grading, density and water absorption measured and appropriate amounts despatched to the participating laboratories. A reference high alkali cement (1.26 % Na_2O-eqv.) was provided by Norcem who despatched the needed amounts to the laboratories.

The field tests

For these tests all the cubes representing one concrete mix (i.e. one aggregate type) were cast at one laboratory (generally in the country of origin of the aggregate) and transported to all the other laboratories (field test sites). 13 aggregate combinations produced at 5 laboratories were evaluated in this way on 8 different field sites from Norway to Spain. For each site two 300mm concrete cubes were prepared with the aggregate combination under test. The concrete mixes were the same as those used in the AAR-3 and AAR-4 specimens i.e. they were made with relatively high cement (440kg/m^3) content and high alkali Portland cement. The cubes were kept for one day in the moulds, demoulded and stored indoors for 6 days in a humid environment before being transported to the different field sites. At the different field sites the reference studs were glued on the concrete surfaces before the

[1] 6 of the laboratories were experienced in performing petrographic analysis.

[2] 8 laboratories used the 40x40x160mm RILEM prisms and 8 used the 25x25x285mm ASTM prisms.

[3] For some of these both the coarse and the fine fraction were tested separately.

[4] Includes 6 extra aggregate types (5 from Iceland and 1 from Norway).

cubes were exposed outdoors. During exposure one cube was stored with its base in a tray filled with water and the other was exposed only to ambient rainfall.

3 COMPARISON OF TEST METHODS

The detailed results from the 413 individual tests are presented in the five technical reports published by SINTEF [1], [2], [3], [4], [5]. The summarised results for the methods are compared in Table 2A, 2B and 2C with the preliminary results of the field site tests and with the reported reactivity in structures. They are presented in three groups according to whether their reported reactivity is:

- reactive in "normal" timescales (5-20 years)
- slowly reactive (+20 years)
- non-reactive

There are, however, some aggregates where the information on their reactivity is uncertain or where there is known variability in the source and the sample tested may not reflect the compositions in the reactive structures.

4 DISCUSSION

RILEM methods

In the first group (reactive in normal timescales) all of the methods agreed with each other and with the field site results and the reported reactivity except for D1. In this aggregate there is a known strong pessimum effect and it is presumed that the results for the concrete methods reflect the presence of an amount of opaline flint that takes the combination past the pessimum amount when the fine and coarse aggregates are used together.

In the second group, of slowly reactive aggregates, the petrographic method (AAR-1), the accelerated mortar bar method (AAR-2) and the accelerated concrete method (AAR-4) successfully identified the reactivity, but did not necessarily show that the expansion would be slow. The concrete prism method (AAR-3) was better at demonstrating the slowness of the expansion of these aggregates, but in a few cases the expansion did not pass the critical limit within the one year timescale of the test. However, it can be seen from the expansion curves that the expansion in most of these cases is continuing, and more than a year may be needed for some slowly reactive aggregates to produce expansion over the critical limit in the conditions of this test. In this respect therefore, the AAR-3 method, together with the German- and the Norwegian concrete prism methods, corresponds better with field experience for these slowly reactive aggregate types. In contrast to AAR-3, the AAR-4 method produced relatively higher expansions for the slowly reactive aggregates compared with the normally reactive aggregates. According to Folliard [pers. comm.], the general experience in USA is that the 20 week expansion in the 60°C method is normally about 60 % of the one year expansion in the 38°C method. In the PARTNER project the corresponding ratio between 60°C expansion and 38°C expansion was also less than 1 for most "normally" reactive aggregates. However, for several slowly reactive aggregates (e.g. It2, N4 and N5), the ratio was increased to about 2 (i.e. considerably higher expansions were obtained in the 60°C concrete prism method). However, the relatively high inter-laboratory variations make this comparison somewhat uncertain.

In the non-reactive group, the results of the concrete methods agreed with the reported reactivity in all cases where the information on reactivity was clear cut. In the case of S1 and P1 there is uncertainty about the composition of the samples tested compared to the aggregates in the structures where damage was reported. Similarly, the accelerated mortar test (AAR-2) was effective in all cases except with F3 This aggregate is reported to have a marked pessimum effect and it is probable that the difference in result between the concrete and mortar methods reflects the fact that the proportion of reactive material in the fines is within the pessimum proportion but when the coarse and fines are tested together in concrete the amount of reactive material exceeds the pessimum. The petrographic method (AAR-1) is effective in identifying those aggregates which contain either no or very low amounts of reactive material but is unable to identify correctly those aggregates where (possibly pessimum effects) lead to such aggregates being innocuous in structures.

Overall, the accelerated mortar test (AAR-2) and the accelerated concrete test (AAR-4) seemed the most effective of the RILEM methods across the whole range of European aggregates, including the identification of slowly reactive aggregate combinations. Additionally, these methods have the advantage of producing (relatively) fast results.

The petrographic method (AAR-1) can produce an even quicker result. The averaged results for this method seem quite effective at identifying reactive materials, but can conflict with field experience when pessimum effects operate. The consistency of individual results for this method is the main issue, however. The spread in results between the laboratories for about half of the aggregate types tested was very high and this high variability even applied to the results from some of the six laboratories which carry out petrographic analyses on a regular basis. As discussed in relation to the precision test, below, there is a clear need for more education and inter-laboratory comparisons if the petrographic method is too used on a European scale.

Other test methods

The German and Norwegian tests behaved almost exactly like the AAR-3 method; identifying the "normally" reactive aggregate combinations and non-reactive combinations effectively, but giving marginal results with some of the slowly reactive combinations.

The two Danish methods were effective with most materials. However, the TI-B51 test appears to underestimate the reactivity of some slowly reacting materials when the standard 8 or 20 weeks are used, although at 26 or 52 weeks the method generally agrees well with the other concrete methods. The one exception is the result for Norwegian material N2 which was classified incorrectly by the TI-B51 method; so far no explanation for this discrepancy is obvious.

The field site tests

In summer 2007 the samples had been exposed in the field sites for approximately 3½ years. This time is too short for slowly reactive aggregates to cause a deleterious ASR in concrete. Thus only preliminary conclusions are possible. After 3½ years all concrete samples containing "normally" reactive aggregates are showing significant signs of a deleterious ASR-like expansion (over 0.04%) or cracks with widths ≥ 0.2 mm. In the second, group of concretes containing slowly reactive aggregates, only the samples D2 and possibly N2 show signs of a deleterious ASR. The concrete compositions with "non-reactive" aggregates are not exhibiting any sign of cracking.

The experiments were carried out in various climate zones representative of Europe in order to take into account the influence of different environmental conditions in practice. However, the results are indicating that a deleterious ASR occurs in the same way in northern and in southern Europe with the difference that the reaction occurs earlier in southern Europe probably due to the higher mean temperature. It is also noteworthy and surprising that there is often higher expansion in the specimens exposed only to ambient rainfall than in those stored partly immersed in water. Some specimens were even stored alongside a highway in Sweden to study the additional influence of alkali supply from outside under severe conditions but so far there is no difference in the performance of these concrete cubes compared with those stored in a nearby forest. The field site tests will be continued in the future with yearly measurements.

Critical Limits

Final evaluation of the critical limits will need to be undertaken when longer term results for the field site tests are available. Based on the preliminary results of the field trials and comparison of the laboratory results with the reported reactivity in field structures, together with previous work by RILEM, the following critical limits can be suggested:

- AAR-2: 0.10% expansion after 14 days distinguishes a non-reactive and reactive aggregate when using the long thin prisms. The short thick prisms initially expand more slowly and either a lower limit (e.g. 0.08%) or a longer test period will be necessary with these test specimens.
- AAR-3: expansions of less than 0.05% after 1 year indicate that the aggregate combination can be regarded as non-reactive. This limit will be effective for aggregates that react in normal timescales, but with some slowly reacting aggregates a longer test period may be necessary. The shape of the expansion curve will help to identify such aggregates.
- AAR-4: expansions of less than 0.03% after 20 weeks indicate that the aggregate combination can be regarded as non-reactive. For this test the standard time period of 20 weeks is sufficient for both normally and slowly reacting aggregates.

{N.B. The results of a separate RILEM inter-laboratory trial have suggested that the 15 week results can give an effective prediction of the reactivity of the aggregate. These results support that assessment.}

5 PRECISION OF THE METHODS

The precision of the four RILEM methods has been established in an inter-comparison trial in which the laboratories carried out the methods using samples of the same aggregates together with the reference cement. The procedures strictly follow ISO 5725-94 [15]. The organisation and results of the trial are described in detail in reference [16]. The precision of AAR-4 (Alternative) rather than the

AAR-4 method was assessed because too few laboratories had the reactor necessary for the original method.

Overall precision

The overall precision of the four methods assessed in the trial is set out in Table 3. The mathematical relationships are for the best fit curves in each case and their mathematical form therefore varies. For that reason it is recommended to insert actual values into the different formulas when comparing results.

General definitions (simplified and related to this project)
r = repeatability. This is a measure to determine the spread in results obtained on the individual prisms, tested at the same laboratory, same aggregate combinations and same concrete.
R = Reproducibility. This is a measure to compare the difference in the mean value between the different laboratories.
COVSR = Coefficient of variation for the Reproducibility. By using the coefficient of variation (COV) one relates the spread to the actual expansion. The COV is the standard deviation divided by the mean value. The COVSR is thus used to compare the difference in the spread between the laboratories.

AAR-1 petrography

The results from the AAR-1 petrography showed a large spread between the different laboratories. Their identification of the rocks and minerals is similar, but the classification of the degree of alkali silica reactivity varies a great deal. This is probably due to the regional experience and inexperience of the different reactive rocks. Only porous/opaline flint and mylonite/cataclasite have been classified as reactive by all laboratories.

Overall, the results confirm the necessity of education. Petrographers need to get acquainted with the potentially reactive components in aggregates from different countries in order to use the most appropriate analytical techniques and to make a relevant assessment. Education, in combination with proficiency trials of individual laboratories, is therefore the way forward for future constructive development in this area.

Expansion tests; AAR-2, AAR-3 and AAR-4 (Alternative)

Overall the precision is very good and it is possible to detect small differences in reactivity.

AAR-2

Both options, using the long and thin prisms (25x25x285 mm) and the short and thick prisms (40x40x160 mm) are working adequately. At the standard 14 days test age the long and short prisms give different results, with the long prisms having the highest expansion. At 14 days, therefore, the short prisms would need a different (smaller) limiting requirement to differentiate reactive and non-reactive aggregates. However, the results are equalising after 20days and even more so after 28 days. The difference between laboratories is generally less than 1 standard deviation of the overall mean value. If the use of both prism sizes is still to be recommended in the same method, it seems necessary to continue the test for 28 days or to use a correlation factor. The precision trial also indicates that using 3 prisms instead of 5 actually improves the precision data, probably because with only 3 prisms they can all be in the same container. At the proposed limiting value for differentiating reactive and non-reactive aggregates, 0.10 % (for the long prisms), the band of uncertainty is less than 0.025%.

AAR-3

In this method the repeatability is good whereas the reproducibility is quite poor, i.e. each laboratory produces results within a narrow range, but the difference in results between the laboratories are large. A coefficient of variation in the repeatability of up to 20 % is acceptable but the results indicate that AAR-3 does not achieve this with the most expansive material. Equally, a coefficient of variation in reproducibility (COVSR) of above 50 % is unacceptably high. It is therefore concluded that that the precision of AAR-3 is not sufficient to discriminate between different levels of reactivity. The results of the precision trial do, however, confirm that the method can be used to discriminate between non-reactive and reactive materials. The reproducibility is shown to be about half of the expansion value. At the level of 0.05%, suggested as the limiting value to differentiate reactive and non-reactive aggregate combinations when using AAR-3, there is therefore a band of uncertainty of 0.025% and the lowest result for a reactive aggregate should exceed 0.075 %. This was found to be the case for all the aggregates which react in normal timescales and where their field reactivity is well established. However, the AAR-3 method is not well suited to identifying slowly reactive aggregates.

AAR-4 (Alternative)

The AAR- 4 Alt. method has a better overall precision than AAR- 3 and can therefore detect smaller differences in reactivity than the AAR 3 method. The "overlap" between the different materials (e.g. categories of reactivity) is less, approximately half that of the AAR 3 test. The coefficient of variation in reproducibility, COVSR, is about one third of the mean test result while the repeatability COV is about 10 to 15 % which is acceptable.

Like AAR-3, the precision of the AAR-4 Alternative method is sufficient to distinguish between non-reactive and reactive materials but not between different levels of reactivity. At the proposed limiting value for differentiating reactive and non-reactive aggregates, 0.03%, the band of uncertainty is less than 0.01%.

6 PETROGRAPHIC ATLAS

As part of the PARTNER a petrographic atlas of the potentially alkali-reactive rocks in Europe was produced and published. The aim of this petrographic atlas is to assist geologists who work in the field of the concrete degradations and in particular in the field of alkali-silica reaction to recognise potentially reactive rock types and to differentiate these from rock types that will be resistant to alkali reactions. It will particularly be of assistance to petrographers who carry out the AAR-1 (petrographic method) on aggregates that are from a part of Europe with which they are unfamiliar.

A paper version of the Atlas is published by the Belgian Geological Survey [17]. Additionally, there is an electronic version which is accessible on *www.aarig.org*. It is planned to maintain the electronic version under the auspices of RILEM.

The rocks are firstly classified under their origin (sedimentary, metamorphic or igneous) using the international nomenclatures. Secondly, they have been grouped under families of similar species. For each rock family, a general description is given in the header including the most particular characteristics of the different rock species from different countries. The reactive components are emphasized within the descriptions and, when possible, within the pictures which illustrate the type of aggregate. Despite the fact that this atlas is not exhaustive, it is nevertheless representative of the majority of the European alkali-reactive rocks.

7 STATE OF ART REPORT

As part of the PARTNER project a state-of-art report on key parameters influencing the alkali aggregate reaction was produced [18]. Annex A of the report includes a description of the existing national standards and requirements in the different European countries. The main objective of this report is to give an updated description of the mechanisms of AAR that can influence the results from the different test methods used in the PARTNER project. The ultimate challenge when testing for AAR in a laboratory is to provide quick, reliable results regarding the reactivity of certain types of aggregate, or, even more important, an assessment of specific concrete job mixes (i.e. performance testing). The results are required to mirror the durability behaviour in real structures designed for a service life up to 100 years.

The report identified many parameters that will influence the alkali aggregate reactivity. Some of the parameters will only influence the reactivity in the laboratory, while others will have an overall contribution, both in the laboratory and in real structures. The following key parameters are discussed in the report in relation to AAR:

- Temperature
- Humidity, moisture and degree of saturation
- Content of alkalis
- Role of calcium hydroxide (CH)
- Types and content of reactive rock types
- Aggregate particle size / grading
- Size of test prisms
- Air entrainment, paste porosity and water/cement ratio
- Storage conditions - leaching

The influence of any changes in a parameter may vary a lot dependent of the situation, both when performing a laboratory test and in a real concrete structure. However, the experience has shown that in particular any variations in the humidity and/or the alkali content (due to leaching) in the test specimens can lead to incorrect results. It is also very important to bear in mind the influence of the different parameters when undertaking a performance test to reflect how a given concrete mix will behave in a real concrete structure over a long service life.

8 CONCLUSIONS

- In the majority of cases all the RILEM test methods were able to correctly identify the reactivity of the 22 aggregates tested. The tests were particularly successful in identifying aggregates that react in "normal" time scales (i.e. 5 to 20 years) and in identifying non-reactive aggregates. There was less certainty in identifying "slowly" reactive aggregates, i.e. those that react in greater than 20 years. Whether these experiences can be applied to all European regions will have to be verified by additional local examinations.
- Where there were discrepancies between the results of the tests and field experience, these can usually be attributed to either uncertainties about the field results, to variability in the aggregate source or to pessimum effects.
- Overall, the accelerated mortar test (AAR-2) and the accelerated concrete test (AAR-4) seemed the most effective of the RILEM methods across the whole range of European aggregates, including the identification of slowly reactive aggregate combinations. Moreover, these methods have the advantage of (relatively) fast results.
- The petrographic method can produce an even quicker result. The averaged results for this method seem quite effective at identifying reactive materials, but can conflict with field experience when pessimum effects operate. The consistency of individual results for this method is the main issue, however.
- Precision statements for the four RILEM methods have been made. These confirm the poor precision of the petrographic method unless the laboratories carrying out the test are familiar with the materials being evaluated. The precision of the expansion methods is much better, and the results confirm the conclusion that the AAR-2 and AAR-4 methods are the most repeatable and reproducible.

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Table 1: Brief outline of test methods

Test method	Brief outline of method
RILEM AAR-1 Petrographic method [6]	The reactivity of the aggregate is classified on the basis of its petrographic composition. Depending on the nature of the aggregate this can either be by hand separation, crushing and point counting under a microscope or by microscopic examination in thin section.
RILEM AAR-2 Accelerated mortar bar method [7]	Mortar prisms made with the aggregate and a reference high alkali cement are stored in 1M NaOH at 80°C and their expansion monitored over a 14 days period.
TI-B51 - The Danish mortar bar test [8]	Mortar prisms made with the aggregate are stored in saturated NaCl solution at 50°C and their expansion is monitored for 52 weeks.
The Danish Chatterji method [9]	The degree of reaction between silica in the aggregate and KCl is determined by measuring the alkalinity after 24 hours reaction to a non-reactive standard.
RILEM AAR-3 Concrete prism method [10]	Accelerated expansion test for 12 months. Wrapperd concrete prisms made with the aggregate and a reference high alkali cement are stored in individual containers within a constant temperature room at 38°C and measured at 20°C.
RILEM AAR-4 Accelerated concrete prism method [11]	Accelerated expansion test for 20 weeks. Concrete prisms made with the aggregate and a reference high alkali cement are stored in individual containers within a reactor at 60°C and measured at 20°C.
RILEM AAR-4 Alt. Accelerated concrete prism method [11]	Accelerated expansion test for 20 weeks. Wrapped concrete prisms made with the aggregate and a reference high alkali cement are stored in individual containers within a constant temperature room at 60°C and measured at 20°C.
German concrete method [12]	Test duration of 9 months. Concrete prisms and one cube are stored in a fog chamber at 40°C with measurements taken immediately with no cooling down period.
Norwegian concrete prism method [13]	Accelerated expansion test for 12 months. Large concrete prisms (100x100x450 mm) made with the aggregate and a reference high alkali cement are stored in individual containers within a constant temperature room at 38°C and 100% relative humidity and measured at 20°C.
Field site method	300mm concrete cubes stored externally on exposure sites. Measurements of expansions and maximum crack widths.

Table 2A. Comparison of results of test methods with behaviour in field sites and structures

Aggregate	Fraction/ Combi-nation	Reactivity/evaluation							
		AAR-1	AAR-2	AAR-3	AAR-4/ AAR-Alt	TI-B51/ Chatterji	German/ Norwe-gian	Field site test after 3½ years**	Reported reactivity in structures?
"Normally" reactive aggregate combinations									
B1 - Silicified limestone	F	R	R			R/R			Yes
	C	R							
	C+F			R	R/R		R/R	R	
	C+NRF			R	R/R			R	
UK1 - Greywacke	F	R	R			R/R			Yes
	C	R							
	C+F			R	R/R		R/R	R	
G1 - Gravel with siliceous limestone and chert	C	R	R			R/-			Yes
	C+NRF			R	R/R		R/-	R	
G2 - Gravel with opaline sandstone and flint	C	R	R			R/-			Yes
IT1 - Gravel with silicified limestone and flint	F	R	R			R/-			Yes
	C	R	R						
	C+F			R	R/R				
N1 - Cataclasite	C	R	R			R/R			Yes
	C+NRF			R	R/R		R/R	R	
UK2 - Gravel with quartzite and chert	F	R	R			R/R			Yes (moderate)
	C	R							
	C+F			R	R/R				
D1 - Gravel with opaline flint	F	R	R						
	C	R	R			R/R			Yes, but pessimum effect
	C+F			?*	NR/NR		NR/-		
D2 - Sea gravel semi-dense flint	F	R	R			R/R			Yes 10-15 y
	C	R	R						
	F+NRC			NR/MR?	R/MR			R	

Table 2B. Comparison of results of test methods with behaviour in field sites and structures

Aggregate	Fraction/ Combi-nation	Reactivity/evaluation							
		AAR-1	AAR-2	AAR-3	AAR-4/ AAR-Alt	TI-B51/ Chatterji	German/ Norwe-gian	Field site test after 3½ years**	Reported reactivity in structures?
"Slowly" reactive aggregate combinations									
IT2 - Gravel with quartzite	F	R	R			NR/-			Yes 50 y
	C	R	R						
	C+F			NR	R/R			n.r.	
N2 - Sandstone	C	R	R			NR/R			Yes 15-20 y
	C+NRF			R			-/R	p.r.	
N4 - Gravel with sandstone and catacl. rocks	F	R	R			R/R			Yes 20-25 y
	C	R	R						
	C+F			MR	R/-		MR/MR	n.r.	
N5 - Gravel with rhyolite and quartzite	F	R	R			R/R			Yes 20-25 y
	C	R	MR						
	C+F			MR	R/-		MR/MR		
N6 - Gravel with sandstone, rhyolite and mylonite	F	R							Yes 20-25 y
	C	R							
	C+F			MR			-/MR		

Table 2C. Comparison of results of test methods with behaviour in field sites and structures

Aggregate	Fraction/ Combi-nation	Reactivity/evaluation							
		AAR-1	**AAR-2**	**AAR-3**	**AAR-4/ AAR-Alt**	**TI-B51/ Chatterji**	**German/ Norwe-gian**	**Field site test after 3½ years****	**Reported reactivity in structures?**
"Non-reactive" aggregate combinations									
F1 - Gravel with flint	C	R	NR			NR/R			No, but known pessimum effect
	C+NRF			NR	NR/NR		NR/-	n.r.	
F2 - Non-reactive limestone	F	NR	NR						No
	C	NR							
	C+F			NR	NR/NR		NR/NR	n.r.	
F3 - Gravel with quartzite, flint, greywacke and granitoids	F	R	R			NR/R			No, but likely pessimum effect
	C	R							
	C+F			NR	NR/NR				
S1 - Gravel with metarhyolite and greywacke	F	R	R			R/R			Yes, but source variable in composition
	C	R							
	C+F			NR	MR/-		NR/MR	n.r.	
P1 - Silicified limestone	C	R	NR			NR/-			Yes, but source and informa-tion uncertain
	C+NRF			NR	MR/MR			n.r.	
N3 - Granitic sand	F	NR	NR			NR/NR			No
	C	NR							
	C+F			NR	NR/NR		NR/NR		
E1 - Dolomitic limestone	F	NR	NR						Information uncertain
D3 - Siliceous sand	F	NR	NR			NR/-			No

F = fine aggregate; C = coarse aggregate
NRF = non-reactive fine aggregate (=N3F) NRC = non-reactive coarse aggregate (=F2C)
R = reactive (according to the critical limits in the different testing methods)
NR = non-reactive (according to the critical limits in the different testing methods)
MR = marginally reactive (i.e. expansions just above the critical limits in the different testing methods)
p.r. = possibly reactive aggregate combination n.r. = no rating yet possible
* = one result strongly reactive, second non-reactive
** = the evaluation of the preliminary results from the field sites is based on measurements of crack widths after about 3 ½ years of exposure and of expansions during the last 2 years (the expansion measurements were re-started in 2005 due to problems with the zero measurements at some field sites).

Table 3. Precision statements for all assessed methods. *m* is the mean value

Method	repeatability standard deviation Sr	coefficient of correlation r^2	reproducibility standard deviation. SR	coefficient of correlation R^2
AAR- 1	Not determined		SR =_0,143*m????*	0.60
AAR- 2, 14 days 25x25x285 mm 5 prisms????	$Sr = 0.015m^{0.539}$	0.50	$SR = 0.194m^{1.812}$	0.82
AAR- 2, 14 days 40x40x160 mm 5 prisms???	$Sr = 0.002 + 0.039m$	0.78	$SR = 0{,}922m^{1.854}$	0.85
AAR- 2, 28 days 25x25x285 mm 5 prisms???	$Sr = 0.022m$	0.35	$SR = 0{,}245m^{2.593}$	0.80
AAR- 2, 28 days 40x40x160 mm 3 prisms	$Sr = 0.005 + 0.015m$	0.87	$SR = 0{,}161m^{0.704}$	0.63
AAR- 3	$Sr = 0.257m^{1.232}$	0.99	$SR = 0.001 + 0.512m$	1.0
AAR- 4 Alt.	$Sr = 0.741m^{1.919}$	0.93	$SR = 0.453m^{1.32}$	0.92

See section 5 for further definitions. Sr relates to the differences/spread within one laboratory, whereas SR relates to the spread between laboratories. The coefficient of correlation r^2 (and R^2) is 1.0 if the correlation is perfect; a good correlation is about 0.9 or better. In the table r^2 is used to assess the validity of the formula, i.e. if r^2 is about 0.9 or higher the formula can be used, with a reasonable amount of certainty, to e.g. calculate the expected difference in test results if the same material is sent to different laboratories.