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RILEM TC 191-ARP: 'Alkali-reactivity and prevention - Assessment, specification and diagnosis of alkali-reactivity'

RILEM Recommended Test Method AAR-0: Detection of Alkali-Reactivity Potential in Concrete – Outline guide to the use of RILEM methods in assessments of aggregates for potential alkali-reactivity

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The text presented hereafter is a draft for general consideration. Comments should be sent to the TC Chairman: Dr. Philip Nixon, Building Research Establishment (BRE), Garston, Watford WD2 7JR, UK; Tel.: +44 923 664 239; Fax: +44 923 664 010; Email: nixonP@bre.co.uk, by 31 January 2004.

1. INTRODUCTION

Initial work by RILEM TC 191-ARP (and its predecessor TC 106) concentrated on the assessment of the alkali-reactivity potential of aggregates, but, in recognition that damaging expansion involves interaction between all the main components of a concrete mix, more recent investigation has focused on the evaluation of particular mix combinations. After consideration of a wide range of existing and proposed methods for the alkali-aggregate reactivity (AAR) assessment of aggregates, TC 191-ARP initially concentrated upon the preparation of three procedures: petrographical examination (AAR-1), an ultra-accelerated (mortar-bar) expansion test (AAR-2) and an accelerated (concrete prism) expansion test (AAR-3). Work has continued on an ultra-accelerated performance test for concrete (AAR-4) and also specialised procedures for the assessment of carbonate aggregates (AAR-5).

A recommended scheme for the integrated use of these assessment procedures has now been developed, including some preliminary advice on the interpretation of their findings. An outline of this draft scheme is described in the following sections and the principles are illustrated by the flow chart given in Fig. 1.

2. AGGREGATE ASSESSMENT

Aggregates from both new and existing sources frequently require to be assessed for their suitability for use in concrete. The investigation of AAR potential is one essential part of the assessment, but it should be recognised that, in many or most cases, other properties will have a more important potential influence on the performance and durability of aggregates. Therefore, the evaluation of AAR potential should not be carried out in isolation, but rather as a specialised extension to the routine suitability assessment of an aggregate.

Consideration of AAR potential is complicated by the so-called 'pessimum' behaviour of some aggregates, whereby expansion of concrete is maximised at a certain

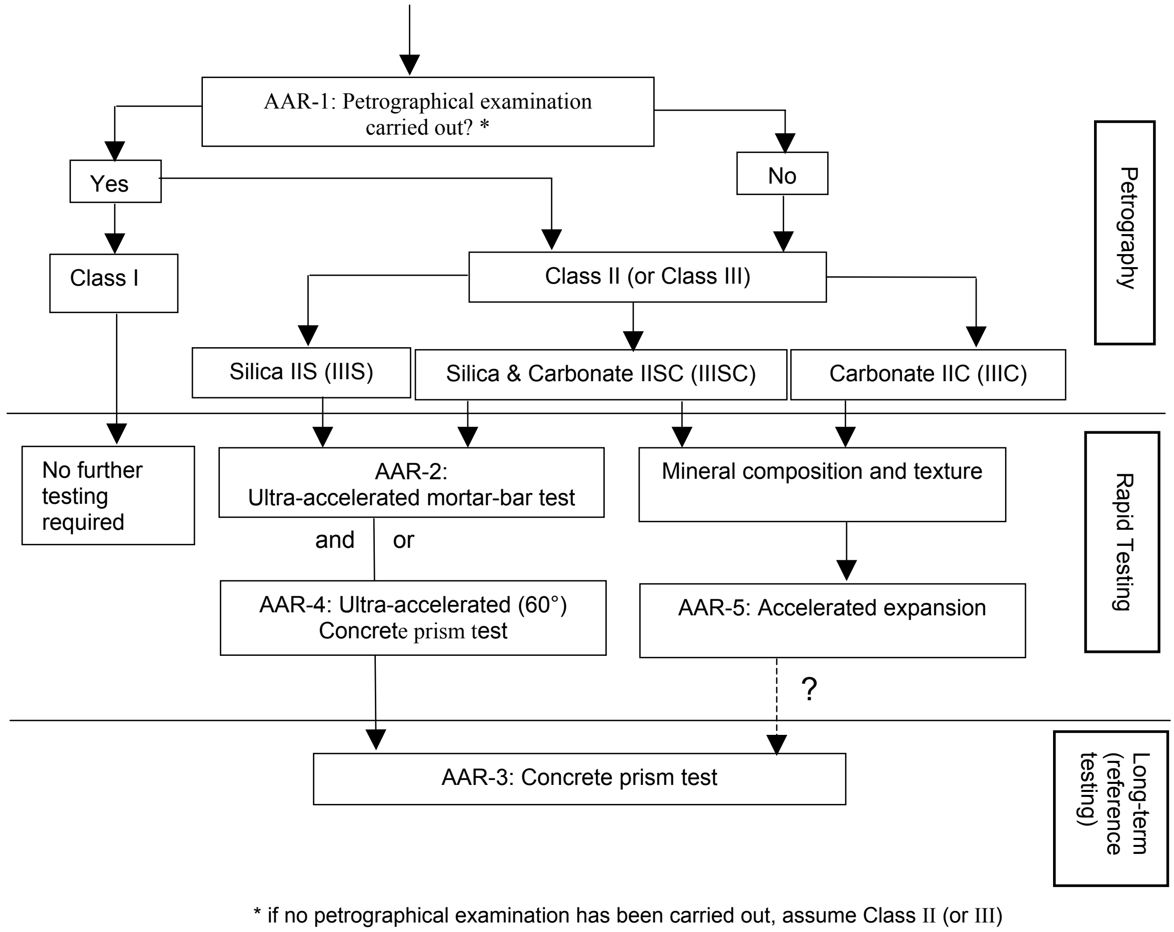

Fig. 1 - Integrated assessment scheme.

level of reactive constituent in the aggregate and progressively reduced for both greater and lesser levels. It is consequently important for AAR assessment to consider the total combination of coarse and fine aggregates, rather than only the individual materials.

In addition to inherent reactivity, some aggregates can influence the reactivity potential of a concrete mix by releasing alkalis that are additional to those derived primarily from the cement. TC 191-ARP is developing reliable procedures for determining any content of releasable alkalis in aggregates, but this is not part of the present assessment scheme.

3. PRINCIPLE

Any assessment of an aggregate combination for AAR potential should ideally commence with petrographical examinations of the component aggregates, which establishes their individual and combined compositions and identifies the types and concentrations of any potentially reactive constituents. This usually allows an aggregate combination to be assigned to one of three categories, as follows:

Class I - very unlikely to be alkali-reactive
Class II - potentially alkali-reactive or alkali-reactivity uncertain
Class III - very likely to be alkali-reactive

In the case of new aggregate sources, Class II is common and further testing will be required. For existing aggregate sources, when experience of use can be taken into account for local applications, Classes I or III are more often possibilities. Class III is exceptional for new aggregates and essentially limited to those found to contain opal or opaline silica.

When petrography indicates Class II (or Class III), it becomes necessary to decide on the most appropriate further tests. Aggregates which are either mainly siliceous, or carbonates with a potentially reactive silica content, are designated Class II-S or III-S and may be subjected to the RILEM expansion tests. Aggregates which are either mainly carbonate, or mixtures including potentially reactive types of carbonate, are designated Class II-C or III-C and may be subjected to the specialised procedures for carbonate materials. Some aggregates of mixed composition might be designated Class II-SC or III-SC and thus need to be subjected separately to tests for alkali-silica reaction (ASR) and for carbonate aggregates.

In the case of the RILEM expansion tests, the concrete prism method is currently regarded as the reference test, on the basis of accumulated experience of its use in various forms. However, the concrete prism test requires a lengthy period, up to 12 months, for reliable results to be obtained and, consequently, the ultra-accelerated mortar-bar test has been developed for the provision of an earlier indication of the outcome.

At present, following petrographic assessment, it is considered unwise to rely solely on the results of the ultra-accelerated mortar-bar test and the preliminary indication from that method should always be confirmed by the longer-term concrete prism test. Also, practical experience has suggested that the ultra-accelerated mortar-bar test might be unreliable for Class II-S aggregates containing porous flint (a type of chert) as a potentially reactive constituent. Greater experience with the ultra-accelerated mortar-bar test may, in due course, enable this advice to be modified.

RILEM TC 191-ARP has developed and is currently assessing an ultra-accelerated version of the concrete prism test, which it is hoped might also be used for assessing the reactivity performance of particular concrete mixes. However, although preliminary indications are encouraging, it is not yet possible to demonstrate a definite correlation between the results of this test method and field performance, so that guidance on its use in practice cannot be provided at present. It is hoped that further development and international trials might, in due course, enable the performance variant of this method to be used for acceptance testing on a project-by-project basis.

All sources of natural aggregates exhibit both systematic and random variations in composition and properties. Suitability assessments have therefore to be repeated periodically and this is particularly the case with evaluations of AAR potential.

4. SAMPLES

Laboratory investigations are only reliable if the samples are representative. It is therefore important to ensure that the sample used for AAR assessment is properly representative of its source. In the case of an operating existing quarry, it is usually appropriate to take samples from the current stockpiles of processed aggregates, following the sampling procedures given in national and international standards for aggregate testing.

In the case of a new or prospective quarry, it might be more appropriate for an experienced geologist to take rock lump samples directly from natural outcrops and/or to drill cores from rock bodies to be extracted as quarrying for aggregates proceeds. Different rock types would be tested separately or in controlled combinations at the discretion of the field geologist: the test samples should endeavour to represent the aggregates which will be produced for actual use.

Guidance on the taking of representative samples is included in RILEM AAR-1 (petrographical examination).

TC 191-ARP has established some sources of suitable reference materials, including high-alkali Portland cement and both reactive and non-reactive natural aggregates. Some further reference materials may be identified in due course. These reference materials are summarised in Annex A, which also includes some information on some specialised testing accessories.

5. PETROGRAPHICAL EXAMINATION - AAR-1

A procedure is given in RILEM AAR-1 for the petrographical examination and classification of aggregate samples for AAR potential. This procedure enables any potentially alkali-reactive constituents to be identified and, if necessary, quantified. The identification is based primarily upon basic petrological or mineralogical type(s), supported, whenever possible and appropriate, by local experience.

As explained earlier, petrographical examination will lead to one of three Classes: I, II or III. In the case of Class II (or Class III), it will also be necessary for the petrographical examination to determine whether the aggregate is wholly or partly siliceous (Class II-S or III-S), or wholly or partly carbonate (Class II-C or III-C), or possibly a combination containing significant proportions of both siliceous and carbonate materials (Class II-SC or III-SC). If petrography is not available or was inconclusive, the material being evaluated should be regarded as being Class II (or III).

The main procedure described in AAR-1 results in a quantitative petrographic analysis for the sample under investigation, whereby each particulate constituent has been petrologically (or mineralogically) identified, its relative proportion determined and its alkali-reactivity status (judged innocuous or potentially reactive) established. This information is then used to classify the aggregate sample, for the purposes of the AAR assessment, into one of the three categories I, II or III, suffixed -S, -C or -SC as appropriate.

Acceptance and experience with reactive constituents differ between countries, and thus, final assessment and classification should follow any national or regional experiences, recommendations and specifications. Therefore, it is recommended by TC 191-ARP that, whenever possible, petrographers should apply local guidance and/or local experience to assist with this classification.

In the case of Class II and III aggregate samples, additionally sub-classify the material according to the siliceous and/or carbonate nature of the potentially reactive constituents, using the following definitions:

Classes II-S & III-S aggregate samples contain particulate constituents judged to be potentially alkali-silica reactive (ASR).

Classes II-C & III-C aggregate samples contain particulate carbonate constituents judged to be potentially reactive.

Classes II-SC & III-SC aggregate samples contain both particulate constituents judged to be potentially alkali-silica reactive (ASR) and particulate carbonate constituents judged to be potentially reactive.

In the case of Class II-S or III-S materials, it is then appropriate to carry out the RILEM test methods for alkali-silica reactivity (ASR): the ultra-accelerated mortar-bar test, AAR-2 and the concrete prism test, AAR-3. In due course, the ultra-accelerated concrete prism test, AAR-4, might be an additional option. In the case of Class II-C or III-C materials, it is instead appropriate to carry out test procedures for carbonate aggregates. It will be apparent that, very occasionally, it will be necessary to conduct tests for both ASR and carbonate aggregates on Class II-SC or III-SC materials.

Practical experience has indicated, however, that Class II-S or III-S aggregates containing more than 2% by mass porous flint (chert) as a potentially reactive constituent cannot be reliably assessed using the AAR-2 ultra-accelerated mortar-bar test. Such aggregates are widely encountered, for example, in several northern European countries, including Belgium, Denmark, the Netherlands and the United Kingdom. Some porous flint (chert) aggregate combinations that have been established as being expansively reactive in actual structures were not detected as being expansive in the ultra-accelerated mortar-bar test. Class II-S or III-S aggregates found by petrography to contain more than 2% porous flint (chert), therefore, should either be assessed using the AAR-3 concrete prism test or accepted as being potentially alkali-reactive and precautions taken to minimise the risk of ASR damage to any concrete in which the material is used .

6. ULTRA-ACCELERATED MORTAR-BAR TESTING - AAR-2

An ultra-accelerated test method for ASR, using mortar-bar specimens, is given in RILEM AAR-2. The method is unsuitable for porous flint (chert) aggregates (see above).

Experience has shown that the test procedure is able to detect pessimum behaviour, but it is not certain that the pessimum proportion indicated by the test corresponds with that exhibited by a comparable concrete. It is therefore recommended that a series of tests is carried out, in which the test aggregate is mixed with a non-reactive material in a range of proportions. Guidance on this procedure is given in the annex to RILEM AAR-2.

Criteria for the interpretation of the results of RILEM AAR-2 have not yet been finally agreed. However, on the basis of trials carried out by RILEM on aggregate combinations of known field performance from various parts of the world, it seems that results in the test (after the standard 16-days) of less than 0.10% are likely to indicate non-expansive materials, whilst results exceeding 0.20% are likely to indicate expansive materials. It is not currently possible to provide interpretative guidance for results in the intermediate range 0.10% to 0.20% and, for all practical purposes in the absence of additional local experience, aggregates yielding AAR-2 results in this range will need to be regarded as being potentially alkali-reactive.

It follows that, in the case of aggregate combinations producing AAR-2 results of 0.10% or higher (after the standard 16-day test), unless concrete prism testing or field performance indicates otherwise, precautions will probably need to be taken to minimise the risk of ASR damage to any concrete in which the material is used. These tentative criteria refer to the preferred specimen size given in AAR-2, which also provides guidance on comparison with the larger specimen size that is permitted therein as an alternative.

7. CONCRETE PRISM TESTING - AAR-3

An accelerated concrete prism test method for ASR is given in RILEM AAR-3.

Coarse and fine test aggregates are tested together in a standard mix combination and, where pessimum behaviour is suspected (or where it is unknown whether a pessimum behaviour might be expected), repeat tests can be carried out in which the coarse and fine fractions are variously replaced by a non-reactive material. In some cases, it might be considered more desirable to conduct the tests using the actual aggregate combination planned for a particular project, although, in such cases, the usual interpretation criteria could be less applicable.

The test should always be carried out using the cement and alkali contents stipulated in RILEM AAR-3, including the higher cement content permitted for certain types of aggregate combination. The interpretation criteria suggested below for RILEM AAR-3 would not be in any way applicable to concrete mixes with lower cement and/or alkali contents.

Criteria for the interpretation of the results of RILEM AAR-3 have not yet been finally agreed. However, on the basis of trials carried out by RILEM on aggregate combinations of known field performance from various parts of the world, it seems that results in the test (usually after 12 months) of less than 0.05% are likely to indicate non-expansive materials, whilst results exceeding 0.10% indicate expansive materials[1]. It is not currently possible to provide interpretative guidance for results in the intermediate range 0.05% to 0.10% and, for all practical purposes in the absence of additional local experience, aggregates yielding AAR-3 results in this range will need to be regarded as being potentially alkali-reactive.

It follows that, in the case of aggregate combinations producing AAR-3 results of 0.05% or higher (after 12 months), in the absence of local experience to the contrary, precautions should be taken to minimise the risk of ASR damage to any concrete in which the material is used[1].

8. ULTRA-ACCELERATED CONCRETE TESTING - AAR-4

An ultra-accelerated concrete prism test method for ASR has been developed as RILEM AAR-4 and is currently being assessed by an international trial. It is envisaged that the AAR-4 method might be used in three optional modes: as an ultra-accelerated version of the AAR-3 test, as a test for establishing the alkali threshold of a particular aggregate combination, or as a performance test for particular concrete mixes. At present, TC 191-ARP has only started fully to evaluate the first of these modes; an accelerated test for a combination of aggregates.

The international trial currently being undertaken by RILEM TC 191-ARP will assess the effectiveness of the method at differentiating aggregate combinations and concrete mixes unequivocally known to be variously expansive and non-expansive from field performance. All participants in the trials will also be testing similar combinations of reactive and non-reactive reference aggregates, to establish precision data for the method.

It is too early to suggest any universally applicable criteria for the interpretation of the results of RILEM AAR-4. However, the initiators of the test method have found 3-month expansion levels of 0.02% and less to be indicative of non-expansive combinations[2].

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[1] *These suggested criteria apply only to results using the preferred prism size in AAR-3. The use of larger prism sizes, which is permitted as an alternative, is thought likely to produce different values.*

[2] *When using the preferred reactor box storage procedure. No data are yet available for the alternative wrapping technique.*

9. CARBONATE AGGREGATE TESTING - AAR-5

RILEM TC 191-ARP has started to consider the possible procedures for assessing carbonate aggregates and draft methods are being prepared that will be subjected to international trials as soon as possible. Preliminary evaluation has suggested that a two-stage approach might be appropriate, with potentially reactive carbonates being first characterised by petrographical examination and/or chemical analysis and subsequently tested using a modified form of the AAR-2 ultra-accelerated (mortar-bar) expansion method. Arrangements are now being made by RILEM TC 191-ARP for an international trial of these petrographical and test procedures.

10. CONCLUSIONS

Petrographical examination (RILEM AAR-1) should be carried out in all cases. On some occasions this will lead directly to definitive outcomes, either Class I 'unlikely to be alkali-reactive', or Class III 'very likely to be alkali-reactive'. In many cases, petrographical examination will lead to an indefinite outcome, Class II 'potentially alkali-reactive', and further testing will be required.

Siliceous aggregates (and carbonate aggregates with a significant siliceous content) may be assessed for ASR, usually using first the ultra-accelerated test (RILEM AAR-2) and ultimately the accelerated concrete prism test (RILEM AAR-3). The findings of the concrete prism test should always take precedence. The AAR-2 test cannot be used for Class II aggregates containing porous flint (chert) as a potentially reactive constituent.

An ultra-accelerated concrete prism test (RILEM AAR-4) is being developed that it is hoped will eventually be suitable for acceptance testing on a project-by-project basis.

Carbonate aggregates (and siliceous aggregates with a significant carbonate content) may be assessed using the AAR-5 methods currently being prepared by RILEM TC 191-ARP.

RILEM REFERENCES

[1] RILEM Recommended Test Method AAR-1 'Detection of Potential Alkali-Reactivity of Aggregates: Petrographic Method - Final Draft', Committee Document RILEM/TC-ARP/02/09

[2] RILEM Recommended Test Method AAR-2 (formerly TC-106-2) 'Detection of Potential Alkali-Reactivity of Aggregates: A - The Ultra-accelerated Mortar-bar Test', *Mater. Struct.* **33** (229) (2000) 283-289.

[3] RILEM Recommended Test Method AAR-3 (formerly TC-106-03) 'Detection of Potential Alkali-Reactivity of Aggregates: B - Method for Aggregate Combinations using Concrete Prisms', *Mater. Struct.* **33** (229) (2000) 290-293.

[4] RILEM Recommended Test Method AAR-4 'Detection of Potential Alkali-Reactivity - Accelerated Method for Aggregate Combinations and Concrete Mix Designs using Concrete Prisms' - Committee Document RILEM/TC-ARP/01/20.

ANNEX A - Guide to reference materials

Preamble

This guide is intended to provide assistance to any laboratories undertaking the RILEM TC 191-ARP expansion tests, using either mortar-bar specimens (AAR-2) or concrete prism specimens (AAR-3 and AAR-4). It includes information on the use of reference cement or aggregate materials and various accessories required for conducting the tests.

A1. INTRODUCTION

The use of reference cement and aggregate materials is not mandatory in the AAR-2, AAR-3 and AAR-4 test methods. However, in any testing, the use of reference materials, with known and constant properties or behaviour, may be useful, or stipulated, in certain circumstances, including the following:

- to establish the reliability and accuracy of a new test procedure,
- to assess the competence of a laboratory or the testing personnel,
- to provide reassurance in the case of tests yielding variable results,
- to provide controls for direct comparison with material under evaluation.

In particular relation to the three TC 191-ARP expansion tests for alkali-aggregate reaction, reference materials may be specifically used as follows:

- **Reference High-Alkali Cement**: to minimise any variations arising from using cements of different sources, compositions and properties,
- **Reference Reactive Aggregate**: to provide reassurance to laboratories undertaking tests for the first time, to enable routine checking of testing facilities or their personnel and for use in inter-laboratory precision experiments,
- **Reference Non-Reactive Aggregate**: to enable a baseline movement to be established for testing facilities and for use in programmes for identifying any pessimum behaviour.

A2. SELECTED REFERENCE MATERIALS

A2.1 High-alkali cement

Two sources of suitable high-alkali Portland cement have been selected, one from Europe (Norcem, Norway♣) and one from the Indian sub-continent (NCB, India♣).Property data for these cements are given in Table A1.

♣ *Contact information on the supplier and product details will be sent by the publisher upon request. (The same note applies further down to the other cited suppliers, marked by ♣).*

Table A1 - Property data - Reference high-alkali cements*		
Source	**Norcem A/S, Norway**	**NCB, India**
Type	CEM I 42.5 RR	OPC Gr43
Description/Sample	Quality Declaration	Shree, Beawar
Date	04/03/2003	--/3/1997
CHEMICAL ANALYSIS	% by mass	% by mass
Loss on ignition	2.5	3.21 - 4.48
Insoluble residue	1.0	na
Silica, SiO_2	20.7†	20.43 - 21.91
Alumina, Al_2O_3	5.1†	4.83 - 5.23
Ferric oxide, Fe_2O_3	3.3†	3.74 - 4.06
Lime, CaO	63.6†	60.10 - 60.62
Magnesia, MgO	2.32 - 2.65	1.98 - 2.95
Sulfur trioxide, SO_3	3.7	1.70 - 1.92
Potash, K_2O	0.97 - 1.25	1.09 - 1.23
Soda, Na_2O	0.33 - 0.51	0.46 - 0.57
Chloride, Cl^-	≤0.08	0.018 - 0.023
Free lime	1.3	<0.5
Total alkali, Na_2Oeq (clinker alone)	1.15 (1.25)	1.18 - 1.38
Lime saturation factor	96	85 - 87
C_3S	63	38 - 48
C_2S	12	22 - 35
C_3A	8	6 - 8
C_4AF	10	11 - 12
Gypsum	~4	na
Limestone	~4	na
PHYSICAL PROPERTIES	EN 196	IS 8112 & 4032
Fineness, Blaine, m^2/kg	550	347 - 380
Sieve analysis: >90 µm, % by mass	na	4.4 - 5.9
Soundness, Le Chatelier, mm	1	1.0
Soundness, autoclave, %	na	0.11 - 0.17
Setting times, min: initial final	 100 180	 90 - 110 135 - 150
Compressive strength, MPa: 1 day 2 days 3 days 7 days 28 days	 35 43 na 49 57	 na na 25.0 - 27.5 33.5 - 35.5 42.0 - 44.0

* These data are summarised from certificates supplied to RILEM TC 191-ARP by the manufacturers.
† Clinker values na = not advised.

A2.2 Reactive aggregates - ASR

Many 'reactive' aggregates have been used in experimental research into ASR, variously using natural and synthetic materials. RILEM TC 191-ARP (formerly TC 106-AAR) decided that a natural aggregate should be selected and that the preferred material should have exhibited a sensibly uniform behaviour in various test methods. After reviewing the options, a crushed siliceous limestone from Spratt's Quarry, near Ottawa in Canada was selected.

A stockpile of material from the appropriate strata at Spratt's Quarry has been established by the Ontario Ministry of Transportation♣, who are prepared to supply modest amounts (Minimum quantity: 25kg).

Geological information, together with some analytical and test data, is given in Figs. A1 and A2 and Tables A2 and A3.

A precision trial using an accelerated mortar-bar test (Annex ref. [2]) was carried out in North America in 1995 (Annex ref. [6]). This indicated an average 14-day expansion of about 0.42%, with all compliant laboratories yielding results greater than 0.30%.

In a concrete prism test (CSA method), using cement with an alkali content of 1.25% (as Na_2Oeq) and 38°C

Table A2 - Information and data - Reference reactive Spratt's aggregate*		
CHEMICAL ANALYSIS[1]	whole rock	acid insoluble portion
	% by mass	
Acid insoluble residue	10	100
Silica, SiO_2	8.70	86.92
Alumina, Al_2O_3	0.59	4.24
Titania, TiO_2	0.04	0.21
Phosphate, P_2O_5	0.29	0.45
Ferric oxide, Fe_2O_3	0.58	1.28
Lime, CaO	48.47	0.26
Magnesia, MgO	1.67	0.78
Soda, Na_2O	0.04	0.08
Potash, K_2O	0.08	0.78
Sulfur, S	0.13	1.16
Loss @ 1050°C	39.55	4.02
Total	100.14	100.18
MINERALOGY[2]	whole rock	acid insoluble portion
	phases detected & order of concentration	
Calcite	major	---
Quartz	minor	major
Dolomite	minor	---
Pyrite	nd	minor
Illite (clay mineral)	nd	minor

* These summary data are collated from detailed information held on file by RILEM TC 191-ARP.

nd = not detected (below lower level of detection for method)

[1] X-ray fluorescence, by Hung Chen, Canada Cement Lafarge Ltd, Montreal

[2] X-ray diffraction, by Hung Chen, Canada Cement Lafarge Ltd, Montreal

Table A3 - ASR test data - Reference reactive Spratt's aggregate*	
ASTM C289 CHEMICAL METHOD[1]	R_c/S_c millimoles/litre (classification)
300-150μm (acid insoluble component)	36/307 (deleterious)
<150μm (acid insoluble component)	52/391 (deleterious)
ASTM C227 MORTAR-BAR TEST[2]	% expansion, range (various storage types)
13 weeks (3 months)	<0.05 - 0.14
26 weeks (6 months)	<0.10 - 0.28
39 weeks (9 months)	<0.10 - 0.34
ASTM C1260 ACCELERATED MORTAR-BAR[3]	% expansion, range (mean)
after immersion for 14 days	0.29 - 0.50 (0.36)
after immersion for 21 days	0.37 - 0.68 (0.49)
after immersion for 28 days	0.48 - 0.88 (0.65)
CSA CONCRETE PRISM TEST[4]	% expansion @ 1 year (0.92% Na_2Oeq)
moist room @ 23°C	0.041 (& cracking)
5% NaCl @ 23°C	0.045
steel box with wicks @ 38°C	0.101 (& cracking)
plastic bags & water, moist room @ 23°C	0.045 (& cracking)
CSA CONCRETE PRISM TEST[4]	% expansion @ 1 year (1.25% Na_2Oeq)
moist room @ 23°C	0.047
5% NaCl @ 23°C	0.070 (& cracking)
steel box with wicks @ 38°C	0.162 (& cracking)
plastic bags & water, moist room @ 23°C	0.044
CSA CONCRETE PRISM TEST[5]	% expansion @ 1/2 years (mix 1)[6]
plastic pails (control storage method)	0.170 / 0.193
plastic sleeves in pails	0.150 / 0.167
other containers used by participants	0.166 / 0.189
CSA CONCRETE PRISM TEST[5]	% expansion @ 1/2 years (mix 2)[6]
plastic sleeves in pails	0.162 / 0.176
other containers used by participants	0.176 / 0.195

* These summary data are collated from detailed information held on file by RILEM TC 191-ARP.

[1] Grattan-Bellew, P E, July 1987 (whole rock testing gives 128/32, in the innocuous field)
[2] Cement total alkali content 1.17% as Na_2Oeq, Ontario Hydro-MTC study
[3] Rogers et al 1996, inter-laboratory trial, data for standard cement after removal of outliers
[4] Spratt's coarse aggregate with Guelph non-reactive sand, 0.40 water/cement ratio, C A Rogers, 1988
[5] Fournier & Malhotra 1996, inter-laboratory study, Spratt's coarse aggregate with non-reactive sand
[6] Mix 1: CANMET control sand & cement (0.85% Na_2Oeq); Mix 2: local sand & cement (0.9± 0.1% Na_2Oeq)

storage, expansion values with Spratt's coarse aggregate and non-reactive sand) at 1 year have been reported in the range 0.08% to 0.16%. An inter-laboratory concrete prism test study (CSA method), using mixtures of Spratt's coarse aggregate and non-reactive sand, produced average expansion values in the range 0.16% to 0.18%, depending upon mix details and storage conditions (Annex ref. [5]).

A2.3 Reactive aggregates - carbonate

A stockpile of reactive carbonate aggregate material from the Pittsburg Quarry at Kingston, Ontario, Canada♣, has been established by CANMET, who are prepared to supply modest amounts.

The geological location of Pittsburg Quarry is shown in Fig. A1 and some preliminary analytical and test data are given in Table A4.

A2.4 Non-reactive siliceous aggregate

After consideration, it was not thought necessary to identify a particular non-reactive siliceous aggregate for general use as a reference material. Instead, a suitable non-reactive aggregate is defined using an unusually demanding criterion in the AAR-2 ultra-accelerated mortar-bar test. In this way, a suitable non-reactive aggregate will consistently yield expansion results in the AAR-2 test of less than 0.05%.

In the TC 191-ARP trials of the AAR-4 ultra-accelerated concrete prism test, a crushed limestone from Boulonnais in France has been identified for use as the non-reactive reference aggregate.

A.3 TEST ACCESSORIES

A3.1 Cloth for wrapping concrete prisms

The AAR-3 concrete prism method involves the wrapping of specimens in cloth and polythene. This is also an alternative storage method for specimens in the AAR-4 ultra-accelerated concrete prism test. One source of suitable cloth is Joli Triste (UK) Professional Sourcing & Marketing, United Kingdom♣.

It has been reported that the maximum width of the available towelling is less than the maximum prism length permitted in the AAR-3 and AAR-4 test methods. At present this problem can only be overcome either by using shorter prisms (but within the permitted range) or by using two strips of cloth to wrap the longer prisms.

A3.2 Storage containers for concrete prisms

The AAR-3 concrete prism test involves the storage of wrapped specimens in a suitable container, as defined in the method. This is also an alternative storage method for specimens in the AAR-4 ultra-accelerated concrete prism test. One source of suitable containers is Merck Eurolab Limited, United Kingdom♣.

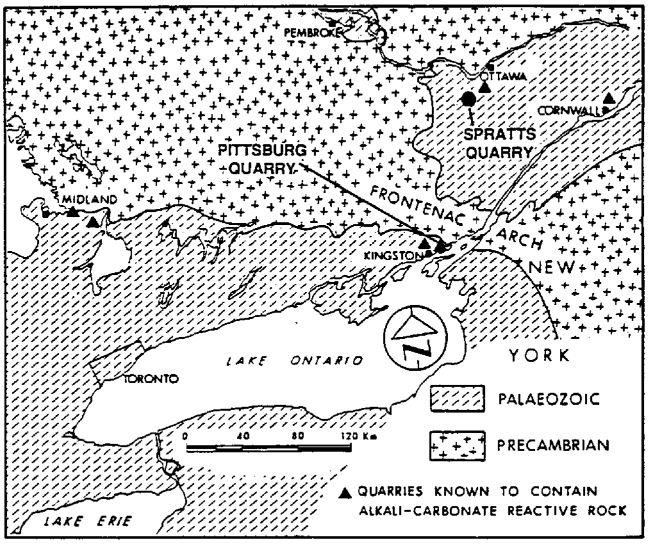

Fig. A1 - Geological Map showing location of Spratt's Quarry.

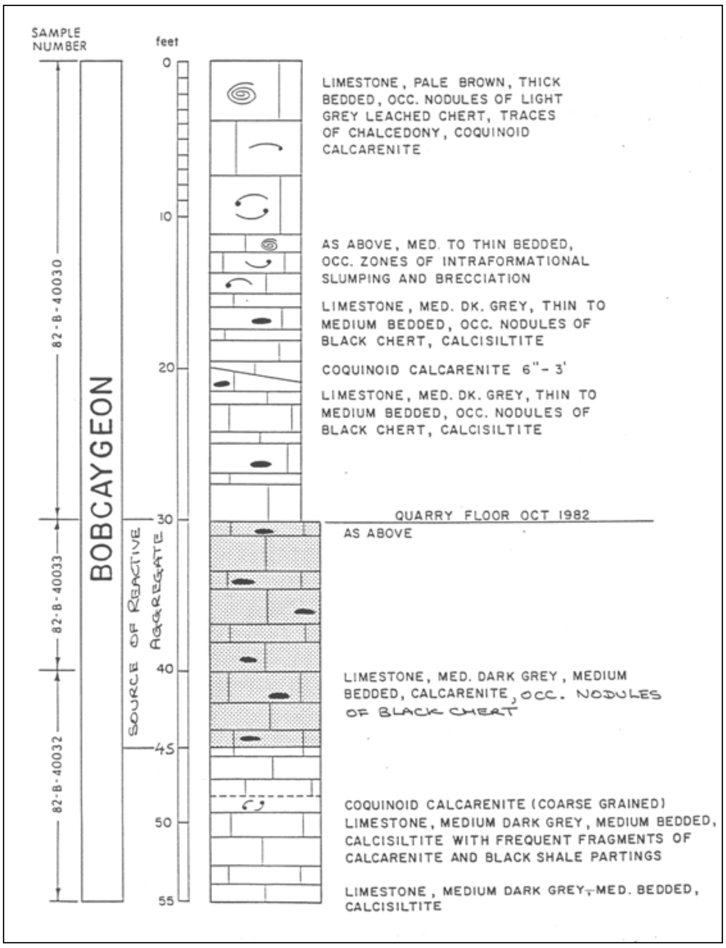

Fig. A2 - Stratigraphic column showing layers exposed in Spratt's Quarry.

A3.3 Reactor storage for concrete prisms

The preferred storage for concrete prisms in the AAR-4 test utilises the reactor system. One suitable apparatus is the 'SF2i', which is available in 9 and 12 container versions. Information on this apparatus may be obtained from Chaudronnerie Mécanique Générale, France♣, and Espo-Sud, France♣.

Table A4 - Analytical & test data - Reference reactive Pittsburg carbonate aggregate*	
ASTM C586 ROCK CYLINDER TEST	% expansion
1 day	0.04
3 days	0.08
7 days	0.28
15 days	0.81
28 days	1.72
64 days	3.50
CSA CHEMICAL ANALYSIS	% by mass
CaO	40.9
MgO	6.29
Al_2O_3	2.70
Classification by CaO/MgO Ratio v Al_2O_3	Potentially expansive
PETROGRAPHY	observations @ NRC & CANMET
texture	rhombic crystals of dolomite (20-50μm) in a matrix of micrite & clay minerals
study by XRD of effect of NaOH treatment	formation of brucite (after 14 days) & progressive reductions in dolomite & quartz
CSA CONCRETE PRISM TEST	% expansion
1 week	0.038
2 weeks	0.103
4 weeks	0.270
8 weeks	0.345

** These summary data are taken from Committee Document RILEM/TC-ARP/01/11.*

APPENDIX REFERENCES

[1] ASTM C586, 'Standard test method for potential alkali reactivity of carbonate rocks for concrete aggregates (rock cylinder method)', American Society for Testing and Materials, Philadelphia, USA (1992).

[2] ASTM C1260, 'Standard test method for potential alkali reactivity of aggregates (mortar-bar method)', American Society for Testing and Materials, Philadelphia, USA (1994).

[3] Canadian Standards Association, 'Methods of test for concrete. 14A, Potential expansivity of cement-aggregate combinations (concrete prism expansion method): CSA A23.2-94-14A', CSA, Rexdale, Ontario, Canada (1994).

[4] Canadian Standards Association, 'Methods of test for concrete. 26A, Potential expansivity of cement-aggregate combinations: CSA A23.2-26A', CSA, Rexdale, Ontario, Canada (1994).

[5] Fournier, B. and Malhotra, V.M., 'Inter-laboratory study on the CSA A23.2-14A concrete prism test for alkali-silica reactivity in concrete', in: Shayan, A (Ed.), Proceedings of the 10th International Conference on Alkali-Aggregate Reaction in Concrete, Melbourne, Australia (1996) 302-309.

[6] Rogers, C.A., Boothe, D. and Jiang, J., 'Multi-laboratory study of the accelerated mortar bar test for alkali-silica reaction', Report EM-101, Engineering Materials Office, Ontario Ministry of Transportation, Downsview, Canada (1996).