RILEM Recommended Test Method **AAR-0**
Detection of Alkali-Reactivity Potential in Aggregates for Concrete
DRAFT 8 (Version 3)

OUTLINE GUIDE TO THE USE OF RILEM METHODS IN ASSESSMENTS OF ALKALI-REACTIVITY POTENTIAL

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Draft 5 (Version 4) of AAR-0 was the basis of the draft AAR-0 published in Materials & Structures in August-September 2003. Drafts 6 & 7 of AAR-0 were updated to reflect further developments by RILEM TC 191-ARP. This Draft 8 mainly incorporates the changes agreed at the final meeting of TC 191-ARP in May 2006.

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 accelerated mortar-bar expansion test (AAR-2) and a 38°C concrete prism expansion test (AAR-3). Work has continued on a 60°C accelerated test (AAR-4.1) 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 **Figure 1**.

Additionally, TC 191-ARP has established that some aggregates can release alkalis within concrete and thus enhance the overall content of reactive alkalis, most of which are derived from the cement. A procedure has thus been developed (AAR-8) for the reliable assessment of the releasable alkali content of aggregates.

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 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.

Any results exceeding the criteria given for the expansion tests used in the assessment of AAR potential are taken possibly to be caused by ASR and/or by reactions involving carbonates. However, it is recommended by TC 191-ARP that post-test petrographical examination of specimens should be carried out to confirm that any expansion was caused by a form of AAR.

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. The AAR-8 procedure for determining any content of releasable alkalis in aggregates is not part of the assessment scheme, but is available to be carried out as part of an estimation of reactive alkali content in a particular concrete mix.

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 aggregates comprising or containing carbonate materials, especially if the carbonate includes the mineral dolomite (calcium-magnesium carbonate). Some aggregates of mixed composition might be designated Class II-SC or III-SC and should thus be subjected to the procedures described for carbonate aggregates.

The proportion of silica that can lead to the most damaging reaction will depend on the reactivity of the silica. A small amount of highly reactive silica in the aggregate will be most damaging, whereas, if the aggregate contains a high proportion of such highly reactive silica, there may be little damage. If an aggregate containing highly reactive silica is mixed with a non-reactive aggregate, the behaviour of the mix will vary from very damaging to not damaging at all, depending on the proportions of the mix. This feature is known as the 'pessimum' effect. Conversely, in aggregates containing low reactivity forms of silica or where the silica is not easily exposed to the alkaline pore solution, the worst damage may occur when the greatest amount of silica is present.

Because of this, it is important that the whole aggregate combination is assessed, as amounts of reactive silica that are innocuous in either the fine or coarse aggregate alone may be damaging in the combined aggregate. Conversely, apparently reactive fine or coarse aggregates may be safe when used in combination. Both AAR-3 and AAR-4 are suitable for assessing the combined aggregate.

In the case of the RILEM expansion tests, the AAR-3 concrete prism method has previously been regarded as the reference test, on the basis of accumulated experience of its use in various forms. However, AAR-3 requires a lengthy period, up to 12 months, for reliable results to be obtained and even AAR-4 requires up to 4 months. Consequently, the accelerated mortar-bar (AAR-2) and concrete-bar (AAR-5) tests have been developed for the optional 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 accelerated screening tests and the preliminary indications from those methods should always be confirmed by one of the concrete prism tests. Also, practical experience has suggested that the accelerated mortar-bar test (AAR-2) might be unreliable for Class II-S aggregates containing porous flint (a type of chert) as a potentially reactive constituent. Greater experience with the accelerated mortar-bar test may, in due course, enable this advice to be modified.

It is hoped that AAR-4 might eventually also be usable 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 short-term results of this test method and long-term 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.

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 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.

Petrographical Examination - AAR-1

A procedure is given in 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 accelerated mortar-bar test, AAR-2, for short-term screening purposes and the 38^{o}C concrete prism test, AAR-3, for any long-term confirmation. The 60^{o}C accelerated concrete prism test, AAR-4, may be considered as an alternative to AAR-3.

In the case of Class II-C, II-SC, III-C or III-SC materials, it is instead appropriate to carry out the AAR-5 short-term screening test procedures for aggregates comprising or containing carbonate aggregates. Again, any long-term confirmatory testing will involve either or both of the AAR-4 and AAR-3 methods.

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 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 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 or AAR-4 concrete prism tests 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.

It has been established that carbonate aggregates comprising or containing the mineral dolomite have been particularly associated with AAR damage, but the mechanisms are not fully understood. A specialist team of members within TC 191-ARP is currently investigating the assessment of carbonate aggregates and, in due course, improved guidance on the evaluation of carbonates will be included within AAR-1.

Accelerated Mortar-bar Testing - AAR-2

An accelerated screening test method for ASR, using mortar-bar specimens, is given in 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 AAR-2.

Criteria for the interpretation of the results of 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, using 'long thin' 25 x 25 x 250-300mm specimens) 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.

These tentative criteria refer to the 'long thin' specimen size presently given in AAR-2, although it is probable that the 'short fat' (or 'short thick') specimen size (40 x 40 x 160mm) will become preferred in due course, particularly as this is the recommended specimen size in AAR-5. At present, TC 191-ARP has determined that optional versions of AAR-2 will be available for the long thin (AAR-2.1) and short fat (AAR-2.1) specimens. Based on the current findings of the EU 'PARTNER' research programme, short fat specimens produce lower values than long thin specimens over the same time period; the ratio of expansion of short fat to long thin specimens is in the region of 0.75 to 0.80.

It follows that, in the case of aggregate combinations producing AAR-2 results (after the standard 16-day test) of 0.10% or higher for long thin specimens (AAR-2.1) or 0.08% or higher for short fat specimens (AAR-2.2), 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. The criterion suggested for short fat specimens will need to be reviewed in the light of the final results of the PARTNER project.

There is some evidence, for example from Argentina and Australia, that some slowly reactive aggregates are not detected using the above criteria. In Australia, a lower criterion of 0.08% is sometimes applied at the standard 16-days (using long thin specimens), or the test is extended from 16 to 23 days.

It has been suggested that assessment of the rate of expansion might be a preferable method for interpreting the AAR-2 test and tentative recommendations for this approach are given in an appendix to the AAR-2 method.

38°C Concrete Prism Testing - AAR-3

A 38°C concrete prism test method for ASR is given in 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 AAR-3, including the higher cement content permitted for certain types of aggregate combination. The interpretation criteria suggested below for 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 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]. Again, there is some evidence that a lower criterion at 12 months (perhaps 0.04% or even 0.03%) might be applicable for some slowly reactive aggregates

60°C Accelerated Concrete Testing - AAR-4

A 60°C accelerated concrete prism test method for ASR has been developed as AAR-4 and has been assessed by an international trial. It is envisaged that the AAR-4 method might be used in three optional modes: as an 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 fully evaluated the first and second of these modes, the outcome of which is given in AAR-4.1. Work is continuing to research the possible use of AAR-4 as a performance test (AAR-4.2).

Criteria for the interpretation of the results of AAR-4 have not yet been finally agreed. However, on the basis of an initial assessment of the AAR-4.1 trials carried out by TC 191-ARP on aggregate combinations of known field performance from various parts of the world, it seems that a maximum expansion in the test of 0.03% at 15 weeks indicates a non-reactive aggregate combination. It follows that, in the case of aggregate combinations producing AAR-4.1 results greater than 0.03% at 15 weeks, in the absence of local experience to the

[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.

contrary, precautions should be taken to minimise the risk of ASR damage to any concrete in which the material is used.

In the AAR-4.1 test method, the reactor box is the preferred storage method. AAR-4.1 expansion results produced using the optional wrapping method of storage are only valid in the absence of any significant moisture loss during the test.

Carbonate Aggregate Testing - AAR-5

An accelerated screening test procedure for aggregates comprising or containing carbonate material has been developed as AAR-5 and has been assessed by an international trial. In this procedure, the aggregate material is subjected to testing using both the AAR-2 mortar-bar test and a new derivative test using 'concrete-bar' specimens, in which a 4/8 mm aggregate grading is used instead of the 0/4 mm grading used in AAR-2. In this application, both the AAR-2 and AAR-5 procedures employ short fat specimens.

Interpretation of the AAR-5 findings is based upon comparing the results of the two test methods. In typical ASR, the mortar-bar (AAR-2) method may be expected to produce greater expansion than the concrete-bar method. However, investigations and trials have shown that expansion is greater in the concrete-bar test in the case of carbonate aggregates that have been associated with expansion in concrete structures, also that these materials are not necessarily identified using the AAR-2 method alone. Therefore, in the AAR-5 procedure, if the concrete-bars expand more than the mortar-bars, the reactivity of the aggregate is probably not of the normal ASR type and further investigation using the longer-term AAR-4.1 or AAR-3 concrete prism tests will be required. Interpretation of the comparison between the AAR-2 and AAR-5 results may be summarised as follows:

- AAR-2 > 0.08% :
  - AAR-5 < AAR-2 = potential ASR
  - AAR-5 ≥ AAR-2 = possible combination of ASR & carbonate reaction
- AAR-2 < 0.08% :
  - AAR-5 ≥ AAR-2 = possible carbonate reaction
  - AAR-5 < AAR-2 = no further testing

Releasable Alkalis

TC 191-ARP has started to develop a standardised test method (AAR-8) for assessing the releasable alkali content of aggregates and this procedure is now undergoing trials in various specialist laboratories. Various methods have been suggested and used previously, mostly based upon extraction by a calcium hydroxide solution, but none of these is considered adequately to replicate the possible release of alkalis within concrete. AAR-8 is based upon extraction using an alkali solution and early results suggest that the results may be regarded as meaningful. In due course, TC 191-ARP or its successor TC expects to be able to provide guidance on the interpretation of AAR-8 findings.

Conclusions

Petrographical examination (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 further assessed for ASR, usually using first the short-term (2 or 3 weeks) screening test (AAR-2), then the 60^{o}C accelerated concrete prism test (AAR-4.1), which can be interpreted after 15 weeks. If required, the longer-term (12 months) 38^{o}C concrete prism test (AAR-3) may be carried out. The findings of the concrete prism tests should always take precedence. The AAR-2 test cannot be used for Class II aggregates containing porous flint (chert) as a potentially reactive constituent and the criteria for some slowly reactive aggregate types might need to be modified.

Carbonate aggregates (and siliceous aggregates with a significant carbonate content) may be further assessed using the AAR-5 short-term (2 or 3 weeks) screening procedure, which will identify aggregate reactivity that is probably not of the normal ASR type and indicate when further investigation using the longer-term AAR-4.1 or AAR-3 concrete prism tests will be required.

In addition to assessment of an aggregate combination for reactivity potential, the aggregates may be tested for releasable alkali content using the AAR-8 method that is being developed.

RILEM References

RILEM Recommended Test Method **AAR-1**
Detection of Potential Alkali-Reactivity of Aggregates: Petrographic Method
Materials & Structures, Vol 36, No 261, 2003, 480-496
(additional annex on carbonates in preparation)

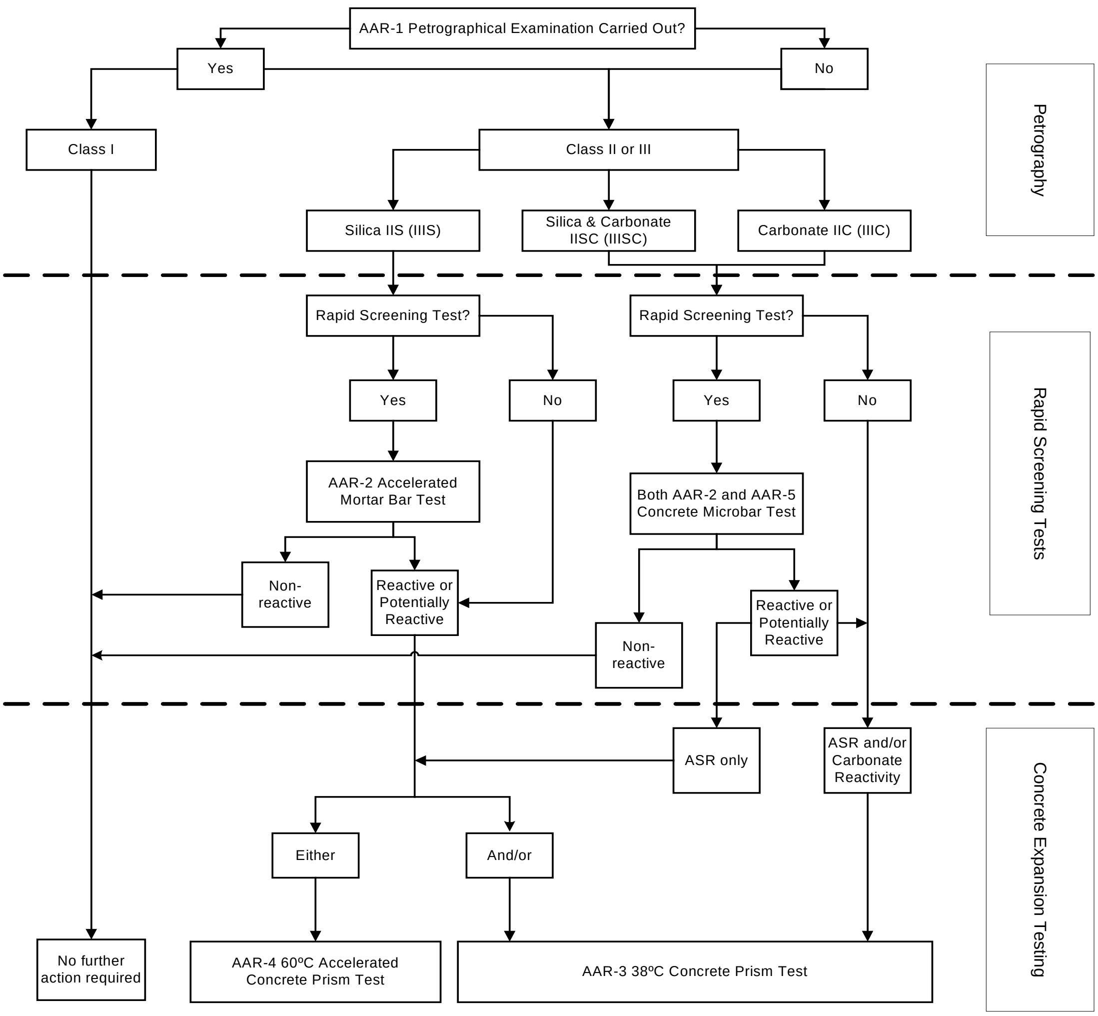
RILEM Recommended Test Method **AAR-2 (formerly TC-106-2)**
Detection of Potential Alkali-Reactivity of Aggregates: A - The Ultra-accelerated Mortar-bar Test
Materials & Structures, Vol 33, No 229, 2000, 283-289
(revised edition of AAR-2, including AAR-2.1 & AAR-2.2, in preparation for publication in Materials & Structures)

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, Materials & Structures, Vol 33, No 229, 2000, 290-293
(revised edition of AAR-3 in preparation for publication in Materials & Structures)

RILEM Recommended Test Method **AAR-4.1**
Detection of Potential Alkali-Reactivity - 60^{o}C Accelerated Method for Testing Aggregate Combinations using Concrete Prisms - Committee Document RILEM/TC-ARP/06/15 (in preparation for publication in Materials & Structures)

RILEM Recommended Test Method **AAR-5**
Rapid Preliminary Screening Test for Carbonate Aggregates
Materials & Structures, Vol 38, No 282, 2005, 787-792

RILEM Recommended Test Method **AAR-8**
Determination of Alkalis Releasable by Aggregates in Concrete
Version January 2005 - Committee Document RILEM/TC-ARP/05/03
(revised edition to be prepared by TC ACS)



* if no petrographical examination has been carried out, assume Class II (or III)

Figure 1: Integrated Assessment Scheme

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 or concrete-bar specimens (AAR-2 & AAR-5) or concrete prism specimens (AAR-3 & AAR-4.1). It includes information on the use of reference cement or aggregate materials and various accessories required for conducting the tests.

INTRODUCTION

The use of reference cement and aggregate materials is not mandatory in the AAR-2, AAR-3, AAR-4.1 and AAR-5 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.

SELECTED REFERENCE MATERIALS

High-Alkali Cement

Two sources of suitable high-alkali Portland cement have been selected, one from Europe and one from the Indian sub-continent, as follows:

- **Norcem, Norway**:
  Cite reference: RILEM reference cement
  Contact: Dr Knut Kjellsen,
  Norcem AS, R&D Department,
  3950 Brevik, Norway
  Telephone: +47 35 57 20 00
  Fax: +47 35 57 04 00
  E-mail: knut.kjellsen@norcem.no
  Minimum quantity: 40kg (& supplied in multiples of 40kg)

- **NCB, India**:
  Contact: Mr R C Wason, National Council for Cement and Building Materials,
  Calibration, Testing & Quality Control
  34 Km Stone, Delhi-Mathura Road (NH-2)
  Ballabgarh 121 004, Haryana State, India
  Telephone: +91 129 242051 to 56
  Fax: +91 129 242100

Property data for these cements are given in **Table A1**.

Reactive Aggregates - ASR

Many 'reactive' aggregates have been used in experimental research into ASR, variously using natural and synthetic materials. TC ARP (formerly TC 106) 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, as follows:

- **Ontario Ministry of Transportation**:
  Cite: 20-5mm crushed Spratt's aggregate
  Contact: Mr Chris A Rogers, Soils and Aggregates Section
  Central Building, Room 220, 1201 Wilson Avenue, Downsview, Ontario, M3M 1J8, Canada
  Telephone: +1 416 235 3734
  Fax: +1 416 235 4101
  E-mail: chris.rogers@mto.gov.on.ca
  Minimum quantity: 25kg

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

A precision trial using an accelerated mortar-bar test (ASTM C1260) was carried out in North America in 1995 (Rogers et al 1996). This indicated an average 14-day expansion of about 0.42%, with all compliant laboratories yielding results greater than 0.30%. A further study with new samples in 2007 produced a similar average 14-day expansion of 0.39% (Rogers 2007).

In a concrete prism test (CSA method), using cement with an alkali content of 1.25% (as Na_2Oeq) and 38°C 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 (Fournier & Malhotra 1996).

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, as follows:

- **Canada Centre for Mineral and Energy Technology (CANMET)**:
  Contact: Dr Benoit Fournier
  International Centre for Sustainable Development of Cement and Concrete (ICON)
  Materials Technology Laboratory, 405 Rochester Street, Ottawa, Ontario, K1A 0G1, Canada
  Tel: +1 613 992 8394
  Fax: +1 613 992 9389

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

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 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 ARP trials of the AAR-4.1 60^{o}C accelerated concrete prism test, a crushed limestone from Boulonnais in France has been identified for use as the non-reactive reference aggregate.

TEST ACCESSORIES

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 as follows:

- **Universal Towel Company Limited**:
  Cite: white towel rolls
  Contact: Ms Elaine Boyden
  Ashdown House, 1 Spa Industrial Park, Longfield Road
  Tunbridge Wells
  Kent, TN2 3EN
  United Kingdom
  Tel: +44 1892 518822
  Fax: +44 01892 518118
  E-mail: info@u-t-c.co.uk

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-4.1 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.

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 as follows:

- **Merck Eurolab Limited**:
  Cite: BDH ‘Safepak’ bottle carrier, 2500ml capacity, black plastic
  Hunter Boulevard, Magna Park,
  Lutterworth
  Leicestershire, LE17 4XN
  United Kingdom
  Tel: +44 1455 558600
  Fax: +44 1455 558586
  E-mail: uk.sales@merck-ltd.co.uk

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 the following agents:

- **Chaudronnerie Mecanique Generale**:
  27 rue de la Constellation
  Parc St Christophe, BP 8262
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Appendix References

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

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

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

Fournier, B, Malhotra, V M, 1996, 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, 302-309.

Rogers, C A, Boothe, D, Jiang, J, 1996, 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.

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Figure A1

Geological Map showing location of Spratt's Quarry

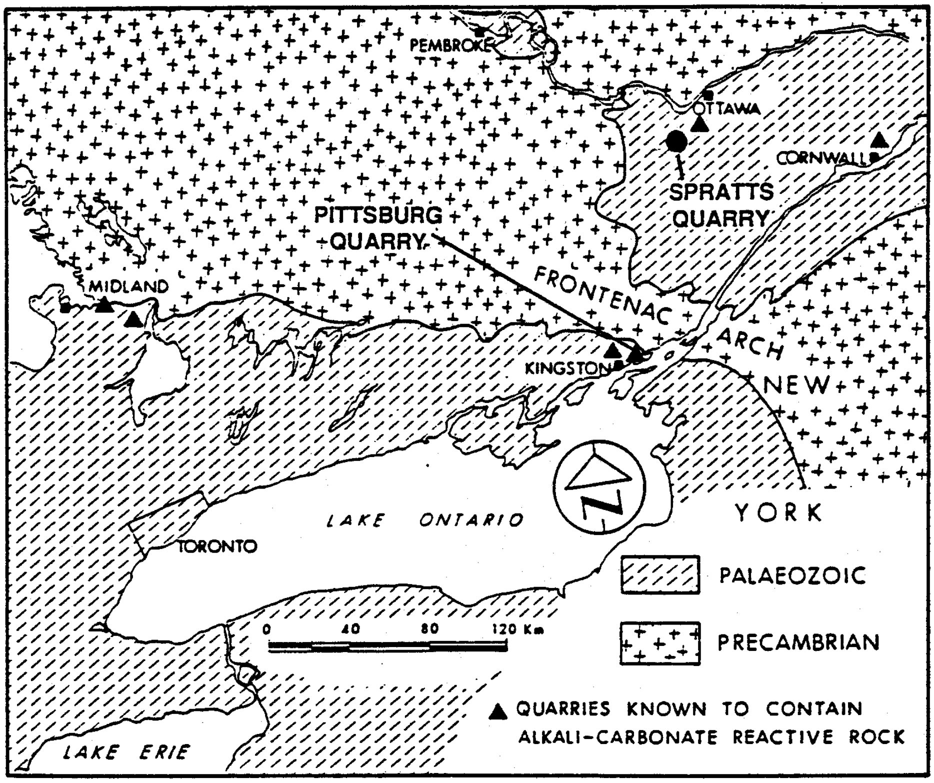

Figure A2

Stratiraphic column showing layers exposed in Spratt's Quarry

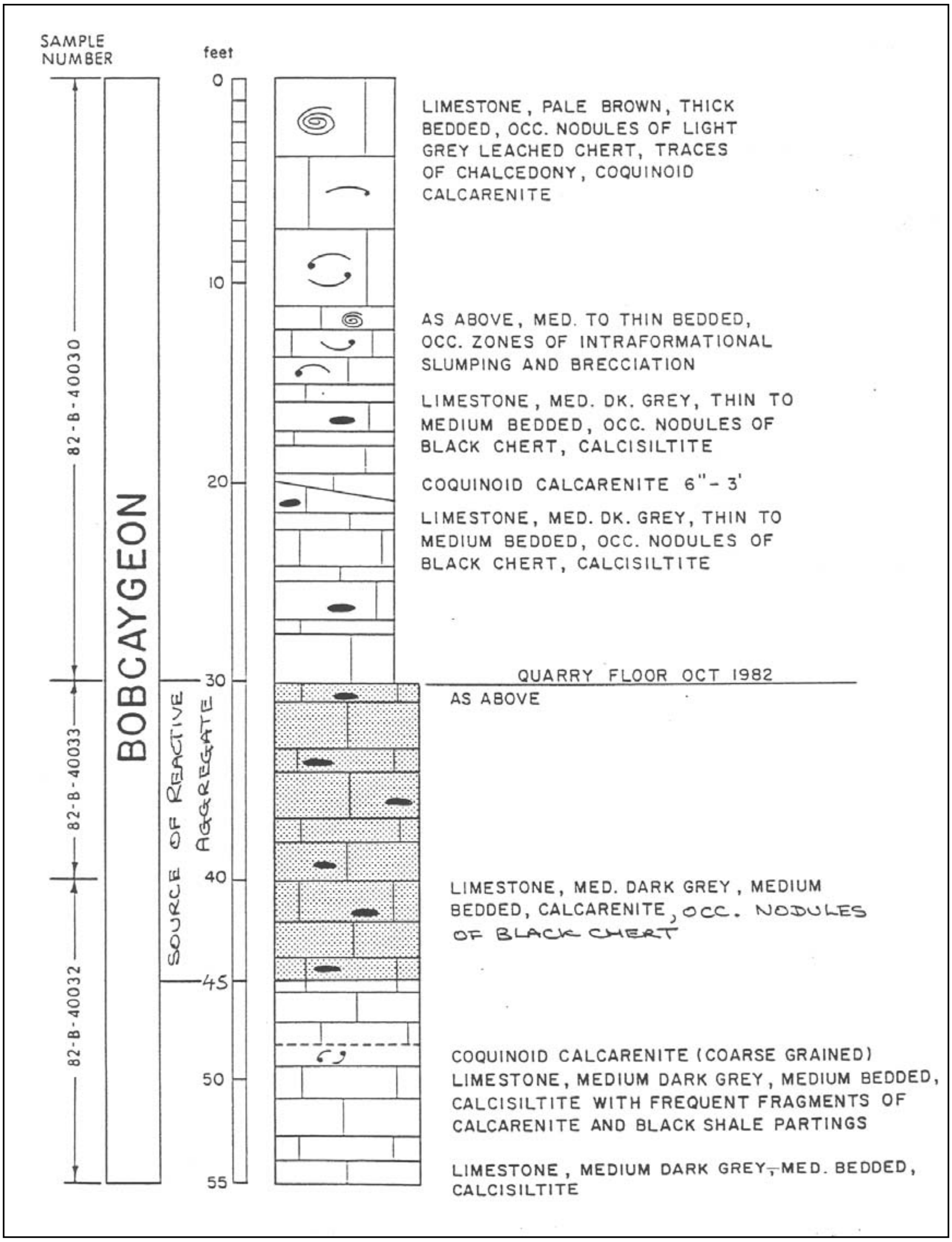

Table A1

Property Data - Reference High-Alkali Cements*

Source:	**Norcem A/S, Norway**	**NCB, India**
Type:	CEM I 42.5 R	OPC Gr43
Description/Sample:	Quality Declaration	Shree, Beawar
Date (day/month/year):	21/2/2007	--/3/1997
CHEMICAL ANALYSIS	% by mass	% by mass
Loss on ignition	2.8	3.21 - 4.48
Insoluble residue	na	na
Silica, SiO_2	19.4	20.43 - 21.91
Alumina, Al_2O_3	4.9	4.83 - 5.23
Ferric oxide, Fe_2O_3	3.5	3.74 - 4.06
Lime, CaO	62.0	60.10 - 60.62
Magnesia, MgO	2.7	1.98 - 2.95
Sulfur trioxide, SO_3	3.8	1.70 - 1.92
Potash, K_2O	1.14	1.09 - 1.23
Soda, Na_2O	0.50	0.46 - 0.57
Chloride, Cl^-	0.04	0.018 - 0.023
Phosphorous pentoxide, P_2O_5	0.15	na
Chromium, Cr^{6+}	0.00 mg/kg	na
Free lime	2.3	<0.5
Total alkali, Na_2Oeq	1.25	1.18 - 1.38†
Lime saturation factor	na	85 - 87
C_3S	na	38 - 48
C_2S	na	22 - 35
C_3A	na	6 - 8
C_4AF	na	11 - 12
Gypsum	na	na
Limestone	3 - 5	na
PHYSICAL PROPERTIES	EN 196	IS 8112 & 4032
Fineness, Blaine, m^2/kg	545	347 - 380
Sieve analysis: >90µm, % by mass	0	4.4 - 5.9
Soundness, Le Chatelier, mm	0.0	1.0
Soundness, autoclave, %	na	0.11 - 0.17
Setting times, min: initial final	 95 na	 90 - 110 135 - 150
Compressive strength, MPa: 1 day 2 days 3 days 7 days 28 days	 32 41 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. Data for presently available batches should be obtained from the manufacturer.
† Clinker values   na = not advised

Table A2

Information and Data - Reference Reactive Spratt's Aggregate*

CHEMICAL ANALYSIS[2]	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
Phoshate, 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^{o}C	39.55	4.02
Total	100.14	100.18
MINERALOGY[3]	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 ARP.
nd = not detected (below lower level of detection for method)

[2] X-ray fluorescence, by Hung Chen, Canada Cement Lafarge Ltd, Montreal
[3] 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 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)

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.