ASR performance testing concepts – RILEM AAR-10, AAR-11 and AAR-12

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Abstract

Three new performance tests as supplement or alternative to prescription (deemed-to-satisfy) based ASR mitigation regulations have been developed and are currently (almost) ready for publication as RILEM recommended test methods AAR-10, AAR-11 and AAR-12.

"Performance test" in the context of these methods is the assessment of the potential alkali-silica reactivity of a combination of concrete constituents, using accelerated concrete expansion tests developed based on ASR aggregate tests. The assessment may comprise either the use of specific reactive/potentially reactive aggregates, the design requirements of cement/binder for generic ASR mitigation measure within a region (or for a group of aggregates), as well as the assessment of a specific job mix. Such different applications set different restrictions for the candidate mix design and/or assessment criteria. Due to the sensitivity of the test results on the test specimens' internal humidity, the concrete constituents in AAR-10, and for most applications in AAR-11 and AAR-12 are to be tested at a fixed water-to-binder ratio (w/b).

AAR-10, AAR-11 and AAR-12 are considered suitable for a major range of concrete composition but cannot be validated for absolutely all types of aggregates and binders. Consequently, assessment and assessment criteria should be considered for local experience involving field observations with local materials, especially aggregates. Wide application of the concept will also depend on product declaration based on factory control and third-party verification/certification.

***Keywords**: ASR; performance testing method; concept*

1. INTRODUCTION

1.1 Significance

National regulations for preventing alkali-silica reaction (ASR) in concrete structure are based on various principles, but often limited to strict limits on properties of aggregate, cement or other constituents, so-called deemed-to-satisfy rules. These rules may be based on local experience, availability of the range of products (concrete constituents) at the time of establishing the regulations, or they may be based on "import" of such criteria from elsewhere. Various testing methods exist for assessing the properties. An updated guide to the application of RILEM recommended test methods is soon to become available [1].

Prescriptive regulations often only offer approval/non-approval criteria on single concrete constituents, leaving little flexibility in optimizing between partly conflicting objectives or interests. The RILEM TC 258-AAA [2] had as one of its objectives to develop and validate one or more performance tests, enabling the assessment of the potential of ASR on a combination of concrete constituents. Important concerns for setting up a performance test as such is thoroughly discussed by Lindgård et al. [3, 4], but the most important dimension is the need to also establish a set of acceptance criteria by correlation with in-situ field-based experience of actual performance of materials combinations.

The current performance test methods have been developed for testing of aggregate combinations together with various binder combinations, i.e. composite cements or CEM I [EN 197-1] cements plus supplementary cementitious materials (SCMs). Generally, performance testing of concrete durability properties offers an alternative to prescriptive specification-based regulations but needs to be adopted together with adequate testing acceptance criteria and within a system of conformity assessment. The latter includes the supplier(s)' responsibility of declaration of product characteristics and, within a regulatory framework preferably also a system of third-party auditing and certification.

This paper describes the background, principles, applications and general methodologies of three new accelerated concrete prism test methods developed by RILEM TC 258-AAA: AAR-10, AAR-11 and AAR-12. These tests are designed for assessing the potential reactivity of different combinations of concrete constituents to support performance based specifications for managing the risk of deleterious ASR expansion in new concrete. They include options for testing standard mix design, project mix designs and the effect of exposure to external alkali sources in service.

1.2 Principles of concrete prism testing

Methods and their use

Various versions of concrete prism tests (CPT) exist. The original RILEM version of the 38°C concrete prism method AAR-3 was developed by RILEM in the late 1990's, followed by an international trial. The trial showed that the method can reliably differentiate reactive and non-reactive combinations for a range of aggregate compositions from around Europe and further. The test, that originally applied prisms wrapped in wet cotton cloths and plastic, was published as a draft in 2000 [5]. RILEM AAR-3 was further developed and amended by RILEM (applying unwrapped prisms [6]) following comments on the draft and the experience of the European PARTNER programme [7] and the Norwegian COIN project [8].

The above test method or versions include accelerating exposure at 38°C. Along with this, other CPTs exist or have existed, e.g. both CSA and ASTM versions of the same (CSA A23.2-14A [16], ASTM C-1293 [9]), the 38°C Norwegian concrete prism test with larger prism cross section [10], as well as 60°C tests (e.g. RILEM AAR-4.1 [6]).

The traditional use of CPTs has been testing of aggregates with a fixed cement and high alkali content. This makes it difficult to assess sensitivity of alkali level and effects of changes in the combination, especially that of the binder.

Maintaining the alkali level

A critical characteristic of most of these methods is the exposure to a humid atmosphere during the long term (period of 20 weeks up to two years) storage. To different degree and depending on testing set-up details and mix design, the test specimens are also open to condensation on the lateral surfaces and leaching of alkalis throughout the storage period. If the internal alkali level drops below a certain level, a critical or so-called threshold level for the aggregate combination, the expansion development may stop and the test results will no more be valid for the assumed lab/field correlation. An evaluation of different, available ASR concrete prims tests in 2006 concludes: "*Leaching of alkalis during testing must be minimized or, preferably, eliminated. This may be achieved by changing the conditions of the test such that moisture can enter the system as required, but without there being direct contact between a large reservoir of water (or condensate) and the surface of the specimen. Using large specimens will also reduce the impact of leaching. However, storage and regular manipulation of such specimens for length change measurements would possibly become an issue*" [11].

As alkalis leached from the concrete test prisms will build up in the reservoir below the specimens, the extent of leaching may be determined during or after the period of testing as one of the measures to validate the test results. The Norwegian CPT [10], with specimen size of 100 x 100 x 450 mm^3 is an effective measure of reducing the leaching, compared to the original AAR-3 cross section 70 ± 5 mm and shorter length (250 mm ± 50 mm) [8] and not compromising health and safety issues if adequately set up (figure 3.3). Furthermore, based on assessment after 15 years of field exposure of the PARTNER cubes prepared in 2004, Borchers et al. [12] concluded that the Norwegian CPT and RILEM AAR-4.1 were the only test methods (of the eight assessed) that were capable of detecting the alkali-silica reactivity potential of the moderately reactive aggregates tested. Based on the above findings, RILEM TC-258 agreed to use the Norwegian CPT [10] as basis for developing the RILEM AAR-10 38°C concrete performance test and RILEM AAR-4.1 [6] as basis for developing the 60°C version.

Significance of temperature level and selection of test method

In the case of the RILEM expansion tests for assessing combinations of aggregates, AAR-3 is regarded as the reference test, on the basis of accumulated experience of its use in various forms. AAR-3 requires a lengthy period, up to 12 months or more, for reliable results to be obtained and even AAR-4.1 requires up to 5 months. Alternatively, AAR-10 or AAR-11 may also be used for aggregate assessment when applying CEM I [EN 197-1] / OPC only (this is particularly useful for input to performance testing, see below). Still, correlation between the relatively short-term results of test methods and long-term field performance has not been demonstrated for all aggregates, so that guidance on the use of test methods in practice must consider aggregate properties as well as exposure conditions. The selection of either AAR-3 or AAR-4.1 should reflect that the degree of aggregate reaction in the test may correlate differently to field behaviour, depending on mineralogy: Some aggregates being triggered to react at 60˚C may not react (that much) at 38˚C (i.e. neither in 38˚C testing methods nor in the field). Also, the applicability of quantitative criteria (lab/field correlation) of the concrete prism tests for assessing aggregates containing chert has not been demonstrated to the same extent as for other aggregates.

AAR-10, AAR-11, AAR-12 below may be used for performance assessment. AAR-10 is a 38˚C test, suitable for combinations of binders and aggregates, where the aggregates are adequately assessed at this temperature. AAR-11 offers the same concept, but testing at 60˚C and may be applied for mix design incorporating aggregates that may be adequately assessed at this temperature level. AAR-11 also includes a special "job mix" option. AAR-12 is also a 60˚C test, but offers a procedure taking into account external alkali supply/exposure and deicers in a direct way. Provided the in-field review for establishing limit values (lab/field relation) includes a sufficient number of structures exposed e.g. to de-icing salts (or other saline conditions), the application of a performance test together with in-situ based criteria (correlation lab/field) may provide a generic, regulatory solution: In such cases, AAR-10 and AAR-11 together with their applied acceptance limits may be considered to implicitly take external alkalis exposure into account (for the relevant concrete quality range).

Table 1.1: Key features of AAR-10, AAR-11, AAR-12 and AAR-13 [13], together with those of AAR-3 and AAR-4 (both in [6]).

Feature	AAR-10	AAR-11	AAR-12	AAR-13[1)]	AAR-3	AAR-4.1
Objective	Mix design performance test	Mix design performance test	Mix design & exposure performance test	Applicable to performance test	Aggregate test	Aggregate test
Temp./ For aggregates with proven lab/field at;	38˚C	60˚C	60˚C	38/60˚C	38˚C	60˚C
Minimum test duration	1 year	20 weeks	20 weeks	-	1 year	20 weeks
Nominal specimen size (mm)	400 x 100 x 100	250 x 75 x 75	250 x 75 x 75	-	250 (+/-) 50 x 75 (+/-5) x 75 (+/-5)	250 (+/-) 50 x 75 (+/-5) x 75 (+/-5)
w/b-ratio	0.48	0.48	0.48	-	0.50	0.50
Wrapping	none	none	none	Incl. defined alk. content	none	none
External alkalis	none	none	Storage in NaCl solution (in addition to cyclic drying and storage over water)	Only as included in wrapping	none	none
Alkali leaching assessment	optional	optional	n.a.	n.a.	-	-
Targeting all binder types	Yes	Yes	Yes	Yes	No	No
Applicable to porous flint/ chert or pessimum aggregates	No	No	No	No	-	-
Explanatory annexes included	Extensive explanatory notes and references	Extensive explanatory notes and references	Some explanatory notes and references	Calculation of alkali con-centration to include in wrapping	Some	Some

1) AAR-13 is an application for balancing internal/external alkali level to avoid alkali leaching but constitutes no complete testing procedure and, hence, must be combined with one of the concrete prism tests to provide a complete testing concept.

Aggregates exhibiting pessimum effects (see AAR-10) lead to special concerns and should not be subjected to testing in accordance with the below test methods without certain measures or procedures. Such procedures are not incorporated in the test methods.

AAR-10 and AAR-12 may be combined with a type of wrapping minimizing alkali leaching if necessary. This measure is described in a separate paper [13], and the procedure is not included in the present one.

2. SCOPE

The test methods AAR-10, AAR-11 and AAR-12 cover the measurement of expansion produced by alkali-silica reaction of concrete prisms stored in an environment which accelerates the alkali-silica reaction (ASR). The test methods shall enable 1) the determination of necessary binder mix design for a given (worst case;) aggregate scenario or 2) the measures for minimum binder composition requirements together with a given aggregate product (supplier), see Figure 2.1.

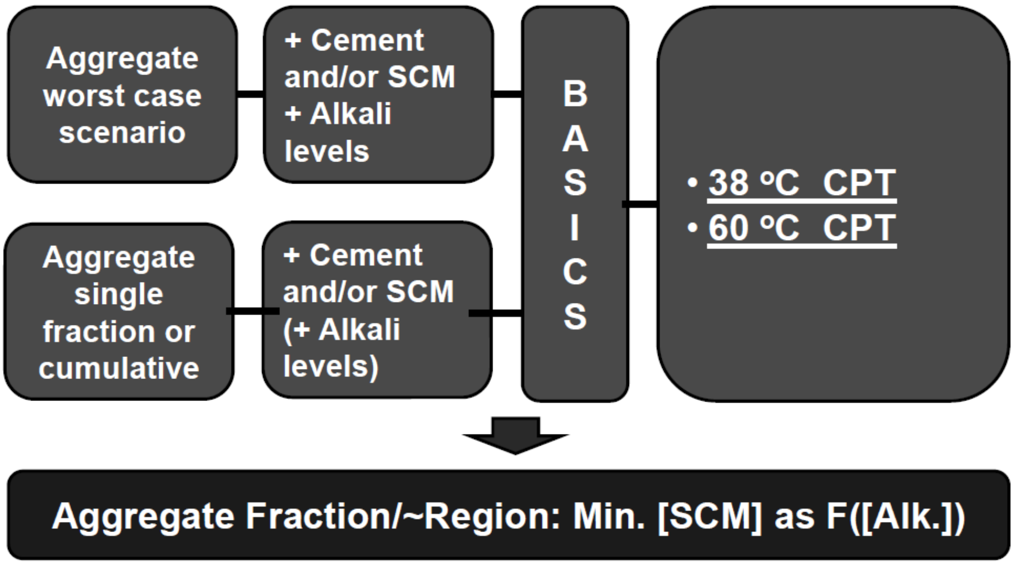

Figure 2.1: Outline of adopted performance testing objectives, applying basic (common testing principles / boundary conditions), and which would typically be to determine the minimum SCM content as a function of clinker alkali content.

As mentioned above, AAR-11 also incorporates an application for direct “job mix” assessment. AAR-12 provides a procedure with addition of external alkalis during the period of testing, especially for cases where lab/field relation investigations cannot sufficiently consider this concern - or if included for other reasons.

The tests shall typically provide outcome on 1) maximum alkali content for an aggregate combination, 2) maximum alkali content for the aggregate when combined with a certain binder combination or 3) minimum binder recommendations for a given aggregate scenario. Schematic examples of how test results may be displayed are given in Figure 2.2.

The procedures shall meet the needs of single manufacturers of aggregates, cement or SCMs, consultants, contractors, building owners or regulators.

The testing concept shall fit into the wider framework of recommended RILEM procedures as described in AAR-0 [1].

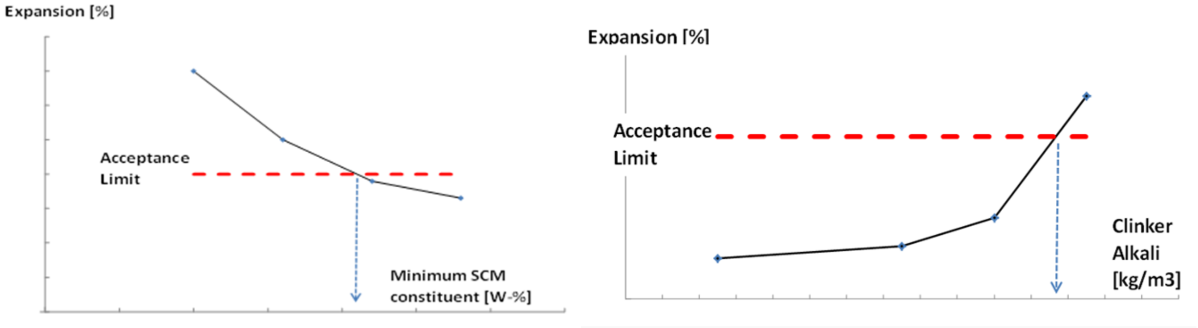

Figure 2.2: Schematic description of the determination of minimum content of SCM (left) or maximum clinker alkali content (right) for a given aggregate or give aggregate plus specific binder combination.

3. TEST METHODS AAR-10, AAR-11 AND AAR-12

3.1 Principles

Concrete prisms are prepared with the selected aggregates and binder combination(s) (detailed mix design rules apply). Sodium hydroxide is added to the mix when necessary to enhance the alkali level (alkali boosting – see [14] for support of this approach). The prisms are then stored under humid conditions at:

- 38°C for 1 – 2 years for AAR-10
- 60°C for 5 – 12 months for AAR-11 and AAR-12 (the latter includes additional, cyclic alkali exposure)

Longitudinal expansion (and weight) measurements are made at periodic intervals to determine whether any expansion (or weight loss) has occurred.

The alkali level for which the aggregate is tested is the sum of the alkalis from the cement clinker contribution and that from any chemical admixtures and other alkali-releasable sources. For cement clinker a usual convention is to substitute “releasable” with “total” alkali content. With SCMs there is the calculatory dilemma that alkalis e.g. from low-calcium fly ash and silica fume are not not assumed to contribute to ASR (they often have a higher alkali level than the cement clinker) as their mitigating effect would else not exist. Nevertheless, it is nescessary to consider their alkali content as well (“on the third axis”), since a specific SCM may not be as effective in mitigating ASR if its alkali content increases (and other phases reduced).

Several alkali boosting levels may be tested to investigate the effect of later modification of the concrete composition or changes in the alkali contribution from its constituents. If needed for the testing objectives, additional levels of SCM(s) content are added to the investigation. Hence, the main variable (scope of testing) may be the level of alkali or level of such SCM in the range of mix designs. The test output will be a maximum alkali level or a minimum SCM content, separately or in combination, to use with this aggregate combination (see Figure 2.2). For the selected aggregate combination, the investigation will typically include three to five levels of SCM or alkali content (or more if both parameters are combined).

Except for AAR-11.3 (“job mix”), all AAR-10 and AAR-11 applications specify a constant water-to-binder ratio (w/b) of 0.48. This is intended to maximize the concrete prism expansion during the test, irrespective of the w/b used in field. Higher w/b may increase the alkali leaching potential during testing. Lower w/b may lower the internal humitity. Both of these effects may negatively affect the bias of established lab/field correlations in a way that is difficult to assess.

The individual test methods are summarized in sections 3.2 – 3.4. Figs 3.1 (AAR-10), 3.2 (AAR-11) and 3.3 (both) show examples of suitable storage containers and facilities. Especially at 60°C but also at 38°C container storage in a reactor (with moisture both inside and outside the container) will reduce (but not eliminate) moisture transport in/out of the containers.

Figure 3.1: Typical containers for RILEM AAR-10 that have proven to be adquate for storage; three specimens per container; the containers are stored in a 38°C dry room.

Figure 3.2: Typical containers for RILEM AAR-11 that have proven to be suitable for storage; three specimens per small container; the small containers are stored at 60°C inside a humid reactor.

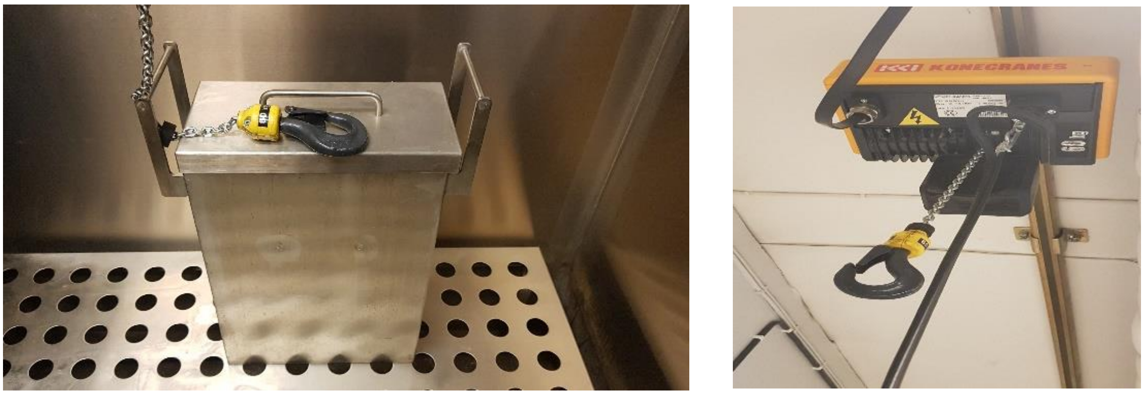

Figure 3.3: Example of suitable health and safety measures for easy handling of the containers.

Additional information

It will be outside of the scope of the present paper to discuss in detail the background of choices made in definition of the test conditions and opportunities of implementation. Normally, the description of test methods are limited to description of the procedure and refrain from explaining the logic. However, the main part and annexes of AAR-10 and AAR-11 contain discussion, guidance and reference to:

- Advice on laboratory and test set-up and interpretation of test results

- Options including opportunities and risks for length change measuring procedure (with/without pre-cooling, horizontal vs. vertical length change measurements) and reasoning
- Examples of how the applied principles have been used elsewhere
- Issues related to deviations from the test methods
- Management and accounting/assessment of alkali leaching during the test: It is essential to maintain the level of alkali within the specimens as constant as possible and in particular above the alkali threshold level of the test aggregate.
- Management of moisture loss during testing
- Maintenance of uniform conditions within (and between) sample containers

3.2 RILEM AAR-10

"*RILEM AAR-10 Determination of binder combinations for non-reactive mix design using concrete prisms – 38°C method*" includes two applications, denoted AAR-10.1 and AAR-10.2, respectively:

- Application 1: Assessment of how SCM content may reduce ASR susceptibility of an aggregate combination: Enabling the use of a specific reactive aggregate product together with critical binder combination(s) (minimum binder requirements) for producing non-reactive concrete.
- Application 2: Assessment of how available binder alkali content can be reduced by SCMs: Enabling the determination of the required general binder composition together with a regional worst-case aggregate combination for producing non-reactive concrete (within that region).

The two applications differ somewhat in mix design requirements, especially those of the aggregate combination.

The special features of AAR-10 include a fixed w/b of 0.48 as described above and specimen dimensions of 100±2 x 100±2 x 400-450 mm^3. The fixed w/b ratio is due to the sensitivity of the w/b ratio on internal moisture level (ASR reaction and shrinkage potential) on one hand and alkali leaching from the specimens on the other. Hence, it is advised to test mix combinations at a “normalized” w/b ratio in order to minimize artefacts in the lab/field relation (established – or to establish). There is no evidence that lowering the w/b ratio will reduce the long term expansion under field conditions, however it will so in the lab test (at a fixed test duration).

Guidance is also given on selection of test material and reference aggregates and binder (cement/SCM) – or mix design concept. Local (national) conditions may motivate deviation from this guidance, but it is essential to establish the field/lab relation, given a few, fixed parameters, like the w/b.

Expansion measurements are preferably performed without pre-cooling (reference method) in order to minimize loss of alkalis and moisture during the pre-cooling overnight (alternative method). The non-pre-cooling procedure assumes a trained and confident operator, otherwise lower consistency between operators may impair repeatability.

3.3 RILEM AAR-11

"RILEM AAR-11 Determination of binder combinations for non-reactive mix design or the resistance to alkali-silica reaction of concrete mixes using concrete prisms – 60°C test method" includes three applications, denoted AAR-11.1, AAR-11.2 and AAR-11.3, respectively:

- Application 1: Assessment of how SCM content may reduce ASR susceptibility of an aggregate combination: Enabling the use of a specific reactive aggregate product together with critical binder combination(s) (minimum binder requirements) for producing non-reactive concrete.
- Application 2: Assessment of how available binder alkali content can be reduced by SCMs: Enabling the determination of the required general binder composition together with a regional worst-case aggregate combination for producing non-reactive concrete (within that region).
- Application 3: Assessment of the ASR-resistance of specific concrete composition to verify its suitability in a performance test.

Again, AAR-11.1 and AAR-11.2 differ somewhat regarding aggregate mix design requirements, but both operates with the fixed w/b of 0.48 and for the same reasons as above, even if this test is slightly less sensitive to changes in w/b.

AAR-11.3 is a free mix design procedure, but a warning is given regarding testing of concrete with low w/b due to e.g. issues with self-desiccation and moisture transport.

Special features of AAR-11 include specimen dimensions of 75±5 x 75±5 x 250±50 mm^3.

3.4 RILEM AAR-12

"RILEM AAR-12 Determination of binder combinations for non-reactive mix design or the resistance to alkali-silica reaction of concrete mixes using concrete prisms - 60°C test method with alkali supply" is based on AAR-11 but allows assessment of direct impact from alkali-based de-icers, without such exposure necessarily being included in the preceding lab/field correlation survey. The storage conditions of AAR-11 have been modified to accommodate for cyclic storage in NaCl, based on existing procedure issued by the German Road and Transportation Research Association. As AAR-11, AAR-12 likewise includes three applications, denoted AAR-12.1, AAR-12.2 and AAR-12.3, respectively:

- Application 1: Assessment of how SCM content may reduce ASR susceptibility of an aggregate combination: Enabling the use of a specific reactive aggregate product together with critical binder combination(s) (minimum binder requirements) for producing non-reactive concrete.
- Application 2: Assessment of how available binder alkali content can be reduced by SCMs: Enabling the determination of the required general binder composition together with a regional worst-case aggregate combination for producing non-reactive concrete (within that region).
- Application 3: Assessment of the ASR-resistance of specific concrete composition to verify its suitability in a performance test.

The main difference to AAR-10 and AAR-11 – and the main feature of AAR-12 - is the alternate storage cycle, between drying at 60°C, fully immersed in NaCl solution at 20 °C and 60°C humid storage in the ASR reactor. Additionally, 28-days of pre-exposure (including wetting and drying) is included. It is based on a method issued by the German Road and Transportation Research Association (FGSV) for evaluating the potential for deleterious ASR in concrete proposed for use in pavements and roading structures [15].

4. SUMMARY

RILEM TC 258 has developed test methods AAR-10, AAR-11 and AAR-12 to evaluate the ASR performance of specific binder/aggregate combinations (AAR-10 & 11) and to assess the effect of exposure to external alkali sources such as de-icing salts, sea water and sea spray (AAR-12). These three test methods complete the value chain provided by the recommended test methods as described in AAR-0 [1]. Their role and value are demonstrated in a flow chart of AAR-0 [1].

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