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ASR Assessment – Concrete Prism Testing Within a Regulatory Framework

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Abstract

The experience of ASR and ASR testing varies substantially across Europe and outside. Several testing procedures exist but are not always linked to service life records. Also, the European concrete standard on this issue refers to regulations valid in place of use. An attempt to provide a complete set of design and assessment tools is explained in this paper, whereby concrete performance testing is one key element but must be regarded exactly as that, i.e. one step only within a framework of additional requirements and still linked to regional experience. The performance testing concept development is briefly explained in order to display opportunities and limitations.

Performance in the sense of combining constituents for concrete prims expansion testing has been adopted in some countries, e.g. in Norway and, hence, providing a tool set for flexible concrete design regulations. Implicitly, several investigations on fly ash quality scatter and processing have been performed. Evidence of the fly ash mitigation effect is provided, but also strong indications supporting performance enhancement when supplied as a composite cement, compared to that of a concrete mixer blend.

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Keywords: alkali-silica reaction; concrete expansion testing; fly ash cement.

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1. Introduction

Several testing methods targeting alkali-silica reaction (ASR) properties of concrete aggregates exist across Europe – and outside. Attempts to standardise testing methods and concrete design specifications on CEN level have failed, partly due to the large variety in regional aggregate characteristics, type and level of local experience and expertise. Although ASR has been reported during several decades, many countries recognise the phenomenon only “slowly”. The reason may be lack of resources, focus or confusion with other detrimental mechanisms, “demagogy” of the building structures (a substantial portion of the structures was erected after the Second World War), combined with change in construction technique and slowly developing damages. In Norway, ASR was recognised as late as in the early 1990’ies [1] and in Finland only recently [2].

Regulations of ASR susceptible aggregates may be very simple in their form, e.g. excluding their application, while most countries need to ensure suitability of at least moderately reactive aggregate sources. A very comprehensive and differentiated system of specification, based on extensive research, was recently adopted by the American Association of State Highways Transportation Officials (AASTHO), see [3]. Less complicated, but combining specifications approach and performance testing and believed to serve Nordic needs may be found in the Norwegian guidelines [4], [5-6].

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Interpretation of between-testing methods (lack of;) correlation [7] should be done with care and follow reference with the single test method to that of in-field service life records.

The EU co-funded "PARTNER" project addressed the development of European standard tests to prevent alkali reactions in aggregates [8], testing 22 different types of aggregate combinations across Europe with documented field performance and involving 24 partners from 14 countries. The testing procedures included those of petrography, accelerated mortar bar testing and concrete prism testing (different versions), all based on previously published RILEM (*International union of laboratories and experts in construction materials, systems and structures)* procedures or such procedures subject to drafting. The test results as well as other on-going studies also provided valuable input to the review of these testing methods, and up-dated testing procedures are expected to be published during 2013.

In the majority of the cases, the investigated testing methods were able to correctly identify the susceptible aggregates, and the RILEM committee, to which the project had a strong link, decided to proceed with further development, including the development of a scheme for concrete performance testing. The present authors have all central position in this work, and the current publication will explain the necessary framework of performance testing as well as provide experience from such testing for national fly ash application and approval testing.

2. Performance testing framework

The application of performance testing must base on certain terms for the correct boundary conditions to be ensured. An outline from the draft AAR-0 outline guide [9] is provided as a flow chart in Fig 1. Detection by petrography of special characteristics prior to further testing may be essential for how to organise this, e.g. recognition of "pessimum" behaviour (the fact that some minerals cause higher degree of damages at low concentrations than at higher ones). Research and outline of the latter is provided by [10]. The current scope of the RILEM "performance testing development" is to pursue the following steps for a performance test based on concrete prism expansion, some of which already exist and some are in progress:

- Standard concrete test for aggregates combinations (fixed alkali level). This already exists [11]
- Concrete test for the detection of alkali threshold level, i.e. which alkali level is critical to a specific aggregate. Draft exists, intended for publication during 2013.
- Concrete test for aggregate combinations incorporating fractions with pessimum effect (see above).
- Concrete test for developing cement/binder combination, with which a specific but ASR susceptible aggregate combination *and grading* will not cause damages.
- Concrete test for developing a (regional?) cement/binder combination to mitigate damages when combined with different aggregates, e.g. a regional "worst case reference aggregate".
- Concrete test for the combination of constituents intended for a specific job mix (but at a fixed, expectedly worst case w/b ratio).

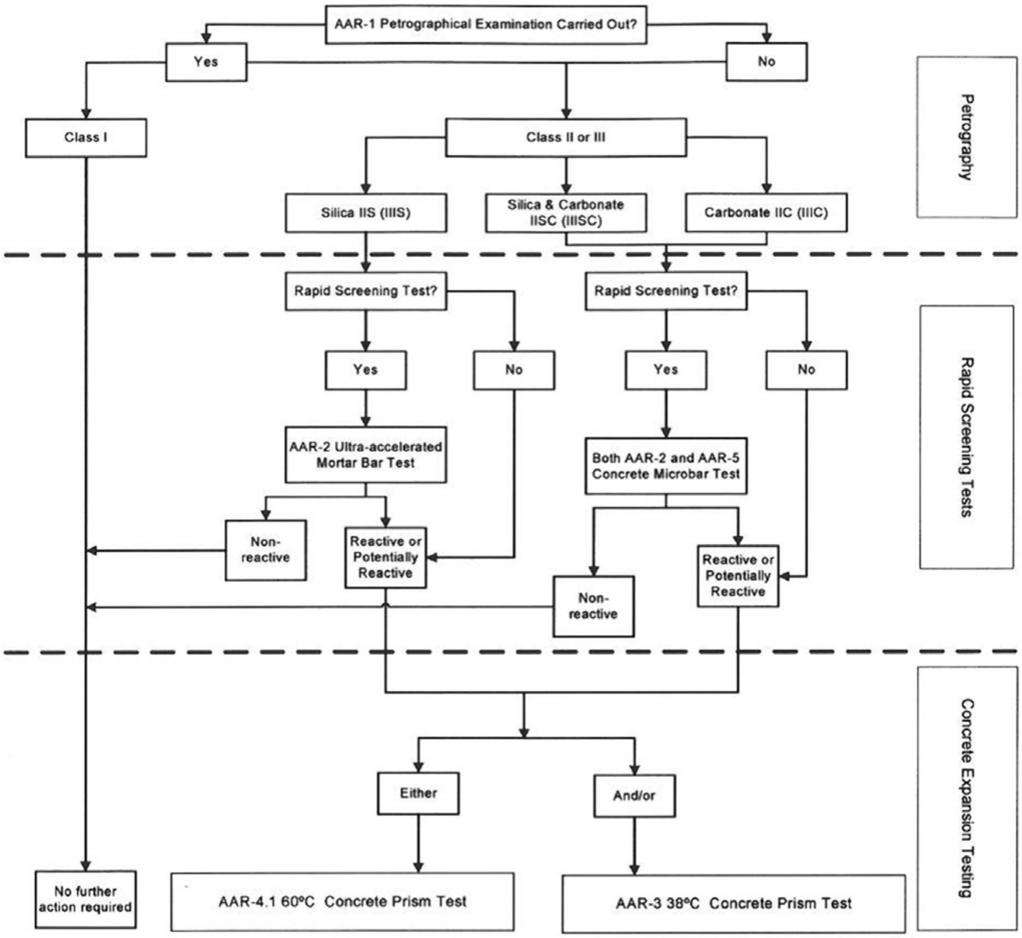
The organising of these objectives into separate or sub- procedures is not final, but their different objectives are emphasized in order to distinguish certain differences in precaution, e.g. how to deal with constituent parameter changes and relating these to design of acceptance criteria.

Hence, the reason for listing these elements is to display the step-by-step approach necessary in order to avoid miss-interpretation. Countries/regions with sufficient reference and without pessimum aggregates should be able to proceed to the latter step.

The extension of performance testing from that of testing aggregates alone to that of including cement and additions as variables leads to a number of concerns, discussed by [12], a summary of which is provided in [13]. Some of these concerns have been subject to further research [14]. More comprehensive results will be available in the PhD dissertation [13]. Bottom line is, however, that concrete performance testing based on development of (RILEM 2000 II [9]) is highly feasible, but that some parameters and procedures may have to be modified. Performance testing has been adopted in Canada (see below), and the AAR 4-1 (RILEM 2013 [15]) forms the basis for French performance testing.

3. Norwegian guide lines including performance testing : Development and general testing set-up

Norwegian guidelines are referred to by the national annex of NS-EN 206-1, i.e. the concrete standard, but are issued by the Norwegian Concrete Association (current editions NCA 2005/2008 [5-6]) and, hence, much less laborious to up-date concurrently with the development of experience. The Norwegian guidelines were developed, taking Canadian experience and standard (CSA A23.2-14A-00 [16]) with "similar" types of aggregates and lab/field experience on application of fly ash into account. Numerous publications support the use of fly ash as an ASR mitigating measure, and a large Norwegian national survey provided data for designing acceptance criteria of various aggregate fractions. Allowed binder combinations and alkali content limits (kg/m^3) are listed in an annex, frequently subject to up-grading. The testing procedure has been used to demonstrate the adequacy of nationally accepted tool for avoiding damages, i.e. mainly the use of fly ash or slag containing cement, marketed by national or foreign suppliers. The current publication reports some of the work performed on the fly ash approach, see below.



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

Fig.1. Integrated ASR assessment scheme in accordance with good practice [14]. Note [21] as first step basic requirement.

4. Effect of fly ash content

The fly ash applied in this study - and below – all comply with EN 450 [19] (e.g. maximum reactive CaO content of 10%).

Fig. 2 exhibits the clear and expected ranking of degree of expansion when gradually increasing the fly ash / CEM I replacement ratio from 0 to 35% for a period of 11 years storage at 38 °C. Initial cement content was approximately 410 kg/m^3 and with 5.0 kg alkalis/m^3 contribution from the cement clinker. The fly ash contained 2.2% alkalis, and, hence, the total alkali content of the mix with 35% fly ash is 6.4 kg/m^3. The aggregate combination is a national "worst case reference".

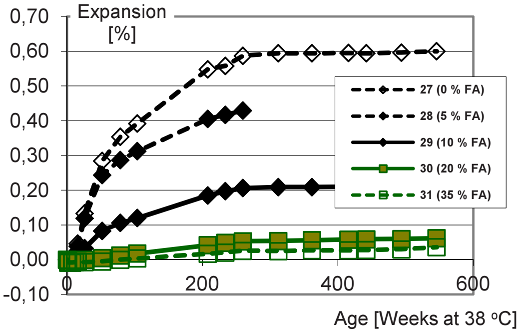


Fig. 2. Concrete prism expansion with increasing fly ash replacement, total alkali content increasing from 5 kg/m^3 (without fly ash) to 6.4 kg/m^3. (The figures 27-31 refer to mix nos.)

5. Effect of fly ash quality variations

The Norwegian "fly ash solution" approach includes requirements of approval testing of new fly ash suppliers. The procedure is to test at a few different total alkali levels and to approve the new constituent for the level deduced from the intersection between expansion interpolation (= conservative) and the limit value, minus a safety margin. The total alkali level includes alkalis from cement clinker, fly ash and alkali boosting. The former and the latter are considered to be 100 % effective, while the fly ash part is not, and for future revision of the procedure the distinguishing between alkali sources should be considered. Nevertheless, with one cement manufacturer only (two plants), the overall quality variations are limited, and the indirect effects of not distinguishing between the alkali sources in this case of limited practical significance. In a larger picture, the story will of course be different.

The request for fly ash approval testing has provided for a substantial accumulated experience base concerning the influence of fly ash quality variations. Fig. 3 compiles a representative selection of approximately 15 years of experience of approval testing (maximum and minimum expansion level all included, duration of testing 1–2 years). For simplicity, only results of 7–7.4 kg/m^3 total alkalis are displayed, implying that the clinker alkali contribution is in the range of 4.5–5 kg/m^3 and alkali boosting level 1–2 kg/m^3. Contrary to the test series above, the testing is made on full scale CEM II/A-V cement, i.e. co-ground clinker, fly ash (and gypsum) in the cement mill. The fly ash content is – in line with the product declaration and ~ certification – between 17 and 20%. Cement content and aggregate combination are in accordance with regulations referred to above. The fly ash sources include such as from the Nordic countries, Middle Europe and the Mediterranean.

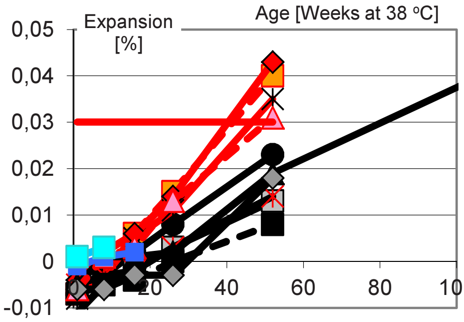


Fig. 3. Expansion of CEM II/A-V (17–20% fly ash) containing various fly ash deliveries, tested at total alkali level of 7.0–7.4 kg/m^3. Horizontal line indicates 1 year acceptance level

Based on supplementing test series, all deliveries were approved for total alkali levels of 6.5 kg/m^3 or above. Implications include:

- The ASR mitigation effect of fly ash depends on their origin, but there is no quite clear correlation between quality parameters related to composition (beyond those of the EN 450 [19] requirements) or fly ash production/ combustion and expansion.
- All fly ashes passed below the 6.5 kg/m^3 limit and hence, proved efficient to various degree of supressing damages.

- No case exhibited negative influence of the fly ash alkali content.

Special attention has been paid to the concern of the properties of co-combustion fly ashes in concrete in general, for which reason there are restrictions on the fuel and ash composition. The topic will be subject to further investigations in future, but Fig. 4 exhibits a single comparison of fly ash produced with and without co-combustion (biofuel added to the coal) from a single supplier. Fig. 4 displays almost identical results, taking the test precision into account.

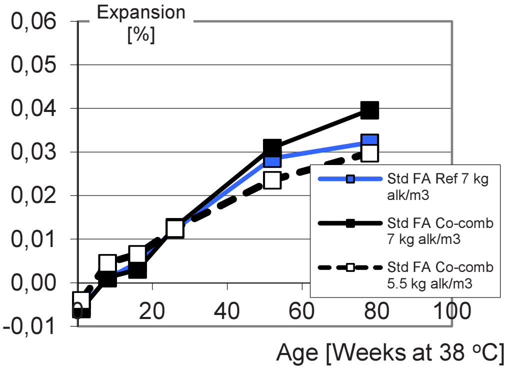


Fig. 4. Single test of pure coal fired and co-combusted fly ash from the same supplier. The solid line data display co-combustion (triangles) and pure coal (squares) fired fly ash, tested at 7.0 kg/m^3 total alkali level.

6. Composite cement versus cement + additions, Cement production process

The Norwegian fly ash cement is produced by co-grinding of cement clinker, fly ash and gypsum in the same mill. This is in contrast to a) mixing at the concrete plant and b) pre-milling of either component, e.g. as usually done with slag cement. The reasons for this specific manufacturing policy are several but includes such as certification and quality control (supplier and "applier"), controlled fineness / gypsum content and composite properties. It is expected that a certain grinding of the fly ash is favourable to performance in many aspects but also for ASR mitigation and has been reported [20].

Fig 5 displays a direct comparison between full scale production and blend of similar cement (identical clinker, same strength level, same market/application segment) and identical fly ash produced in direct sequence at the same cement mill (These are concurrent test conditions that are rarely applied in scientific studies !). The effect is substantial and is attributed to the different fineness of the fly ash. It is however expected that the non-optimal effect in the concrete blend may vary from delivery to delivery.

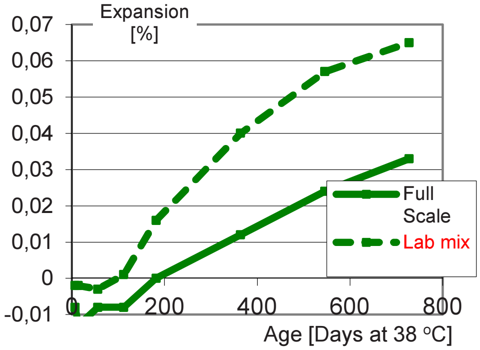


Fig. 5: Expansion with 20 % fly ash, added "as received" to concrete mixer (dotted line) or to the cement mill (solid line) for production of CEM II/A-V. Alkali content is 5 kg/m^3.

Correspondingly, the production sequence at the cement mill has been subjected to investigations: The fly ash may be added to the mill inlet, i.e. together with the clinker, or to the separator at the mill outlet. In the latter case, only the very fine material will pass directly onto the cement silo, while the coarser part will follow the too coarse clinker particles in the return feed to the mill inlet (cement milling is a sequential "loop"). Fig 6 displays studies at two cement plants, demonstrating identical expansion behaviour. All samples were extracted from the silos and the mill in an integrated operation.

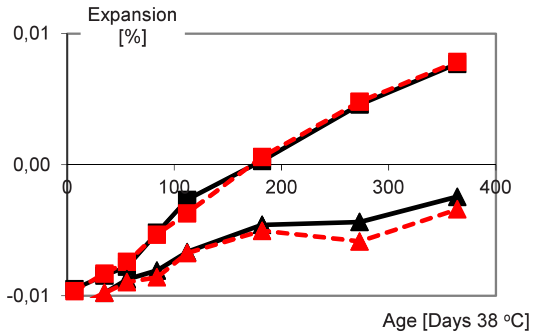


Fig. 6. Effect of fly ash added to the mill inlet (solid line) and to the separator with return feed (dotted line) on concrete expansion. Alkali levels 5.5 (lower level) and 7.0 kg (higher level)

7. Conclusions

The investigations and studies in progress lead to the following conclusions:

- Concrete performance testing will be a valuable tool within a regulatory framework that must include other measures, depending on aggregate mineralogy and e.g. such as petrography.
- Performance testing must be regionally linked to / aligned with field experience, for the sake of correct classification of aggregates and for determining testing acceptance limits.
- The development of performance testing procedures is in progress but will expectedly be limited to “combinations of constituents concept” and e.g. exclude investigation of the effect of varying w/c-ratio.
- Some countries already have adopted performance testing for determination of combined aggregate and cement/binder performance.
- In Norway, performance testing is a formalized approach for approval testing of fly ash cement and other binders. This has been applied to investigate several aspects linked to the application of fly ash together with nationally available aggregates, displaying that :
- There is a significant ASR mitigation effect of fly ash, far beyond that of “neutral dilution effect” of the cement clinker. Likewise and nationally, CEM II/A-V with 20 % fly ash has been found to adequately combine with reactive aggregates to prevent ASR damages up to a practical, total alkali level of 6.5 kg/m^3 (including alkalis from the fly ash) , irrespective of the fly ash (EN 450 [19]) suppliers from across Europe.
- Adding fly ash to the cement mill enables co-processing in a way that appears to enhance the mitigating effect, improving quality assurance and overall performance.
- The procedure of adding fly ash to the cement mill, i.e. the mill inlet or to the separator, seems to be of very limited significance.

Acknowledgements

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