Methods Of Testing Alkali-Silica Reactivity In The Netherlands

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Summary: **In the current Dutch standard NEN 5905 and CUR Recommendation 38, four methods are listed for assessing the alkali-silica reactivity of concrete aggregates. However, procedures outlining how the tests should be performed, and the possible errors associated with such tests, are not given. This makes interpretation of results obtained by any of these methods quite difficult and often impossible. In 2000, the Dutch Ministry of Transport, Public Works and Water Management published a draft procedure for assessing the potential alkali-silica reactivity of concrete aggregates in a fast but robust manner. This procedure, which is intended to form one of the backbone's of the currently reviewed CUR Recommendation 38, consists of a combination of petrographic examination and expansion measurements. For expansion measurement, mortar bars are prepared with the test aggregate, following an assessment in an ultra-accelerated mortar-bar test based on the RILEM TC 106-2 method. This article summarizes the essential elements of the new test procedure, and presents results of tests of several primary as well as secondary (recycled) aggregates.**

Keywords. alkali silica reaction, petrography, microscopy, accelerated mortar bar resting, (recycled) aggregates

1 INTRODUCTION

Alkali-silica reaction in concrete, ASR, is a chemical reaction between the alkalis in the pore solution of the cement paste and certain forms of silica which occur in the aggregate. The product of the reaction is a gel that can imbibe water and swell. In some cases, swelling of the gel can induce internal stresses in the concrete of such magnitude that extensive cracking leading to structural damage and other durability problems can occur. In reinforced concrete structures, corrosion of the reinforcement can occur as a result of the ASR-initiated cracking.

Worldwide, damage of concrete due to alkali-silica reaction continues to increase. In the Netherlands, for example, since the past decade, deterioration of concrete due to attack by alkali-silica reaction has been detected in several structures including bridges, locks, balconies and viaducts. Two example cases are shown in Figure 1. Recent analysis shows that there are at least 60 structures that are affected or suspected to be suffering from deterioration due to alkali-silica reaction (Heijen et al, 1996). The expectation is that this number of affected structures shall increase in the course of time, even though the Dutch widespread and decades long application of CEM III blast furnace slag cements and portland fly ash cements.

The current Dutch standard NEN 5905 (1995) and CUR Recommendation 38 (1994) authorise suppliers of concrete aggregate to provide information regarding their potential alkali-aggregate reactivity. According to these two documents, the potential alkali-aggregate reactivity can be assessed on the basis of one or more of the following:

- long-term experience with the use of the aggregate in concrete
- microscopical analysis of the mineralogical composition of the aggregate
- expansion tests using mortar bars or concrete prisms
- results of a chemical determination of the reactivity.

Go Back

Next Page

Figure 1: ASR-attack in the foundation of a viaduct (left) and a lock (right) in the Netherlands.

The four methods have just been listed but clear procedures outlining how the tests should be performed and the expected limitations, variations and possible errors have not been given. Thus making it difficult to interpret results obtained by any of these methods. In 2000, the Dutch Ministry of Transport, Public Works and Water Management (Bouwdienst-RWS), published a draft procedure (BSRAP-R-00006, 2000) for assessing the potential alkali-silica reactivity of concrete aggregates. The procedure consists of two methods:

- **PFM**: petrographic examination of aggregates to identify and quantify rock types and minerals which might react with alkali hydroxides from the concrete pore solution to produce expansive alkali-silica gel.
- **UAMBT**: ultra accelerated mortar-bar test, designed to determine rapidly the potential alkali-reactivity of aggregates through evaluation of the expansion of mortar-bars immersed in NaOH solution at a temperature of 80 ^{o}C.

As a general rule, the PFM-method is the first step in the assessment of potential reactivity of concrete aggregates. In the Bouwdienst-RWS procedure (BSRAP-R-00006, 2000), petrographic analysis is mandatory for assessing the potential reactivity of aggregates. Owing to the fact the PFM-method is not able to take into account all the potentially reactive constituents, especially in cases where the aggregate sample contains opal or sandstone particles, the reactivity of the aggregate is further assessed by means of the UAMBT-method. Soon after the publication of the Bouwdienst-RWS procedure (BSRAP-R-00006, 2000), several studies have been performed, including a a limited round robin survey with the view to evaluating the effectiveness and reliability of the procedure.

Essentially, it was found that the Bouwdienst-RWS procedure (BSRAP-R-00006, 2000) provided a sound basis for assessing the alkali-reactivity of aggregates. However, the results of a initial round-robin survey indicated that formulation of various portions and instructions given in certain cases easily gave rise to differences in interpretation of the procedures, resulting in factor 2-5 differences in the results of the petrograhic analysis and the UAMBT tests. A subsequently organised workshop (Larbi & Haverkort, 2001) catalised the process of reformulating and further explaining and clarifying the steps set out in Bouwdienst-RWS procedure (BSRAP-R-00006, 2000). At present, it has resulted in a draft revised document, which is intended to be published together with the reviewed CUR Recommendation 38, early 2002.

In the latest version, a specification of 2 %, which was proposed as the maximum acceptable content of potentially reactive constituents in the Bouwdienst-RWS procedure (BSRAP-R-00006, 2000), is currently enforced. Problems regarding reproducibility and limitations, especially in the case of impure sandstone particles, which are also known to be potentially reactive, are yet to be resolved. Current experience (Larbi & Haverkort, 2001) shows that not all types of sandstone have been found to be potentially reactive. As such, the sandstone particles are not directly quantified during the PFM-analysis but rather indirectly evaluated in the UAMBT-method. Work is currently going on to assess which particles should be included.

2 THE DUTCH *DRAFT* PETROGRAPHIC METHOD

Principle

The currently proposed Dutch *Draft* Petrographic Method of assessing the potential alkali-silica reactivity of aggregates is based to a large extent on the RILEM TC 106-1 (2000) method. The method is intended to be used to assess all types of primary aggregates, that is, natural sands and gravel, crushed fine and coarse natural aggregates, including "all-in" as well as secondary alternative or recycled aggregates. The petrographic method is mandatory and is the first step in the assessment of the potential reactivity of concrete aggregates, as well as quality control in the course of production.

Reactive minerals

The rocks and mineral constituents that are considered to be potentially alkali silica reactive are currently essentially porous chert, chalcedony and opal. It should be noted that, apart from porous chert, chalcedony and opal, some types of sandstone,

Go Back

Next Page

quartzite and other mylonitic rock particles have been found to be potentially reactive from diagnosis of Dutch concrete structures affected by ASR. However, at the moment, no investigation has been performed by means of petrography to distinguish between the reactive and non-reactive rock types, although it is generally known that such a distinction may in principle be done by means of petrography. As for now, all such rock types are considered potentially alkali-silica even though many of the particles in question are found to be inert in thin sections prepared from ASR-affected OPC concrete structures. For this reason the potential reactivity of such particles or constituents is assessed after the petrographic analysis by means of the ultra-accelerated mortar-bar test, UAMBT.

Procedure

The procedure involves description of various methods and analyses for assessing the potential alkali-silica reactivity representative aggregate sample by means of petrography for use in concrete. It consists essentially of the following main proce and aspects:

- taking samples from a quarry or a stock pile, including the required sample size for testing in the laboratory according to a specified international standard, EN 932-1
- initial preparation of the samples in the laboratory for examination, which includes homogenising, drying, sieving, splitting by means of quartering, and grinding, EN 932-1
- preparation of thin sections from test specimens according to a specified procedure
- number of thin sections required for a given type of aggregate, for example, crushed coarse natural rock, sand (fraction 0-4) or gravel (fraction 4-16)
- point-counting analysis, with special emphasis on the number of points to be counted for various size fractions
- evaluation of results and report writing.

Sampling

The aggregate producer or supplier, the investigating institute or consultant, or a certified body according to the procedures enshrined in EN 932-1, may do the sampling. The quantity of sample taken is dependent on the maximum particle size of that fraction and varies from 50 kg for a maximum particle size of 63 mm to 5 kg for particle size of 4 mm.

Cursory visual examination

It is as in RILEM TC 106-1, reported by Jensen and Sibbick (2001) elsewhere.

Initial sample preparation

The method of drying, splitting and weighing are all similar to those in RILEM TC 106-1 (Jensen and Sibbick (2001); with respect to **grinding**, the method is a little different from that of RILEM TC 106-1.

For sand 0-4, the sample is first sieved into three sub-fractions: 0-2, 2-4 and > 4 mm. The fraction coarser than 4 mm is then cru to a size fraction smaller than 4 mm, added and eventually homogenised with the fraction 2-4.

For gravel and other coarse aggregate particles, the crushing procedure is more comprehensive than the case recommended in the RILEM TC 106-1 procedure. In the present case, the material is first split into four equal parts by the method of quartering. One-quarter is further sieved into three size fractions: 4-8, 8-12 and 8-16 or 4-8, 8-16 and 16-32 or similar size fractions in the case of different aggregate grading. The various fractions are crushed separately, using a crusher with the opening set to less than 4 mm. The crushed material is mixed and wet-sieved on the 63 µm sieve to remove the fraction finer than 63 µm. Following this, the material is then dried at 105 ^{o}C to a constant weight and homogenised.

Thin section preparation

The current method is the same as in RILEM TC 106-1. Of mandatory importance here is the (proper) use of a fluorescent dye in the impregnation resin and impregnating under vacuum in order to recognise and quantify any porous chert present.

Number of thin sections

The number of thin sections to be prepared and analysed by means of polarising and fluorescent microscopy for the various aggregate size fractions are as follows:

- sand, fraction 0-1: 1
- sand, fraction 0-2: 1
- sand, fraction 0-4: 1 from fraction 0-2 and 2 from fraction 2-4;
- sand, fraction 0-4: 1 from fraction 0-2 and 2 from fraction 2-4;
- gravel and other coarse aggregate: 3 from processed fraction

Go Back

Next Page

Point-counting analysis

Same as in RILEM TC 106-1 [6] except that a minimum of 3000 points in the particles in the thin sections must be counted in order to achieve an acceptable actual error, which from a number of research studies has been found to be less than 0.5 %. This is because the maximum acceptable content of potentially reactive constituents in aggregates is quite low, that is, 2 % by volume.

Determination of the content of PRC

The total content of PRC in the samples, identified and quantified by means of point-counting analysis is determined and recorded for the various size fractions and for that matter the entire aggregate sample.

Criteria for assessment

If from the petrographic analysis, an aggregate is found to contain less than 2 % (in practice 2,49 % with a 95% confidentiality limit) of the potentially reactive constituents (PRC), it is termed "*not potentially reactive*" but has to be tested further by means of the ultra-accelerated mortar-bar test. If the aggregate contains more 2 % of PRC, it is considered *potentially reactive* and can only be used in concrete structures exposed to dry environmental conditions. If it is intended to be used in concrete structures exposed to either wet, seawater, frost-thaw and/or aggresive conditions, the necessary preventive measures need to be taken, such as the already in CUR Recommendation 38 prescribed. Examples are the use of a blast furnace slag cement (CEM III/B resp. CEM III/A) containing specified slag contents (# 66 resp. 50 %) and associated Na_2O contents (< 2 resp 1,1 %, still under discussion), or alternatively a OPC containing ∃ 25% PFA and a Na_2O content of < 1,1%.

Reporting

Same as in RILEM TC 106-1 reported by Jensen and Sibbick [6] elsewhere.

3 THE DUTCH *DRAFT* ULTRA-ACCELERATED MORTAR-BAR TEST METHOD

The method used is the same as that outlined in the RILEM TC 106-2 method (2000). Of importance here is the method of sampling, sample homogeneity and preparation, for which an additional clarification is written.

4 PILOT TESTING

A summary of some results of a pilot study, aimed at evaluating the limitations and general suitability of the current *draft* Dutch procedure is presented in table 2. Micrographs showing some features of the test results are presented in Figures 2, 3 and 4.

Table 2: Summary of results of a pilot study using the new draft Dutch procedure

Material	*Size fraction*	*PRC %*	*Petrographic Assessment*	*UAMBT Expansion, %*
River sand	0 - 1	0.5	Under critical	0.02
River sand (reference)	0 - 2	1.1	Under critical	0.01
River sand	0 - 4	2.8[1]	Potentially Reactive	0.12
Sea sand	0 - 4	4.5[1]	Potentially Reactive	0.23
River gravel 1	4 - 16	1.2	Under critical	0.04
River gravel 2	4 - 32	1.5	Under critical	0.03
Crushed siliceous limestone (reference)	4 - 22	2.8[1]	Potentially reactive	0.26
Recycled concrete	4 - 32	1.8	Under critical	0.02
Recycled concrete containing additional 1 % (by mass) of glass[2]	4 - 32	2.7[1]	Potentially reactive	0.12
Assessment criteria	-	≤ 2	-	0.1 at 14 days

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[1] Under normal circumstances, these samples with more than 2 % potentially reactive constituents would not be tested further using the UAMBT. However, for purposes of comparison and evaluation of the effectiveness of the new procedure, the sample tested further using the UAMBT.

[2] According to NEN 5905 the maximum allowable content of "foreign constituents" is 1% (m/m).

Go Back

Next Page

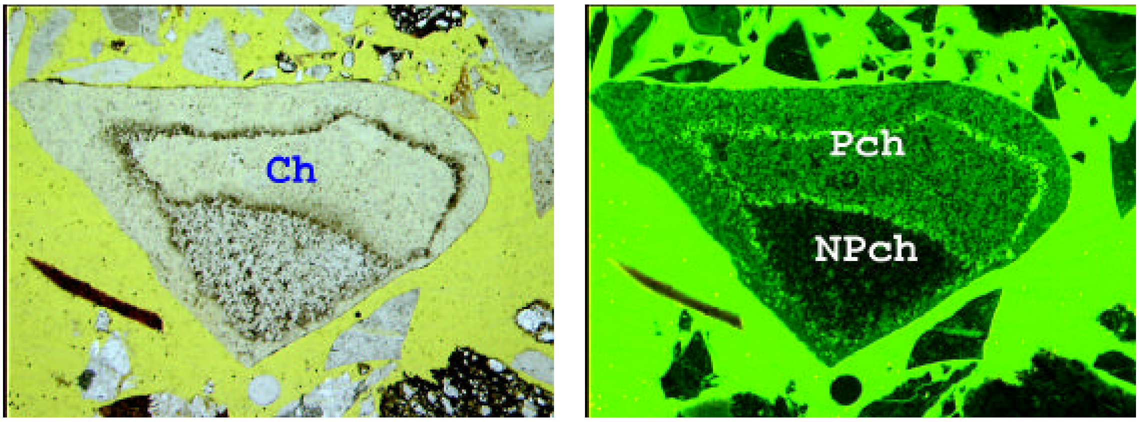

Figure 2: PFM-micrographs showing porous chert, Pch, in one of the thin section examined using the petrographic method. NPch = non-porous chert. Micrograph is 2.7 mm x 1.8 mm.

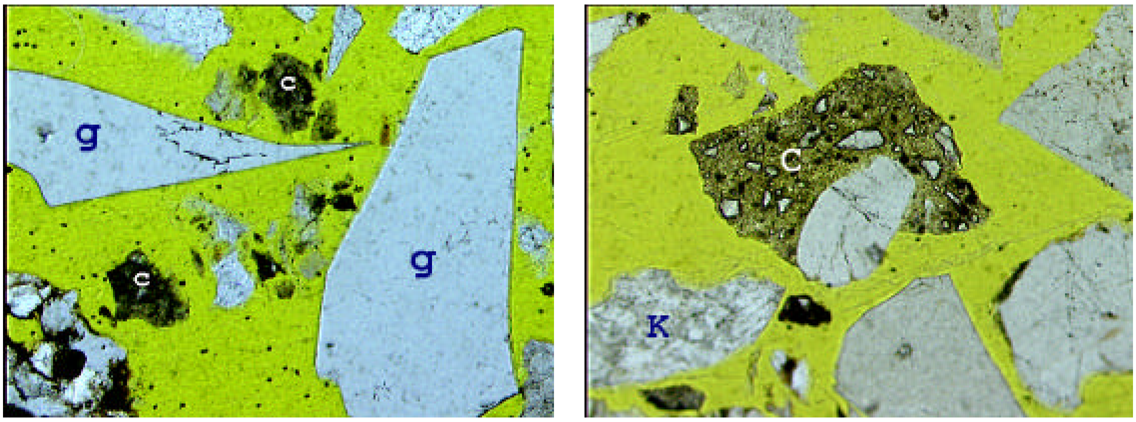

Figure 3: PFM-micrographs showing a glass particle, g, in one of the thin sections prepared from recycled concrete and examined using the petrographic method. C = cement paste. Micrograph is 2.7 mm x 1.8 mm.

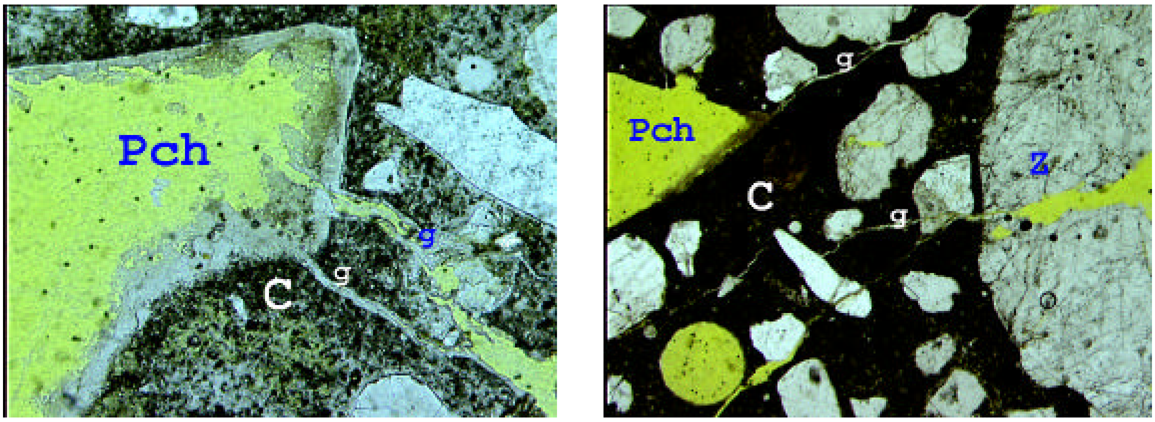

Figure 4: PFM-micrographs showing ASR-gel streaming from two reacted aggregate particles in the mortar-bar of one of the samples of sand tested. Pch = porous chert; Z = sandstone; C = cement paste; g = ASR-gel. A = aggregate. Micrograph is 2.7 mm x 1.8 mm.

Although the results of this pilot test are somehow limited, it can be deduced that a confirmation of the results of the UAMBT, including those of the two reference samples indicates that the Draft method has much potential. The data in table 2 further show that for the two sand samples (fractions 0-1 and 0-2) and both samples of river gravel (fractions 4-16 and 4-32), the presence of sandstone, quartzite and other mylonitic rock types present in the samples have little effect on their potential alkali-silica reactivity. A more extensive and detailed round-robin test involving about seven laboratories in The Netherlands, including two recognised laboratories in Belgium and Denmark is scheduled to take place early 2002.

Go Back

5 DISCUSSION AND CONCLUSIONS

A new, relatively fast and robust, procedure for assessing the potential alkali-silica reactivity of aggregates, partly by means of petrography and partly by means of ultra-accelerated mortar-bar expansion, is currently in preparation and almost completed for use by the Dutch concrete and the building and construction industries.

The two methods in the *draft* procedure are both based on the RILEM TC 106 methods, with some small adaptions. The procedure is intended for use in the assessment of the potential alkali-silica reactivity of ***all types of primary aggregates***, including natural sands and gravel, crushed fine and coarse natural aggregates, and secondary alternative or recycled aggregates.

The method of petrography method is mandatory and is the first step in the assessment of the potential reactivity of concrete aggregates, as well as for quality control during aggregate production. It complies with the general scope for aggregate testing as outlined in CEN TC 154.

Although the procedure is relatively new and not widely tested, the ample experience to date indicates that the current *draft* procedure has much potential.

For materials with more than 2% potentially reactive constituents, a significantly more elaborate and long term (> 1 year testing), RILEM CPT test procedure is currently being considered for review and pilot testing.

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