



Recommendation of RILEM TC 258-AAA: RILEM AAR-8: determination of potential releasable alkalis by aggregates in concrete

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Abstract The test method AAR-8 is intended to be used for assessing the potential amount of alkalis released by aggregates in field concrete in the long-term. This is done by measuring the amounts of sodium and potassium ions released from the fine graded (< 4 mm) aggregate immersed in (0.7 M) KOH and NaOH solutions, respectively, at elevated

temperature when in contact with excess calcium hydroxide. It is of great importance to realise that this accelerated test method must be considered as a mere indication of potential (maximum) alkali release by the aggregates, rather than a quantification used for the alkali inventory calculations.

Keywords Alkalis release · Aggregates · Test method

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1 Foreword

This draft method was based on a literature survey on the subject and on the work developed at LCPC (now Université Gustave Eiffel (prev. IFSTTAR), France), Laval Univ. (Quebec City, Canada), Institute Eduardo Torroja IETcc-CSIC (Spain) and LNEC (Portugal) [1–13].

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2 Scope

This test method is used to assess the potential amount of alkalis released by aggregates in the long-term use in field concrete. This accelerated method must be considered as a mere indication of potential alkali (*see Note 1*) release by the aggregates rather than a quantification used for the alkali inventory calculation.

Results should be seen as a way to categorize the potential alkali release into three groups: the low, medium and high releasers.

Note 1: in this document, the term alkalis refer to the alkali metal ions Na^+ and K^+ .

3 Significance and use

Many field and laboratory investigations on concrete, mortar or aggregate samples demonstrated or suggested that some aggregates or mineral phases present within the aggregate particles can supply significant amounts of alkalis to the pore solution over the service life of the concrete. This becomes a source of concern when concrete is exposed to relative humidity over 80 % and contains potentially AAR aggregates, and when the mitigation for deleterious AAR is arranged by limiting the alkalis from the cement and/or by using specified amounts of supplementary cementing materials.

A number of procedures have been used in the past for assessing the alkali contribution from the aggregates to the pore solution of concrete [14]. Most of these procedures involved immersion of the aggregates in a lime-saturated solution, with or without solid lime in excess, or in alkaline (NaOH, KOH) solutions. However, there is still no consensus about the absolute amounts that can be released by the aggregates in concrete, the procedure to be used to estimate these amounts, and the way to take account for this alkali contribution in the standards or guidelines. Recently, strategies for quantification of alkali metal release from aggregates into the concrete in field were discussed [15]. AAR-8 provides a mean of

evaluating the amount of potential alkalis releasable by aggregates in the long term use in concrete by measuring the amounts of alkali ions released in NaOH (K^+ release) and KOH (Na^+ release) solutions at elevated temperature. The solutions used should be in contact with excess (solid) calcium hydroxide as this is the situation in concrete in practice.

The values obtained by this test method present most likely a significant overestimation compared to the release in field concrete. This overestimation is mainly due to particle size used to accelerate the test method. Fine aggregate is more susceptible to release alkali than coarse aggregate. At this stage, it is only possible to categorize the aggregate according to the amount of alkali release. Low releasers are aggregates that release less than 0.1% $\text{Na}_2\text{O}_{\text{eq}}$ at 26 weeks while high releasers are aggregates that release more than 0.25% $\text{Na}_2\text{O}_{\text{eq}}$ at 26 weeks. For high releasers, extra caution should be taken in the selection of AAR mitigation measures.

4 Principle

Representative samples of a dried aggregate intended for use in concrete are immersed in specific volumes of 0.7 M NaOH or KOH solutions with excess calcium hydroxide maintained at 38 °C, using a solution-to-aggregate ratio of 4 L/kg. Twice a week, the test containers are agitated for 10 seconds. At 2, 6, 13 and 26 weeks, samples of the immersion test solution are removed by pipetting and chemically analysed for potassium (NaOH test solution) or sodium (KOH test solution). The amount of alkalis released are expressed in milligrams of Na_2O , K_2O and % $\text{Na}_2\text{O}_{\text{eq}}$ per kilogram of aggregate.

5 Apparatus

5.1 Sieves

A set of sieves conforming to series A of ISO 6274 [16], having square apertures of 4 mm, 2 mm, 1 mm, 500 μm , 250 μm and 125 μm . Alternatively, the equivalent sieves of series B (4.75 mm, 2.36 mm, 1.18 mm, 600 μm , 300 μm and 150 μm) or C (5 mm, 2.5 mm, 1.25 mm, 630 μm , 315 μm and 160 μm) can be used.

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5.2 Balance

A balance capable of weighing 500 g with an accuracy of 1 g.

5.3 Volumetric flask

Volumetric flask of 0.5 litres.

5.4 Pipettes

10 mL capacity pipettes.

5.5 Containers for aggregate immersion test

Containers for the aggregate immersion tests shall be cylindrical, non-absorbent, non-abrasive, non-brittle material, and made of plastic or other material resistant to corrosion by solutions of NaOH and KOH at a temperature of 38 °C for the duration of the test. Each container must be of such dimension and shape to accommodate the specified volumes of aggregates (100 g) and alkaline solutions (400 mL), and must be provided with a tight screw-lid or other suitable means to prevent any loss of aggregate particles, solution or moisture by leaking or evaporation. The containers for the aggregates must be single use to avoid risk of breakage. An example of a suitable container is shown in the Fig. 1.

Note 2 (dimension and size of containers): It is recommended to use a container that will have a height-to-diameter ratio of at least 1.5, to make the sampling of the test solution that is above the aggregates sitting at the bottom of the containers easier and safer.

Note 3 (nature of containers): Polyethylene Nalgene® type bottles satisfy the above requirements.

5.6 Oven

An oven or room of suitable size to accommodate the required number of containers maintained at temperatures of 38 ± 2 °C.

5.7 Filtration

The apparatus for under vacuum filtration of the 10 mL samples of immersion solutions should include a filter support, filter papers (grade 40), a perforated rubber



Fig. 1 Example of double-closure container, with $\Phi 10\text{cm} \times 15$ cm high

plug, a polyethylene Erlenmeyer flask with a connection for air vacuum, and an air-vacuum pump with an appropriate line for connecting to the Erlenmeyer flask (Fig. 2). Another efficient method for filtration could be a syringe filter. A single-use filter cartridge with a pore size between 0.22 and 0.45 μm is attached to the end of a syringe. The diameter of the micro-filter is 25 mm. A photo of the syringe with the filter and a detail of the micro-filter are shown in the Fig. 3.

5.8 Chemical analysis

Appropriate analytical equipment for determination of potassium and sodium concentrations in the samples

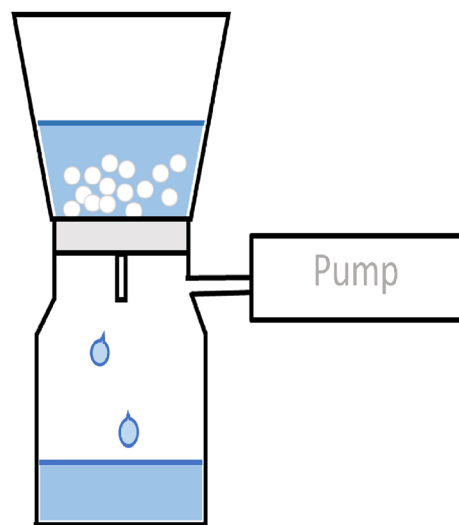


Fig. 2 Diagram of the system of filtration under vacuum

of immersion solutions included: Atomic Absorption (AAS) and Inductively Couple Plasma Optical Emission Spectroscopy (ICP-OES).

6 Reagents and materials

6.1 Water

Distilled or de-ionized water.

6.2 Solid sodium hydroxide

Reagent grade solid sodium hydroxide with high purity $\geq 95\%$.

6.3 Solid potassium hydroxide

Reagent grade solid potassium hydroxide with high purity $\geq 95\%$.

6.4 Sodium hydroxide solution (NaOH) with excess of calcium

Each litre of sodium hydroxide solution shall contain 28.0 g of NaOH and 2.0 g of $\text{Ca}(\text{OH})_2$ dissolved in 900 mL of water and, after cooling to 20 °C; it shall be diluted with additional distilled water to obtain 1.0 litre of solution. The concentration of the NaOH in the solution shall be between 0.69 M and 0.71 M. A minimum of 1 litre of fresh solution should be prepared for each aggregate to be tested.

Note 4 the concentration of 0.7 M is selected based on the pH and the corresponding OH^- ion concentration of the pore solution of a concrete made with a cement of about 1 % $\text{Na}_2\text{O}_{\text{eq}}$ [17, 18].

6.5 Potassium hydroxide solution (KOH) with excess of calcium

Each litre of potassium hydroxide solution shall contain 39.3 g of KOH and 2.0 g of $\text{Ca}(\text{OH})_2$ dissolved in 900 mL of water and, after cooling to 20 °C, it shall be diluted with additional distilled water to obtain 1.0 litre of solution. The concentration of the KOH in the solution shall be between 0.69 and 0.71M. A minimum of 1 litre of solution should be prepared for each aggregate.

Note 5 the concentration of 0.7 M is selected based on the pH and the concentration of ions in the concrete pore solution of a concrete made with a cement of about 1 % $\text{Na}_2\text{O}_{\text{eq}}$ [17, 18].

6.6 Nitric acid

HNO_3 concentrated (65 %).

7 Procedure

7.1 Preparation of the aggregate sample

The quantity of the sample delivered to the laboratory should be in accordance with the sampling procedures recommended in AAR-1 (Detection of Potential Alkali-Reactivity of Aggregates: Petrographic Method) [19] (see Table 1) or shall represent the composition of the aggregate as proposed for use. The material to be tested shall consist of particles ≤ 4 mm, processed according to 7.1.1 and 7.1.2. With the exception of fraction $< 125 \mu\text{m}$, the fractions must be washed over the respective sieve to remove the adhered dust and later dried at 105 °C before the test (see 7.1.3).



Fig. 3 Example of syringe with the micro-filter and a detail of the filter with diameter 25 mm

Table 1 Minimum size sample

Maximum particle size (mm)	Minimum mass (kg)
50	200
40	100
20	15
10	5

7.1.1 Fine aggregate

The fine aggregate shall be tested in the grading as proposed for use except that particles retained on a 4 mm sieve, or equivalent (see 5.1), shall be discarded.

7.1.2 Coarse aggregate

First, the aggregates sample is sieved with a 4 mm sieve, this fraction is discarded. Then the remaining material is crush. After crushing by suitable means, the sample must be graded, according to the procedure described in RILEM AAR-2 [20].

7.1.3 Drying

The aggregate is tested in an oven-dry condition. A moist aggregate shall be dried at 105 ± 2 °C until mass equilibrium (measured at 20 ± 2 °C) before being tested.

7.2 Preconditioning

Before testing, the dry aggregate, alkaline solutions and test containers shall be stored at a temperature of 20 ± 2 °C for $24 \text{ h} \pm 4 \text{ h}$.

7.3 Preparation of test mixtures and initial measurements

7.3.1 Sample preparation

Two representative 100 ± 0.5 g samples of the aggregate to be tested (M_0) shall be placed in two test containers (see 5.5). Then 400 ± 0.1 mL of the 0.7 M NaOH solution in excess of Ca(OH)_2 (2.0 g/L) is added to the first container, while 400 ± 0.1 mL of the 0.7 M KOH solution in excess of Ca(OH)_2 (2.0 g/L) is added to the second container.

7.3.2 Blank samples

Prepare two blank samples by filling one container with 400 ± 0.1 mL of the 0.7 M NaOH solution with excess Ca(OH)_2 (2.0 g/L), and filling a second container with 400 ± 0.1 mL of the 0.7 M KOH solution with excess Ca(OH)_2 (2.0 g/L). The blank samples will be stored and periodically sampled together with the aggregate samples.

7.4 Storage and measurements

7.4.1 Storage conditions

To start the test, the sealed containers are placed in a vertical position in a convection oven or in a water bath maintained at 38 ± 2 °C, avoiding the loss of humidity by the walls of the containers. Each container must be clearly marked with the aggregate tested and the test solution used. Twice a week during the entire testing program, the containers are removed, one after the other, from the convection oven or water bath and then checked if they are tightly closed and agitated for about 30 seconds, rolling the containers about 20 times through a longitude of 80 centimetres (Fig. 4). The containers are then returned to the convection oven or water bath at 38 °C. The rolling is not necessary for the blank samples.

7.4.2 Periodic sampling

Prior to each sampling at the ages of 2, 6, 13 and 26 weeks, the containers are removed from the convection oven or water bath one at a time, agitated for 10 seconds and placed vertically (lid facing up) on a flat surface for 24 ± 2 hours in a room at 20 °C, prior to extracting the liquid sample for analysis.

Note 6 during the test, it is possible that there is some agglomeration of the aggregate in the bottom of the container. If the rolling is not sufficient to deagglomerate the aggregate particles it is possible to use a laboratory stirrer or a shaker apparatus to separate the grains.

After this procedure, the container is opened and 10 mL of solution from each alkaline solution (0.7 M NaOH and KOH solutions) above the aggregate particles is removed by pipetting or using a syringe (see 5.7). From both blank samples without aggregates also 10 mL is taken for analysis. The solutions are then

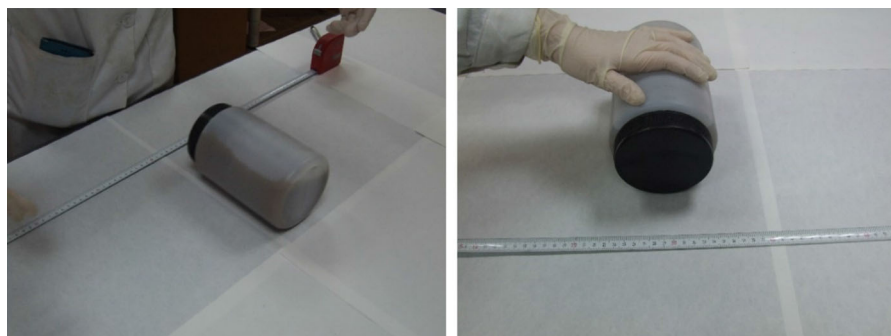


Fig. 4 Rotation of the containers along 80 centimetres on a flat surface

filtered and acidified with 0.25 mL of HNO_3 concentrated and placed in an appropriate closed container to be analysed chemically (see 5.8). If they are not immediately analysed, they can be stored in a refrigerator (between 4 and 10 °C) for 2 days maximum until chemical analyses.

After each sampling, the containers are returned to the convection oven or water bath at 38 °C.

7.4.3 Periodic chemical analysis

The samples of aggregate immersion solutions and of the corresponding blank solutions taken at each age are chemically analysed for sodium and potassium contents using an appropriate method (see 5.8).

The Na^+ content must be determined in the KOH solution and K^+ content must be measured in the NaOH solution. Additionally, K^+ or Na^+ and Ca^{2+} can be determined in each solution to obtain more information. Since alkalis are measured in highly charged solutions containing 0.7 M NaOH or 0.7 M KOH, the matrix has a large effect on the measured concentrations. Special attention should be given to the effect of the matrix. To counteract the matrix effect, it is suggested to prepare the analytical standards with a matrix that represents the samples to be analysed. This implies that the standards must be prepared from 0.7 NaOH and 0.7 KOH stock solutions using the same diluting factors as those used for the samples to be analyzed. For example, the 0 ppm Na^+ standard is assigned to the 0.7 M KOH stock solution diluted and acidified with the same dilution factor as the samples to be analysed. When this technique is used, it is not necessary to subtract the amount of Na^+ present in the KOH solution or the amount of K^+ in the NaOH since these quantities are automatically

considered by the measurement. The result reported should be the average of at least three analyses.

A discussion of the differences between the analytical test methods (ICP, AAS and others) is given in the paper [21].

Note 7 (continuation of measurements): The sampling could be extended after 26 weeks if is intended to obtain the plateau of alkalis release, being in this case the measurements maintained with periodicity of 3 months.

7.5 Safety measures

Reliable safety precautions should be taken, and suitable personal protective equipment should always be used to avoid the hazards of the hot alkaline solution such as severe burns and injuries to unprotected skin and eyes.

8 Calculation and reporting of results

8.1 Alkali concentrations (in mg/L)

The results of the chemical analyses are expressed in milligram of sodium or potassium per litre (mg K^+ /L or mg Na^+ /L).

8.2 Amounts of alkalis released in test solutions (in mg)

8.2.1 Na^+ released in KOH solution (in mg Na^+)

At a given sampling time, the cumulative amount of sodium released in the KOH solution, in milligrams of Na^+ , is the amount present in the volume of the test

solution at the time of sampling, plus the amount present in all 10 mL samples of the test solution taken before, minus the amount of Na^+ initially present in the test solution before contact with the aggregate (blank KOH solution). Accordingly, the cumulative amount of Na^+ released in the KOH test solution at the time of the n^{th} sampling, in milligrams of Na^+ , is obtained using the following relationship:

$$M_{\text{released}}^{\text{Na}} = [V_0^{\text{KOH}} - 0.01 \cdot (n - 1)] \cdot (C_n^{\text{Na}} - C_{0,n}^{\text{Na}}) + 0.01 \cdot \sum_{i=1}^{n-1} (C_i^{\text{Na}} - C_{0,i}^{\text{Na}}) \quad (1)$$

where $M_{\text{released}}^{\text{Na}}$, total solid mass of Na^+ released from the aggregate (mg). V_0^{KOH} , initial volume of KOH test solution, in L (i.e. 0.400 ± 0.002 L). 0.01 , pipetted volume of each solution sampled at the time t , in L (i.e. 10 mL). n , total number of the samplings done ($n=1, 2, 3, \dots$). C_n^{Na} , Na^+ concentration of the KOH test solution with the aggregate at the n^{th} sampling (mg/L). $C_{0,n}^{\text{Na}}$, Na^+ concentration in the KOH blank sample at the n^{th} sampling (mg/L). C_i^{Na} , Na^+ concentration of the KOH test solution with the aggregate at the time t_i , corresponds to the i^{th} sampling (mg/L). $C_{0,i}^{\text{Na}}$, Na^+ concentration in the KOH blank sample at the i^{th} sampling (mg/L). i^{th} sampling of the $n-1$ samplings done ($i = 1, 2, 3, \dots, n-1$). Note 8 (example): As an example, at the time of the 3rd sampling ($n = 3$), i.e. at the age of 13 weeks, the above general relationship corresponds to the following:

$$M_{\text{released}}^{\text{Na}} = [V_0^{\text{KOH}} - 0.01 \cdot (n - 1)] \cdot (C_n^{\text{Na}} - C_{0,n}^{\text{Na}}) + 0.01 \cdot \sum_{i=1}^{n-1} (C_i^{\text{Na}} - C_{0,i}^{\text{Na}}) \quad (2)$$

8.2.2 K^+ released in the NaOH solution (in mg K^+)

Following the same development as for Na^+ , the cumulative amount of K^+ released in the NaOH test solution at the time of the n^{th} sampling, in milligrams of K^+ , is obtained using the following relationship:

$$M_{\text{released}}^{\text{K}} = [V_0^{\text{NaOH}} - 0.01 \cdot (n - 1)] \cdot (C_n^{\text{K}} - C_{0,n}^{\text{K}}) + 0.01 \cdot \sum_{i=1}^{n-1} (C_i^{\text{K}} - C_{0,i}^{\text{K}}) \quad (3)$$

where $M_{\text{released}}^{\text{K}}$, total solid mass of K^+ released from the aggregate (mg). V_0^{NaOH} , initial volume of NaOH test solution, in L (i.e. 0.400 ± 0.002 L). 0.01 , pipetted volume of each solution sampled at the time t , in L (i.e. 10 mL). n , total number of the samplings done ($n=1, 2, 3, \dots$). C_n^{K} , K^+ concentration of the NaOH test solution with the aggregate at the n^{th} sampling (mg/L). $C_{0,n}^{\text{K}}$, K^+ concentration in the NaOH blank sample at the n^{th} sampling (mg/L). C_i^{K} , K^+ concentration of the NaOH test solution with the aggregate, at the time t_i , corresponding to the i^{th} sampling (mg/L). $C_{0,i}^{\text{K}}$, K^+ concentration in the NaOH blank sample at the i^{th} sampling (mg/L). i^{th} sampling of the $n-1$ samplings done ($i = 1, 2, 3, \dots, n-1$)

8.3 Amounts of alkali oxides released by the aggregate (in mg/kg)

8.3.1 Na_2O released (in mg $\text{Na}_2\text{O}/\text{kg}$)

The cumulative amount of Na^+ released by the aggregate in the KOH test solution at the time of the n^{th} sampling, in milligrams of Na_2O per kilogram of aggregate, is obtained using the following relationship:

$$M_{\text{released}}^{\text{Na}_2\text{O}}/\text{kg} = M_{\text{released}}^{\text{Na}} (\text{Eq. 2}) \cdot 1.3480/M_0 \quad (4)$$

where 1.3480, conversion factor to transform a mass of Na^+ to the equivalent mass of Na_2O . M_0 , initial mass of aggregate, in kg (i.e. 0.100 ± 0.001 kg)

8.3.2 K_2O released (in mg $\text{K}_2\text{O}/\text{kg}$)

The cumulative amount of K^+ released by the aggregate in the NaOH test solution at the time of the n^{th} sampling, in milligrams of K_2O per kilogram of aggregate, is obtained using the following relationship:

$$M_{\text{released}}^{\text{K}_2\text{O}}/\text{kg} = M_{\text{released}}^{\text{K}} (\text{Eq.3}) \cdot 1.2046/M_0 \quad (5)$$

where 1.2046, conversion factor to transform a mass of K^+ to the equivalent mass of K_2O . M_0 , initial mass of aggregate, in kg (i.e. 0.100 ± 0.001 kg)

8.3.3 Na_2O_{eq} released (in mg Na_2O_{eq}/kg)

The cumulative amount of alkalis released by the aggregate in the NaOH and KOH test solutions at the time of the n^{th} sampling, in milligrams of Na_2O_{eq} per kilogram of aggregate, is obtained using the following relationship:

$$M_{released}^{Na_2O_{eq}}/kg = M_{released}^{Na_2O}/kg(Eq.4) + [0.658 \times M_{released}^{K_2O}/kg(Eq.5)] \quad (6)$$

where 0.658, conversion factor to transform a mass of K_2O to the equivalent atomic mass of Na_2O

8.4 Amounts of alkali oxides released by the aggregate (in % Na_2O_{eq})

8.4.1 Na_2O released (in % Na_2O)

The cumulative amount of Na^+ released by the aggregate in the KOH test solution at the time of the n^{th} sampling, in % of Na_2O , is obtained using the following relationship:

$$\%_{released}^{Na_2O} = [M_{released}^{Na_2O}/kg]/10^6 \times 100 \quad (7)$$

where 10^6 , conversion factor between kg and mg

8.4.2 K_2O released (in % K_2O)

The cumulative amount of K^+ released by the aggregate in the NaOH test solution at the time of the n^{th} sampling, in % of K_2O , is obtained using the following relationship:

$$\%_{released}^{K_2O} = [M_{released}^{K_2O}/kg]/10^6 \times 100 \quad (8)$$

where 10^6 , conversion factor between kg and mg

8.4.3 Na_2O_{eq} released (in % Na_2O_{eq})

The cumulative amount of alkalis released by the aggregate in the NaOH and KOH test solutions at the time of the n^{th} sampling, in % of Na_2O_{eq} , is obtained using the following relationship:

$$\%_{released}^{Na_2O_{eq}} = \%_{released}^{Na_2O}(Eq.7) + [0.658 \times \%_{released}^{K_2O}(Eq.8)] \quad (9)$$

where 0.658, conversion factor to transform a mass of K_2O to the equivalent atomic mass of Na_2O

8.5 Potential amounts of alkalis releasable by the aggregate in concrete (in kg of Na_2O_{eq}/m^3)

As mentioned in Sect. 3, the values obtained by this test method present most likely a significant overestimation compared to the release in field concrete. At this stage, it is only possible to categorize the aggregate according to the amount of alkali release. Low releasers are aggregates that are very unlikely to release less than 0.1% Na_2O_{eq} at 26 weeks (corresponding to 1.75 kg Na_2O_{eq}/m^3) while high releasers are aggregates that are very likely to release more than 0.25% Na_2O_{eq} at 26 weeks (corresponding to 4.38 kg Na_2O_{eq}/m^3). For high releasers, extra caution should be taken in the selection of AAR mitigation measures.

8.5.1 Field applications

The potential amount of alkalis releasable by the aggregate under study in concrete, in kg of Na_2O_{eq} per cubic meter of concrete, is obtained using the following relationship:

$$M_{released}^{Na_2O_{eq}}/m^3 = M_{released}^{Na_2O_{eq}}/kg(see8.3.3) \times M_e/10^6 \quad (10)$$

where M_e , dosage of aggregate in concrete, in kg/m^3 . 10^6 , conversion factor between kg and mg

8.5.2 General use

The potential amount of alkalis releasable by the aggregate, in kg of Na_2O_{eq} per cubic meter of concrete, is obtained using the relationships indicated in 8.5.1,

where

M_e , average dosage of aggregate in concrete, in $kg/m^3 = 1050 kg/m^3$ for a coarse aggregate, $700 kg/m^3$ for a fine aggregate

10^6 , conversion factor between kg and mg



9 Test report

The following information shall be given in the report:

- Aggregate sample (identification, source, chemical composition (Na and K oxides), petrographic description (if available), date of and condition at delivery at the laboratory, grading as received, etc.).
- Processing undertaken on the aggregate sample in the laboratory (washing, drying, sieving etc.).
- Grading of the aggregate as used in the test.
- Characteristics of the test containers used (brand, model, composition, capacity, dimensions, type of lid, etc.).
- Storage conditions (convection oven or water bath, and characteristics).
- Mass of the aggregates tested.
- Analytical method used for chemical analyses.
- Na^+ concentration in the blank 0.7M KOH solution and K^+ concentration in the blank 0.7M NaOH solution, in mg/L.
- A table giving for each sample, numbered from 1 to n:

- (1) The corresponding sampling time (i.e. 0 (blank solutions), 2, 6, 13, 26 weeks, ...);
- (2) The Na^+ concentration in the KOH blank solution, in mg/L;
- (3) The K^+ concentration in the NaOH blank solution, in mg/L;
- (4) The cumulative mass of Na^+ released in the KOH test solution, in mg;
- (5) The cumulative mass of K^+ released in the NaOH test solution, in mg;
- (6) The cumulative amount of Na_2O released by the aggregate in the KOH test solution, expressed in mg $\text{Na}_2\text{O}/\text{kg}$ of aggregate;
- (7) The cumulative amount of K_2O released by the aggregate in the NaOH test solution expressed in mg $\text{K}_2\text{O}/\text{kg}$ of aggregate;
- (8) the cumulative amount of $\text{Na}_2\text{O}_{\text{eq}}$ released by the aggregates in both test solutions, in mg $\text{Na}_2\text{O}_{\text{eq}}/\text{kg}$ of aggregate;
- (9) The cumulative amount of Na_2O released by the aggregates in KOH test solution expressed in % Na_2O ;

- (10) The cumulative amount of K_2O released by the aggregates in NaOH test solution expressed in % K_2O ;
 - (11) The cumulative amount of $\text{Na}_2\text{O}_{\text{eq}}$ released by the aggregates in both test solutions expressed in % $\text{Na}_2\text{O}_{\text{eq}}$;
 - (12) The potential amounts of alkalis releasable by the aggregate in concrete, in $\text{kg Na}_2\text{O}_{\text{eq}}/\text{m}^3$ based on aggregate contents of $1050 \text{ kg}/\text{m}^3$ for a coarse aggregate and $700 \text{ kg}/\text{m}^3$ for a fine aggregate.
- A combined graph of the cumulative masses of Na_2O , K_2O and $\text{Na}_2\text{O}_{\text{eq}}$ released, in mg/kg of aggregate and in % vs. time, all values being “0” at the beginning of the test
 - Any significant features revealed by examination of the specimens and the alkaline solutions during the test (particle disaggregation, secondary products, color of the solution, etc.)

Declaration

Conflict of interest The authors declare that they have no conflict of interest.

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