Accelerated Mortar Bar Test - Alkali-silica reactivity of aggregate

Test Method
RC 376.03
April 2016

1. Scope

The purpose of this test is to determine the susceptibility of aggregates to alkali attack, leading to expansive reactions in concrete known as alkali aggregate reaction (AAR). The assessment is made by measuring the increase in length of representative mortar bars containing the aggregate concerned, during storage under prescribed test conditions.

Note: The test method is suitable for assessment for Alkali Silica Reactivity. The method is not suitable for assessment for Alkali Carbonate Reactivity.

2. Safety Procedures

The method requires the use of potentially hazardous materials such as cement and sodium hydroxide solution at 80°C, which may cause burns to the unprotected skin and eyes. Protective equipment such as dust mask, full-face shields, rubber aprons and gloves impervious to sodium hydroxide should be used. For full details of safety precautions, the product information brochures should be consulted.

3. Apparatus

The following apparatus shall be used:

(a) *Balance* – of suitable capacity with a limit of performance not exceeding 0.5g.

(b) *Water Baths* – Two water baths are required. One water bath shall be capable of heating water and mortar bars from 23°C to 80°C over a three hour period. This may consist of a container of sufficient capacity, heated by a thermostatically controlled hot plate. The mortar bars shall not be in direct contact with the bottom of the container, but separated by plastic stands or supports.
The other water bath shall be thermostatically controlled to operate at 80 ± 2°C.
The volume of the baths shall be such that the ratio of the volume of solution to the volume of mortar bars placed in them is not less than 4. Alternatively separate containers may be used inside an oven controlled to operate at 80 ± 2°C.

(c) *Sodium hydroxide bath* – Sealable bath made of stainless steel or other suitable material to resist the action of sodium hydroxide, with lid to prevent evaporation of solution and racks to support mortar bars. This bath shall have temperature control as for the water bath at 80 ± 2°C.

(d) *Length comparator and reference bar* – complying with requirements of ASTM C490.
Alternatively, a suitable digital comparator with the same accuracy can be used.

(e) *Mixer, paddle and mixing bowl* – complying with ASTM C227.

(f) *Moulds* – 25 mm × 25 mm × 285 mm length with stainless steel studs complying with ASTM C490.
A gang of three mortar bar moulds is convenient for this purpose.

(g) *Oven* – thermostatically controlled to operate at a temperature within the range 105°C to 110°C.

(h) *Flow table, mould and caliper* – complying with the requirements of AS 2701, Section 5 and Appendices B and C.

(i) *Sieves* – 4.75, 2.36, 1.18 mm and 850, 600, 300 and 150 µm, with square apertures, complying with AS 1152.

(j) *Tamper* – rubber compound or timber complying with AS 2701-2001, Section 5.

(k) *Timer* – readable to one second.

(l) *Trowel* – having a steel blade 100-150 mm long with straight edges.

(m) *Mixing and curing room or cabinets* – laboratory and storage facility conditions as detailed in ASTM C511, protecting the specimens from dripping water. Note that the moist cabinet, if used, shall be calibrated for relative humidity to at least 95%, and actual RH shall be estimated from dry bulb and wet bulb thermometer readings.

(n) *Burette, pipette and beakers for titrations*.

4. Reagents

(a) Sodium hydroxide solution – 1M±0.05 NaOH solution.

(b) Hydrochloric acid – 1M HCl solution.

(c) Phenolphthalene indicator.

(d) Water – distilled or deionised to be used as mixing water.

5. Sampling and Preparation of Cement and Aggregate

5.1. Sampling

(a) Obtain a sample of general purpose cement complying with the requirements of AS 3972 in accordance with AS 2349.
If supplementary cementitious materials are to be used they shall be similarly sampled.

(b) Obtain a sample of the aggregate to be tested in accordance with AS 1141.3.1.
Rock spalls, boulders or drill cores are to be sampled in accordance with AS 1141.3.2.

5.2. Preparation of Cement

The cement shall be sieved over the 850 µm sieve to remove lumps. Cement older than 6 months and that not maintained under sealed conditions shall not be used.

5.3. Preparation of aggregate

The aggregate to be tested shall comply with the grading given in Table 1.

5.3.1. Naturally occurring fine aggregate (after processing)

Sieve the fine aggregate over the 4.75 mm sieve and discard any material retained on that sieve.

5.3.2. Coarse aggregate and fine aggregate produced from crushing

(a) Crush the coarse aggregate sampled at step 5.1(b) and sieve the material into the individual sizes as shown in Table 1.

(b) Wash each size over the sieve on which it is retained to remove the fine dust and adhering particles.

(c) Dry each size to constant mass in an oven operating at 105°C to 110°C.

(d) Combine the individual sizes to provide a grading as shown in Table 1.
Store the dried material in containers with tight fitting lids until used. Dried material may be kept in individual sizes in the separate containers, if required.

Table 1 Grading Requirements

Sieve Sizes (square openings)		Percentage by mass
Passing	Retained	
4.75 mm	2.36 mm	10
2.36mm	1.18 mm	25
1.18 mm	600µm	25
600 µm	300 µm	25
300 µm	150 µm	15

5.3.3. Rock spalls, boulders or drill core

(a) Thoroughly wash the sample of rock spalls, boulders or drill core, as sampled in step 5.1(b), using a stiff wire brush if necessary, to remove adhering clay or soft weathered stone.

(b) Crush the sample to about 50 mm maximum size.

(c) Sieve the crushed sample over a scalping screen and discard the material that passes the screen. If the material is inhomogeneous, remove particles which are at variance from the bulk sample.

Note: The scalping procedure in this test method simulates the anticipated quarry practice, by removing from the test portion material which would not be representative of the quarried product. The size of the scalping screen should be selected on this basis.

(d) Crush the material retained on the scalping screen so as to obtain sufficient particles of the sizes shown in Table 1.

(e) Proceed as detailed in steps 5.3.2 (b) to (d).

6. Preparation of Mortar Bars

6.1. Proportioning and preparation of the mortar

Mortar shall consist of:

1 part of cement (total cementitious material) by mass to 2.25 parts of aggregate prepared to the grading of Table 1, by mass.

Manufacture at least three mortar bars for each aggregate/ cement combination. The amount of materials needed for 3 mortar bars should be about 450 g cement and 1012 g of dry, graded aggregate. Mix the mortar in accordance with ASTM C305, noting that the mixer with approximately 5 litre bowl and appropriate paddle shall be used for mixing the amount of materials needed for one set of 3 mortar bars.

Note: The sequence of addition of the mix ingredients is different in this method from that of AS 2701.3 in which the dry materials are mixed first and water added subsequently.

Note: Mixing of the dry cement and other ingredients can cause a great deal of dust and for this reason, the procedures of ASTM C305 and ASTM C227 are preferred.

The amount of distilled or deionised water for mixing the mortar shall be sufficient to produce adequate flow of the mortar of 5 to 20 mm (which is the same as 5 to 20 % for the 100 mm mould).

Note: For most aggregates, a water/cement ratio of 0.42 to 0.45 by mass should produce the desired flow. Adjustments to the amount of water may be needed for some aggregates with very low or very high water absorption.

6.2. Flow measurement

Measure the flow according to Clause 5.5 of AS 2701, except that the flow table is given 10 drops of 12 mm in 6 seconds (rather than 25 drops in 15 seconds).

Note: this procedure for flow calculation is similar to that in ASTM C1437.

Flow shall be determined in accordance with the following procedure:

(a) Measure and record, in millimetres, the internal diameter of the base of the flow mould (D1), and then

carefully wipe the flow-table top clean and dry and place the flow mould at the centre.

(b) Place in the flow mould a layer of mortar about 25 mm thick and tamp it 20 times. Use just sufficient tamping pressure to ensure uniform filling of the flow mould.

(c) Repeat step (b) until the flow mould is full.

(d) Cut the mortar off to a plane surface flush with the top of the flow mould, by drawing the straight edge of a trowel (held nearly perpendicular to the flow mould) with a sawing motion across the top of the mould.

(e) Wipe the flow-table top clean and dry and take special care to remove any water from around the edge of the flow mould.

(f) Immediately after step (e), lift the mould away from the mortar with a rotating action and give the flow table 10 drops in 6 seconds through a height of 12 mm.

(g) Measure and record, in millimetres, the diameter of the mortar mass at least at four locations spaced at approximately equal intervals, and determine the average diameter (D_2).

(h) Calculate the flow of the mortar from the following formula:

$$F = \frac{D_2 - D_1}{D_1} \times 100$$

where

F = flow, in percent

D_2 = average diameter of mortar mass after flowing, in millimetres

D_1 = internal diameter of base of flow mould, in millimeters

Note: For example, if the internal diameter of the flow mould is 100 mm and the average diameter of the mortar mass after the flow test is 118 mm, then the % flow would be:

$$F = \frac{118-100}{100} \times 100 = 18\%$$

Note: Reference to a flow of 110 ± 5 in Clause 5.4 of AS 2701 (2001) is not appropriate to RC 376.03.

A flow of 5-20 % shall be achieved. If the flow is larger than this range, then discard the sample and prepare a new batch. If the flow is smaller, then return the sample to the mixer, add a few millilitres of water and remix for 30 seconds and retest for flow. If the flow is in the prescribed range, then return the sample to the mixer and remix for 30 seconds again and follow the procedure below.

7. Procedure

The procedure for preparation, curing, exposure to alkali and length measurement testing shall be as follows:

(a) After mixing is completed, prepare the mortar bars in accordance with ASTM C490 procedure. The gauge length of the mortar bars, so prepared, shall be 250 mm.

(b) Immediately after the specimen in the mould has been prepared, place the filled mould in a fog-room, or a moist cabinet, at 23 ± 2°C (relative humidity very close to 100 % but not less than 98%) for 24 ± 2 h. It is good practice to place a strip of plastic on the top surface of the mould to protect the mortar from dripping water if a fog-room is used.

(c) Remove the moulds from the storage cabinet or room and de-mould the specimens, ensuring that the bars are protected from loss of moisture and care is taken to ensure that the studs are not moved. Mark each mortar bar specimen with a unique identification. Mark with the letter (T) one end of the specimen which will always be at the top when placed in the comparator.

(d) Immediately place the mortar bar in the fog-room, or moist cabinet, at 23 ± 2°C (relative humidity of very close to 100%, but not less than 98%) for 48 ± 2 h. The humidity of the moist cabinet shall be such that the specimens look moist at the surface during the curing period.

(e) If using a dial gauge, record the reading for the reference bar. If using a digital comparator, zero the unit when the reference bar is placed in the comparator in the correct position.

(f) After completion of the exposure step (d), remove the mortar bars from the moist room and keep under a moist cloth. Take mortar bars one at a time and record the initial reading (L_1) of each mortar bar in the length comparator to the nearest 0.002 mm.

(g) Immediately place the mortar bar in a water bath (room temperature) and heat gradually at a rate of 18-20°C/hr to a temperature of 80 ± 2°C in three hours and maintain the mortar bars at this temperature for 1 hour.

(h) Remove the mortar bars from the water bath, one at a time, wrap the bar in plastic and dry the end gauge studs on a towel. Using the comparator, record the length of the bar (L_2). Complete this process within 15□5 sec of removing the specimen from the water.

Note 1: The reference bar should be read prior to each set of specimens since the heat from the mortar bars may cause the length of the comparator to change.

Note 2: The thermal expansion of the mortar bar can be calculated based on L_1 and L_2 measurements, if required.

(i) Immerse the mortar bar in the bath containing the1M sodium hydroxide solution at 80 ± 2°C. Ensure that the bars are immersed and supported in the bath so that the solution has access to the whole bar.
The bars shall not touch the sides of the bath or each other and shall be immersed always whilst soaking.
The bars, if stood upright shall not be supported by the metal gauge stud.

(j) Make subsequent comparator readings of the specimens (L_n) as detailed in Step (g) 1, 3, 7, 10, 14, and 21 days after placing in the 1M NaOH solution at 80°C.

Note: It is good practice to continue the measurements at least until 28 days to note the behavior of the mortar bars after the prescribed 21 days.

(k) Measure the concentration of the NaOH bath solution by titration with the hydrochloric acid solution and the phenolphthalene indicator and adjust the concentration, as necessary, to meet the requirements of 1M ± 0.05M NaOH.

8. Calculations

Calculate the following:

(a) The expansion (E_n) of each mortar bar from the following equation:

$$E_n = \frac{L_n - L_2}{250} \times 100$$

and, if required, the value of thermal expansion:

$$TE = \frac{L_2 - L_1}{250} \times 100$$

where:

E_n = expansion at the time n days, after immersion in the 1M NaOH solution at 80°C in percent, in percent

TE = thermal expansion after heating to 80°C in the water bath, in percent

L_n = comparator reading at time n days after immersion of mortar bars in the 1M NaOH solution, in mm

L_1 = Initial comparator reading, in mm

L_2 = comparator reading after heating to 80°C in the water bath, in mm

(b) The mean expansion of the three mortar bars for each batch.

9. Reference Testing

(a) A reference test shall be carried out to demonstrate that the testing laboratory, its equipment, procedures and staff are capable of testing any aggregate with a defined within-laboratory repeatability.

For reference testing, the above procedures shall be carried out on a known non-reactive aggregate, previously established to give a 21-day expansion of not more than 0.03%. Other aggregates proved to be insensitive to alkali could also be used.

(b) If the expansion measured from the reference test does not exceed 0.03% at 21 days, the in-house procedures and parameters shall be deemed satisfactory. These in-house procedures and parameters shall be documented and strictly followed in all further testing. No further reference tests are required unless any of the documented procedure or parameters are changed.

(c) If the expansion measured from the reference test exceeds 0.03% at 21 days, the in-house testing procedure and parameters shall be examined and appropriately altered. Further reference tests shall be carried out until the measured expansion is less than 0.03%.

(d) New sources of cement shall be tested in combination with the reference non-reactive aggregate to determine the influence of the new cement on aggregate reactivity and to determine the possible contribution of the cement to the measured expansion of other aggregates, for example through MgO hydration.

10. Test Report

Report the following:

(a) Type and source of aggregate, rock spalls, boulders or drill core.

(b) Type and source of cement and/or supplementary materials and their proportion used.

(c) For each required time, the expansion, in percent, to the nearest 0.001 and the number of days after placement in the 1M NaOH solution.

(d) Observations of cracks or other features revealed by examination of the specimens during and after the test.

(e) When required a plot of the expansion versus time of soaking.

11. Aggregate Reactivity Classification

(a) Aggregate shall be classified based on the 10 and 21 days expansion values in accordance with Table 2, which tabulates the requirements of VicRoads Standard Specification Section 610 – *Structural Concrete*.

(b) Some glassy basalts may cause excessive mortar bar expansion, due to the production of fine glassy particles in the fine aggregate grading required for mortar bars. The reactivity of coarse aggregate of the same source needs to be verified, because the glassy phase within compact coarse basalt aggregates may not be accessible to alkali, and may not cause excessive concrete expansion. Concrete prism tests in accordance with VicRoads RC 376.04 or concrete block tests may be required for this purpose. Experience has shown that concrete prisms made with such basalts may or may not expand, which indicates that each aggregate needs to be assessed individually.

Table 2 Aggregate Reactivity Classification

Mortar Bar Expansion (%) in 1M NaOH (80%)		Classification
10 days	21 days	
< 0.10 #	< 0.10 #	Non-reactive
< 0.10 #	> 0.10 #	Slowly reactive
> 0.10 #	» 0.10 #	Reactive
# 0.15% for naturally occurring fine aggregate		
Individual results shall not differ from the mean by more than 15%.		

If you would like to receive this publication in an accessible format, please contact: vicroadstechnicalservices@roads.vic.gov.au, or request it using VicRoads website feedback form.

VicRoads Test Method - Revision Summary

RC 376.03 – Accelerated Mortar Bar Test - Alkali-silica reactivity of aggregate

Date	Clause	Description of Revision	Authorised by
April 2016	Cl 11, Table 2	Re-added note re expansion limit for sand Defined sand as naturally occurring fine aggregate Added requirement for tolerance	Manager – Construction Materials
June 2013	Full document Cl 3 (m) Cl 6.2 Cl 7 (a) Cl 8 (a) Cl 9 (d) Cl 11 (a) Cl 11 (b)	Re-issued with minor corrections made Change to calibration requirements for moist oven Added new sub-heading Moved text from Cl 6 to new position Added definition for TE Text re-positioned and re-written to make clear Added reference to VicRoads Section 610 Changed to concrete prism test method	Manager – Construction Materials