

- 1) The cement content is increased to 420 kg/m³, still adjusting the alkali content 1.25% (Na₂O eq.) by mass of cement by adding NaOH to the mixture water, to give a concrete alkali content of 5.25 kg/m³.
- 2) The cement used for the test is a normal Portland cement with an alkali content of $\pm 0.1\%$ (Na₂O eq.), compared to $\pm 0.2\%$ in the current standard.
- 3) The effective water/cement is controlled between 0.42 to 0.45.
- 4) The proportion between coarse and fine aggregates is fixed to 60/40 (with some exceptions for high- and low-density aggregates).
- 5) The cross section of the concrete prisms is fixed at 75 x 75 mm with the possibility for their length to vary between 275 and 405 mm.
- 6) The test is always performed at 38°C (even when testing for alkali-carbonate reactivity).
- 7) The 30-minute immersion in water at 23°C before measurement is taken out.
- 8) The storage container is a 22 to 25-litre plastic pail with air tight lid; a wick absorbent material is still placed around the inside wall of the container. It is possible to use an alternative storage container at certain conditions.

The test can be used for evaluating the potential alkali-reactivity of coarse or fine aggregates, using a non-reactive fine or coarse aggregate, respectively, that expands less than 0.1% in the Accelerated Mortar Bar Method ASTM C 9 - Proposal - P 214, or less than 0.015% in the CSA Concrete Prism Method (new procedure). A 1-year, 0.04% expansion limit is still used for acceptance. In our opinion, the test could be also used for testing coarse-fine aggregate combinations.

Conclusion on the new proposed test procedure -- The new procedure proposed should allow detection of most slowly-expanding reactive aggregates which the current test procedure failed in recognizing. However, based on Quebec experience and at least for concretes made with cement contents of less than 375 to 385 kg/m³, the method might be severe for many innocuous or marginally reactive aggregates, in particular for natural and quarried carbonate aggregates. Indeed, half of all representative gravels from Quebec that have been tested at Laval University, using a cement content of 410 kg/m³, expanded more than 0.04% after 1 year, while just a few of them are considered to be deleterious reactive in the field (25). In another study on representative quarried carbonate aggregates from Quebec, in which the concrete prisms were made with a significantly lower cement content (e.g. 350 kg/m³) than the one proposed, it was necessary to adopt a less severe criterion of 0.06% after 1 year to distinguish between reactive and non-reactive aggregates, based on known field performance of the aggregates tested (see Figs. 7 and 9).

Accelerated Concrete Prism Methods in 1N NaOH solution

The CSA Concrete Prism Method requires one year to conclude, and is therefore not satisfactory in many situations. A number of accelerated concrete methods have been proposed to accelerate the process of aggregate characterization, using autoclaving

immersion in alkaline solution at high temperature for most of them. These methods are discussed elsewhere (2).

Immersion in 1N NaOH at 38°C -- In a study sponsored by the Canadian Electrical Association (CEA) on mass concrete structures affected by AAR (26), a number of concrete test procedures were investigated, among which: 1), the current CSA Concrete Prism Method; 2), a procedure that is very similar to the new proposed CSA concrete prism method described before, and 3), a procedure consisting in immersing concrete prisms made in accordance with the current CSA procedure, but tested in 1N NaOH at 38°C. The latter procedure looked very promising for several reasons:

- 1) The current CSA Concrete Prism Method failed in detecting 4 of the 9 reactive aggregates tested in that particular study (Fig. 8), in addition to the slowly expanding aggregates mentioned before.
- 2) The new proposed CSA Concrete Prism Method was not able to detect one of the reactive aggregates tested (a natural lithic gravel from Alberta) (Fig. 8), while being severe for many other natural gravels and quarried carbonate aggregates from Quebec, as mentioned before.
- 3) In the meantime, testing CSA concrete in 1N NaOH at 38°C properly classified all aggregates tested in this study, 9 reactive and 2 non-reactive, according to a 6-month, 0.04% expansion limit criterion (Fig. 8).
- 4) The latter method allowed the best differentiation between aggregates.
- 5) It showed the lowest variability between companion prisms tested together.
- 6) The specimens are not subjected to alkali leaching during the tests.
- 7) The results can be obtained in 6 months, using the usual 0.04% expansion limit, compared to 1 year for the two other procedures.

Immersion in 1N NaOH at 80°C -- In Quebec, concrete test prisms are also made in accordance with the CSA Concrete Prism Method and tested in 1N NaOH solution at 80°C (2,26) with the expectation to obtain more realistic results, because testing concrete specimens, than with the corresponding accelerated method on mortar specimens (ASTM C 9 - Proposal - P 214). A 24-day, 0.04% expansion limit criterion is suggested for aggregate acceptance in this so-called "Accelerated Concrete Prism Method". Up to now, the test has been performed on a large number of aggregates of various types and compositions proving to be severe for numerous innocuous or presumably innocuous aggregates (2), particularly for a number of quarried carbonate aggregates (Fig. 9), natural gravels (25) and other aggregates with a granitic composition (26).

CONCLUSION

In Canada, a number of testing methods proved to be not reliable enough to be adopted as routine tests, such as the Chemical Method ASTM C 289, the Mortar Bar Method ASTM C 227 and the Accelerated Concrete Prism Method performed at 80°C in 1N NaOH, while others are very promising, for instance the Concrete Prism Method performed at

38°C in 1N NaOH. At the present state of knowledge, only three methods are considered applicable to most concrete aggregates: 1), the Petrographic Examination ASTM C 29, 2), the Accelerated Mortar Bar Method (ASTM C 9 - P 214 or CSA proposal), and 3), the Concrete Prism Method CSA A23.2-14A. Accordingly, the decision chart shown on Figure 10, which is, however, mainly based on Canadian experience of AAR and could not necessarily apply to all aggregates found in other countries, has been included in the proposed version of the CSA Standards for AAR (1).

However, as shown on this figure, the most realistic information on the potential alkali-reactivity of concrete aggregates is provided by their field performance in existing structures. If such information is not available or judged insufficient for a number of reasons, the aggregates then have to be tested in the laboratory. In such situations, it must be highly emphasized that the Petrographic Examination is always the first step to do. It can be used to accept or even to reject the aggregate under study, or at least to select the most appropriate test methods to run, in order to prevent poor choices and reduce the amount of work. Indeed, some testing methods are not capable of detecting some deleterious aggregates, while being too severe for innocuous ones. The only other rapid testing method that is statistically dependable enough and more highly recommended as a routine test is the Accelerated Mortar Bar Method. This method cannot be used to reject materials because it is severe for numerous innocuous aggregates. However, it remains a very powerful screening tool since only a few deleterious aggregates cannot be detected, which can be readily recognized in the Petrographic Examination. The current CSA Concrete Prism Method is considered as the most realistic testing method for determining the potential reactivity of concrete aggregates except for a number of slowly expanding aggregates which, however, should be easily detected using the new proposed CSA Concrete Prism Method.

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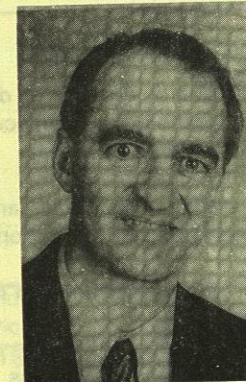
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Table 1 -- Mineral Phases and Corresponding Rocks Susceptible to Deleterious Alkali-Aggregate Reactions in Concrete.

A. ALKALI-REACTIVE SILICA MINERALS AND ROCKS	
A.,	Alkali-Reactive Poorly Crystalline or Metastable Silica Minerals, and Volcanic or Artificial Glasses (Classical Alkali-Silica Reaction).
Reactants:	Opal, tridymite, cristobalite; acid, intermediate, and basic volcanic glasses; artificial glasses, beekite.
Rocks:	<p>Rock-types containing opal such as shales, sandstones, silicified carbonate rocks, some cherts, flints, and diatomite.</p> <p>Vitrophyric volcanic rocks: acid, intermediate and basic, such as rhyolites, dacite latites, andesites and their tuffs, perlites, obsidians; all varieties with a glassy groundmass; some basalts.</p>
A.,	Alkali-Reactive Quartz-Bearing Rocks.
Reactants:	Chalcedony; cryptocrystalline to microcrystalline quartz; quartz with deformed crystal lattice, rich in inclusions, intensively fractured or granulated; poorly crystalline quartz at grain boundaries; quartz cement overgrowths (in sandstones).
Rocks:	<p>Cherts, flints, quartz veins, quartzites, quartz-arenites, quartzitic sandstones which contain microcrystalline to cryptocrystalline quartz and/or chalcedony.</p> <p>Volcanic rocks such as A, but with devitrified, cryptocrystalline to microcrystalline groundmass.</p> <p>Micro-granular to macro-granular silicate rocks of various origins which contain microcrystalline to cryptocrystalline quartz:</p> <ul style="list-style-type: none"> • Metamorphic rocks: Gneisses, quartz-mica schists, quartzites, hornfels, phyllites, argillites, slates. • Igneous rocks: Granites, granodiorites, charnockites. • Sedimentary rocks: Sandstones, greywackes, siltstones, shales, siliceous limestones, arenites, arkoses. <p>Sedimentary rocks (sandstones) with epitaxial quartz cement overgrowths.</p>
B. ALKALI-REACTIVE CARBONATE ROCKS	
Reactants:	Dolomite (dedolomitization process) and active clay minerals (illite) exposed to dedolomitization process.
Rocks:	Argillaceous dolomitic limestones, argillaceous calcitic dolostones, quartz-bearing argillaceous rocks, calcitic dolostones.

Table 2 -- Testing Methods Commonly Used in North America for AAR.

TESTING METHOD	Used	For
	ASR	ACR
Petrographic Examination (ASTM C 295) (≥ 1 d)	X	X
Chemical Methods		
• Chemical Method CSA Proposal A23.2-26A (1-2 d)	X	
• Chemical Method ASTM C 289 (2-3 d)	X	
Mortar Bar Methods		
• Mortar Bar method ASTM C 227 (6 m)	X	
• Proposed Accelerated Method ASTM C 9 - P 214 or CSA (2 w)	X	
Concrete Prism Methods		
• Concrete Prism Method CAN/CSA A23.2-14A (1 y)	X	X
• Proposed method in 1N NaOH at 38°C (used in Canada) (6 m)	X	?
• Accelerated Method in 1N NaOH at 80°C (used in Canada) (1 m)	X	?

ASR: Alkali-silica reactivity. ACR: alkali-carbonate reactivity.

Table 3 -- Expansion Limit Criteria Proposed for Aggregate Acceptance with the Accelerated Mortar Bar Method.

Reference	Aggregate type	Criterion for acceptance	Remarks
Davies & Oberholster (12) (South Africa)	All types	$< 0.10\% - 12$ d	0.10-0.25%: sl. exp.; >0.25%: rapidly exp.
Shayan et al. (18) (Australia)	All types	$< 0.22\% - 22$ d	$< 0.10\%/10d$ & >0.10%/22d: sl. exp.; >0.10%/10d: rap. exp.
Grattan-Bellew (15) (Canada)	Siliceous limestones Greywackes, argillites Others	$< 0.10\% - 14$ d $< 0.20\% - 14$ d $< 0.15\% - 14$ d	
Bérubé et al. (16) (Canada)	Quarried aggregates Natural sands & gravels	$< 0.10\% - 14$ d $< 0.20\% - 14$ d	
Hooton & Rogers (17) (Canada)	All types	$< 0.15\% - 14$ d or $< 0.33\% - 28$ d	
ASTM C 9 - Proposal -P 214 (14) (U.S.A.)	All types	$< 0.10\% - 14$ d	0.10-0.2%: sl. exp.; >0.20%: rapidly exp.
CSA Proposal (1) (Canada)	All types	$< 0.15\% - 14$ d	Indications in the standard regarding this limit which might be too severe for some aggregates while not enough for others

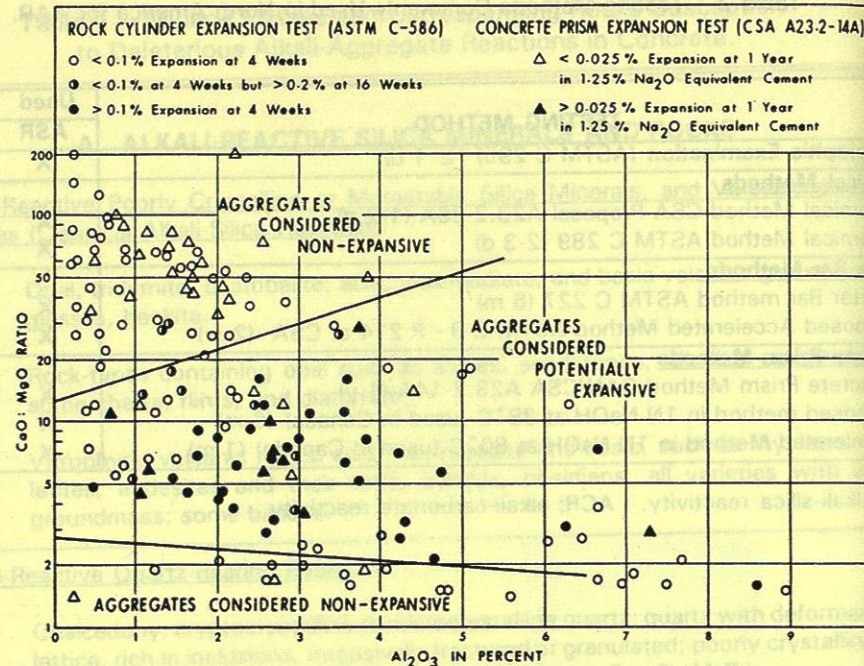


Fig. 1 -- Illustration of the division between non-expansive and potentially expansive alkali-carbonate reactive rock on the basis of chemical composition. (Proposed method CSA A23.2-26A for detecting alkali-carbonate reactivity (1)).

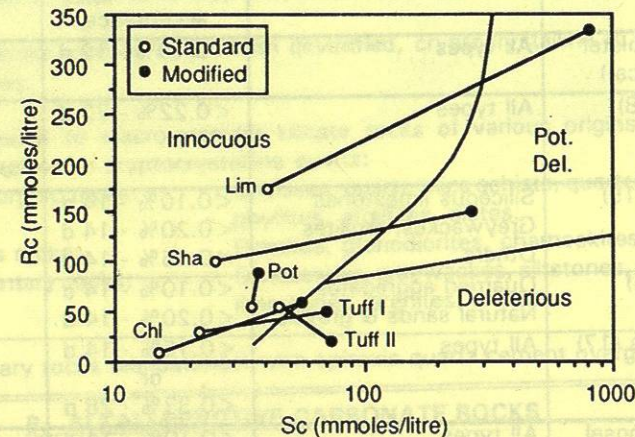


Fig. 2 - Examples of alkalisilica reactive aggregates from Quebec (Canada) that are detected using the standard Chemical Method ASTM C 289. However, most of them appear deleterious or potentially deleterious when the test is performed on the insoluble residue in accordance with the so-called "Modified Chemical Method" (6). (Lim = siliceous limestone; Pot = Potsdam sandstone; Chl = chloritic schist; Sha = siliceous shale; I & II = rhyolitic tuff I & II).

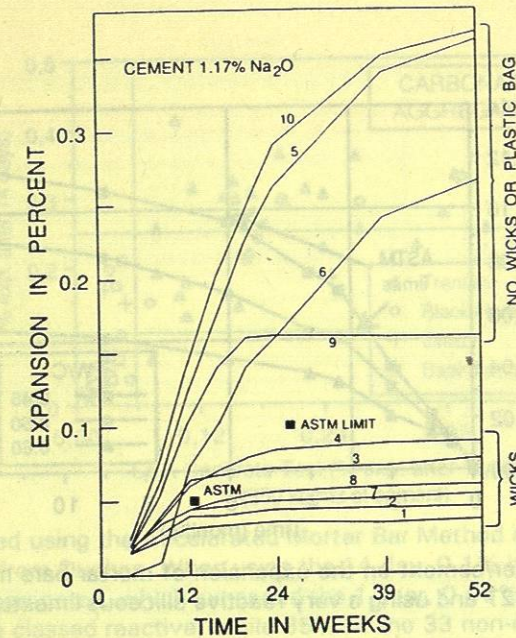


Fig. 3 - Expansion of mortar bars made and tested in accordance with ASTM C 227 with a very alkali-silica reactive limestone from Ottawa (Ontario, Canada), and stored in various types of containers. The presence or absence of wicks inside the containers is very critical. Container #1 is the container proposed in the ASTM standard. From reference (11).

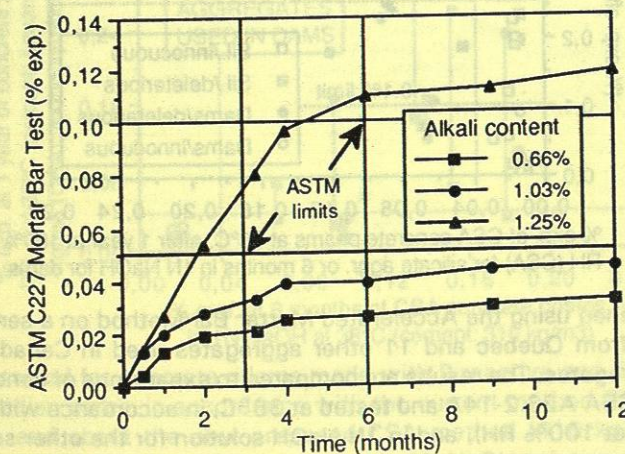


Fig. 4 - Effect of the alkali content (%Na₂O eq. by mass of cement) on the expansion of mortar bars made and tested in accordance with ASTM C 227 and using a very reactive siliceous limestone from Ottawa (Ontario, Canada).

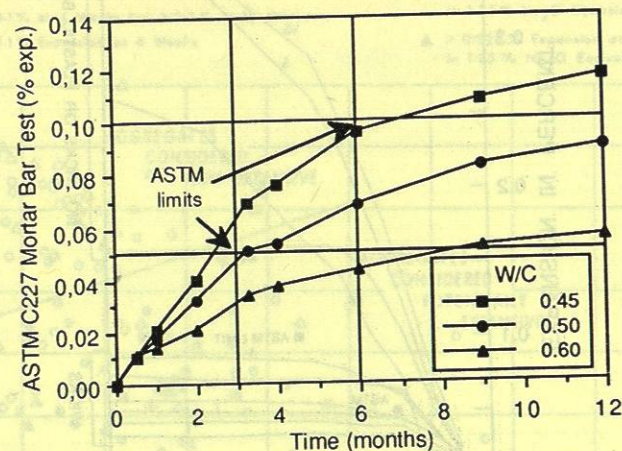


Fig. 5 - Effect of the water/cement on the expansion of mortar bars made and tested in accordance with ASTM C 227 and using a very reactive siliceous limestone from Trois-Rivières (Quebec, Canada).

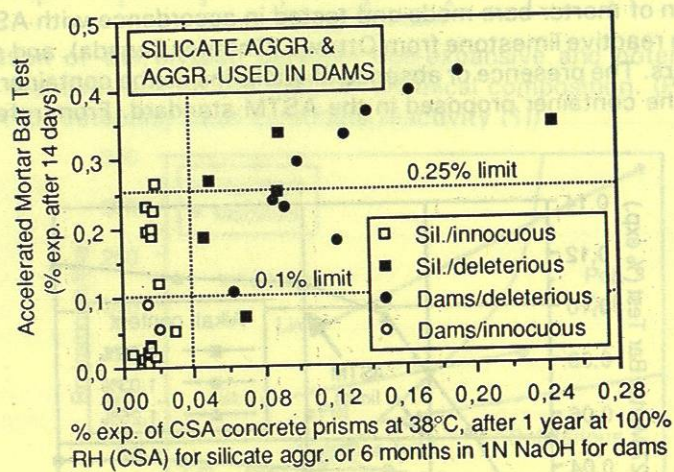


Fig. 6 - Results obtained using the Accelerated Mortar Bar Method on a series of 22 quarried silicate aggregates from Quebec and 11 other aggregates used in Canadian dams, compared to expansions of concrete prisms in accordance with CSA A23.2-14A and tested at 38°C, in accordance with this standard. The first series (e.g. at 100% RH), and in 1N NaOH solution for the other series. When using the 14-day, 0.10% proposed mortar bar expansion limit, all 15 deleterious aggregates in the field, which induced concrete prism expansion > 0.04% after one year (CSA test) or 6 months (immersion test), respectively, are classed reactive (all except the Potsdam sandstone), while only 11 of the 18 innocuous or presumably innocuous aggregates were evaluated correctly.

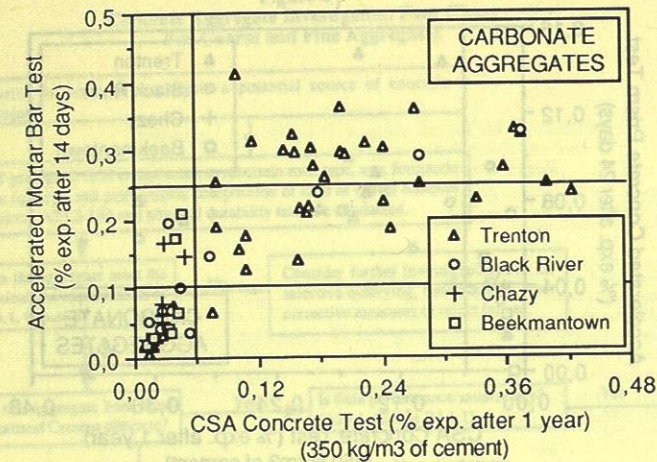


Fig. 7 - Results obtained using the Accelerated Mortar Bar Method on a series of 71 quarried carbonate aggregates from Quebec. When using the 14-day, 0.1% mortar expansion limit, 37 of the 38 expansive aggregates, which exceeded the 1-year, 0.06% concrete expansion limit used in that study, are classed reactive, while 85% of the 33 non-expansive aggregates are evaluated correctly.

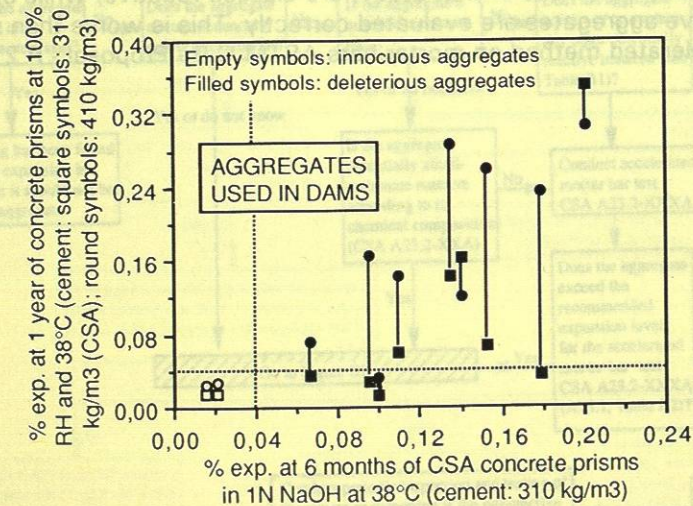


Fig. 8 - Results obtained for concrete prisms made with 9 reactive and 2 non-reactive aggregates used in Canadian dams, in accordance with the current method CSA A23.2-14A (310 kg/m³ of cement), and about the new proposed CSA method (410 kg/m³ of cement), and tested at 38°C, at 100% RH (both concretes) and in 1N NaOH solution (CSA concrete). The latter procedure was the only one able to properly classify all aggregates tested, using a 6-month, 0.04% expansion limit criterion. The current and the new proposed CSA methods failed in recognizing 4 and 1 of the reactive aggregates tested, respectively.