ALKALI - AGGREGATE REACTION 1981
ALKALI - AGGREGAATREAKSIE
S252

CANADIAN EXPERIENCE OF ALKALI-EXPANSIVITY IN CONCRETE

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SYNOPSIS

The Canadian Standards Association (CSA) and the American Society for Testing and Materials (ASTM) standards and tests for aggregates, cements, flyash and pozzolans are reviewed and their relevance to preventing or minimizing cement aggregate reactions giving rise to excessive expansion of concrete is discussed. Recently, the use of a CSA type 50 sulphate-resistant portland cement was found to reduce dramatically the expansion of some concrete made with reactive aggregate. The composition and alkali content of typical Canadian portland cements is listed. The effect of replacing part of the cement in concrete with a pozzolan or flyash is discussed.

SAMEVATTING

Die standaarde en toetse vir aggregate, sement, poeierkoolas en possolane van die Canadian Standards Association (CSA) en die American Society for Testing and Materials (ASTM) word oorsigtelik behandel en die toepaslikheid daarvan om sement-aggregaatreaksie wat tot buitengewone uitsetting van beton lei, te voorkom of tot 'n minimum te beperk, word bespreek. Daar is onlangs vasgestel dat die uitsetting van sekere beton, wat met reaktiewe aggregaat vervaardig is, drasties deur die gebruik van 'n CSA-tipe 50-sulfaatbestande portlandsement verminder is. Die samestelling en alkali-inhoud van tipiese Kanadese portlandsement word aangegee. Die uitwerking daarvan om 'n deel van die sement in beton met 'n possolaan of poeierkoolas te vervang, word bespreek.

S252/6

Conference on alkali-aggregate reaction in concrete
Cape Town - South Africa
March 30 - April 3, 1981

Konferensie oor alkali-aggregaatreaksie in beton
Kaapstad - Suid-Afrika
30 Maart - 3 April, 1981

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1. INTRODUCTION

The first case of alkali-expansivity in Canada was reported almost 20 years ago. Since then, examples of potentially expansive aggregates have been identified from the east to the west coasts and from the Great Lakes in the south to inside the Arctic Circle in the north. Alakli-reactivity has been shown to be the primary cause of deterioration of a number of concrete structures exposed to high humidity (mostly bridges and dams in Eastern Canada)[1]. Once cracking has been initiated by the alkali-aggregate reaction, deterioration may be hastened by the action of cycles of freezing and thawing.

The deterioration of concrete bridges due to alkali-aggregate expansivity is exacerbated by the use of de-icing salts, NaCl and $CaCl_2$. Smith[2] has shown that the addition of NaCl increases the expansion of alkali-carbonate expansive aggregates. Despite examples of alkali expansivity, most concrete structures in Canada are durable, but potential problems due to the alkali expansivity of aggregates exist in certain regions. Some aggregates from Western Canada, which now perform satisfactorily in concrete made with the low alkali cement currently used there, could give rise to problems if the alkali content of the cement were raised as a result of environmental or economic reasons. The Canadian Standards Association has therefore drawn up standards and recommendations for the testing and use of proper quality aggregates.

2. CANADIAN STANDARDS

Materials:

(a) *Portland cement.* The Canadian Standards Association (CSA) specifies five types of portland cement (CAN3-A5-M77)[3], corresponding to ASTM types I to V[4]:

(i) normal portland cement, type 10;
(ii) moderate (heat of hydration) portland cement, type 20;
(iii) high early strength portland cement, type 30;
(iv) low heat of hydration portland cement, type 40;
(v) sulphate resisting portland cement, type 50.

The current standards do not include specifications for blended blastfurnace slag cement, but blends containing 25 to 65 per cent slag will be included in the new specifications for blastfurnace slag portland cement. The new specifications will also cover the use of slag-modified portland cements containing between 7 and 20 per cent slag. At present, blended blastfurnace slag cements are used only in the Hamilton area of Southern Ontario. The chemical and physical requirements for portland cement listed in CAN3-A5 show that from the viewpoint of alkali-aggregate reactivity there is no requirement covering the alkali content of portland cement. This matter is currently under study by a committee of the Association. Despite a forecast of rising alkali levels in cement as new plants come into production[5], figures issued by the industry indicate that there has been virtually no change in alkali content during the last 10 years (Figure 1). Owing to the availability of raw materials with low alkali content and the requirement for low alkali cement in parts of the USA to which cement is exported, low alkali cement is produced in Western Canada. Relatively high alkali cements are produced in Eastern Canada.

(b) *Pozzolans.* The chemical and physical requirements for pozzolanic mineral admixtures, as specified in CAN3-A266-3-M78[6], are shown in Table 1, page 2. In contrast with the standard for portland cements in which there is no mention of alkalis, the standard for pozzolans requires that the purchaser be supplied with an analysis showing the maximum available alkali content if the pozzolan is to be used with reactive aggregates. Two types of pozzolanic admixtures are specified in A266-4: Type N, consisting of raw or calcined shales, volcanic glass, opal, chert and diatomaceous earth; and Type F, flyash. Very little Type N is used and the standard does not comment on it. About one million tons of Type F (flyash) are produced annually in Canada, but only 100 000 tons are used. The standard states that Type F may be used to replace 10 to 40 per cent of cement to increase resistance to sulphate attack and to reduce the effects of the alkali-silica reaction.

(c) *Limestone addition to portland cement.* A new standard has been recommended permitting the replacement of portland cement by 5 per cent limestone crushed to Blaine fineness between 4 000 and 9 000 cm^2/g. Tests have shown that not only is the durability of concrete unaffected by the addition of limestone but that it promotes increased development of compressive strength (Figure 2, page 2). Neither the small reduction in the amount of cement nor the increased compressive stength is likely to have an appreciable effect on the expansion of concrete made with alkali-expansive aggregates.

(d) *Aggregates.* The grading and limits for deleterious substances in fine and coarse aggregates, specified by A23-1-M77[7], are shown in Tables 2 and 3, pages 3

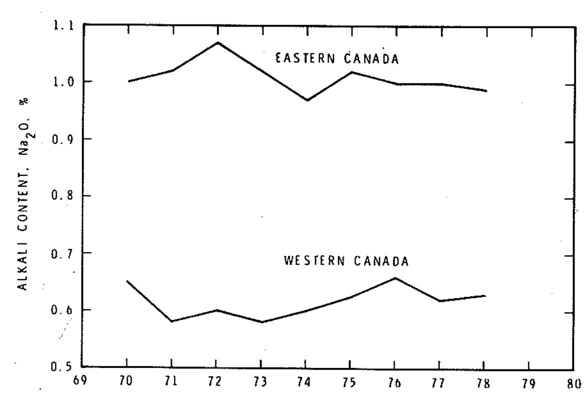


FIGURE 1: Variation of the average alkali contents of cements produced in Eastern and Western Canada between 1970 and 1978

TABLE 1(a) : Testing procedures for pozzolans*

Test	Reference Standards	
Chemical tests:		
Sulphur trioxide (SO_3) content	CSA CAN3-A5	
Available alkalis as Na_2O	ASTM C311	
Moisture content	ASTM C311	
Loss on ignition	ASTM C311	
Physical tests:		
Pozzolanic activity with portland cement	ASTM C618	
Water requirement	ASTM C618	
Pozzolanic activity with lime	ASTM C595	
Drying shrinkage	ASTM C311	
Relative density	ASTM C188	
Soundness	ASTM C311	
Reactivity with cement alkalis	ASTM C441	
Uniformity of air content	ASTM C618	
Fineness-wet sieved on 45 μm sieve	ASTM C430	except use a representative sample of pozzolan instead of hydraulic cement
* (After CSA CAN3-A266.3-M78)		

TABLE 1(b) : Chemical requirements for pozzolans*

Property	Maximum per cent Pozzolan type N	Maximum per cent Pozzolan type F	Minimum frequency of testing
Sulphur trioxide (SO_3)	3,0	3,0	One test per lot or every 10 000 tonnes.
Available alkalis as Na_2O	1,5	1,5	
Moisture content	3,0	3,0	One test per lot or every 100 tonnes
Loss on ignition (LOI)	10,0	12,0	
* (After CSA CAN3-A266.3-M78)			

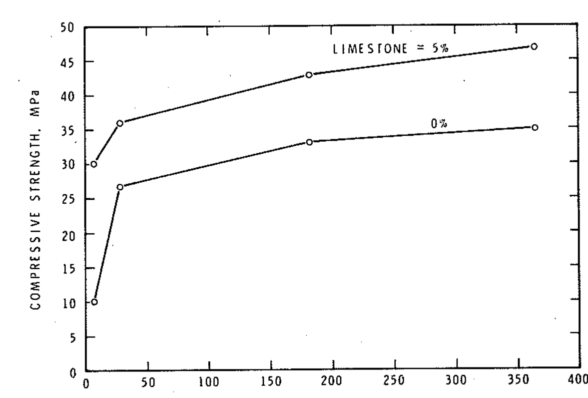


FIGURE 2: Effect of the addition of ground limestone on the compressive strength of concrete cylinders, with time of curing

and 4, respectively. Clause 5.3.3.3.1 states that fine aggregate in concrete subject to frequent wetting or high humidity or in contact with moist ground shall not react with the alkalis in the cement to result in excessive expansion of concrete. Clause 5.3.3.2.1 dealing with coarse aggregates, is essentially the same, but it concludes with the statement 'such reactive aggregate may be used only when corrective measures acceptable to the authority are applied'. The corrective measures are not specified.

3. TEST METHODS

The approved test for alkali-expansivity of fine aggregates is the mortar bar method, ASTM C227[8]. The concrete prism test, CAN3-A23.2-14A[9], or the rock cylinder test, ASTM C586[10], are acceptable for detecting potential alkali-expansivity in coarse aggregate.

TABLE 2(a) : Grading limits for fine aggregate*

Sieve size	Total passing sieve percentage by mass
10 mm	100
5 mm	95 - 100
2,5 mm	80 - 100
1,25 mm	50 - 90
630 μm	25 - 65
315 μm	10 - 35
160 μm	2 - 10
* (After CSA CAN3-A23.1-M77)	

TABLE 2(b) : Limits for deleterious substances in fine aggregates*

Substances	Maximum percentage by mass of total sample
Clay lumps	1,0
Coal or lignite	0,5
Material finer than the 80 μm sieve	3,0
Chert, shale, siltstones, sandstones, argillaceous limestones, friable particles, etc	
Reactive aggregates	(see Clause 5.3.3.3)
* (After CSA CAN3-A23.1-M77)	

In the Appendices to CAN3-A23.2-1 (not a mandatory part of the standard) additional precautions to guard against deleterious expansion of concrete made with reactive aggregates are discussed and the types of alkali-expansive aggregate likely to be encountered are listed. Appendix B1 states that it may be impossible to use aggregates containing reactive rock types in concrete exposed to a continuously moist environment, even if they show only small expansions. If significant penetration of concrete by salt solutions is likely (for example, bridge decks treated with de-icing salts), reactive aggregate should not be used even with low alkali cement. The marked increase in the rate of expansion of concrete cured in salt solutions over that of concrete cured at 100 per cent relative humidity (RH) is shown in Table 4, page 4. Appendix B1 also states that the 'replacement of a portion of the cement by pozzolanic material has effectively reduced the expansion in many cases of alkali silica reactivity but alkali carbonate expansivity is relatively unresponsive to pozzolans'.

Appendix B2 (CAN3-A23.2-1) lists:

(i) Alkali-silica reactivity involving opal, chert, chalcedony, glassy or cryptocrystalline volcanic rocks, etc;
(ii) Reactivity involving siliceous rocks such as greywacke, phyllite, schist, quartzite (slowly expanding siliceous aggregates);
(iii) Alkali-carbonate reactivity involving certain fine-grained dolomitic limestones.

Clause B2.1 suggests that if a petrographic test indicates the presence of potentially reactive rocks, preventive measures should be taken until test results are available. Clause B2.2 states that it is not possible to identify expansive carbonate rocks by petrographic methods.

TABLE 3(a) : Grading requirements for coarse aggregates (after CSA CAN3-A266.3-M78)

	Nominal size of aggregate mm	Total per cent by mass passing each sieve with apertures in mm of:										
		112	80	56	40	28	20	14	10	5	2,5	1,25
Group I	40 - 5	-	-	100	95 - 100	-	35 - 70	-	10 - 30	0 - 5	-	-
	28 - 5	-	-	-	100	95 - 100	-	30 - 65	-	0 - 10	0 - 5	-
	20 - 5	-	-	-	-	100	90 - 100	-	25 - 60	0 - 10	0 - 5	-
	14 - 5	-	-	-	-	-	100	90 - 100	45 - 75	0 - 15	0 - 5	-
	10 - 2,5	-	-	-	-	-	-	100	85 - 100	10 - 30	0 - 10	0 - 5
Group II	80 - 40	100	90 - 100	25 - 60	0 - 15	-	0 - 5	-	-	-	-	-
	56 - 28	-	100	90 - 100	30 - 65	0 - 15	-	-	0 - 5	-	-	-
	40 - 20	-	-	100	90 - 100	25 - 60	0 - 15	-	0 - 5	-	-	-
	28 - 14	-	-	-	100	90 - 100	30 - 65	0 - 15	-	0 - 5	-	-
	20 - 10	-	-	-	-	100	85 - 100	-	0 - 20	0 - 5	-	-
	14 - 10	-	-	-	-	-	100	85 - 100	0 - 45	0 - 10	-	-
	10 - 5	-	-	-	-	-	-	100	85 - 100	0 - 20	0 - 5	-

Note: Group I grading normally used on concrete. Group II provides for special grading required in gap grading, concrete for pumping, etc.

4. CASE HISTORIES

(a) Appalachian region

This region, which covers Nova Scotia, Newfoundland and New Brunswick (Figure 4), is underlain by Palaeozoic rocks, viz, metamorphosed sediments, greywacke, phyllite, quartzite, argillite and sandstone, and volcanic rock rhyolites. An extensive survey and test programme for alkali expansivity in Nova Scotia has been carried out by Duncan et al[14-17]. Although some of the aggregates in use in Nova Scotia (for example, a quartzite used as aggregate in Halifax) were found to be non-expansive, a number of structures showed serious deterioration due, primarily, to alkali-aggregate expansivity. The deterioration of a bridge in New Glasgow is shown in Figure 5. Examination of the concrete by Duncan[18] showed that expansion was due to reaction of quartzite and a rhyolite coarse aggregate. A concrete prism test on the rhyolite (by the author) showed it to have a rate of expansion of $13{,}5 \times 10^{-3}$ $days^{-1/2}$ and an expansion of 0,12 per cent in 450 days.

A hydro electric dam built in 1925 at Malay Falls, Nova Scotia, showed considerable deterioration of the concrete. Extensive repairs were carried out in 1952, but they were not entirely successful and cracking occurred in the new concrete. The original concrete for the dam was made with a feldspathic quartzite, which is now exposed above the dam. It consists of 83 per cent quartz grains, 15 per cent microcrystalline material of clay size, and 2 per cent feldspar number 73-50[19]. The expansion of concrete prisms made with this aggregate and low and high alkali cements is shown in Figure 6, page 6.

From the number of cases of alkali-expansivity documented in Nova Scotia, it would appear to be prudent to use low alkali cement for major construction projects, such as bridges, unless the aggregate to be used has a history of satisfactory performance. Although one cement company has a silo full of low alkali cement, none is used at present in this area. The premium price charged for low alkali cement discourages its use because satisfactory results have so far been obtained in most cases with aggregates from established pits and normal high alkali cement.

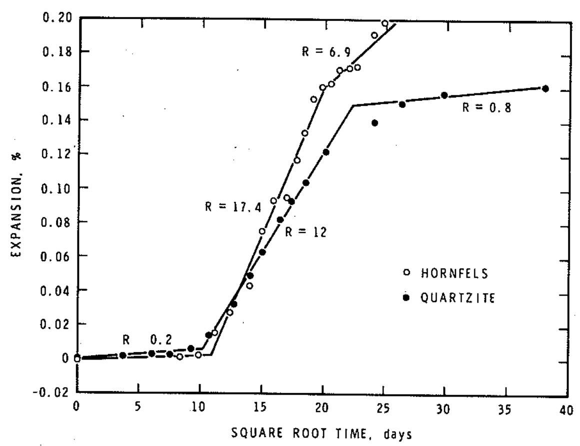


FIGURE 3: Expansion of concrete prisms plotted against √time, for an expansive dark grey quartzite from Sudbury, Ontario, and a hornfels from Cape Province, South Africa[13]

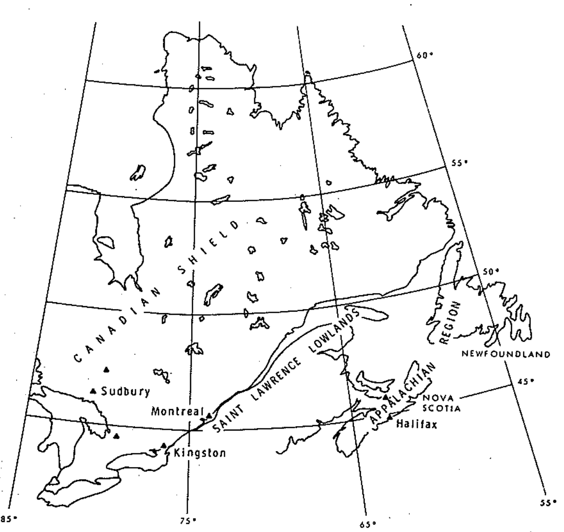


FIGURE 4: Map of Eastern Canada showing locations where structures damaged by alkali expansivity of concrete have been identified (locations marked by a triangle ▲)

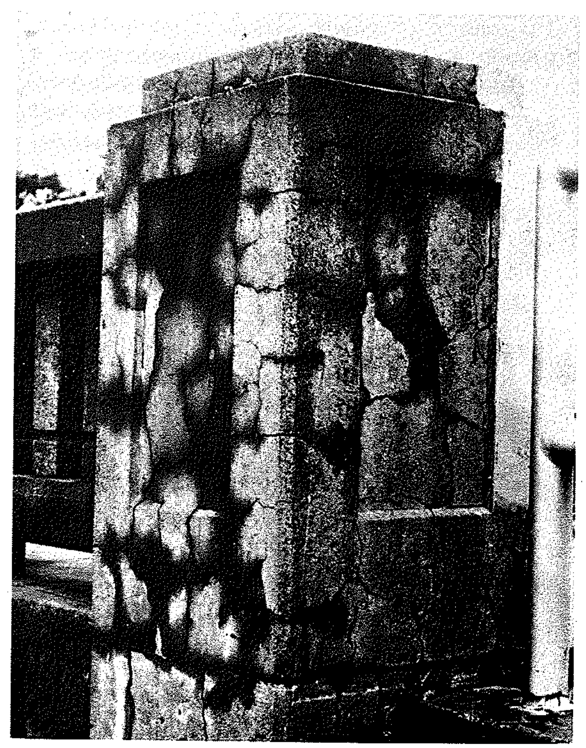


FIGURE 5: Severe cracking of part of a bridge in New Glasgow, Nova Scotia, due to alkali-aggregate reaction

TABLE 3(b) : Limits for deleterious substances and physical property requirements for coarse aggregate*

Exposure conditions	Maximum allowable, per cent				
	Clay lumps	Coal particles	Material finer than 80 μm	Magnesium sulphate soundness loss	Abrasion loss
A and B	0,25	0,5	1,0	12	50
C and D	0,5	1,0	1,0	18	50

* (After CSA CAN3-A266.3-M78)

TABLE 4 : Effect of NaCl on the expansion of concrete prisms (after Smith[2])

Concrete prisms	Alkali content of cement % Na_2O equiv	Rate of expansion, $days^{-1/2} \times 10^3$ of concrete cured in	
		100% RH	NaCl solution
Expansive	0,45	4,1	7,7
Expansive	1,1	8,1	29,0
Non-expansive	1,1	1,1	1,5

The following test methods are approved by A23-1: ASTM C227[8], the mortar bar method; ASTM C295[11], petrographic examination; ASTM C289[12], chemical method; ASTM C586[10], rock cylinder method; and CAN3-A23.2-14A alkali-aggregate reaction (concrete prism test).

Concrete prism test (CAN3-A23.2-14A). The specimens for the concrete prism test may have dimensions within the following limits: 75 x 75 x 350 mm to 120 x 120 x 450 mm. The curing temperature is 23 °C at 100 per cent RH; the alkali content of the cement, 0,9 ± 0,1 per cent Na_2O equivalent brought up to 1 per cent alkali content by the addition of NaOH. When cements with alkali contents above 1 per cent are encountered, the cement with the highest alkali content should be used for the test.

The standard states that the evaluation of the potential expansivity of an aggregate should be based on the interpretation of test results and the performance of field structures. This is important because it is extemely difficult to evaluate the likely performance of a concrete structure from the results of, for example, the concrete prism test.

Limits of expansivity for test A23.2-14A. For concrete subject to moist conditions, viz, bridges, dams, piers, etc, expansion is considered deleterious if it exceeds 0,02 per cent in three months. In a relatively dry environment the limit is set at 0,04 per cent in three months. These limits are, however, quite unsatisfactory because they imply that expansions less than those specified do not indicate deleterious expansion. In slowly expanding siliceous aggregates it may take one or two years before the concrete shows significant expansion. For example, a fine-grained dark grey quartzite from Sudbury expanded by 0,15 per cent in eighteen months, although the expansion at four and a half months was only 0,015 per cent. Another example, a hornfels from South Africa[13] expanded by 0,19 per cent in 20 months, but showed less than 0,02 per cent at five months. Both samples are deleteriously expansive and would be classed as non-expansive according to the specifications (Figure 3, page 5).

The recommendation that aggregates be evaluated by comparison of laboratory test data with field experience of concrete made with the same aggregate is often inappropriate, for example, in the evaluation of an aggregate from a new quarry.

(b) St Lawrence lowlands

This is a region of Palaeozoic sediments running parallel to the St Lawrence River along the southern margin of the Precambrian rocks of the Canadian Shield.

(c) Montreal area

The first case of alkali expansivity reported in this area was related to the Mercier Bridge, built in 1928, which expanded and cracked[1] after 20 years. Examination of cores from the bridge showed coarse aggregate grains surrounded by reaction rims; pockets of gel were also observed (Figure 7). A chalcedonic phyllite was identified as the probable reactive aggregate.

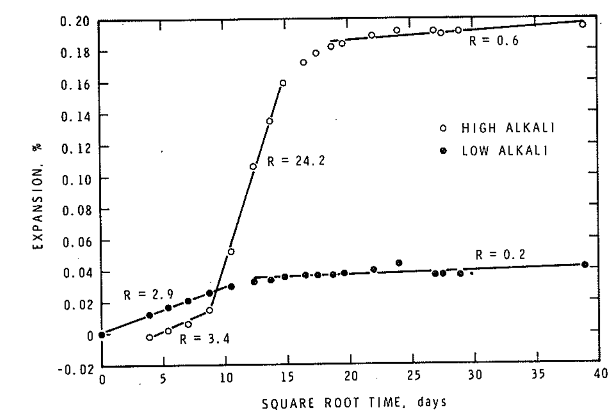
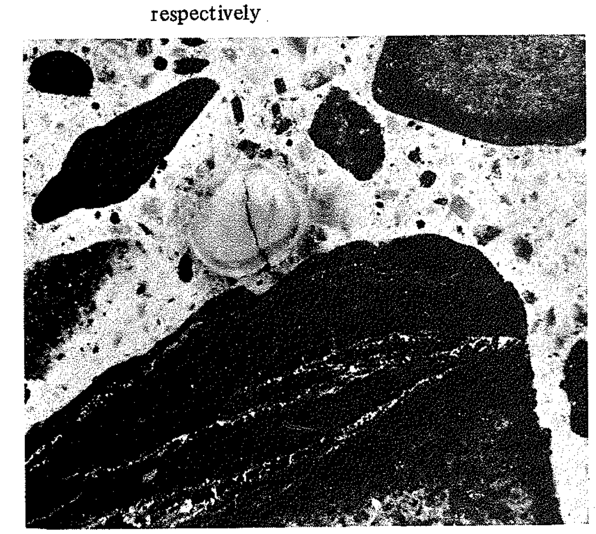


FIGURE 6: Expansion of concrete prisms stored at 38 °C and 100% RH made with feldspathic quartzite from Malay Falls, Nova Scotia, with low and high alkali cement, LA and HA respectively



1 cm

FIGURE 7: Optical micrograph of polished surface of concrete showing reaction rims around reactive aggregate particles and also a void filled with gel

More recently, Berard and Lapierre[20] showed that some horizons in the Potsdam sandstone caused deleterious expansion of concrete when used as aggregate with high alkali cement (Figure 8). The expansive sandstone consists of interlocking grains of quartz with some chert; the latter was probably the reactive component. Not all horizons of this sandstone are expansive.

Some patio slabs made with limestone from Montreal show expansion and pop-outs. Concrete prism test results have shown the concrete to be expansive (Figure 9, page 7). Some rail ties made of reinforced precast concrete using limestone from Montreal, have also shown alkali-expansion that resulted in cracking. The limestone is of variable composition ranging from a coarse biospartite to a micrite (fine-grained limestone with clay and recrystallised dolomite rhombs). Some chert grains occur in this rock.

It is not known how much of the Montreal limestone is reactive, or whether the reactivity is confined to occasional horizons. To the present time no precautions have been taken in its use. The Potsdam sandstone is not commonly used as concrete aggregate.

(d) Kingston

The expansion of argillaceous dolomitic limestone from a Kingston quarry has been extensively studied by Swenson and Gillott[21]. Other alkali-carbonate aggregates have been

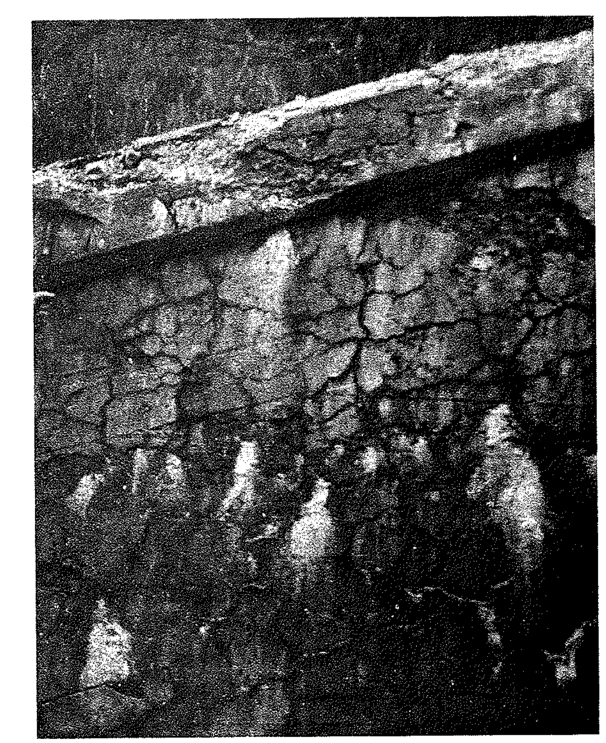


FIGURE 8: Cracking and deterioration of concrete retaining wall of railway viaduct near Valleyfield, Quebec. The aggregate is Potsdam sandstone

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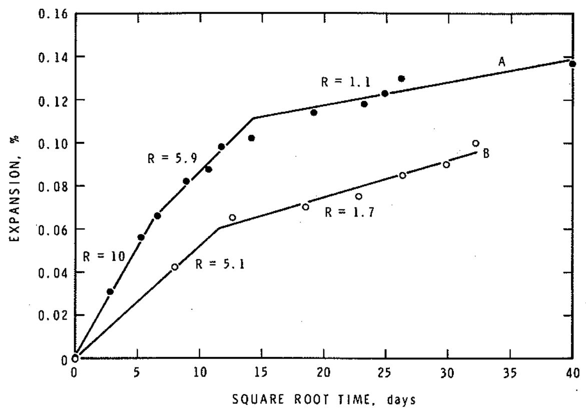

FIGURE 9: Expansion of patio slab 'H' on walk in Ottawa, Ontario (B) and of concrete prism cut from an unexposed duplicate slab, and stored at 38 °C and 100% RH (A)

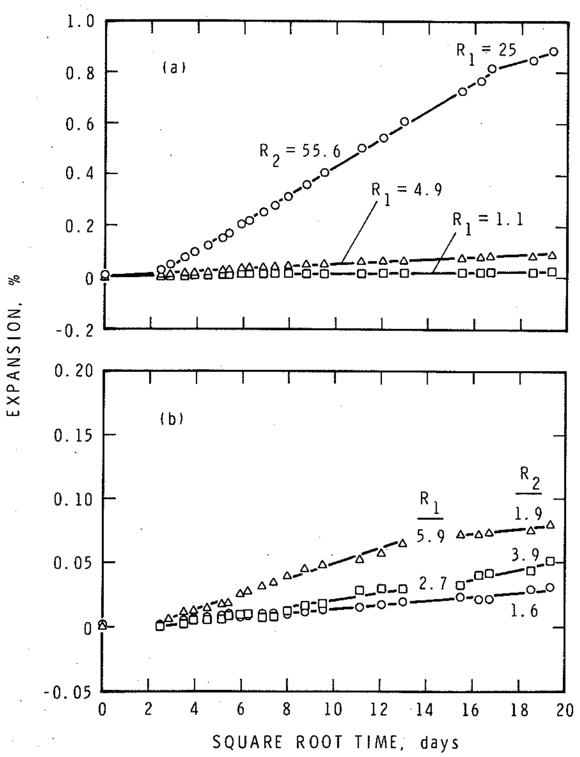

FIGURE 10: Expansion of concrete prisms made from various horizons in the top lift of the Pittsburg quarry in Kingston, Ontario. The rates of expansion (R) for the horizons are also shown

described by Smith[2], Dolar-Mantuani[22,23] and Ryell et al[24]. The expansivity of the rock varies considerably from layer to layer (Figure 10), and owing to this, systematic sampling is required to detect the presence of expansive horizons. With this very expansive aggregate even concrete structures that are not exposed to high humidity show considerable cracking and spalling (Figure 11). The most expansive material from this quarry would be deleteriously expansive even with a relatively low alkali cement. For example, concrete prisms made with sample number 78-16 from a quarry depth of six metres and cement with an alkali content of 0,68 per cent had a rate of expansion of 21,6 x 10^{-3} days$^{-1/2}$ and expanded 0,36 per cent in a year. The aggregate from this quarry is no longer used for concrete manufacture.

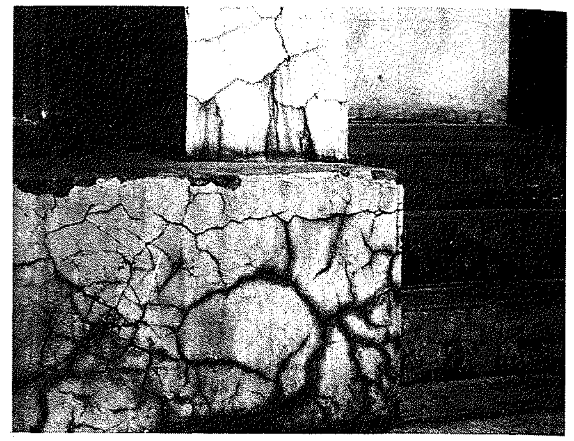

FIGURE 11: Deterioration of concrete at Barryfield, near Kingston, Ontario, due to alkali-carbonate expansivity

(e) Canadian Shield

The vast area of Northern Ontario is underlain by the Canadian Shield, which is composed of Precambrian rocks. Dolar-Mantuani[25] reported damage to a dam at Lady Evelyn Lake, north of Sudbury, in 1969 which resulted from alkali-expansivity of the cement-aggregate combination used in the construction. The expansive aggregate is an argillite consisting of 16 per cent quartz grains in a fine matrix of chlorite, illite, clay-sized quartz and feldspar. Large amounts of gel were visible in the broken concrete when the dam was demolished and replaced. This aggregate is expansive even with low alkali cement (Figure 12, page 8).

Another small dam in the Sudbury area showed cracking, which was thought to be due to alkali expansivity. As a result, the author carried out concrete prism tests on the quartzites found in the fluvio-glacial gravel deposits currently used for concrete aggregate. The pit-run coarse aggregate consisted of 10 per cent granite, 10 per cent norite and 80 per cent quartzite and should probably be classed as marginally expansive; concrete prisms made with high alkali cement expanded by 0,06 per cent in three years and had a rate of expansion of 5,4 x 10^{-3} days$^{-1/2}$. To counteract possible expansion of the concrete, a low alkali cement was specified for the airport at Sudbury.

Concrete prisms made from several quartzite boulders from the Sudbury gravels were found to be excessively expansive. An example is shown in Figure 3 and others are documented in another presentation to this Conference[26]. Minor cracking and pop-outs were observed in recent concrete structures in the Sudbury region.

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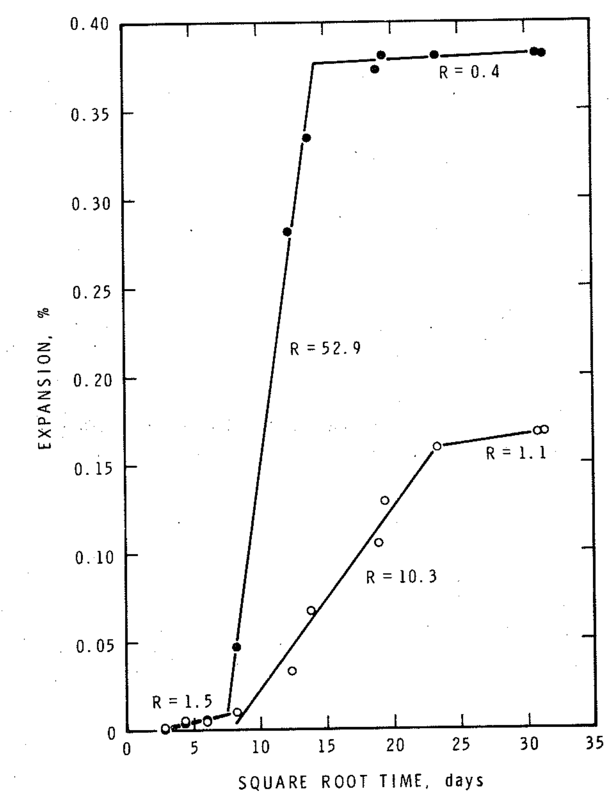

FIGURE 12: Expansion of concrete prisms made with argillite from Lady Evelyn Lake, Northern Ontario, with low and high alkali cement, LA and HA respectively

(f) **Arctic**

A case of deterioration in concrete, possibly due to alkali-expansivity of the aggregate, was reported by Gillott and Swenson[27] from Alert, which is at the northernmost tip of Ellesmere Island, NWT. The sub-zero temperatures that prevail there for most of the year might be expected to slow the rate of expansion of concrete made with the expansive aggregates; this effect would, however, be offset by the heating of the buildings. Cracking was observed in the concrete floor of one building. Two subgreywackes, which occur in the aggregate, were shown by Gillott to be expansive. The rates of expansion of two concrete prisms calculated from Gillott's data are 20×10^{-3} days$^{-1/2}$ and $9,5 \times 10^{-3}$ days$^{-1/2}$. Rates of expansion greater than about 6×10^{-3} days$^{-1/2}$ should probably be considered deleteriously expansive. In this situation, where the cement has to be shipped in from many thousands of miles to the south, the added cost of low alkali cement would be negligible and it should be used if an alternative source of non-expansive aggregate cannot be found.

(g) **Prairies**

The huge expanse of flat land that comprises the Canadian Prairies is underlain by Mesozoic sediments (Figure 13). An expansive siliceous shale containing opaline silica has been identified from the South Saskatchewan River by Price[28]. Mortar bars made with it and high alkali cement showed excessive expansion. At the time no structures made with this aggregate had shown distress, possibly because low alkali cement was normally used in the region. Chakrabarti[29], however, described the deterioration of a concrete floor in Saskatchewan several years later.

The construction of an earth-filled dam on the South Saskatchewan River called for the placement of 500 000 tons of concrete for various structures associated with the dam. The groundwater contains 1 per cent sulphate, and gypsum crystals are found on the surface. A type 50 sulphate-resisting cement was therefore specified for the concrete. Flyash, produced locally, was also added to the concrete, but to prevent any possibility of alkali-expansivity the siliceous shale was removed from the aggregate by heavy media separation. The flyash contained from 1,35 to 3,1 per cent Na_2O equivalent. Type 50 cement, 0,5 per cent Na_2O equivalent alkali content, was used in the concrete. The dam and ancillary structures are in good condition after about 15 years service. A commemorative plaque was mounted on a concrete plinth constructed after the dam was built and evidently with aggregate that had not been beneficiated, for it shows cracking and pop-outs characteristic of alkali-expansivity of this type of aggregate. Siliceous shale particles were observed at the bottom of the pop-outs. This seems to indicate that the precautions taken in building the dam were warranted.

(h) **British Columbia**

This region encompasses the Palaeozoic sediments of the Rocky Mountains on the east side, the volcanic rocks of the central region, and the granites of the Coast Ranges in the west. Some potentially expansive aggregates have been identified, but due possibly to the use of low alkali cement no cases of alkali-expansivity have been confirmed. Mindess and Gilley[30] reported a type of alkali-reactivity that gave rise to staining of concrete, but mortar bars made from this aggregate did not expand excessively.

Andesite is dominant in the aggregate supplied by Mindess and examined by the author, consisting of phenocrysts of plagioclase in a matrix of either small plagioclase laths, microlaths or glass. Chalcedonic silica was also observed. Andesite has frequently been reported as an expansive aggregate and because of the glassy matrix and the cryptocrystalline silica was considered to be potentially expansive.

(i) **Exotic aggregates**

Lightweight concrete roof panels. Deterioration was observed of lightweight concrete roof panels made of portland cement and expanded shale. Expansion and bowing of the panels was thought to be due to moisture absorption and swelling of the concrete. The main problem, however, was the spalling of pieces of concrete from the roof into the work area. The spalling was probably due to a reaction between the expanded shale and the alkalis in the cement. As it did not present a structural threat to the concrete, reme-

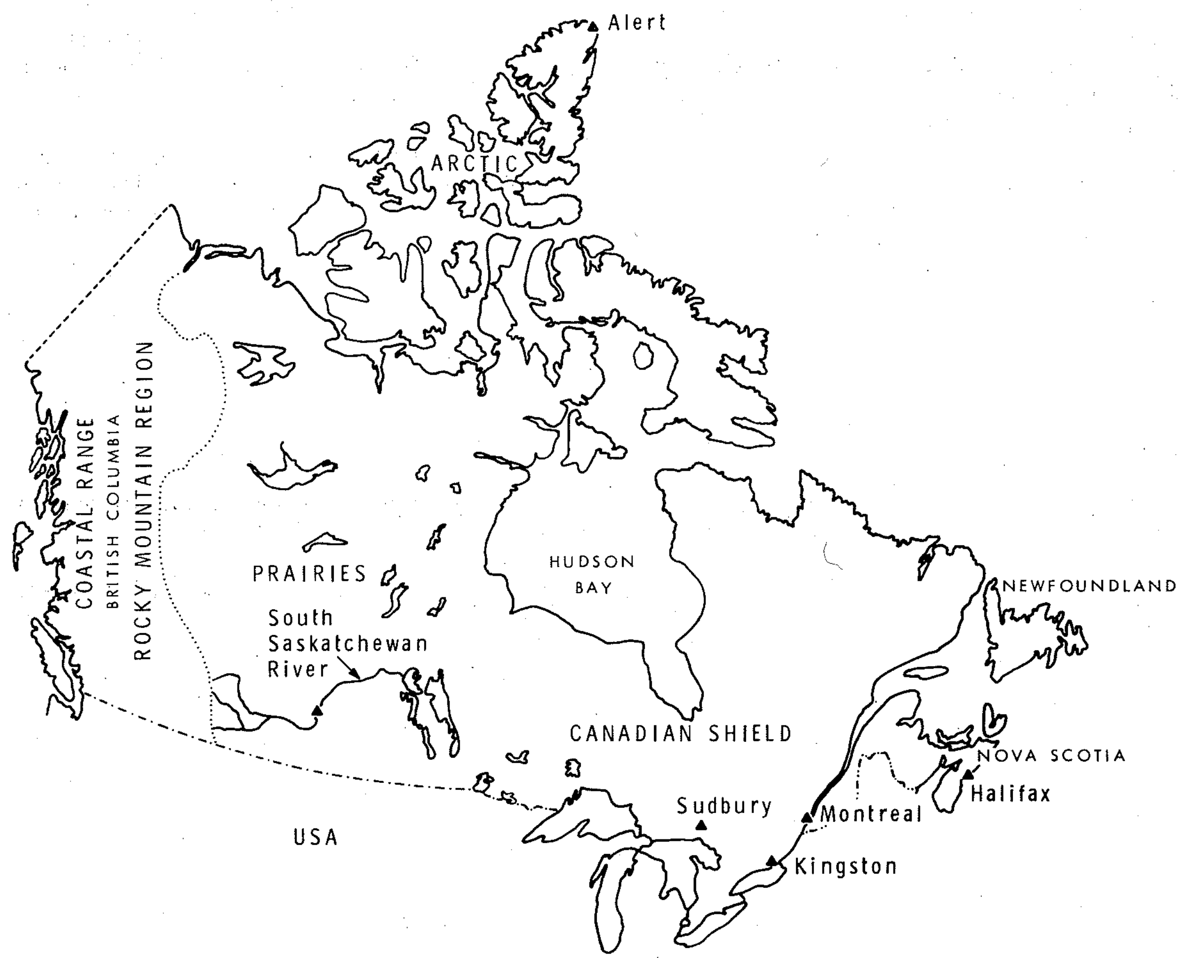

FIGURE 13 : Map of Canada showing locations across the country where alkali expansive aggregates have been identified (expansive aggregates shown by a triangle ▲)

dial action consisted of coating the concrete to prevent pieces from falling into the work area.

Exposed glass aggregate precast concrete facing panels. The panels of a building made of exposed glass aggregate precast concrete show pattern cracking, long cracks parallel to the length of the panels, and bowing. Some panels bowed out 1,2 cm (½ inch) or more in 3,4 m (11 feet). Expansion and cracking were not uniform, some panels showing greater deterioration than others. This may have been due, in part, to the influence of the prevailing direction of driving rain. Absolute evidence of alkali-expansivity as the cause of the problem was not obtained, although it seemed the most probable explanation. The conclusion to be drawn from this case is that care needs to be exercised in the use of exotic aggregates in ornamental concrete made for architectural use.

5. CONCLUDING STATEMENT

Owing to the number of potentially alkali-expansive aggregates identified throughout the country, there is clearly a need to include analysis of alkalis in the Canadian standard for portland cement (CAN3-A5-M77).

The limit of expansion of concrete test prisms in CAN3-A23.2-14A is 0,02 per cent at three months in a moist environment. It may not, however, be a reliable guide to the expansivity of concrete. A number of slowly expanding aggregates have been found that expanded less than 0,02 per cent at three months, but showed excessive expansion and cracking after two years of storage at 100 per cent RH. The ASTM C227 limit of expansion of 0,10 per cent at six months, the mortar bar test, is unsatisfactory for the same

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reason. Because of wide variations in the expansivity of aggregates, it is impossible to find an expansion limit that is applicable to all cement-aggregate combinations. Instead, limits have to be worked out for each suite of rocks in combination with locally used cements.

Apart from the difficulty of setting limits for the expansion of test prisms, the main disadvantage of the concrete prism test is that it may take two years or more to obtain conclusive results. There is rarely such a long lead time before the commencement of construction on a project. This difficulty can only be overcome by the development of new rapid test procedures.

Petrographic examination of aggregates prior to testing is very desirable in order that the type of alkali-reactivity to be expected may be identified and an appropriate test method selected.

ACKNOWLEDGEMENTS

The author is indebted to all his Canadian colleagues, without whose careful observations and research this paper could not have been written. Acknowledgements to individual authors are given in the text.

This paper is a contribution from the Division of Building Research, National Research Council of Canada, and is published with the approval of the Director of the Division.

DISCUSSION

Prof S Diamond (Purdue University, USA) referred to the statement that, experience in Canada, of the use of fly ash or other pozzolans as an ameliorating agent had not been very successful in the case of alkali-carbonate rock reactivity. He asked if this were also true in situations where some of the alkali might also come from the rock.

Dr Grattan-Bellew affirmed this, saying that in this instance it would be a slow reaction releasing the alkalis from the rock or from any external source. He mentioned that papers by Dr Stark (PCA, Skokie, Illinois) inferred that some alkalis seemed to be coming from the aggregate itself, i.e. an andesite.

Prof S Diamond (Purdue University, USA) speculated that pozzolans worked where the alkali was readily available in the pore solution. They could absorb the alkali and remove it from the field. In cases where alkali in the rock itself was contributing to the problem it was surely going to react with the aggregate and 'having a little bit of pozzolan scattered here and there throughout the concrete' he thought would not be very effective. This notion would be difficult to prove, but he offered it as a speculative idea.

Dr Grattan-Bellew mentioned that in some ways, Canadian standards actually recognised this fact. They stated that if there was a salt solution going through the concrete, the use of low alkali cement and reactive aggregate would not be a solution.

Prof G Blight (University of the Witwatersrand, Johannesburg, South Africa) referred to the case shown by Dr Grattan-Bellew of the railroad tie that had split longitudinally. He cautioned against the overhasty conclusion that the splitting was caused by alkali-aggregate reaction. He had seen a number of cases where longitudinal splitting had occurred in these ties and it generally originated at the spike of malleable iron which was cast in and which held the rail fastening. This constituted a stress raiser on the concrete tie, especially under the lateral loads transmitted to the rail by the wheels on the curve. Therefore cracks tended to propagate from this point, and because the sleeper was pre-tensioned or post-tensioned the only direction in which the crack could propagate was longitudinally. Thus longitudinal splitting could in fact be caused not by alkali-aggregate reaction but be purely a stress phenomenon.

Dr Grattan-Bellew concurred, and added that there had, however, been many transverse cracks, and in some cases they did originate from the spike that held the rail fastening down. Some studies had been done at the University of Montreal and pockets of silica gel had been found in the concrete. Currently, the aggregate was being investigated, but preliminary results indicated that the cause was alkali reactivity. He mentioned that some of the ties which had been stored as reserves had exhibited the same pattern cracking, which indicated fairly conclusively that it had nothing to do with salt solutions or anything in the ballast.

Mr H C Parolis (Jeffares and Green, Mowbray, Cape Town) referred to the statement that it was costly and possibly impractical for researchers to prescribe a low alkali cement to prevent alkali-aggregate reaction. He asked if this would not be less expensive than costly repair work to damaged structures.

Dr Grattan-Bellew amplified his statement by stressing the need for care when making recommendations. A consultant or individual in a consulting capacity, unless there were no alternative, should not generalise by saying that a particular aggregate was likely to be reactive simply because it was a greywacke, and the majority of greywackes were reactive. If a quarry contained greywacke, and a consultant told the owner it would be reactive without doing any tests, the owner might go out of business as a result. It was essential to take all the factors into account in order to make a reasoned judgement.