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ALKALI–AGGREGATE REACTIVITY IN CANADA

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ABSTRACT

In Canada, three types of alkali-aggregate reaction are recognized. Each type is evaluated using different tests. Corrective measures such as the use of low alkali cement, lower cement contents, or pozzolans are seldom used with reactive aggregates. Beneficiation or selective extraction is used with some reactive aggregates. Work is being conducted on multilaboratory study of existing tests and new, rapid tests.

INTRODUCTION

The oldest Canadian concrete structure known to have been affected by alkali-aggregate reactivity (A.A.R.) was the Hurdman Bridge built in Ottawa in 1906 and demolished in 1987. It was not until the 1950's, however, that A.A.R. was first documented in Canada (Swenson, 1957). Over the past thirty years, cases of A.A.R. have been found in many parts of Canada (Figures 1 and 2) with a variety of different rock types (Table 1). There are now over 160 reports and papers documenting Canadian work on A.A.R. (Rogers and Worton, 1988).

The wide range in rock types capable of causing damage due to A.A.R. gives some idea of the difficulty of selecting appropriate testing procedures and corrective measures. For instance, the mortar bar expansion test used for alkali-silica reactive rocks only gives small expansions with expansive dolomitic limestone susceptible to the alkali-carbonate reaction (A.C.R.) or greywackes and argillites susceptible to the alkali-silicate reaction. For convenience, alkali-aggregate reactions in Canada have been grouped into three types, each having different tests or criteria used in evaluation:

1. Alkali-carbonate reaction with dolomitic limestones and calcitic dolostones of Ordovician age. Chemical analysis for CaO:MgO and Al_2O_3, rock cylinder expansion test (ASTM C 586), and concrete prism expansion test (CAN3 A23.2-14A, 1986) are useful for identifying these rocks.

2. Alkali-silica reaction with silica (chalcedony, opal, cristobalite, etc.) is usually evaluated in the mortar bar expansion test (ASTM C 227); concrete prism and rock cylinder expansion tests are also used. The quick chemical test (ASTM C 289) is also used, but gives misleading results when carbonates are present.

3. Late/slow alkali-silica/silicate reaction with sandstones and granites containing strained quartz and metamorphosed sediments such as phyllite, argillite, and greywacke, where exfoliation of phyllosilicates causes swelling of aggregate particles. Rocks susceptible to this type of reaction usually perform well in conventional alkali-aggregate tests. A concrete prism expansion test at 38°C and high alkali

contents is the most useful procedure. Rock cylinder or miniature rock prism expansion tests are also useful.

The procedures necessary to determine the type or types of reaction to which aggregate may be susceptible are not simple. Flow charts used for determining the type of reaction and the necessary tests were described in a paper at the 1986 conference (Rogers, 1987).

CANADIAN CEMENTS

Figures 1 and 2 show that the majority of areas of A.A.R. are in central and eastern Canada where low alkali cements are seldom used. West of Ontario, most of the normal Portland cements (CSA Type 10) have alkali levels of less than 0.8% (Na_2O equivalent) and, as a result, there are very few documented cases of A.A.R.

In central and eastern Canada, the majority of normal cements have alkali levels of more than 0.9%. For the nineteen normal cements made in Canada, the Na_2O/K_2O ratio ranges from 1.09 to 0.07 with a mean of 0.38 (median 0.31). In a 1977 survey of the alkali contents of Canadian Type 10 cements, six of twenty-three sources had alkali contents of more than 1.0% (Grattan-Bellew et al, 1978). In 1988, only two of nineteen producers had mean alkalies of more than 1.0%. This reduction in alkali contents can generally be attributed to the closing of obsolete plants that used high alkali raw materials.

At present, only one normal Portland cement is made in Canada which contains a pozzolanic mineral admixture (a Type 10P with 8% silica fume); the remainder are Portland cements with usually up to 5% limestone interground with the clinker.

Six plants (three in the east and three in western Canada) which normally make high alkali cements also make a lower alkali cement, usually without 5% limestone addition, to meet American requirements. Many state highway authorities adjacent to the Canadian border specify either a low alkali cement (<0.6%) or a reduced alkali cement (<0.7%). These lower alkali cements are usually reserved for the export market to the U.S., and not normally sold in Canada.

The specification of low alkali cement is unusual in eastern Canada. In northern Ontario, the Ministry of Transportation used low alkali cement on four bridges in 1970, but has seldom specified it since. Recently, however, Canadian National Railways has started to specify low alkali cement for all concrete, irrespective of the nature of the aggregate. The reason for this was the costly and tedious deterioration of prestressed concrete railroad ties due to A.A.R. The cement companies regard the universal adoption of such a solution to A.A.R. with concern. The older, wet process plants can often make a low or reduced alkali cement by not recycling alkali-rich dust from the precipitators. The newer, dry process plants can only achieve a low alkali cement by selecting low alkali raw material sources. In either case, the cost of production is usually increased. There is a natural apprehension that other authorities or purchasers will begin to specify the universal use of low alkali cement to reduce the likelihood of A.A.R.

CANADIAN RESEARCH

In an effort to prevent the universal adoption of restrictions on maximum alkali levels, the Canadian Standards Association Committee on Cement(A5) formed a subcommittee in 1980 to look for and recommend the adoption of rapid test procedures to evaluate concrete aggregates for A.A.R. At present, many of the current procedures require several months or years of testing, with the result that the structure is usually under construction or even completed by the time the aggregate testing is finished. The sub-committee has a membership of about thirty people. Meetings are held at least twice yearly, one of which is combined with a field trip to review interesting cases of A.A.R. A secondary purpose of the committee is to provide a means of communication for those people in Canada involved in work on A.A.R.

A number of authorities are sponsoring research into A.A.R. The Canadian government, through CANMET, is funding investigations by consultants of the incidence of A.A.R. in many of the provinces and funding investigations of Canadian pozzolans. This work is hampered, to some extent, by the lack of reliable, rapid test procedures. The Canadian government also funds work by university researchers through NSERC operating grants. There has, as well, been federal funding for individual projects such as that reported at this conference by Chen and Grattan-Bellew. Some of the eastern provinces also fund A.A.R. research. This work is either performed or funded by provincial authorities such as electrical utilities or transportation departments. Over the past five years, the total amount of money spent in Canada on investigations and testing of A.A.R. probably has not exceeded an average of about $1m yearly. The amount currently spent on research is small compared to the direct and indirect costs of damage caused by A.A.R. However, this is not as important as the presence of experienced, dedicated researchers, which we are fortunate to have in Canada.

EVALUATION OF AGGREGATES

The first step recommended by CSA in the evaluation of the suitability of concrete aggregates is a thorough petrographic examination and investigation of prior field performance. This will determine what tests, if any, are needed. Failure to properly classify the aggregate or to recognize minor deleterious components will upset the remainder of the testing program. Petrographic examination should, if possible, be based on a knowledge of the prior field performance of similar aggregate. A simple classification of the rock types and minerals present is rarely satisfactory. In Canada, the acquisition of field peformance is often impossible due to construction in remote and undeveloped areas.

Many of the tests used in Canada have been found to suffer from such problems as lack of correlation with field performance or poor multilaboratory precision. The concrete prism expansion test is being subjected to a multilaboratory study to find less variable storage conditions than the conventional humid curing room. The mortar bar expansion test has been found to be susceptible to alkali leaching caused by the presence of wicks in the storage container (Rogers and Hooton, 1989).

The CSA sub-committee has established a draft procedure for the accelerated mortar bar test (1 molar NaOH @ 80°C for 14 days) of Oberholster and Davies (1986). This test appears reasonably precise and capable of recognizing the majority of reactive aggregates found in Canada. A multilaboratory study is being conducted to finalize some details and investigate precision. It is likely that only aggregate giving more than 0.15% expansion at fourteen days will be classed as potentially reactive.

The quick chemical test (ASTM C 289) is generally unsatisfactory with alkali-silica reactive carbonate aggregates because much of the alkali-soluble silica released is re-precipitated as calcium silicate hydrates. Researchers in Quebec (Berard and Roux, 1986, Fournier et al, 1987) have had considerable success with modifying the test so that it is done on the insoluble residue of quarried carbonate rocks. This test is described in a draft CSA document and is being investigated in a multilaboratory study.

A rapid procedure of expansion testing of concrete cores proposed by Scott and Duggan (1987) is being studied by researchers at the Universities of Calgary and Manitoba to determine the mechanism of expansion. This procedure has similarities to the Conrow test (ASTM C 342) and, at present, does not appear to be satisfactory for separating reactive from non-reactive aggregate.

To assist in calibration of existing and new procedures, the Ontario Ministry of Transportation has established three 110-tonne stockpiles of known reactive aggregates. Aggregates from these stockpiles are available free of charge for calibrating test procedures or research into A.A.R.

CORRECTIVE MEASURES

The use of low alkali cement is not a universally satisfactory solution because of its lack of availability in eastern Canada. In Alberta, an engineer recently proposed the use of a maximum cement alkali content of 0.3% for dam construction. Such a cement is not available in Canada. Such caution is, nevertheless, understandable, given the high cost of insurance.

Reducing cement contents and, hence, alkali levels is often not practical because of the severe Canadian climate which generally requires low w/c ratio, air-entrained concrete for all exposed work. In practical terms, this calls for minimum cement contents in the order of 325-450 kg/m^3 if durability is to be ensured.

The use of blast furnace slag cement has generally not been adopted to control A.A.R., despite its apparent efficiency at high levels of substitution (>50%). Laboratory salt-scaling tests (ASTM C 672) and limited field performance has shown that, at 50% substitution levels, the scaling loss from the surface may become unacceptable. For this reason, the Ontario Ministry of Transportation only permits a maximum of 25% substitution.

Other pozzolans such as fly ash and silica fume are used in Canada, but rarely for the purpose of controlling A.A.R. A notable exception was the successful use of 20% fly ash by Ontario Hydro on the Lower Notch Dam to prevent an alkali-silicate reaction with an argillite (Sturrup et al, 1983). Pozzolans are more commonly used for their other advantages such as reduced cost, increased strength-producing properties, or reduced heat of hydration.

The most commonly used control measure is the beneficiation or selective quarrying of aggregate. A technique used in areas of Ontario that contain significant amounts of chert in glacial drift is to selectively crush oversize gravel (>40 mm) which normally contains much less chert. Other techniques used are heavy media separation to remove shale and chert or jigging, which has been used in the past but with limited success. Reserving a specific level or bench of superior quality in carbonate bedrock quarries is a common practice. The underlying or overlying beds may be alkali-reactive, but careful, conscientious extraction and stockpiling can ensure an adequate supply of non-reactive rock.

THE NEXT TEN YEARS

New cases of A.A.R. will be discovered in Canada. A group of reliable, rapid test procedures will become available for each type of reaction. Each of these tests will have known multilaboratoy precision and will be calibrated with known reactive aggregates. Corrective measures will generally only be used where non-reactive aggregates are more expensive. There will be more frequent specification of low or reduced alkali cements, and a more widespread adoption of lists of pre-qualified, non-reactive aggregate which only Ontario uses at present.

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TABLE 1: Types of Alkali-Reactive Rock Found in Canada

Phanerozoic

Andesites and associated volcanic rocks in British Columbia

Quartzite in Rocky Mountains of British Columbia and Alberta

Opaline shale/siliceous shale in Saskatchewan and Manitoba

Upper Silurian subgreywacke on Ellesmere Island

Devonian and Silurian chalcedony-bearing chert in glacial drift in northern Ontario and in quarries and glacial drift in southern Ontario

Middle Ordovician siliceous and slightly siliceous limestone in southern and eastern Ontario and the St. Lawrence Lowlands of Quebec

Middle Ordovician dolomitic limestone and calcitic dolostone in Hudson Bay Lowlands and southern Ontario

Cambrian sandstones and orthoquartzites in eastern Ontario and southwestern Quebec

Rhyolitic tuff, southeast of Quebec City

Phyllite in southeastern Quebec

Phyllites, greywackes, siltstones, argillites, schists, silicified tuff, devitrified glass, and quartzites of New Brunswick, Nova Scotia, and Newfoundland

Rhyolite in Nova Scotia

Precambrian

Granite and granite gneiss with strained quartz

Sandstone, quartz-wacke, arkose, greywacke, and argillite of the Huronian Supergroup in central Ontario and western Quebec

Chert in banded iron formations (taconite)

Figure 1: Location and Alkali Contents of Type 10 Cements in Eastern Canada

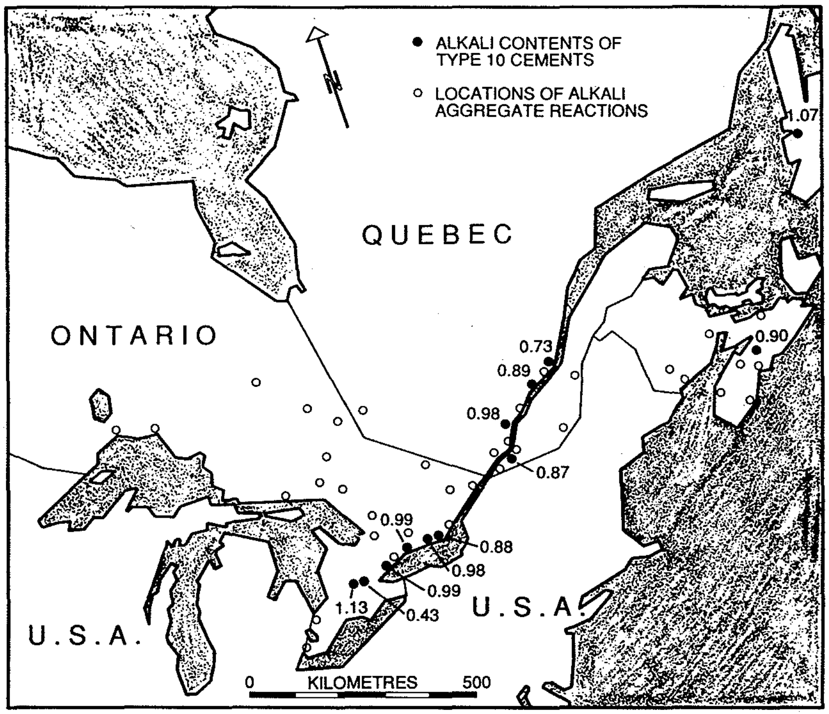

Figure 2: Location and Alkali Contents of Type 10 Cements in Western Canada