THE GEOLOGY, PROPERTIES AND FIELD PERFORMANCE OF ALKALI -AGGREGATE REACTIVE SPRATT, SUDBURY AND PITTSBURG AGGREGATE DISTRIBUTED BY THE ONTARIO MINISTRY OF TRANSPORTATION

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Abstract

In 1986, in an effort to promote development of better tests, the Ontario Ministry of Transportation established stockpiles of three aggregates found to cause deleterious expansion and cracking due to alkaliaggregate reaction (AAR). The aggregates are as follows: Spratt aggregate (a siliceous limestone susceptible to ASR) from a quarry. Sudbury aggregate (mixed siliceous gravel containing ASR susceptible greywacke, argillite and quartz-wacke). Pittsburg aggregate (a dolomitic limestone susceptible to so-called alkali-carbonate reaction (ACR) from a quarry. This paper describes the geology and field performance of these materials. The chemical and physical properties of the aggregates are summarized.

Keywords: Spratt, Pittsburg, Sudbury, Alkali-Aggregate Reaction, Ontario

1 INTRODUCTION

In the early 1980's test methods used for detecting the potential for alkali-aggregate reaction (AAR) in aggregates proposed for use in concrete were not as useful as those available today. The tests at that time failed to detect the potential for AAR in many aggregates that subsequently caused serious damage due to AAR in construction. This was caused by a variety of testing issues, such as: excessive leaching of alkalies, insufficient alkali content, insufficient temperature or humidity or tests not capable of detecting AAR with some aggregates.

At least two research studies on the properties of cement on AAR conducted in Canada in the early 1980's failed or were only partially successful because of the inability to obtain aggregates that were deleteriously expansive because of AAR. These were expensive studies with specially formulated laboratory made cements to study the effects of cement mineralogy on AAR. In addition it was starting to be recognized that the conventional test methods for AAR did not recognize all the aggregates that seemed to be exhibiting deleterious expansion in the field. In 1986, in an effort to promote research leading to the development of improved tests and studies into the impact of cement mineralogy and the beneficial effects of supplementary cementing materials, the Ontario Ministry of Transportation established 100 tonne stockpiles of three aggregates found to cause deleterious expansion and cracking in concrete. Initially the aggregates, graded from 20 to 5 mm, were stored out-of-doors but when suitable facilities became available they were stored out of the weather in an unheated building. The aggregates from these stockpiles are made available to

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researchers to develop suitable tests to detect AAR. Material is also made available to researchers studying means of preventing AAR. A third application is for the calibration of existing tests by laboratories doing routine testing. The materials were and are made available free of charge with the users being asked to pay for the costs of shipping and undertaking to publish relevant results. An exception is made with those organizations that are not willing to publish their results. In these cases the aggregates are not normally available. The source locations of the aggregates are shown in Figure 1 and the expansivity of concretes in relation to alkali content are shown in Figure 2.

2 DESCRIPTION OF AGGREGATES

2.1 Spratt aggregate

General

This aggregate has been the most popular aggregate for use and over 200 tonnes has been used and a third stockpile of 100 tonnes established in 2005 is being used and has been qualified in an multi-laboratory study described by Fournier and Rogers in 2008 [1]. It is a limestone from a quarry in Stittsville, Ontario, just west of the City of Ottawa. The aggregate is a Middle Ordovician, medium grey coloured, horizontally medium bedded, fine to coarse crystalline limestone. The material is slightly siliceous (9% SiO₂) and has been used as a convenient alkali-silica reactive aggregate for investigating alkali-silica reaction expansion tests [2,3,4]. The stone meets all the normal physical requirements for concrete aggregate. There are small amounts of visible black chert with a conchoidal fracture with chalcedony visible in thin section. The majority of the silica is only observed when a surface is etched in acid leaving a fine network of silica (Figure 3). In thin section, little silica is observed because the silica is very fine grained and is also masked by highly birefringent calcite.

Field performance

This aggregate was fortunately only used for a short time before the alkali-silica reactive nature was recognized (no alkali-reaction testing had been done prior to approval). In about 1975 it was used as coarse aggregate for concrete in a retaining wall on the east side of Colonel By Drive in Ottawa. The appearance in 2011 is shown in Figure 4. Cement alkali content was probably about 1.0%; cement content is unknown but probably in the range of 340-370 kg/m³. Cracking was also observed in concrete curbs and in precast concrete units such as steps. By about 1982 the material had been withdrawn for use in concrete because of complaints of cracking. In 1991 an outdoor exposure site was established in Kingston, Ontario using the Spratt aggregate. This work is described by Afrani and Rogers [5] and subsequent performance in Hooton et al in 2006 [6]. The expansion of unreinforced concrete over a period of 20 years is shown in Figure 5.

Laboratory expansion testing

This aggregate has been used in several multi-laboratory testing programs for both the accelerated mortar bar test [1,7] and in concrete prism tests [3,7] and Fournier, Rogers and MacDonald this volume (2012). Data is summarized in Table 1. Concrete made with the Spratt aggregate has been crushed and the potential for renewed ASR with recycled concrete aggregate studied by Shehata et al [8].

2.2 Sudbury aggregate

General

This aggregate is partially crushed gravel containing a mixture of sedimentary rocks of Middle Precambrian age. There are also high grade metamorphic gneisses and igneous rocks present. The alkali-silica reactive components are the sedimentary rocks which consist of greywacke, argillite and quartz-wacke and quartzite. These rocks are slightly metamorphosed. Much of the exposed bedrock in the general area is composed of these same rocks. The material was obtained from a gravel pit adjacent to Sudbury airport which is a large kame/delta deposit. These reactive rocks were previously studied by Grattan-Bellew in 1978 [9] and first described by Dolar-Mantuani in 1969 [10].

Field performance

This aggregate has been used for many years for most of the structural concrete in the Sudbury area. Magni et. al [11] described studies into the petrographic characteristics of the 26 bridges known to be affected by the reaction of these rock types. A number of water control and power dams (on the order of 20) in this area are also affected. The progress of the reaction has seriously reduced the functional life of all structures and concrete pavements in which it has been used and increased the need for repair and replacement. The use of this aggregate was finally stopped in 1984 when petrographic criteria of a maximum of 15% reactive rock types was agreed to. Since then nearly all concrete coarse aggregate in this area has been sourced from quarries in non-reactive rock. Figure 6 shows the appearance of the soffit of one of the last large structures built with this aggregate. An annoying feature of this aggregate and many other known reactive aggregates in Canada was that it met or passed all the conventional tests for AAR at that time [12]. For instance, the conventional ASTM C227 mortar bar expansion (Table 1) does not show deleterious expansion based on criteria used at that time. This brought about a search for more effective test methods such as adoption of the NBRI accelerated mortar bar test (CSA A23.2-25A, 1994) and a radical improvement to the concrete prism expansion test by increasing both cement content and temperature of storage to 38°C (CSA A23.2-14A, 1994).

Laboratory expansion testing

This aggregate has been used in a multi-laboratory testing program for the concrete prism test [3]. Data is summarized in Table 1.

2.3 Pittsburg aggregate

General

This aggregate represents rock susceptible to the so called alkali-carbonate reaction or more properly alkali-carbonate rock reaction (ACR). It was obtained from the upper bench of the Pittsburg quarry on west side of Highway 15, 5 km north of Kingston, Ontario. This bench of about 6 m is a thin to medium horizontally bedded medium grey coloured dolomitic limestone. The dolomite occurs as well defined rhombohedra about 30 to 80 µm in size distributed in a finer gained calcite matrix with very fine gained silica and clay minerals. The clays are illite, chlorite and kaolinite. The dolomite contains little clay. The rock is in the same sequence as that of the Spratt quarry but of lower stratigraphic elevation. It is of Middle Ordovician age. The rock was laid down in a shallow marine sea and although not found within the 6 m thick quarried section there are thin bentonite clay rich beds found within the sequence that are interpreted as volcanic ash beds. The rock in natural exposure deteriorates by freezing and thawing within a few years and it is not possible to obtain unweathered samples except from fresh quarry exposures. A 100 tonne stockpile was obtained from the last extraction of the upper bench of this quarry in about 1985.

The rock was first used in concrete in the early 1950's and within about 2 to 3 years the concrete had expanded and cracked and had to be replaced. The reaction was extensively studied by Swenson and Gillott at the Division of Building Research in Ottawa. This aggregate was noteworthy because it did not expand significantly in the ASTM C227 mortar bar test [13]. Also the dolomite converts to brucite and calcite (de-dolomitization) when stored in alkali solutions. Alkali-silica gel is not normally visible in concrete made with

this aggregate. When tested as coarse aggregate in concrete beams stored at 23 °C the rock gives noteworthy expansion and this became the basis of the Canadian concrete prism expansion test. The rock is also unusual because it will expand when placed in alkali-hydroxide solutions with no external source of calcium ions. This became the basis of the rock cylinder expansion test described in ASTM C586. Rock cylinders of rock from the upper 6 m bench of the quarry will expand up to 2.5% within 4 weeks in a 1 normal NaOH solution but will not expand in a neutral solutions containing K or Na.

There are numerous papers exploring the geology, mineralogy and possible mechanism of expansion. Gillott and Swenson [14] speculated that the de-dolomitization reaction caused micro-fractures that then allowed water access to previously dry clay mineral surfaces. The adsorption of water then caused irreversible expansion. More recently it is postulated that the ACR is a unique variant of ASR [15,16]. It is thought that the calcium necessary to form an expansive alkali-silica gel is generated within the rock by the de-dolomitization reaction and the silica source is very fine quartz. The rock swells due to internal ASR and little alkali-silica gel is found in the surrounding concrete.

Field performance

Because of the dramatic expansivity of this rock it has not been used in concrete for over 50 years. Swenson and Gillott [17] give a description of field performance observations. It should be noted that the quarry they describe as "quarry A" is the same as the Pittsburg quarry and the 0-24 ft quarry level is approximately the same as that supplied from stockpile. In 1985 a series of concrete slabs on grade were placed in Kingston. This is described by Rogers and Hooton [18]. Long term field expansion is shown in Figure 7.

3 USES OF THE AGGREGATES

Calibration of alkali-aggregate reactions tests

These aggregates have all been tested in multi-laboratory testing programs of various designs. The results are summarized in Table 1. These are excellent materials to use for the calibration of existing test methods to evaluate the potential for ASR. Periodically testing these materials will demonstrate that a laboratory is capable of conducting the test correctly.

Research into effectiveness of supplementary cementing materials and lithium

Extensive research has been published on research using these aggregates to find ways of mitigating the damage due to alkali-aggregate reaction. Over 50 papers have been published.

4 CONCLUSIONS

The Ontario Ministry of Transportation established these large stockpiles of aggregate with the object of improving the test methods to evaluate the potential for alkali-aggregate reaction and to aid in improving the quality of testing. Over the past 25 years, test methods capable of detecting alkali-aggregate reactive aggregates have been developed and the number of experienced laboratories in Canada to do this testing has increased from about 3 or 4 to about 30. The initial investment of \$20,000 has been repaid many times in preventing early and unnecessary deterioration of structures and pavements due to alkali-aggregate reaction.

The aggregates are available free of charge from the Ontario Ministry of Transportation for studies of alkali-aggregate reactions and for calibrating laboratory expansion tests. Generally these materials are not made available unless the user undertakes to publish or release pertinent results. (To obtain supplies contact Carole Anne MacDonald at (+1) 416-235-3738 or <u>caroleanne.macdonald@ontario.ca</u>).

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Table 1: Chemical and physical properties of concrete aggregates			
Physical and chemical properties	SUDBURY	SPRATT	PITTSBURG
Water Absorption, %	0.46	0.72	0.46
Bulk Relative Density	2.710	2.712	2.682
Mag. Sulphate Sound. %	1	4	1
Los Angeles Abrasion and Impact, %	13	19	18
Petrographic composition	Sandstone and arkose 32%,	Siliceous Lmst. 96%,	Dol. Lmst. 92%,
	Argillite & greywacke 32%,	Sltly. Shaley Lmst. 2%,	Sltly. Shaley Dol. Lmst. 6%,
	Quartz & Quartzite 11%,	Cherty Lmst. 0.5%,	shaley Dol. Lmst. = 2%, shale
	Igneous & gneiss 25%	Shaley Lmst & shale 1%	= 0.5%
Chemical composition		SiO ₂ 7.72%, Al ₂ O ₃ 0.43%,	SiO ₂ 6.65%, Al ₂ O ₃ 1.75%, Fe ₂
		Fe ₂ O ₃ 0.26%,CaO 48.70%,	O3 0.74%,CaO 42.41%, MgO
		MgO 1.72%, Na ₂ O <0.01%,	5.50%, Na ₂ O <0.01%, K ₂ O
		K ₂ O 0.10%, MnO 0.04%,	0.70%, MnO 0.03%, P2O5
		P ₂ O ₅ 0.18%, TiO ₂ 0.04%,	0.02%, TiO ₂ 0.1%, CO ₂
		CO2 39.7%, S 0.08%, LOI	38.4%, S 0.05%, LOI 42.62%
		42.35% Spratt No.3, 2012, s	Pittsburg 2012, $s = 3$
		= 3	
ASTM C 289 on acid insoluble part		36/307 (deleterious)	
(acetic acid), 300μm-150 μm ,<150 μm		52/391 (deleterious)	
ASTM C227 - leaching reduced by	3 month 0.017%	3 month 0.032%	
removing wick material from	6 month 0.049%	6 month 0.071%	
container; * In plastic sleeve + 1.25%	12 month 0.087%	12 month 0.120%	
Na ₂ Oe		*12 month 0.319%	
Accelerated Mortar Bar Test		low – high (mean) Std Dev	
ASTM C1260 (n = 23) 14 d		0.276-0.457 (0.389), 0.044	
21 days		0.407-0.580 (0.495), 0.058	
28 days		0.488- 0.700 (0.584), 0.058	
CSA A23.2-25 (n = 28) 14d		0.307-0.486 (0.372), 0.042	
21 days		0.383-0.592 (0.482), 0.052	
28 days		0.450-0.725 (0.582), 0.068	
CSA A23.2-14A (2004) and ASTM C	low – high (mean) Std Dev	low – high (mean) Std Dev	
1293 (2005), $n = 35$ and 36			
Using control sand, 1 year	-	0.128-0.334 (0.204), 0.050	-
Using local sand, 1 year	0.040-0.170 (0.093) 0.0370	0.104-0.268 (0.175), 0.039	
Using local sand, 2 year	Mean = 0.139, S. Dev 0.0674	-	
CSA A23.2-14A, 1990, Cement 310			low – high (mean) Std Dev
kg/m^3 , n = 15 – 17, local sand			
One year at 23°C			0.105-0.210 (0.153), 0.0294
Two years at 23°C			0.158-0.250 (0.193), 0.0350
One year at 38°C	0.021% (3.9kg/m ³ Na ₂ Oe)	0.134% (3.9kg/m3 Na2Oe)	0.218-0.466 (0.307), 0.0716
	0.159% (9.3 kg/m ³ Na ₂ Oe)	0.193% (9.3 kg/m3 Na ₂ Oe)	
Two years at 38°C			0.235-0.537 (0.375), 0.0862

Notes: n = number of labs, s = number of samples tested, Std Dev = standard deviation. ASTM C227 data is from Rogers and Hooton [2] using cement with alkalies 0.93 – 1.17% Na₂Oe. Concrete expansion data for Sudbury is from a multi-laboratory study (Fournier and Malhotra, [3]). Concrete expansion data for Spratt is that for most recent stockpile in a multi-lab study described by Fournier, Rogers and MacDonald (this volume). Pittsburg expansion data from Rogers [19] and unpublished data.



FIGURE 1: Location of source of Sudbury, Spratt and Pittsburg Aggregates.



FIGURE 2: Expansion of concrete at various concrete alkali levels for Pittsburg, Spratt and Sudbury aggregates [20].



FIGURE 3: SEM view of acid etched surface of Spratt limestone showing lattice of silica, fibrous crystals are unknown. Excerpted from [21].



FIGURE 4: Top of a retaining wall on Colonel By Drive adjacent to the Rideau Canal, Ottawa, Ontario, constructed about 1975 with Spratt aggregate using high alkali cement. Photo 2011.



FIGURE 5: Unrestrained expansion of Spratt aggregate concrete in non-steel reinforced beams (0.6 X 0.6 X 2 m) in outdoor exposure.



FIGURE 6: Post-tensioned deep deck bridge with Sudbury coarse aggregate 1980-2010, Regional Road 55 and Hwy. 17, Lively, Ontario.



FIGURE 7: Field expansion of concrete made with Pittsburg aggregate and non-reactive sand in Kingston, Ontario (data from [18] and [20].



FIGURE 8: Concrete slab made with high alkali cement and Pittsburg aggregate, after 20 years, expansion about 0.7% at 13 years.