GEOLOGY AND PARTICLE SIZE EFFECTS ON ALKALI-AGGREGATE-REACTIVITY IN WESTERN CANADA – 14th ICAAR

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Abstract

In testing sources of aggregate from the western provinces of Canada, where multi-lithological fluvial-gravel aggregates are typically used for production of concrete, opportunities to test aggregates of a range of sizes are common. Over several years' of evaluation, variations in AAR expansions have been observed of some aggregate sources, apparently related to the grain size ("nominal size") of the aggregate products. Comparison of test results from within certain sources can provide opportunities to evaluate differences in test expansions that may be attributed to grain size and to lithology.

Results were examined for sources in Alberta, where aggregates are dominantly composed of sedimentary rock types, and from British Columbia, where aggregates are commonly composed of crystalline igneous and metamorphic rock types. Due to their fluvial origins, hydraulic sorting effects on lithological composition are frequently observed in various aggregate products.

Results of the tests are examined and discussed, and our conclusions and recommendations are presented.

Keywords: lithology, geological composition, alkali-aggregate-reactivity, grain size, Alberta, British Columbia

1 INTRODUCTION

To meet the design requirements for concrete to be used in various construction projects, concrete aggregate producers typically produce a variety of purposely-graded coarse and fine aggregate products. Testing is conducted on these products to ensure compliance with regional and application-specific requirements, typically at a frequency that is not much greater than bi-annually. Alkali-Aggregate-Reactivity (AAR) testing is a common requirement, in particular the Concrete Prism Test (CPT) which is considered more reliable than the 14-day Accelerated Mortar Bar Test (AMBT). One drawback with the CPT is the length of time required to produce results (i.e., one year for 'standard' tests; two years for 'mitigated' tests).

Often, the results of AAR evaluation from the CPT are needed before the 1 year data have been generated, in order to enable decisions to be made relevant to project planning. In other cases, the results may be needed for a coarse or fine aggregate product that has a different grading than those previously tested or is from a different source or period of production. In these situations, it is often necessary to make interpretations on the basis of existing CPT and lithology data, and possibly in combination with new and more quickly obtained AMBT data.

The AAR potential of an aggregate product is in part dependent on its geological composition and, in particular, the presence (and proportion) or absence of alkali-reactive rock and mineral components. Due to hydraulic sorting of sediments that form deposits of sand and gravel, lithological composition can vary for different particle size ranges and within a source. Based on numerous programs of evaluation that included both Petrographic Examination and AAR testing undertaken in western Canada, it has been observed that AAR potential can vary significantly with time within some source locations of aggregate. This effect appears to sometimes be linked with the grain size of the materials tested. It has often been found that products of different grain size have different AAR expansion levels; additionally, geological composition also varies with certain particle sizes, and production periods. Considering these factors, the prediction of AAR potential may become more complex and difficult for these kinds of aggregate sources, given the constraints imposed by project timelines.

Based on numerous programs of evaluation that included both Petrographic Examination and AAR testing, and as noted in earlier work (Shrimer, Briggs, Hudson, 2008), it was observed that the following factors affect AAR potential in the AMBT and CPT test methods:

- Lithological composition, particularly the percentage of rock and mineral components that are considered to have AAR potential
- Distribution of particle size ranges, due to variations in geology and available particle surface area
- Particle shape and surface condition, ranging from cubic and smooth to flat and/or elongated and freshly fractured.

Additional factors, such as the type of non-reactive sand or stone used in the CPT, are also thought to have contributory effects on AAR potential.

This paper examines CPT, AMBT and geological data collected from multiple years of testing two fluvial (and thus, poly-lithologic) sources of aggregate -- one location in Alberta and another in British Columbia. We compare the results of AMBT data obtained through testing of specific lithologies to try to better understand the relationship between the factors listed above to their contribution to specific gradations of concrete aggregate products.

2 AGGREGATE GEOLOGY

The materials tested and analyzed as reported in this paper were obtained from two sources -- one in central Alberta and the second in the south coast region of British Columbia (BC). Both sources are operated by commercial aggregate producers; both are currently active and have a production history of over 20 years.

The lithological composition of the material from central Alberta is almost exclusively of lithic sandstones, chert, quartz sandstone and quartzite, with only small amounts of limestone, igneous rock (volcanic, granite) and ironstone. The main lithologies from this source are all potentially alkali-reactive, containing both unstrained and metamorphically strained varieties of quartz. The three most common concrete aggregate products generated from this source are a 20 mm stone ("coarse aggregate"), a 14 mm stone and a washed concrete sand ("fine aggregate").

This material is mapped as preglacial/fluvial in origin and is typically mined from a number of near surface deposits within a 10 km radius. The raw mined material is trucked to a processing facility where it is combined, washed, crushed and sorted in the plant.

The south coast BC aggregate is characterized by a diverse lithological composition, with typical geological makeup that includes an array of volcanic and plutonic igneous rocks, various metamorphic rocks such as gneiss, schist and phyllite, and clastic sedimentary rocks such as sandstone and quartzite, as well as chert. The material from BC is fluvial in origin. This source frequently produces a wider range of sized products, including 2 or 3 concrete sands, 10 mm stone, 14 mm stone, 20 mm stone, and 28 mm stone.

Previous testing programs have shown that both these sources of aggregate exhibit variable reactivity levels, with results ranging from "moderately reactive" to "highly" or even "extremely reactive", when classified in accordance with the CSA A23.2-27A classification system. The range and variance in reactivity levels has prompted consideration of what causes these changes – is it due to fluctuations in testing, or changes in geological composition within the deposits; has processing affected the proportion of certain reactive components; and so on. These variations have also provided challenges to the reliable prediction of potential AAR levels and how to "design around" them in practical terms for various projects.

It has been observed that quarried sources of aggregate frequently have much higher uniformity of AAR test data (with some exceptions), but that natural sand-and-gravel sources, by their very nature, tend to exhibit higher variability in AAR potential. Within the fluvial/glaciofluvial sources, though, some locations exhibit higher-than-typical variability, and these are the focus of this paper.

3 TEST PROGRAM

For this research, we selected two sources of aggregate with which we have familiarity, having tested them at least annually for a number of years. The testing programs have typically included an array of physical testing, Petrographic examinations, and alkali-aggregate reaction tests.

As outlined in De Grosbois and Fontaine (2000), we reviewed historic data from both AMBT as well as the CPT and compared against new test results from a program of AMBT testing targeted at specific lithologies. We reviewed historic petrographic data of the aggregates themselves, to assess whether trends could be discerned that would link AAR potential with lithological composition.

The program was two-fold: (1) compare historic data records of AMBT, CPT and Petrographic examinations done on various nominal aggregate sizes, and (2) determine the reactivity levels of individual rock types within each of the sources.

For the lithology-specific tests, samples of current production aggregate from these two sources were screened and then manually sorted through to obtain subsamples of various rock types of interest: chert, quartzite, sandstone for the Alberta sample; granite, volcanic and chert for the British Columbia sample. These samples were then crushed and prepared and evaluated in the AMBT, in a 'standard' test, as well as in a series of 'SCM-mitigated' tests.

All testing was conducted in accordance with Canadian Standards Association (CSA) standards[1,3]. The segregation of specific lithologies for targeted AAR testing was completed in accordance with relevant CSA Standards[2]. The lithologies presented in this report have been simplified; in most cases, commonly accepted "non-reactive" lithologies with less than 5% contribution were ignored.

4 RESULTS

Petrographic Examination of the 20 mm and 14 mm stone and concrete sand from the Alberta source reveal variable proportions of each lithology between the products of coarse and fine grading (Table 1). With some minor exceptions, the general trend for years 2005 to 2010 appears to be that chert and quartzite is more abundant in finer fractions, while quartz sandstone is more common in larger fractions. Lithic sandstones/wackes were present in variable proportions.

Chert contents for the 14 mm stone compared with the 20 mm stone were as follows (see Table 1 & Figure 1): in 2005, 13 and 5%; in 2006, 3 and 11%; in 2007, 8 and 5%; in 2008, 14 and 11%; in 2009, 17 and 10%; in 2010, 18 and 12%. We observed that chert contents in finer coarse aggregate materials, such as 10 mm stone, were sometimes orders of magnitude higher than that seen in coarser stone products such as 14, 20 or 28 mm stone products.

The alkali-reactivity levels of specific rock types were evaluated in this research program and the results are summarized in Figure 4. The data suggests that quartzite is more reactive than quartz sandstone. Although chert from the Alberta source was not separately tested, chert from the south coast BC source was tested.

Along with chert, the other lithologies tested from the BC source included granite/metagranite, and volcanics ranging from mafic to felsic in mineral composition. The results of AMBTs on these materials are summarized in Figure 5, which indicates that volcanic rock types are most reactive, followed by chert, quartzite, granite/metagranite and quartz sandstone.

Interestingly, when the BC chert was evaluated on its own in the AMBT, it exhibited a lower reaction potential than the full aggregate sample. The AMBT conducted on the volcanic rock produced higher expansion than the full sample, which supports the prevailing idea that regional volcanic rocks in the western parts of Canada and the US are highly reactive (Shrimer, 2005 http://pubs.usgs.gov/bul/b2209-k/b2209k.pdf).

Historical data for AMBT and CPT testing were available to review for the Alberta source only. The following observations and trends were observed (Figures 2 and 3):

- Consistently, on an annual basis, the 52-week CPT expansion value was highest in the smallest sand fraction, followed by the 14 mm stone and then by the 20 mm stone. In years where the two distinctly graded stone products were not individually tested, the sand was higher than the blended 20 x 5 mm stone aggregate. This trend was observed over six years of testing.
- There was an overall trend of decreasing 52-week CPT expansion during the 6 years of data.
- There was no discernible annual trend in the AMBT data set.
- The average 14-day AMBT expansion over 5 years had no significant trend of increasing or decreasing; it was consistently high for all sand and stone products.

5 DISCUSSION

The following conclusions can be made on the basis of this testing.

1. The results of the testing program appear to support the concept that the degree of reactivity measured in length-change-based predictive AAR tests is influenced by the proportion of certain reactive rock

type components. If it were possible to isolate individual rock types methodically (some of these sources are composed of more than a dozen geologically-distinct rock types), it might be possible to develop a more complete understanding of which rock types contribute strongly to AAR development and which rock types tend to contribute only a small reaction potential, or are inert.

2. One of the assumptions of the program was the notion that siliceous rocks, chert, and glassy volcanic would prove most reactive. This was in part based on experience with these aggregates, as well as work done by others (Fournier 2004). Project experience involving AAR-affected concrete in BC has also suggested that some regional granites contribute to AAR, albeit over a long time period (e.g., 60+ years); thus, granitic rock from the BC aggregate was also included as reactive.
3. The result indicating higher potential for Alberta 14 mm stone compared to 20 mm stone, as evaluated by the CPT could be due to the following factors:
    a. There was generally more chert in the 14 mm stone fraction compared to the 20 mm stone, and chert typically has high AAR potential.
    b. The particle surface area-to-mass ratio in the 14 mm stone would be higher compared to the 20 mm stone due to inclusion of crushed material.
4. The inconsistent annual trend for the AMBT results could be due to the following:
    a. Crushing and re-grading per the AMBT method appears to alter the lithological distribution by high-grading stronger materials and removing weaker ones. Often, the reactive rock types tend to also be composed of strong rock types.
5. Comparison of lithological data from various years and between different petrographers highlights the complications that may result due to the subjective aspects of classification of some rock types that are similar, and that may have a gradational composition between them. For example, the distinction between a 'quartzite' versus 'quartz sandstone' and an 'orthoquartzite' may differ between individual petrographers. Thus the precision of distinguishing between some lithological classifications may not be appropriate for such a study. Perhaps further work will be needed to develop reliable and precise lithological definitions to assist in identification of some potentially deleterious rock types, within regions where such rocks have been implicated in deleterious AAR. As noted in Morrison and Roy(Morrison, 2000) and Shrimer *et al* (2008), instances of deleterious AAR in Alberta are not widespread or well-documented. Some work by Fournier (2004) sought to assess AAR and rock types for some Alberta aggregates.

6 CONCLUSIONS

Based on the results of the current research, the following concluding remarks are provided.

- Understanding that there is a direct relationship between AAR potential and geological composition is essential in developing a sound and practical perspective on why AAR potential can or may change at aggregate sources. This is particularly true for sand-and-gravel pit sources, i.e., fluvial / glaciofluvial deposits where geological composition is mixed and variable.
- Recognition that hydraulic sorting of sediments composing a sand-gravel deposit, horizontally as well as with depth is important, as such sorting can concentrate reactive components according to size.
- It is useful for the purposes of reliable and consistent engineering design of concrete mixes made with potentially-reactive aggregates to have an appropriate amount of information available. It is most useful is such information takes into account the vagaries of geological composition within aggregate products.
- Accounting for geological variability within sand-and-gravel deposits may only be possible within broad limits. More precision may be generated through a combination of Petrographic assessment

and AAR testing. However, the frequency of such evaluation may need to be increased from is considered 'typical' (e.g., annually) to more often.

- Rock types such as volcanic rocks, siliceous rocks such as chert, quartzite and quartz-rich sandstones – often considered to be potentially reactive in many areas – appear to be appropriately considered as such in the two sources included in this study. The relative AAR potential levels are slightly different for the rock types assessed in this study, but sufficient definition between these rock types may not be obtained using the AMBT method. It is thought that the CPT method may provide better resolution of relative AAR potential between suspected reactive rock types.
- The effects of particle size on AAR potential may be more dependent upon the concentration of geological components than previously realized. Additionally, overprinting of the effects of particle shape, surface area-to-mass, and enriching of geological elements due to crushing of oversize particles and subsequent blending should also be considered as possible contributors to AAR potential variability throughout the extraction and processing period for specific sources.

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8 TABLES AND FIGURES

Table 1 – Annual Lithological Comparisons, Alberta source, 20 mm and 14 mm

Lithology	**Year - Stone Type (mm)**											
	2005		2006		2007		2008		2009		2010	
	14-5	20-14	14-5	20-14	14-5	20-14	14-5	20-14	14-5	20-14	14-5	20-14
Lithic Sandstone	19.0	24.2	12.5	33.6	27.4	32.1	11.4	9.6	8.0	11.7	4.4	14.1
Quartz Sandstone	35.9	45.2	69.9	9.8	51.2	21.0	25.4	28.0	31.3	43.3	42.3	39.3
Quartzite	32.3	25.5	15.1	45.5	13.9	41.9	48.9	51.0	44.0	35.0	35.2	35.1
Chert	12.9	5.2	2.5	11.2	7.5	5.0	14.4	11.4	16.8	9.9	18.1	11.5

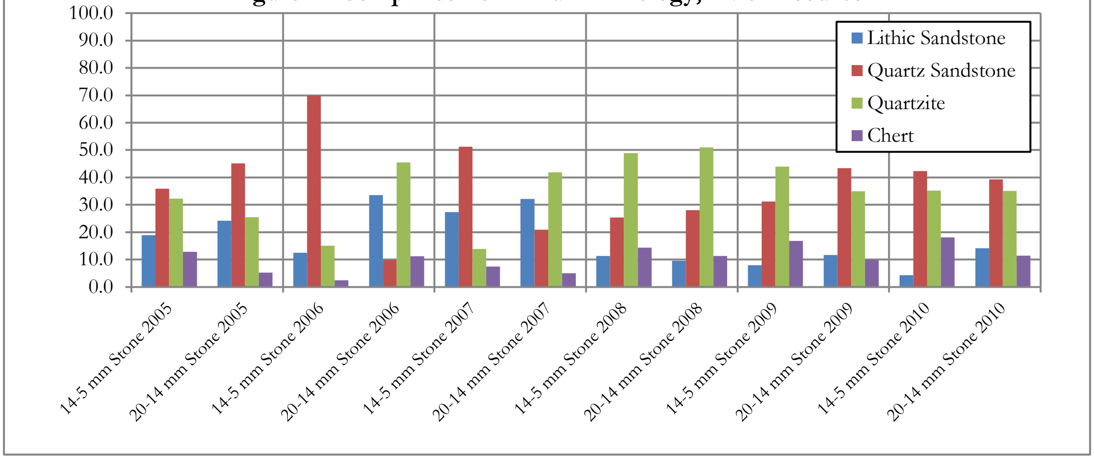

Figure 1 - Comparison of Annual Lithology, Alberta source

Figure 2 – Comparison of Annual AMBT Expansion Data and Aggregate Size

Type	**14-day Expansion %**
Sand 2005	0.243
-combined-	-
20-5 stone 2005	0.343
Sand 2006	0.280
14-5 mm stone 2006	0.300
20-14 mm stone 2006	0.280
Sand 2007	0.326
-combined-	-
20-5 mm stone 2007	0.342
Sand 2008	0.330
14-5 mm stone 2008	0.326
20-14 mm stone 2008	0.387
Sand 2009	0.302
14-5 mm stone 2009	0.360
20-14 mm stone 2009	0.256

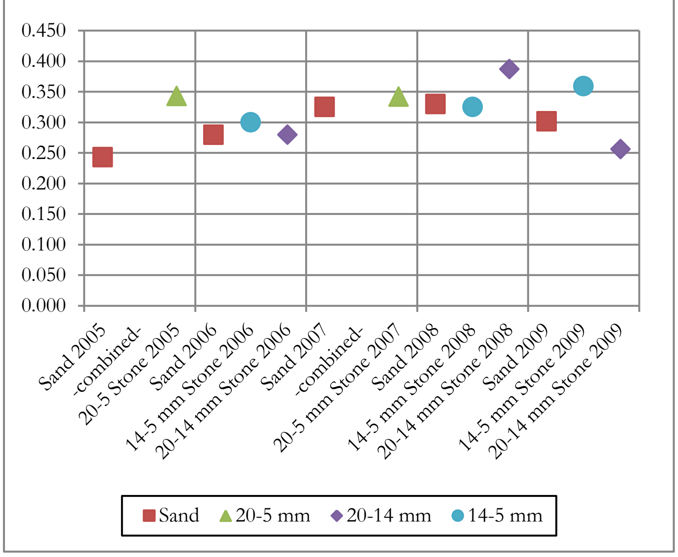

Figure 2 - Comparison of AMBT 14-day Expansion

Table/Figure 3 – Comparison of Annual CPT Expansion Data and Aggregate Size

Type	**52-week Expansion %**
Sand 2005	0.207
-combined-	
20-5 mm Stone 2005	0.115
Sand 2006	0.177
-combined-	
20-5 mm Stone 2006	0.090
Sand 2007	0.190
-combined-	
20-5 mm Stone 2007	0.053
Sand 2008	0.077
14-5 mm Stone 2008	0.052
20-14 mm Stone 2008	0.034
Sand 2009	0.056
14-5 mm Stone 2009	0.038
20-14 mm Stone 2009	0.031
Sand 2010	0.101
14-5 mm Stone 2010	0.042
20-14 mm Stone 2010	0.039

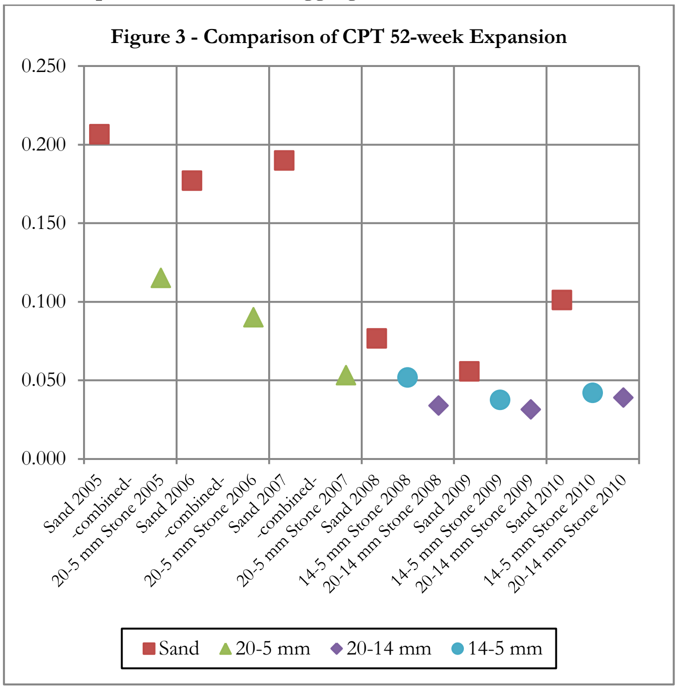

Table 4 – AMBT Expansion Data for Specific Lithologies from an Alberta Source

Lithology	**Average Expansion (day-%)**												
	0	3	5	7	10	12	**14**	17	19	21	24	26	28
Standard	0	0.073	0.133	0.181	0.251	0.296	**0.332**	0.386	0.418	0.446	0.494	0.521	0.549
Quartz Sandstone	0	0.041	0.082	0.121	0.173	0.216	**0.244**	0.290	0.316	0.340	0.383	0.407	0.434
Quartzite	0	0.069	0.129	0.174	0.242	0.286	**0.321**	0.375	0.408	0.438	0.489	0.516	0.544

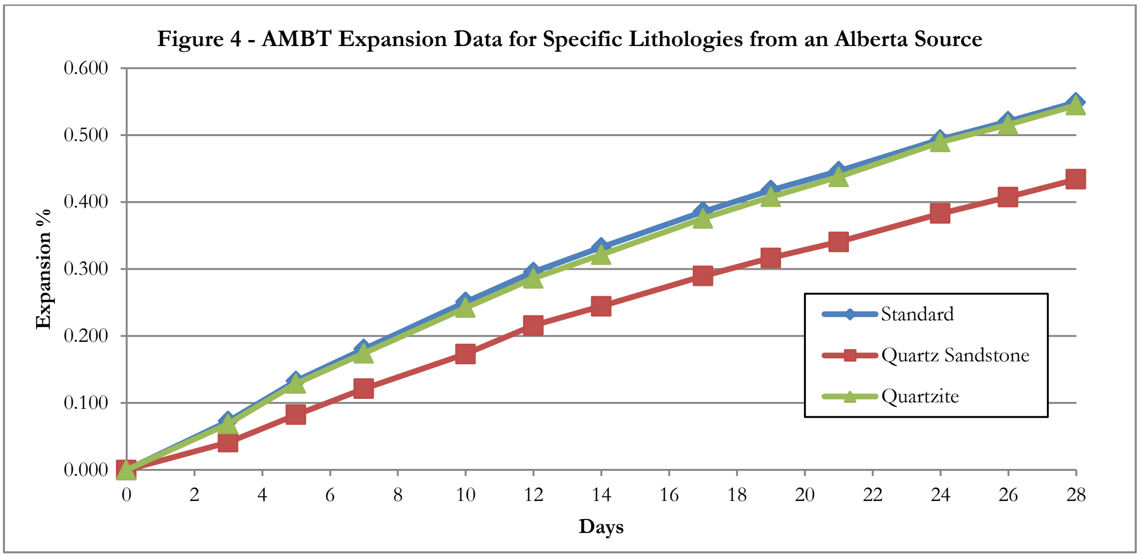

Table 5 – AMBT Expansion Data for Specific Lithologies from a British Columbia Source

Lithology	Average Expansion (day-%)												
	0	3	5	7	10	12	**14**	17	19	21	24	26	28
Standard	0	0.092	0.205	0.279	0.375	0.429	**0.473**	0.535	0.574	0.606	0.660	0.690	0.721
Volcanic	0	0.116	0.236	0.307	0.402	0.456	**0.500**	0.564	0.604	0.636	0.693	0.725	0.757
Granite	0	0.028	0.070	0.118	0.200	0.246	**0.282**	0.330	0.361	0.381	0.423	0.445	0.468
Chert	0	0.158	0.240	0.296	0.371	0.414	**0.448**	0.499	0.527	0.551	0.585	0.607	0.626