EVALUATION OF AN ALKALI-REACTIVE AGGREGATE UNDETECTED BY PETROGRAPHIC METHODS

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Abstract

Evaluation of the potential for Alkali-Aggregate Reactivity (AAR) was carried out on a source of aggregate from Guyana. Concerns about the aggregates' potential for AAR were expressed, and were based on the initial field diagnosis of the aggregate's lithology as "Andesite", as well as the awareness that andesites have, in some regions, been known to be reactive in concrete.

During the initial portion of the study, samples were submitted for two phases of testing to be run concurrently: Petrographic Examination (ASTM C-295), and the Mortar Bar Accelerated Test (MBAT)(CSA A23.2-25A). The Petrographic Examination determined the lithology of the sample to be Diabase, which has not been reported to be associated with expansive AAR behaviour in concrete. The MBAT procedure furnished expansion results which were more than double the suggested 14-day expansion limit in CSA. Due to the apparently conflicting results, a decision was made to undertake additional investigation, consisting of in-depth diagnosis of the rock's composition, as well as Concrete Prism Testing (CSA A23.2-14A) of the aggregate.

The details of the investigation conducted for potential AAR of this aggregate are presented and discussed. This case serves as a reminder of the need to carefully conduct AAR evaluations, and emphasizes that in-depth petrographic and other diagnostic techniques may be required for correct identification of potentially reactive aggregates.

Keywords: Alkali-Aggregate Reaction, Diabase, Mortar Bar test, Concrete Prism test.

INTRODUCTION

Alkali-Aggregate Reactivity (AAR) is a reaction which takes place between the alkali compounds present in Portland cement and certain minerals present in aggregates. The reaction produces an alkali-silica product which occupies greater volume than the original constituents, resulting in a net expansion of the affected concrete. The expansive effects of AAR can produce cracking, crack networks, surface spalling of concrete elements, displacement of concrete elements, discontinuities in concrete, and in general, premature failure of or a reduced service life of the affected concrete elements.

AAR requires the following in order to develop:

- reactive aggregate
- a certain "threshold" alkali content in the concrete
- a source of moisture
- sufficient time

These elements are interdependent and proportions of each of the above requirements can vary considerably. The amount of reaction observed depends on the interaction of these elements; as a result, damage to concrete elements and structures can also vary considerably.

PROJECT BACKGROUND

In 1991-92, HBT AGRA Limited was retained to undertake an assessment of the potential for alkali-aggregate reactivity ("AAR") of a coarse aggregate sample from Guyana. At the project site, a potential source of concrete aggregate had been identified by field engineers. The field description of the rock type had been given as "Andesite". Project personnel were aware that Andesitic aggregates, in *some* regions, had been known to be the reactive component in concrete. On that basis, it had been decided to initiate a program of investigation to determine whether these rocks had a potential for AAR.

The project was sited in an area of Guyana where the relative humidity and mean temperature were both quite high. The alkali content of the proposed cement source was uncertain, but was expected to be "moderate to high". Design strengths for the proposed concrete mixes for the project were expected to range from 20 to 40 MPa. It was not known at the time the assessment was initiated whether a low-alkali content source of flyash was available for the project.

PROGRAM FOR ASSESSMENT OF AAR POTENTIAL

The program of investigation for this aggregate followed the suggested course recommended in CAN/CSA A23.1-M90, Figures B1, B2 and B3. Petrographic Examination in accordance with ASTM C-295 was conducted at the same time as the Mortar Bar Accelerated Test ("MBAT")(CSA A23.2-25A). Under normal circumstances, a Petrographic Examination would have been undertaken prior to any further investigative work, since results from the Petrographic Examination have been considered the important "first step" upon which the aggregate may be rejected or accepted, and upon which any ensuing program of investigation may be based. In this particular case, due to project construction schedules, the information necessary for acceptance of the proposed concrete aggregate was urgently required. Therefore, rather than wait for Petrographic Examination results, the MBAT procedure was run concurrently.

PETROGRAPHIC EXAMINATION

The samples consisted of angular blocks of rock ranging from approximately 50 mm up to 200 mm in least dimension. The rock was dark grey to black in colour, fine-grained in texture, dense, and strong. The texture appeared to be fairly consistent for most of the rock particles. Rusty brown to orange surfaces were interpreted as weathered exterior surfaces or exposed opened joint planes, containing oxides of iron.

Numerous veins transected the rock particles, and there was evidence that displacement along some of the healed joints had occurred. Vein fillings consisted of quartz and minor calcite. Occasional pyrite was seen in some of the vein material.

PHYSICAL CHARACTERISTICS

The rocks samples examined were found to have excellent strength and toughness. With respect to strength and durability in concrete, or for other construction aggregate uses, these rocks were projected to provide good to excellent performance.

THIN-SECTION EXAMINATION

Thin-sections were prepared from representative samples of the rock. The thin-sections were noted to have a greenish cast in plane light. The mean crystal size was approximately 0.1 mm. One of the thin-section samples had overall finer grain size than the others.

Examination of the rocks in thin-section revealed an assemblage of minerals including pyroxenes, amphiboles and plagioclase feldspar *(see Figure 1)*. Alteration of mafic

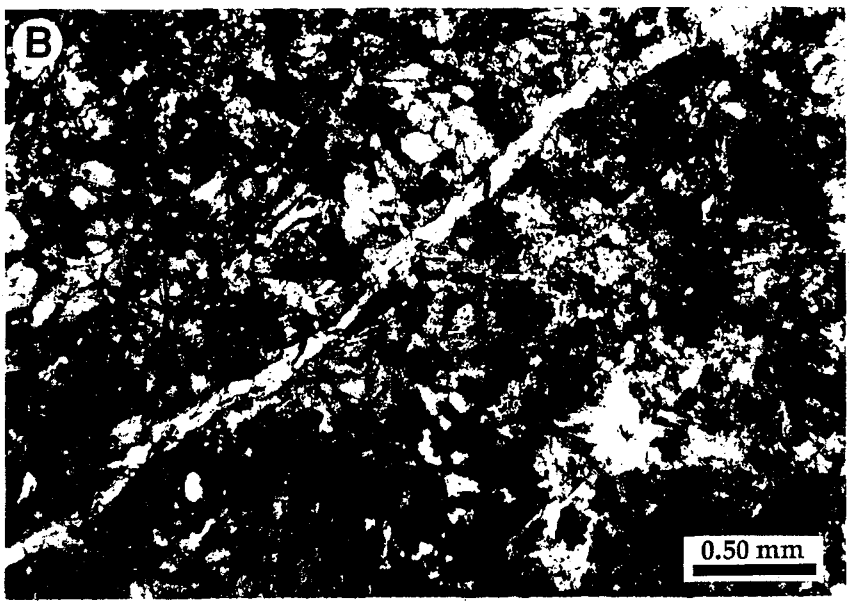

Figure 1: Micrograph of thin-section of diabase rock, showing amphibole and altered feldspars. 100x, crossed polars.

minerals to chlorite was fairly common. Feldspars were cloudy and altered. Vein materials consisted of quartz and minor calcite. Secondary albite and prehnite was present in some of the samples. Sulphide minerals were present, mostly in the matrix, although some occurred in the veins. The sulphides were present as discreet crystals and irregular masses throughout the rocks. The sulphide minerals were estimated to be constitute 2 or 3 percent (by volume) of the rocks. Quartz was not visible in the matrix of the samples in thin-section. The thin-sections had a 'hazy' or 'cloudy' appearance.

On the basis of the thin-section examinations, the rocks were identified as *'Diabase'*, being intermediate to mafic in overall mineralogy and having crystalline texture consistent with a dike, sill or plutonic rock. However, sufficient of the original mineralogy had been altered or replaced that the term *'Altered Diabase'* was assigned.

Chlorite

In hand specimen, chlorite alteration tended to obscure the crystalline texture of the rocks, with the effect that identification of the rock was made more difficult. Some amount of chlorite dust might be produced during crushing of this rock for aggregate. Chlorite dust might tend to reduce aggregate-to-cement bond, if not washed off.

Commentary on 'Andesite' vs. 'Diabase' Nomenclature

Although the field description for these rocks was *'Andesite'*, in thin-section they were described as *'Altered Diabase'*. Diabase has a composition which is generally equivalent to Basalt (i.e., the mafic end-member in the volcanic rocks). Andesite is less mafic in composition and is fine-grained to aphanitic in texture, due to its extrusive formation, whereas these rocks had a composition more mafic than andesite, and a texture which was consistent with a hypabyssal mode of occurrence (i.e., in a sill or a dike). Andesite quite commonly contains vesicles and/or phenocrysts, which were not observed in these rock samples.

For these reasons, it was felt that the term *'Diabase'*, rather than *"Andesite"*, would be more correct to describe these rock samples.

MORTAR BAR ACCELERATED TEST

Samples of the diabase aggregate were submitted for AAR testing using the Mortar Bar Accelerated Test (MBAT) procedure. This rapid test provides results in fourteen days, in contrast with the more conventional "Concrete Prism" method (CSA A23.2-14A), which takes one year to generate final results.

This test procedure is recognized as being fairly severe, and is considered as such to be a *screening* test. Typically, the cement-aggregate mortar bars will display a net expansion in length. The percent of length change is used as an indication of the aggregate sample's *potential* for alkali reactivity, if greater than a specified threshold limit. The threshold expansion value specified by CSA is 0.15%, while ASTM uses 0.20% as the threshold value. Aggregates which display expansion values in excess of these percentages are considered to be *potentially alkali-aggregate reactive*, and are recommended to be further evaluated for potential AAR. Aggregates which display expansion values *below* these values are considered to be innocuous with respect to the potential for AAR.

Results of the MBAT

The expansion levels recorded in the MBAT using the Guyana diabase aggregates were 0.36%. This was more than double the threshold value allowed in CSA, and nearly double that specified by ASTM. On the basis of these results, it was concluded that there was a need for further evaluation of the aggregate.

The expansion results obtained in the MBAT seemed inconsistent with the Petrographic Examination results (which appeared to indicate that the aggregate should have innocuous behaviour). For this reason, additional diagnostics were carried out, to supplement the thin-section analysis.

ADDITIONAL DIAGNOSIS AND EVALUATION OF THE ROCK

In-depth analyses of the rock samples, consisting of Scanning Electron Microscopy (SEM) and X-Ray Analysis (XRA) were conducted at CANMET facilities in Ottawa. The results of CANMET's study indicated that the "cloudy appearance" observed in the thin-sections was a very fine-grained form of quartz. XRA data gave strong Si amd O peaks, again indicating quartz. The quartz had not been identified using high magnification under the petrographic microscope.

Additional information was obtained by running the "Gel Pat" Test. In this test, samples of the rock are immersed in a solution of NaOH 1N at 23°C, and examined for reaction "corrosion figures", or the appearance of silica gels. Corrosion patterns, which are indicative of reactive behaviour, were noted on the diabase samples. SEM and XRA study of the samples from the Gel Pat Test confirmed that the material which was associated with the corrosion patterns in the Gel Pat Test was a fine deposit of quartz.

CONCRETE PRISM TEST

In accordance with CSA requirements, the aggregate was evaluated in the Concrete Prism Test (CSA A23.2-14A). The results of the Concrete Prism Test of the Guyana diabase aggregate are plotted in Figure 2, and are summarized as follows:

Test Sample Condition	Percent Expansion		
	at 52 wks	at 104 wks	CSA limit, 52 wks
Relative Humidity >95% @ 38°C	0.054	0.099	0.040
Immersed in 1N NaOH, @ 38°C	0.065	-	

The diabase aggregate, on the basis of the Concrete Prism Test, was considered to be *"potentially alkali-reactive"*, when used in Portland cement concrete.

Project-Specific Mitigative Measures

Since the project had to proceed, and since environmental conditions conducive to the development of AAR existed at the project site, specific recommendations were drafted for the concrete at the project, to mitigate potential AAR related to the aggregate. These included:

- the use of a low-alkali cement;
- partial cement replacement using a low alkali flyash;

- prevention of ingress of moisture into the concrete elements through waterproofing membranes and coatings;
- structural design to accomodate potential displacement of concrete; and,
- mix designs which incorporated moderate cement contents.

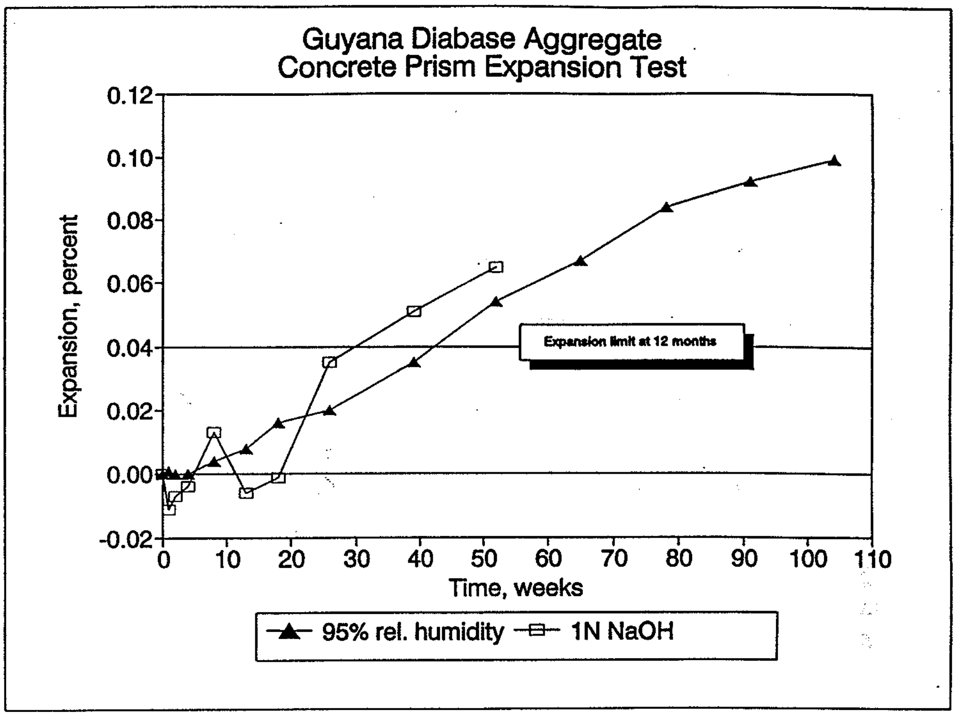

Figure 2: Plot of Concrete Prism Expansion Test Results

DISCUSSION

The experience gained in this test program indicate that "things are not always what they appear". The prevailing accepted procedures, based on previous experience and research, were followed in the assessment of the diabase aggregate. If the normal route of evaluation had been utilized, the diabase aggregate would likely have been considered "innocuous", on the basis of the geologic description provided by the Petrographic Examination. However, the data from the MBAT test prompted further investigation of the rock. Rather than determining that the aggregate was "innocuous", the Concrete Prism test results determined that the aggregate was "potentially alkali reactive".

This case serves to underscore the importance of Petrographic Examination in an evaluation of aggregate for potential use as a concrete aggregate. It must be stressed that analyses of sufficient detail may be required to clarify unclear aspects of certain cases. Caution and care must be exercised particularly when investigating rocks which have been affected by alteration and/or metamorphism.

Comment on Current Procedures

Does this case suggest that the current procedures are ineffective to assess aggregates effectively? No, rather, the current procedures used in Canada *are* considered adequate, in a general sense. However, this case suggests that those conducting AAR evaluations should bear in mind that exceptions may be encountered from time to time which may not be detected using current state-of-the-art procedures.

A second observation about this case would be that the role of the Petrographic Examination should be enhanced, particularly in assessments of aggregates which have no or little previous testing or field performance history. Thin-section analyses should perhaps be conducted on a more routine basis in Petrographic Examinations of previously untested aggregate supplies. Where the thin-section analysis is not able to resolve all mineral phases of a geologic component of an aggregate, then the petrographer should be encouraged to resolve the identification by means of in-depth analyses of the rock, so that all avenues of investigation can be explored, and a complete and thorough assessment is completed on the aggregate in question.

If the steps noted above are not carried out, the Petrographic Examination could become an ineffective tool in the assessment of aggregates for AAR, due to incomplete analysis of rock types present in aggregates.

RECOMMENDATIONS

1. It is recommended that existing standards and recommended procedures be reviewed and amended to carry cautionary notes which emphasize that investigation techniques in addition to standard microscopic examination may be required in Petrographic assessment of aggregates. Furthermore, detailed study to identify suspect unidentified phases of rocks should be encouraged.

2. It is recommended that a distinction should be made between Petrographic Examinations conducted for:

   A. Routine testing ("annual checkup") of a current production sample, from an aggregate source with a long established history of performance in concrete, as well as a long record of test results; and,

   B. Evaluation of a proposed, new or current source of aggregate with either no or little previous history of testing *or* history of use in concrete.

3. It is recommended that consideration be given to include the rock type "Diabase" on lists of potentially alkali-reactive rock types.

CONCLUSIONS

The study undertaken has shown that much care is required in the assessment of an aggregate's potential for alkali-aggregate reactivity. Petrographic Examination must be conducted to a level of detail sufficient to resolve any unidentified phases present in the aggregate.

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