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Evaluating Potential Alkali-Reactivity of Concrete Aggregates – How Reliable are the Current and New Test Methods?

Avaliação da Reatividade Potencial de Agregados para Concreto – O Quanto Confiáveis são os Métodos Atuais e os Novos Métodos de Ensaio?

B. FOURNIER [a]
bfournie@nrcan.gc.ca

D. LU [c]
duyoulu@njut.edu.cn

K. J. FOLLIARD [e]
folliard@mail.utexas.edu

P.-C. NKINAMUBANZI [b]
pnkinamu@nrcan.gc.ca

M. D. A. THOMAS [d]
mdat@unb.ca

J. H. IDEKER [f]
ideker@mail.utexas.edu

Abstract

Although the Concrete Prism Test (CPT) (e.g. ASTM C 1293) is commonly considered as the most reliable test procedure for evaluating the potential alkali-reactivity of concrete aggregates, its one-year test period and somewhat high between-laboratory variability remain as its main limitations, which result in limited industry acceptance in some regions/countries. During the past decade, researchers in France and North America have identified the potential for an accelerated version of the CPT, performed at 60°C instead of 38°C, to quickly evaluate the potential alkali-silica reactivity of concrete aggregates. The Accelerated Mortar Bar Test (AMBT) (e.g. ASTM C 1260) is generally recognized as a good screening test for evaluating potential alkali-reactivity of concrete aggregates. However, the test is severe for a number of aggregates, inducing somewhat excessive expansion; on the other hand, some aggregates induce unexpectedly low expansion in the AMBT (compared to that obtained in the CPT or in field performance). Recently, a concrete microbar test was developed to facilitate timely identification of potential alkali-carbonate reactivity of carbonate aggregates; the test also appeared to identify some atypical alkali-silica reactive aggregates that displayed limited expansion in the AMBT. This paper reviews recent data on the use of the above test procedures and discusses their reliability in the evaluation of the potential alkali-reactivity of concrete aggregates.

Keywords: alkali-silica reaction, accelerated testing, accelerated mortar bar test, concrete prism test, concrete microbar test.

Resumo

Embora o teste com prisma de concreto (CPT) (por exemplo, ASTM C1293) seja costumeiramente considerado como o procedimento de ensaio mais confiável para se avaliar a reatividade potencial de agregados para concreto frente aos álcalis, seu tempo de um ano de teste e a relativamente elevada variabilidade nos ensaios entre laboratórios constituem suas maiores limitações, o que resulta em limitada aceitação por parte da indústria em algumas regiões e paises. Durante a última década, pesquisadores na França e América do Norte identificaram o potencial para uma versão acelerada do CPT, executada a 60°C ao invés de 38°C, para rapidamente avaliar a reatividade potencial álcali-sílica de agregados para concreto. O método acelerado da barras de argamassa (AMBT) (por exemplo, ASTM C 1260) geralmente é reconhecido como um bom teste classificatório para se avaliar a reatividade potencial aos álcalis de agregados para concreto. Entretanto, o teste é severo para vários agregados, induzindo de alguma maneira excessiva expansão; por outro lado, alguns agregados induzem uma inesperadamente reduzida expansão no AMBT (comparado àquela obtida no CPT ou em desempenho de campo). Recentemente, um teste de concreto em microbarras foi desenvolvido para facilitar a identificação, a tempo, da reatividade potencial álcali-carbonato de agregados carbonáticos; o teste parece, também, identificar alguns agregados com reação álcali-sílica atípica que mostraram limitadas expansões no AMBT. Este trabalho revisa dados recentes sobre a utilização dos procedimentos de teste acima descritos e discute sua confiabilidade na avaliação da reatividade potencial álcali-agregado.

Palavras-chave: reação álcali-sílica, teste acelerado, teste acelerado de barras de argamassa, teste do prisma de concreto, teste da microbarra de concreto.

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[a] *Manager, Concrete Technology Program, CANMET-MTL, Canada (bfournie@nrcan.gc.ca)*
[b] *Research Scientist, Concrete Technology Program, CANMET-MTL, Canada (pnkinamu@nrcan.gc.ca)*
[c] *Associate Professor, Nanjing University of Technology, Nanjing, P.R. China (duyoulu@njut.edu.cn)*
[d] *Professor, University of New Brunswick, Canada (mdat@unb.ca)*
[e] *Professor, University of Texas in Austin, U.S.A.(folliard@mail.utexas.edu)*
[f] *Ph.D. Candidate, University of Texas in Austin, U.S.A (ideker@mail.utexas.edu)*

1 Introduction

Alkali-aggregate reactions (AAR) are chemical reactions between the alkali hydroxides (K^+, Na^+ - OH^-) from the concrete pore solution and some mineral phases within the coarse and/or fine aggregates in concrete. As such reactions may lead to expansion, cracking and loss in serviceability of the concrete structures affected, it is imperative that the potential alkali-reactivity of concrete aggregates are reliably evaluated prior to their use and, if proven potentially reactive, appropriate preventive actions be taken.
The potential alkali-reactivity of aggregates can be determined through the field performance survey of concrete structures incorporating the aggregate under evaluation. Such an approach is, however, often not possible (e.g. for new sources of aggregates) or practical (e.g. time availability). This could also result in misleading information when the survey is performed by people with limited experience in the assessment of AAR in structures or when the basic criteria for "diagnostic" structures (as described in the Appendix B of CSA A23.1-04 [1]) are not fully met. CSA Standard Practice A23.2-27A [2] provides a global approach for the evaluation of the potential alkali-reactivity of aggregate sources based on a series of laboratory investigations. Such a systematic assessment of concrete aggregates in controlled conditions can allow, depending on the test used, to classify aggregates according to their reactivity level and to select appropriate preventive actions based on criteria such as the risk they represent for the type of structure to build, the expected service life and the environmental conditions to which it will be exposed to.

Figure 1 – One-year concrete prism expansions for concretes incorporating reactive Canadian aggregates. Concretes were made either with a low-alkali cement (LAC, 0.40% Na_2Oeq) (~1.7 kg/m³, Na^2Oeq) or with a high-alkali cement (HAC, 0.90% Na_2Oeq), without (~3.8 kg/m³, Na_2Oeq) or with (~5.3 kg/m³, Na_2Oeq) added alkalis.

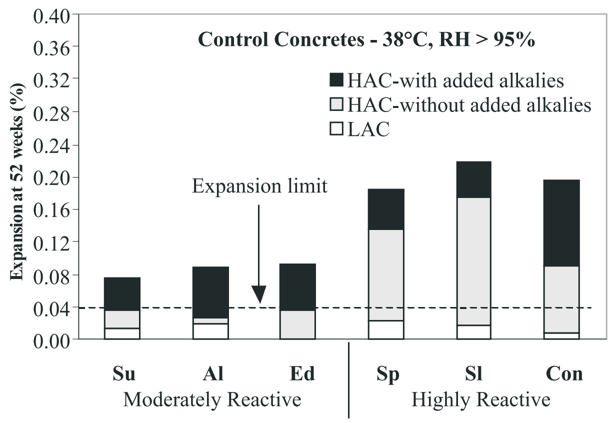
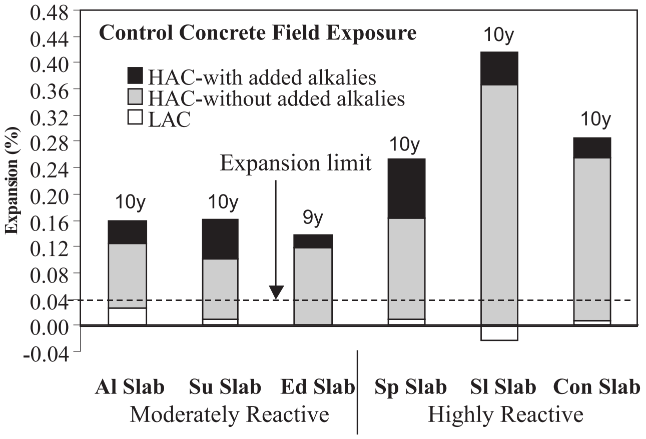


Figure 2 – Expansion of control concrete slabs (710 by 710 by 150 mm in size) after 9 or 10 years exposed outdoors on CANMET exposure site in Ottawa, Canada.



This paper presents experimental data and some thoughts on the reliability of emerging and commonly used test procedures/approaches for evaluating the potential alkali-reactivity of concrete aggregates.

2 Concrete prism test (CSA A23.2-14A (3), ASTM C 1293 (4))

2.1 Mixture Characteristics and Limit Criteria

Canadian Standards recognize that the concrete prism test (CPT) is the best test procedure available for evaluating the potential alkali-reactivity of concrete aggregates. The "reference" character we attribute to the CPT is based on our confidence that it reliably predicts the long-term performance of aggregates in AAR. Actually, the original CPT was significantly modified in the mid 1990's by raising the cement content (from 310 to 420 kg/m³), the alkali content (from 3.88 to 5.25 kg/m³) and the storage temperature (from 23 to 38°C). These modifications were made to recognize potential alkali-reactivity of a wider range of aggregates known to be reactive in field structures, yet could not be recognized as such under previous test conditions. Figure 1 shows that, for concrete incorporating a series of Canadian natural aggregates, concrete prism expansion increases with increasing alkali content in the system. Increasing the alkali content in concrete prism testing was critical for moderately-reactive quartz-bearing rock types (e.g. Su, Al, Ed), the induced expansions of which were less than the 0.04% limit in concrete without added alkalis (i.e. passed the former CPT), but failed in field specimens subjected to outdoor exposure (Figures 2 and 3).
The CPT uses single concrete mixture design (cement content of 420 kg/m³, alkali raised to 1.25% Na_2Oeq by cement mass) and provides a "black or white" evaluation of

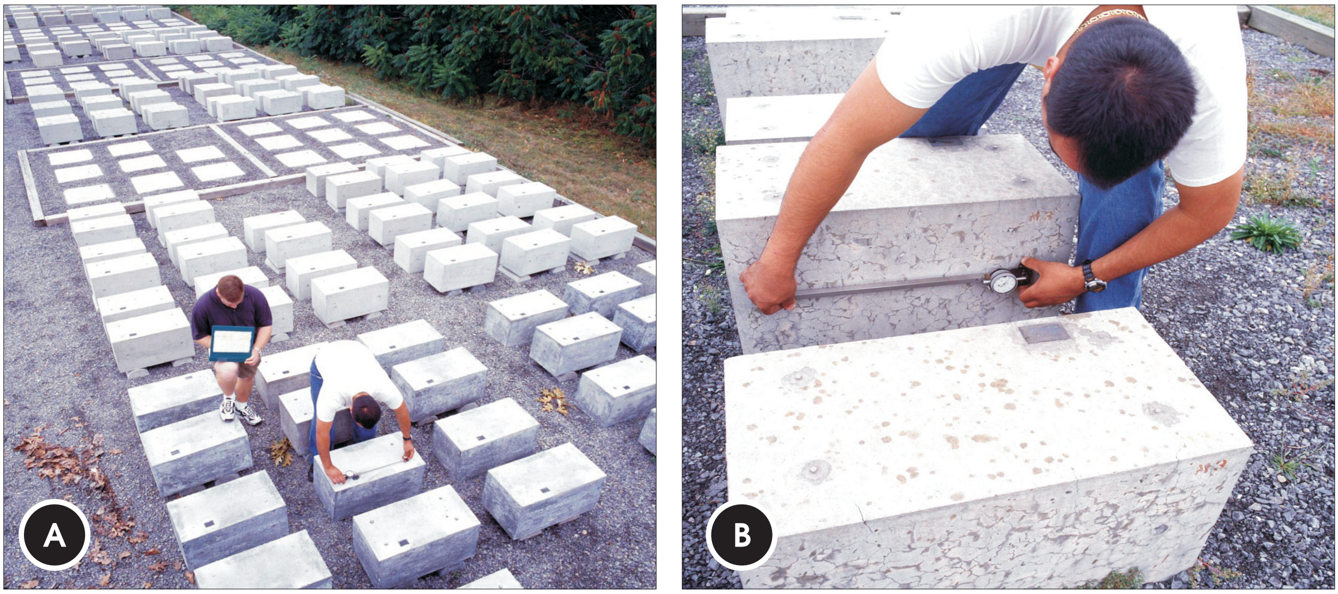
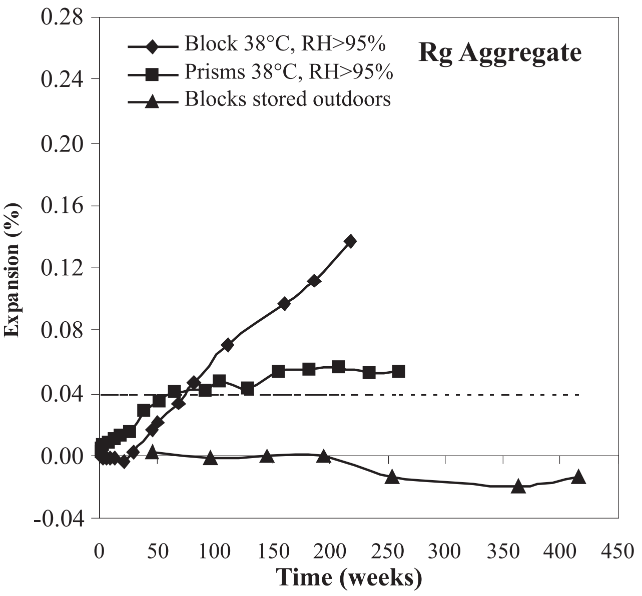


Figure 3 – CANMET outdoor exposure site. (A) Overview of the site with length change measurements taken on the top of a block; (B) length change measurement on the side of a control concrete block showing extensive ASR cracking.

the potential alkali-reactivity of the aggregate based on a single one-year expansion limit of 0.04%. The use of a fixed expansion limit at a fixed time period sometimes raises concerns, especially in the case of aggregates that induce concrete prism expansions close to the limit or that show continued increasing expansion at the time limit. For example, the aggregate Rg in Figure 4 induced concrete prism expansion of 0.035% at one year and about 0.05% at two years. This aggregate is classified as non-reactive according to CPT expansion limit criterion and has shown adequate field performance in concrete structures using low-alkali cements, however. Interestingly, a concrete block (380 by 380 by 710 mm in size) made from the same mixture and kept in the same test condition (i.e. 38°C, R.H. > 95%) expanded at a steady rate and significantly more than the test prisms (Figure 4), thus suggesting some potential for deleterious expansion in high-alkali systems; however, a companion concrete block exposed outdoors has not shown any significant expansion after 9 years of field testing. The above results demonstrate the need for a more detailed analysis of the expansion test data and perhaps using expansion rates in the establishment of limit criteria.

Figure 4 – Expansion of concrete specimens (prism: 75 by 75 by 300mm in size; block: 380 by 380 by 710 mm in size) incorporating marginally-reactive aggregate Rg and submitted to laboratory and field (Ottawa, Canada) test conditions.



2.2 Variability of the CPT Procedure

Fournier and Malhotra [5] and Fournier et al. [6, 7] showed that the CPT has the potential for good within- and between laboratory reproducibility when testing conditions and parameters are well controlled (e.g. using same control materials for testing); however, the between-laboratory variability of the CPT was found to generally increase significantly when local cements and control non-reactive aggregates are used (Table 1). In a study currently in progress at CANMET and the University of Texas in Austin, test results have shown that the nature of

Table 1 – Statistical data for within- and between-laboratory investigations on the CPT

Series (note below)	Spratt Aggregate Avg. (%)	Spratt Aggregate Std. Dev.	Spratt Aggregate C.V. (%)	Sudbury Aggregate Avg. (%)	Sudbury Aggregate Std. Dev.	Sudbury Aggregate C.V. (%)
1	0.146	0.010	6.8	0.125	0.007	5.8
2	0.187	0.013	7.1	0.158	0.003	2.1
3	0.229	0.005	2.0	0.150	0.015	10.0
4	0.170	0.021	12.2	–	–	–
5	0.176	0.045	25.6	0.093	0.037	39.6

- **1** Expansion testing of prisms cast from identical control concrete mixtures repeated 5 times by the same operator in the same laboratory (A) over a six-month period, using cement & aggregates from same lot (FOURNIER et al.[6]).
- **2** Same as series 1 but in Laboratory B (FOURNIER et al. [6]). The materials used for testing in Series 1 (Lab A) and Series 2 (Lab B) were all prepared from the same lots.
- **3** Expansion testing of prisms cast from one mixture made in one laboratory but expansion testing performed in four different laboratories (FOURNIER et al. [7]).
- **4** Expansion testing of prisms cast from concrete mixtures made and tested in 27 laboratories using pre-weighted materials (all prepared in one laboratory) and with provided storage containers (FOURNIER and MALHOTRA [5]).
- **5** Expansion testing of prisms cast from concrete mixtures made and tested in more than 15 laboratories using bulk reactive aggregates (unsieved) and using participant's storage containers (Spratt) or provided storage containers (Sudbury). (FOURNIER and MALHOTRA [5]).

the non-reactive sand used in combination with the reactive coarse aggregate under test can induce fairly large variations in the test results (Figures 5A and 5B). All non-reactive sands in the above study met the requirements of CSA A23.2-14A [3] for non-reactive control aggregate (i.e. 14-day expansion < 0.10% in the accelerated mortar bar test).

The variability of the CPT may also be due to the type of cement used in the test. CSA A23.2-14A [3] requires the cement used in the test to contain an alkali content of 0.90 ± 0.10% Na_2Oeq. In regions/countries where such high-alkali cements are not available, people have been using cements of lower alkali contents while adding larg-

Figure 5 – Expansion of test prisms (38°C) incorporating Spratt (A) and Sudbury (B) reactive coarse aggregates, in combination with 5 "non-reactive" sands.

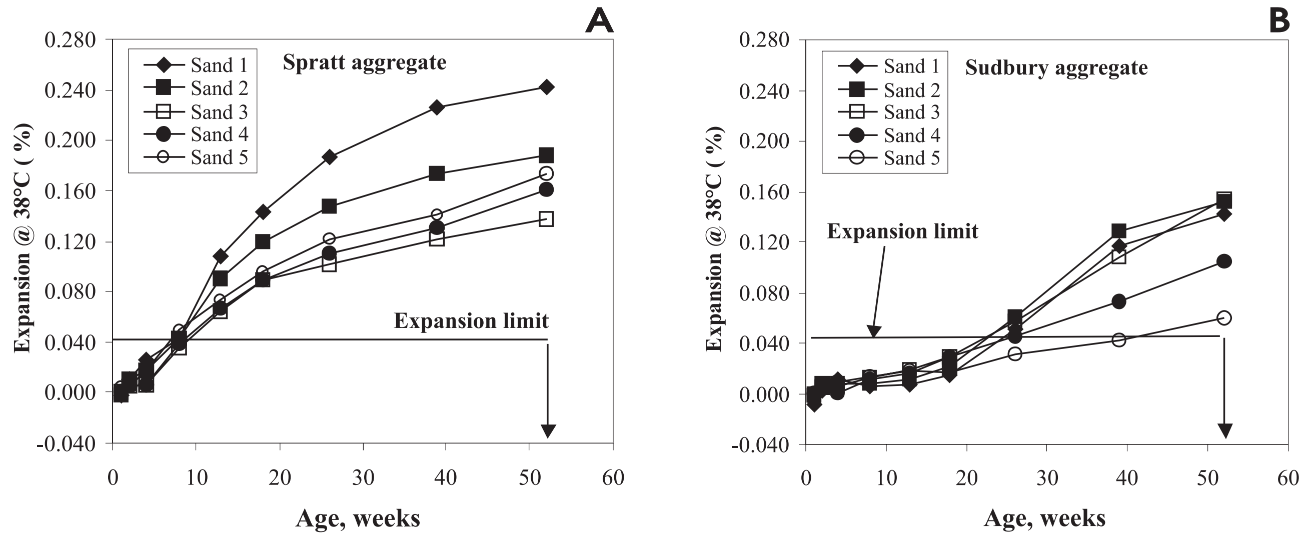
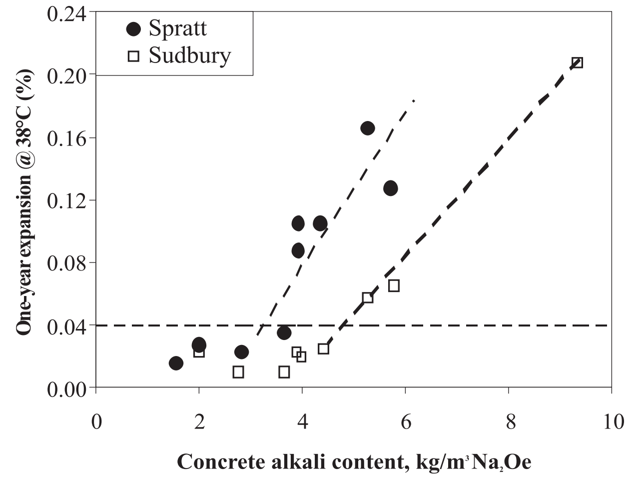


Figure 6 – Concrete prism expansions as a function of concrete alkali content for two reactive aggregates from Ontario, Canada. (From Rogers et al. (9)).



er amounts of NaOH to the mixture to reach the 1.25% Na_2Oeq (per cement mass) requirement; this can also contribute to the multi-laboratory variability of the test.

The above observations stress the importance of running regular testing using control reactive aggregates (e.g. Spratt limestone) and appropriate "non-reactive" aggregate to monitor potential variations in test results.

2.3 Limitations/Expectations of the CPT

The CPT has often been used to evaluate the threshold concrete alkali content necessary to induce deleterious expansion with a range of aggregates. Field testing and performance surveys have shown, however, that deleterious expansion can occur in field concrete at lower alkali contents than that indicated in concrete prism testing. Indeed, Figure 6 suggests that a minimum alkali content of 3 kg/m³, Na_2Oeq, will be necessary to induce deleterious expansion in concrete incorporating the Spratt reactive limestone; however, a concrete block made with low alkali cement (1.9 kg/m³, Na_2Oeq) and exposed outdoors actually showed evidence of ASR (0.05% expansion with slight pattern cracking) after 8 years of field exposure (mix no. 5, Figure 7). Similarly, Figure 6 suggests that the threshold alkali content for a reactive gravel from Sudbury would be about 5 kg/m³, Na_2Oeq; however, field inspection of concrete structures in the Sudbury area showed that expansion in structures actually occurs at a significantly lower concrete alkali content (Rogers, Ontario Ministry of Transportation, personal communication). Reasons for this discrepancy could include progressive alkali contributions from sources other than the cement in field structures (e.g. from the aggregates or from external sources such as de-icing chemicals, sea water), and alkali leaching from the laboratory test prisms. Indeed, considering the relatively small size of the laboratory test specimens (i.e. 75 by 75 by 300 to 400 mm in size) and the high humidity conditions in the storage containers used in the CPT, progressive leaching of alkalis from the test prisms occurs (Rivard et al. [8], Fournier et al. [7]), thus significantly reducing the expansion rates in the later stages of testing. Figure 8 shows the expansion curves of concrete test specimens incorporating an extremely reactive Australian aggregate, exposed outdoors and at 38°C with R.H. > 95%. The expansion curve of the test prisms is seen levelling off after about one year of testing at 38°C, while the larger block in the same condition, despite a slower start, continue to expand at a steady rate even after four years of testing. The block specimen exposed outdoors (in Ottawa, Canada) reached the 0.04% expansion level after about 4 years; since then, it has been expanding at a rate almost similar to that of the block stored at 38°C. Because of the above issues, it appears that the CPT, using the one year expansion level, does not necessarily indicate the maximum potential for expansion of concrete aggregates; this can also be observed by comparing expansion levels from Figs 1 and 2.

Fournier et al. [6] stressed the importance of evaluating the potential alkali-reactivity of the combinations of coarse and fine aggregates proposed for use in field applications, since the relative reactivity levels of the fine and coarse aggregates might lead to unexpected results when tested together (i.e. compared to when tested with non reactive coarse or fine aggregates). Finally, since the CPT uses high cement (420 kg/m³) and alkali (5.25 kg/m³) contents to accelerate the process of ASR within a year and forecast the long-term reactivity of the aggregate, the test is not really suitable, at least in its current form, to reliably evaluate the potential alkali-reactivity in job mix designs, for instance those using low-alkali cements.

Figure 7 – Expansion of unreinforced concrete beams (0.6 by 0.6 by 2.0 m in size) at MTO outdoor exposure site in Kingston, ON, Canada. (From Rogers et al. (10)).

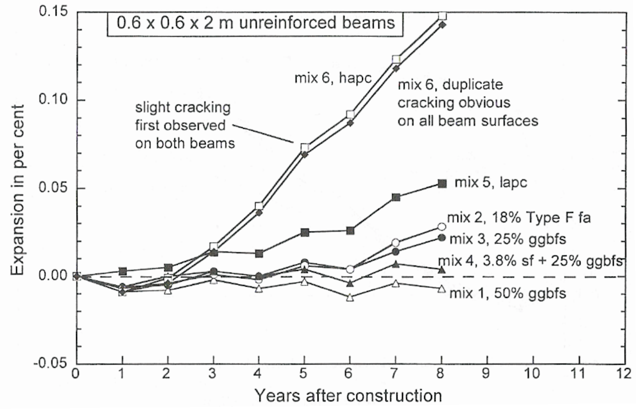
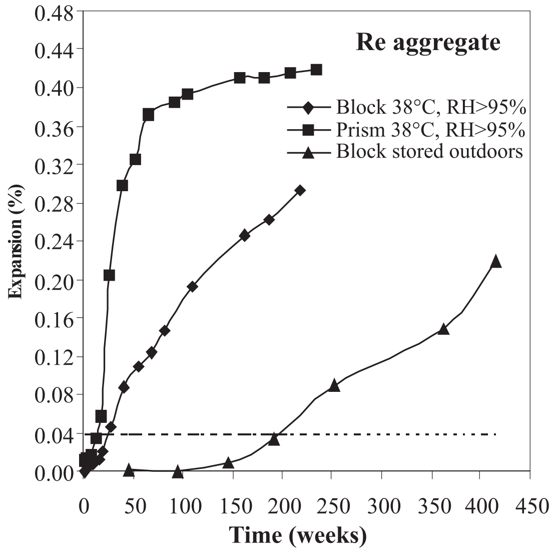


Figure 8 – Expansion of concrete specimens (prism: 75 by 75 by 300mm in size; block: 380 by 380 by 710 mm in size) incorporating extremely-reactive aggregate Re and subjected to laboratory and field (Ottawa, Canada) test conditions.



3 Accelerated mortar bar test

3.1 Test Conditions and Limit Criteria

The Accelerated Mortar Bar Test (AMBT), as given in CSA A23.2-25A [11] and ASTM C 1260 [12], is probably the most widely used accelerated test for determining the potential alkali-silica reactivity of aggregates. It uses severe test conditions (i.e. mortars made with sand-size aggregate particles; test specimens immersed in a 1N NaOH solution at 80°C) in order to generate data within two weeks (OBERHOLSTER and DAVIES [13]). The maximum 14-day expansion limit for non-reactive aggregate falls somewhere between 0.08 and 0.20%, with a value of 0.15% appearing generally applicable (Fournier and Bérubé [14]).

3.2 Variability of the AMBT Procedure

Within- and multi-laboratory coefficients of variation of about 5 to 10% (FOURNIER and BÉRUBÉ [14]) and 15% (ROGERS [15]), respectively, were reported for the AMBT.

3.3 Limitations/Expectations of the AMBT

The reliability of the AMBT is generally determined by comparing accelerated mortar bar expansions to that obtained in the CPT or to the field performance of the aggregates under test. Figure 9 compares the AMBT and CPT expansions for a set of 11 aggregates classified as non-reactive (PH & RG), moderately-reactive (MQ & QL), or highly-reactive (PO, NQ, PEN, CO, NRS, SPH & RE) according to CSA A23.2-27A [2]. Figure 9 It shows that the degree of reactivity of the above aggregates is not similarly assessed by the two test procedures. However, although there is no satisfactory correlation (R^2=0.44) between the 14-day AMBT expansion and the 1-year CPT expansion (Figure 10), 9 out of 11 aggregates are properly qualified as either non-reactive or reactive by both tests. Results obtained at CANMET on a larger number of aggregates from various countries (Figure 11) and from other investigations reported in the literature confirmed the presence of "anomalies" between the two tests. In the case of aggregates in the upper left quadrant (also qualified as "false negative") (e.g. aggregate RG on Figure 10), the AMBT seems severe. Such aggregates include rock types incorporating mineral forms that show increased instability at higher temperature or when ground to sand size, thus resulting in "excessive" expansion in the AMBT. They may also include aggregates that have some potential for alkali-reactivity in

Figure 9 – Comparison of concrete prism and accelerated mortar bar expansions for a series of aggregates from different parts of the world. Indicated on the graph are the 0.15% expansion level (limit for the AMBT) and the zone between 0.04% and 0.12% expansion corresponding to moderately-reactive aggregates according to CSA A23.2-27A (2) (CPT expansion < 0.04% = non reactive; expansion > 0.12% = highly-reactive). (PH: Phonolite (Canada); RG: granitic gravel (Australia); MQ: quartzite (USA); QL greywacke (Australia); PO: orthoquartzite (Canada); NQ: quartzite (Norway); CO: greywacke (Canada); NRS: Sandstone (Norway); SPH: greywacke (Canada); PEN: greywacke (USA); RE: devitrified acidic tuff (Australia)).

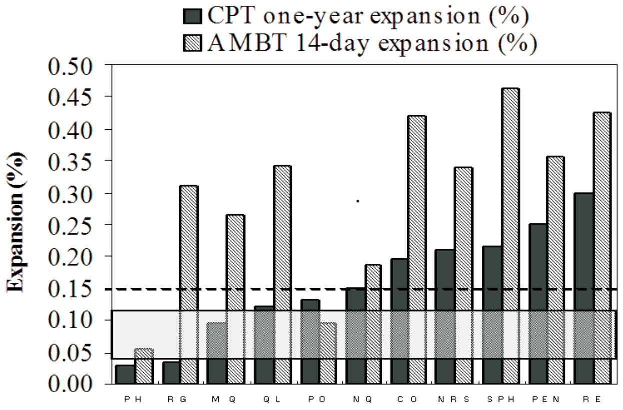
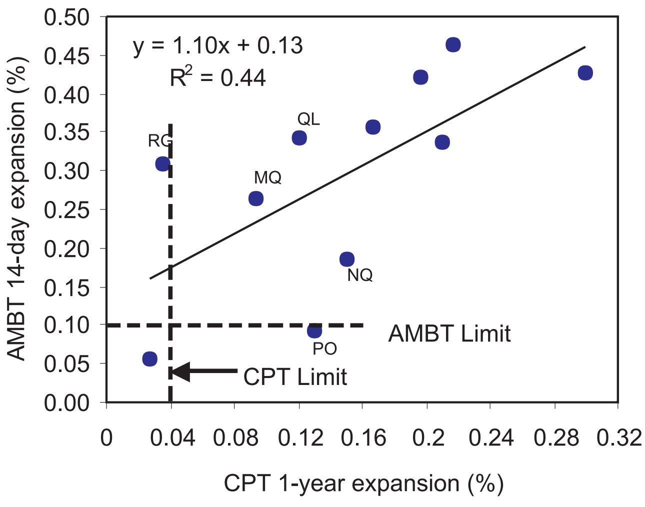


Figure 10 –14-day AMBT expansions plotted against 1-year CPT expansions for a selection of coarse aggregates.(FROM LU et al. (19)).



very severe conditions and that would likely require preventive measures when used in critical structures with very long expected service life. In the case of the aggregate RG (Rg in Figure 4) for instance, the aggregate expanded significantly in the AMBT while the CPT expansion was < 0.04% at one year; on the other hand, a larger block specimen stored at 38°C showed some potential for deleterious expansion (Figure 4). CSA A23.2-27A [2] recommends not to reject "false negative" aggregates for use as concrete aggregates on the basis of the AMBT results only, and that the aggregate be further tested in accordance with the CPT.

Figure 11 – 14-day AMBT expansions plotted against 1-year CPT expansions for a large variety of coarse aggregates. (FROM FOURNIER et al. (6)).

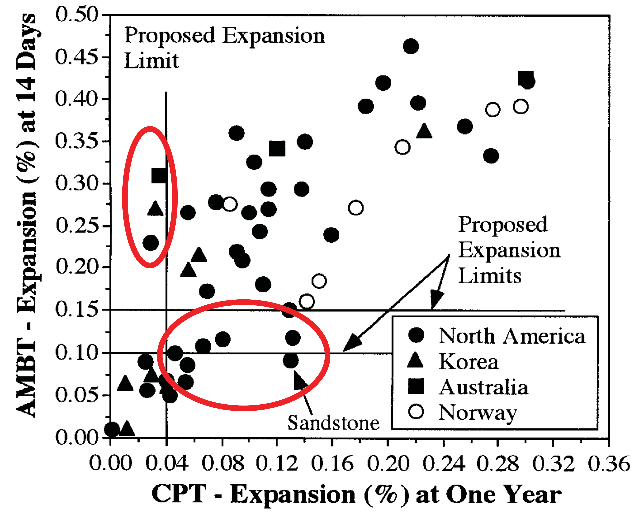
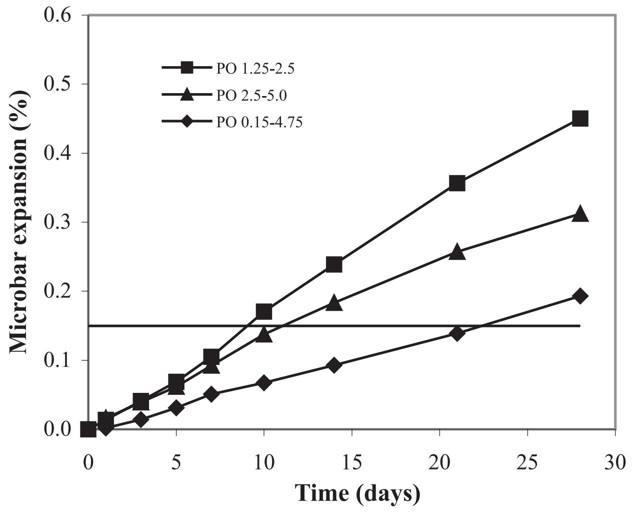


Figure 12 – Effect of particle size on expansion in the CMBT with the PO aggregate (orthoquartzite). Testing of the 1.25-2.5 and 2.5-5.0-mm size fractions was done using 40 by 40 by 160 mm bars (RILEM-type); the 0.15-4.75-mm fraction was tested using typical C1260 bars (25by25by285mm). (Modified from LU et al. (19)).



The "anomalies" are however more critical with aggregates in the lower right quadrant of Figure 10, e.g. PO, which meet the expansion limit for the AMBT, but fail the CPT, and are often known to be reactive in field structures. A first option to try improving correlation with CPT expansion data with such aggregates would be to extend the testing period in the AMBT. Such an approach, which has been adopted by a number of organizations in different countries/states, will likely result in the rejection of aggregates with satisfactory field performance if it is generically applied (e.g. to all aggregates) where the AMBT is the only test used for evaluating potential alkali-reactivity of concrete aggregates. CSA A23.2-27A [2] rather identifies rock types susceptible to such behavior and alerts the users that the potential alkali-reactivity of such aggregates cannot be reliably assessed by the AMBT, and that further testing should be done using the CPT. Johnston et al. ([16], [17], [18]) proposed a new approach, based on a kinetic model of ASR reaction/expansion, for the interpretation of AMBT data. This method appears to provide improved capabilities for predicting potential alkali-reactivity of atypical aggregates.

Research is still needed to correlate the excessive expansions measured in the AMBT with the physical and compositional (including mineralogy) characteristics of the aggregates involved, including further evaluation of the effect of temperature and particle size on the expansion of mortars incorporating a range of reactive aggregates in the AMBT conditions. For instance, in the particular case of the PO ag-

Figure 13 – 10-day expansion in modified CMBT (i.e. 2.5-5.0-mm aggregate particles) plotted against the 1-year CPT expansions. (from LU et al. (19)).

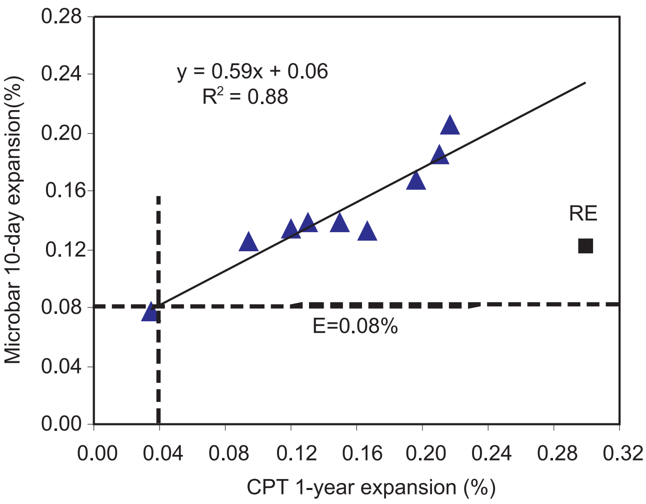
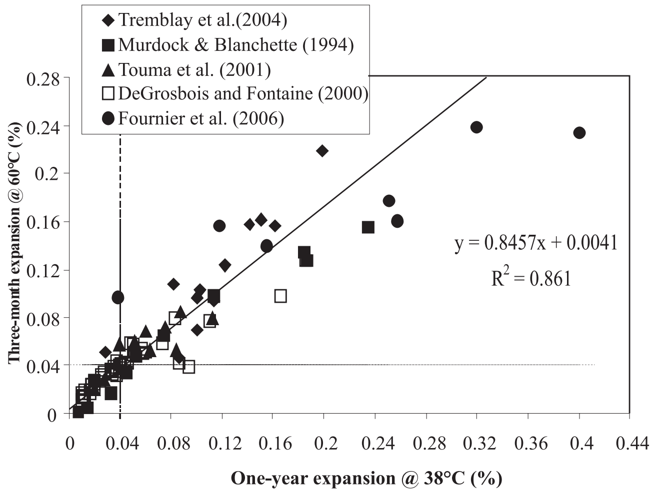


Figure 14 – Comparison of concrete prism expansions (38 vs 60°C) obtained in various studies.



gregate in Fig. 10, Lu et al. [19] showed that increasing the particle size of the aggregate material in AMBT conditions could actually help in recognizing the potential alkali-reactivity of this aggregate by preserving the textural characteristics of the aggregate that was lost when using finely ground material (Figure 12); the authors reported that a modified version of the AMBT (also called Concrete Microbar Test) using larger particle sized material in the AMBT conditions actually resulted in improved correlation with the results obtained in the CPT for the set of aggregates tested by the authors (Figure 13).

4 Accelerated concrete prism test (ACPT) (60°C, R.H. > 95%)

4.1 Test Conditions and Limit Criteria

In the early 1990's, Ranc and Debray [20] proposed an ACPT for evaluating, in a timely manner (i.e. < 2

Figure 15 – Expansion of concrete prisms incorporating Spratt (A) and Sudbury (B) reactive aggregates, as obtained in five different laboratories. All test prisms had been cast in the same laboratory. (From FOURNIER et al. (7)).

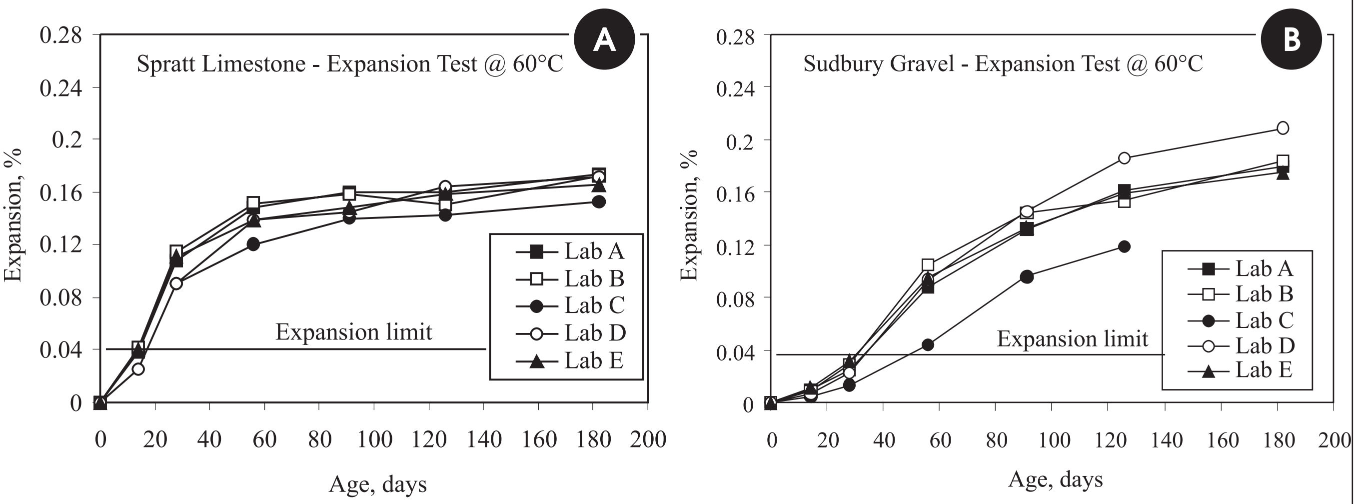
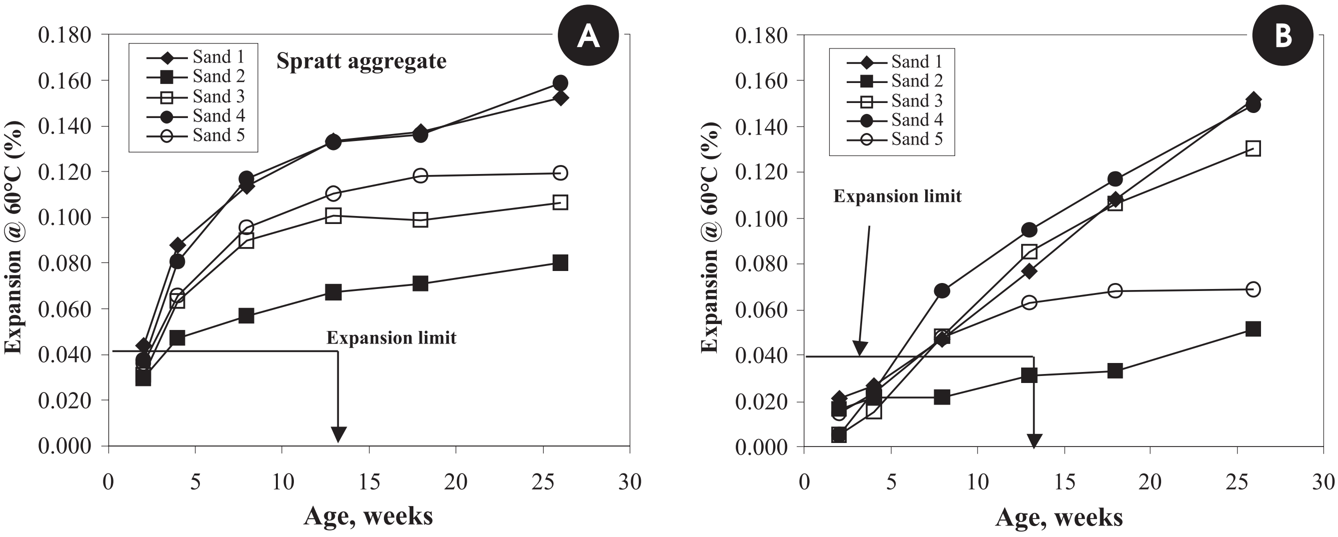


Figure 16 – Expansion of test prisms (60°C) incorporating Spratt (A) and Sudbury (B) reactive coarse aggregates, in combination with five "non-reactive" sands.



months), the performance of job mix designs regarding their potential ASR. Since the main parameters of the concrete mixtures were fixed by using job mix designs, the authors proposed to accelerate the process of reaction/expansion by increasing the testing temperature from 38 to 60°C. Since then, a number of studies have been carried out and they confirmed that an accelerated version of the "conventional" CPT (i.e. performed at 60°C instead of 38°C) has the potential to quickly evaluate the potential alkali-silica reactivity of concrete aggregates. Figure 14 compares the one-year CPT expansion (38°C) and the three-month ACPT expansion (60°C) obtained in the above studies. Using a 13-week 0.04% expansion at 60°C, the accelerated CPT gives the same assessment (reactive & reactive, non-reactive & non-reactive) as the conventional CPT (0.04% expansion at one year) in more than 95% of the cases.

4.2 Variability of the ACPT Procedure

Fournier et al. [7] showed that for test prisms <u>cast in one laboratory</u> and tested at 60°C in five different laboratories, fairly similar expansions (C.V. of 6% and 15% at 91 days for the Spratt and Sudbury aggregates, respectively) were obtained among the five laboratories despite the use of different storage containers and temperature-controlled cabinets (Figure 15). However, the results of a study currently in progress at CANMET and the University of Texas in Austin indicates that the type of non-reactive sand used in the concrete (i.e. when evaluating the potential alkali-reactivity of coarse aggregates) can have a significant impact on the expansions measured in the ACPT, thus raising concerns about the multi-laboratory variability of the test (Figure 16). In the above program, five different non-reactive sands were used in concretes incorporating the moderately-reactive Sudbury gravel and the highly-reactive Spratt limestone. As mentioned earlier, all the above sands met the requirements of CSA A23.2-14A [3] for non-reactive control aggregate. Interestingly, the use of Sand S2 in combination with the Sudbury aggregate resulted in a non-reactive assessment in the ACPT at the 13-week proposed time limit.

4.3 Limitations/Expectations of the ACPT

The applicability of the ACPT was also evaluated on a series of carbonate aggregates, some of which are known to be susceptible to alkali-carbonate reactivity. Figure 17 gives the expansion curves obtained in the conventional CPT (38°C) for the series of aggregates in question, i.e. dolomitic limestones (±argillaceous) from different layers of the Pittsburg quarry (Kingston, Ontario, Canada) (Pit-xx specimens), limestone from Virginia, USA (VG), dolostone from China (CH) and, for comparison purposes, the <u>alkali-silica</u> reactive Spratt limestone from Ottawa (Canada)(SP). The one-year expansion values varied extensively from one aggregate to another, ranging from 0.009% (Pit-14) to 0.616% (Pit-16). Interestingly, all the "reactive" aggregates from the Pittsburg quarry, as well as the VG and CH aggregates, showed a fairly rapid onset of expansion at early ages. On the other hand, the alkali-silica reactive SP aggregate showed the commonly reported three-phase ("S-shaped") expansion process for ASR, including an induction phase at early ages (Grattan-Bellew [21]). Despite the limited number of aggregates tested

Fig. 17 – Concrete prism expansions for a series of carbonate aggregates.

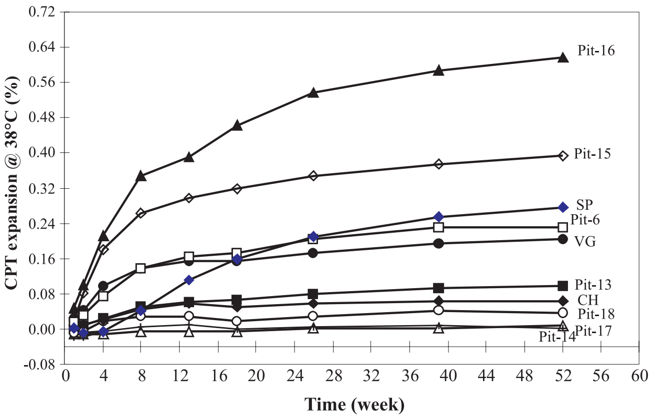
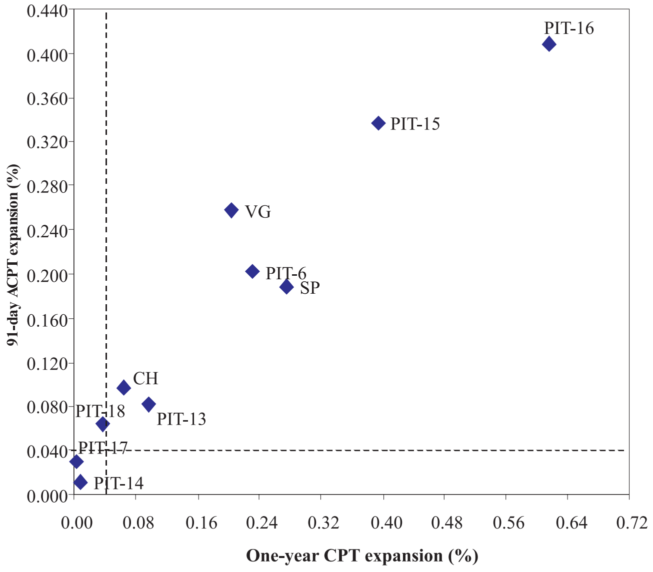


Figure 18 – 91-day ACPT expansions plotted against 1-year CPT expansions for a series of carbonate aggregates.



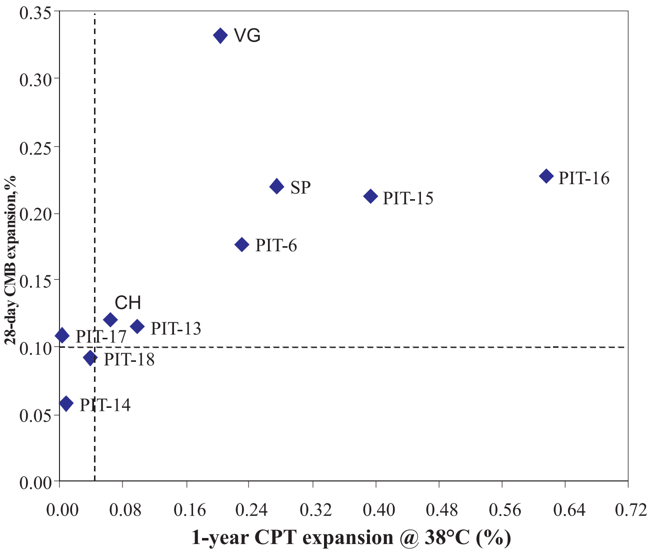
in that series, the applicability of the ACPT appears quite encouraging, as illustrated on Figure 18.

5 Concrete microbar test (CMBT)

5.1 Test Conditions and Limit Criteria

The CMBT was originally proposed by Xu et al. [22] for evaluating the potential alkali-carbonate reactivity of limestone/dolostone aggregates. The test method is essentially similar to ASTM C 1260 except that the bar size is 40 x 40 x 160 mm and the aggregate is graded to pass a 10 mm sieve and be retained on 5 mm sieve. The mixture proportions include one part portland cement to one part of aggregate, while the water-to-cement ratio is 0.30. The testing period in the 1N NaOH solution at 80°C is 30 days. A tentative limit of 0.10% at four weeks had been proposed in the original work performed by Xu et al. [22].

Figure 19 – 28-day CMBT expansions plotted against 1-year CPT expansions for a series of carbonate aggregates.



5.2 Applications/Limitations/Expectations of the CMBT

Lu et al. [23] further evaluated the effect of the type and source of alkali, particle size of the aggregate, and bar size, on expansion of concrete microbars incorporating limestone/dolostone aggregates from several horizons of the Pittsburg quarry (PIT-xx) (Kingston, Canada), from Virginia (USA) (VG) and from China (CH). Figure 19 compares the 28-day CMBT expansion results with that obtained after one year in the CPT. With the exception of the Pit-17 aggregate that generated significantly higher expansion in the CMBT, both tests similarly qualified the aggregates as reactive or non-reactive using the limits proposed.

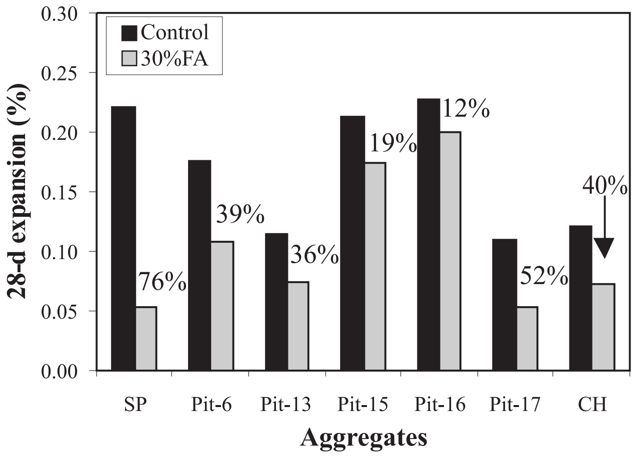
Sommer et al. [24] suggested to compare the expansion of test specimens in the CMBT (RILEM Method AAR-5) and the AMBT to assess the potential contribution of alkali-carbonate reactivity in the expansion process of carbonate aggregates. Alkali-carbonate reactive aggregates have indeed been reported to generate much lower expansion (i.e. < 0.10% at 14 days) in the AMBT than when tested in the CMBT. In order to better differentiate alkali-carbonate reactive lime-

Table 2 – Comparative test results for a set of carbonate aggregates

Aggregates	CPT Control 1yr exp., %	AMBT Control 14d exp., %	CMBT Control 28d exp, %	 with 30% FA 28d exp, %
SP	0.275	0.300	0.22	0.05 (-76%)
Pit-6	0.232	0.065	0.18	0.11 (-39%)
Pit-13	0.097	–	0.12	0.07 (-36%)
Pit-15	0.393	0.078	0.21	0.17 (-19%)
Pit-16	0.616	0.113	0.23	0.20 (-12%)
Pit-17	0.003	–	0.11	0.05 (-52%)
CH	0.064	0.064	0.12	0.07 (-40%)

stone/dolostone aggregates from alkali-silica reactive ones, Dr. Grattan-Bellew from the National Research Council of Canada had proposed to repeat the CMBT using 20 to 30% Class F fly ash, knowing that such a proportion of ash will significantly reduce alkali-silica related expansion but would have limited effect at controlling alkali-carbonate reactivity. Table 2 compares the expansion of various carbonate aggregates at the time limit in the CPT, AMBT and the CMBT; Figure 20 compares the expansion of concrete microbars incorporating selected carbonate aggregates, with and without 30% low-calcium (Class F) fly ash. The results in Fig. 20 show that the use of 30% Class F fly ash reduced SP expansion by the highest proportion at 76%, while it had relatively limited impact at reducing expansion with the Pit-15 (19% reduction) and Pit-16 (12% reduction) aggregates. The alkali-silica reactive character of the SP aggregate would be confirmed by the relatively high 14-day AMBT expansion of 0.300%, while the significantly lower AMBT expansions for aggregates Pit-15 (0.078%) and Pit-16 (0.113%) would support their potential for alkali-carbonate reactivity. The situation is however unclear for the other four aggregates for which expansion reductions related to the use of fly ash in the CMBT ranged from 39% to 52%, while aggregates CH and Pit-6 induce low AMBT expansion (~ 0.065% at 14 days).

Figure 20 – Effect of fly ash on the 28-day expansion of concrete microbars with selected carbonate aggregates. (From LU et al. (23)).



Grattan-Bellew et al. ([25], [26]) evaluated the use of the CMBT (however using –12.5 + 4.75 mm particle sized aggregate) on a wide selection of carbonate and siliceous aggregates from various countries and that had been tested over the years at CANMET. The results showed good correlation between expansion of concrete microbars containing alkali-silica reactive limestone aggregates and in the CPT, with a proposed expansion limit of 0.09% at 30 days. The correlation was not so good for the assortment of ASR aggregates tested, which included greywackes, sandstones, volcanic rocks, gravels, mylonite and cataclastite; however, it was found that the aggregates, which exhibited concrete microbar expansions of less than 0.04% at 30 days, were found not to expand significantly in the CPT as well.

6 Conclusions

This paper commented on the reliability of four of the most commonly used or emerging test procedures for evaluating potential alkali-reactivity of concrete aggregates. The Concrete Prism Test, considered by many as the most reliable test for AAR, still suffers from its one-year long testing period and the relatively high multi-laboratory variability. The accelerated version of the CPT, i.e. performed at 60°C, has shown some promise; however, the inherent issues related to alkali leaching from the test specimens and the nature of the so-called "non-reactive" sand used in the test (i.e. when evaluating potential alkali-reactivity of coarse aggregates), that "haunt" the conventional version of the test at 38°C are actually somewhat amplified at 60°C, thus requiring more work.

The accelerated mortar bar test is often considered as a good screening test for ASR. Anomalies exist between the results of the AMBT and the CPT. In the case of "false negatives", i.e. (expansion > proposed limit in the AMBT but < proposed limit in the CPT), it is recommended that the CPT be performed to confirm potential alkali-reactivity of such aggregate. However, in the case of aggregates passing screening testing on mortars but failing the CPT, the situation requires critical attention. In order to resolve the issue with such aggregates (e.g. some siliceous sandstones, some granite/granitic gneiss, alkali-carbonate limestone aggregates), several organisations have decided to extend the testing period in the AMBT; such an approach could result in the rejection of aggregates with adequate field performance if the rule is generically applied (e.g. to all aggregates) especially where the AMBT is the only test used for evaluating potential alkali-reactivity of aggregates. The identification of such "outliers" with recommendations that they be tested in the CPT and/or a more detailed analysis of the expansion test data are other approaches to try dealing with the issue. Recent work using a Concrete Microbar Test, which uses larger particle sized aggregates in the AMBT conditions, has shown some promise in recognizing some of the above "atypical" aggregates.

There remains a need to review the overall approach for the analysis of expansion data generated in the laboratory to take advantage of the information generated, e.g. using expansion rates. However, this has to take account of the fact that the expansion process generated in laboratory test conditions, i.e. 38 or 60°C at R.H. > 95% in concrete prism tests, or 1N NaOH at 80°C in the case of the accelerated mortar bar or concrete microbar tests, is very different and that aggregates in fact respond very differently to the above conditions depending on their nature and composition (chemistry and mineralogy).

Because of the above limitations of laboratory test procedures, increasing comparative field exposure and laboratory testing under well-controlled conditions, similar to that performed by the authors and others (e.g. Rogers et al. [10], Rogers and Hooton [27], Hobbs [28], Oberholster [29], Thomas et al. [30], Ideker et al. [31], etc.), continues to be essential in order to critically evaluate the reliability of laboratory test procedures, needed for evaluating potential alkali-reactivity of concrete aggregates and preventive measures against deleterious expansion due to AAR.

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