Testing

for

Alkali-Aggregate Reactivity

RECENT DEVELOPMENTS IN TESTING FOR ASR IN NORTH AMERICA

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ABSTRACT

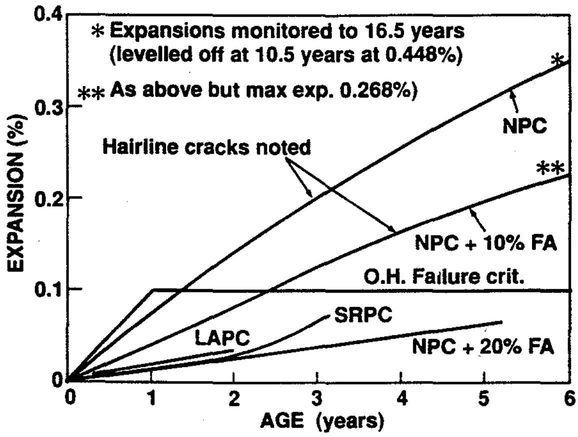
Traditional ASTM test methods have been found to be deficient for detection of several types of reactive aggregates. As a result, a new rapid mortar bar expansion test method, ASTM C1260-94 (formerly Proposal P214-89) has been standardized in the US as well as in Canada (CSA A23.2-25A-M94). This rapid test is suitable for screening aggregates but should not be used in isolation for rejection of aggregates. As a longer term referee test, the modified CSA A23.2-14A-M94 concrete prism test has been approved as ASTM C1293-95. It is thought that combined with the petrography, the appropriate tools are now in place to develop a new ASTM Guide document offering better guidance for prevention of ASR.
Keywords: alkali silica reactivity, ASTM, CSA, testing.

INTRODUCTION

Until recently, the only standard ASTM test methods for alkali silica reactivity (ASR) had been those developed in the 1940's and 1950's. These are the C227 mortar bar expansion test at 38°C, the C289 quick chemical test, and the little used C342 Conrow mortar bar expansion test. Since then, little attention appears to have been paid to their adequacy for predicting performance since they had originally appeared to be suitable for the narrow range of aggregates on which their development was based. As a result, engineers and specifiers became complacent and as new aggregate sources were developed in different parts of North America, and sometimes gave false satisfactory test results, unwittingly deleterious aggregate-cement combinations were used in some structures. One of the specific problems with C227 was the problem of alkali leaching from the mortar bars (Rogers & Hooton, 1991).

In the 1960's, Ontario Hydro (O.H.) discovered by examination of old hydraulic structures such as the Lady Evelyn Lake dam, that greywacke-argillite rock found in Ontario was deleteriously reactive but that ASTM C227 expansions and C289 quick chemical test results were satisfactory (Sturrup, *et al.* 1983; Dolar-Mantuani, 1969). Laboratory testing indicated that C227 bars initially expanded at a slow rate but continued to expand steadily for many years. While the Appendix to ASTM C33 suggests a safe expansion limit of 0.10% at 6 months, some of these aggregates did not exceed 0.10% until 12 to 24 months (Fig. 1). Later, similar experiences in eastern Canada were documented by Duncan, *et al.* (1973) in Nova Scotia. Surprisingly though, there has been no action to tighten limits for C227 expansion.

This led the Canadian CSA A23 standards subcommittee on AAR to consider use of a concrete prism test to evaluate ASR. This evolved from its original development by Swenson & Gillott (1964) for detection of alkali-carbonate reactive aggregates and has undergone numerous revisions to make it suitable for reliably detecting alkali-silica reactive aggregates and the latest version, CSA A23.2-14A-M94, is the one that has been recently adopted as C1293-95 by ASTM. Unfortunately expansions must be monitored for up to 12 months.



Mat'ls	K_2O	Na_2O	Na_2O Equiv.
NPC	0.85	0.37	0.93
LAPC	0.37	0.11	0.35
SRPC	0.58	0.01	0.38
Fly Ash	Detroit Edison, LOI = 4.16%		

Fig. 1. ASTM C227 mortar bar expansions-greywacke with argillites crushed rock-Lower Notch GS - Effects of cement and fly ash.

In addition, there was interest in development or adoption of a more rapid, reliable screening test for alkali silica reactivity. Numerous methods were tried and one which attracted a lot of interest was the rapid 14-day mortar bar expansion method published by Oberholster and Davies (1986). (This method was developed at the National Building Research Institute (NBRI) in South Africa and has been referred to since as the South African or NBRI test).

DEVELOPMENT OF ASTM C1260/CSA A23.2-25A

From an initial investigation of several of the over 40 published accelerated test methods, Hooton and Rogers (1989) found that the NBRI test was the only one that successfully separated a range of known deleteriously reactive from non-expansive aggregates in Ontario. This method was also used by others (Grattan-Bellew 1989)(Fournier & Berube, 1991)(Durand *et al.* 1991)(Hooton, 1991).

Standard ASTM C227 mortar bars are cast (with the exception that a fixed W/C is used rather than adjusting for constant flow as is done in C227. Note that in C1260, W/C = 0.47 is used for all tests, whereas the CSA test uses W/C = 0.50 for crushed coarse aggregate tests). After the molds are stripped at one day, the bars are placed in water which is then heated up to 80°C. On the second day, the initial length readings are made and the bars are transferred to a 1N NaOH solution at 80°C where they are stored. Expansions are monitored for a period of only 14 days in the sodium hydroxide solution at which point the expansions obtained are comparable or higher than those obtained after one year in the ASTM C 227 test (38°C at 100% humidity) (Oberholster & Davies, 1986)(Hooton & Rogers, 1989).

After initial success, the author drafted a standard test method in 1988 for the ASTM subcommittee on Chemical Reactions in Concrete. After several modifications, and with input from many others, this method was published as a ASTM Proposal standard P 214 in 1989. Proposal standards are not adopted, but also can be published for 2 years while the technical committee is finalizing its development. C1260 was adopted in 1994. Simultaneously in Canada, a similar draft method was developed for CSA which was adopted as CSA A23.2-25C in 1994.

This very accelerated test has become widely used but there are several points that need to be mentioned with respect to ASTM C1260 (CSA A23.2-25A).

Effect of Cements

Because the mortar bars are immersed in a 1N NaOH solution at an age of 2 days, the alkalies rapidly penetrate to the aggregate and there is a relatively unlimited supply and OH^- available to promote reaction. This, combined with the 80°C storage temperature means that reaction and expansion will occur very quickly. The 1N solution of NaOH is also higher than the alkalinity of the pore solutions normally found in a high alkali, high cement content concrete. Therefore, the alkali content of the cement used in this test has little effect on expansion (Oberholster & Davies, 1986, Hooton & Rogers, 1992). This means that C1260 is only suitable for evaluation of potential reactivity of aggregates and not cement-aggregate combinations.

In addition, the periclase (MgO) content of the portland cement can influence expansions. At 23°C or even 38°C, periclase only slowly hydrates to brucite ($Mg(OH)_2$) and has not been a concern. However, at 80°C this expansive hydration reaction is greatly accelerated and can influence 14 day expansion results. This was first noted by Delaware DOT, and more extensive unpublished work by Iowa DOT and by the author have confirmed this effect. As a result, the C1260 test requires the use of a portland cement with an ASTM C151 autoclave expansion (3 hours in 216°C steam) of less than 0.2%. This is much more restrictive than the 0.8% autoclave expansion limit required for ASTM C150 portland cements or the 1.0% limit for CSA A5 portland cements.

Use for Evaluation of Supplementary Cementing Materials (SCM)

Oberholster and Davies (Oberholster & Davies, 1987) had published a paper showing that while the NBRI test was not useful for evaluation of the benefits of low-alkali portland cement, it appeared to give reasonable results for appropriate replacement levels of SCM. Similar results were obtained by others (Plaxton 1987), (Berube & Duchesne, 1992). However, the ASTM Committee thought that the understanding was lacking of why the test appeared to work for SCM in combination with deleteriously reactive aggregates. After the short two day curing period prior to immersion in the hot NaOH solution, it was thought unlikely that the SCM have hydrated sufficiently to become so impermeable as to prevent NaOH from penetrating the small cross section of the mortar bars. However, it has been suggested that with silica fume (Fournier & Berube, 1991), large reductions of the alkalies in the pore solution may result from increased incorporation of alkalies in CSH at lower Ca/Si ratios. The reduction of calcium hydroxide contents in the paste fraction and the reduction in porosity of the paste-aggregate interfacial zones may also play a role.

As a result of these uncertainties, neither the ASTM C1260 nor the CSA A23.2-25A test methods currently suggest their use for the evaluation of SCM.

Interpretation of Expansions

In the author's research on Ontario Aggregates, it was found that all aggregates with known deleterious ASR field performance expanded more than 0.10% after 14 days in NaOH solution (16 days after casting the bars) (Hooton, 1991). This is similar to the results reported by Oberholster and Davies (1986) and others (Grattan-Bellew, 1989, Fournier & Berube, 1991, Stark *et al.* 1993). However, it was found that in South-Western Ontario gravel deposits containing leached chert particles resulted in 14 day expansions of 0.17 to 0.18%. Many of these aggregates had a long satisfactory history of field performance in concrete with respect to ASR (the leached chert contents are restricted since they do absorb water and result in pop-outs due to freezing and thawing). The range of expansions of these so-called "marginal aggregates" is shown in Fig. 2. Unlike the reactive aggregates, the expansions of these cherty sands and gravels slowed down before 28 days and the author suggested a secondary 28 day expansion limit of 0.33%, if an expansion of 0.15% at 14 days was exceeded (Hooton 1991).

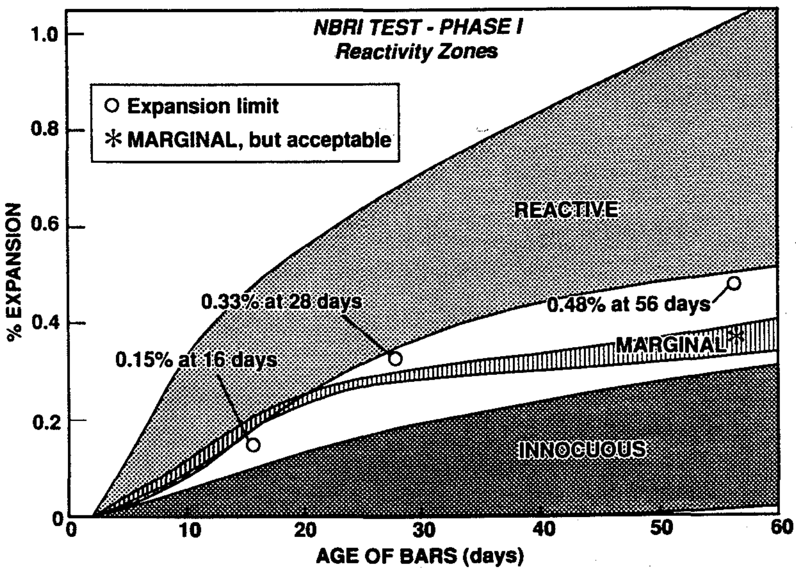


Fig. 2. Range of NBRI mortar bar expansions for aggregates with known field performance (Hooton, 1991).

As a result, in the 1994 Canadian Standard A23.1 Appendix B, a 14 day expansion limit of 0.15% has been adopted but a footnote mentions the possibility of also using 0.33% at 28 days. Other footnotes to the stated limit mention that for some siliceous limestones, a lower limit of 0.10% can be exceeded even when concrete prism expansions are less than the 0.04% limit. This latter footnote, combined with other documentation in the CSA standard, make the point that the longer term, concrete prism expansions should take precedence over the accelerated mortar bar expansions.

This may seem very complicated but it is important to recognize that a single expansion limit may not be suitable for all types of aggregates. Also, if a test limit is set too low in order to "catch" every potentially of deleterious aggregate, then numerous aggregates of good field performance and alarms will be raised for numerous likely satisfactory new sources of aggregate.

Also, the C1260 test is very accelerated and should only be used, together with petrography, as a rough screening test and not as a basis for rejection of aggregate. This lack of understanding has become a headache to aggregate producers in some regions of the U.S. where agencies have adopted the C1260 test and a 0.10% 14 day expansion limit for rejection of aggregates. Because there has been until 1995 no ASTM concrete prism test for ASR, and no ASTM guidance document exists (other than the terse Appendix to C33), the aggregate producers have had no recourse.

Possibilities for Modification of C1260

Stark (1993) has suggested that if the strength of the NaOH storage solution is reduced to match that of the pore solution expected for a particular portland cement (eg: low-alkali cement), then the C1260 test could be modified to evaluate cement aggregate combinations. It is suggested that for a water to cement ratio of 0.50 (close to the 0.47 used in C1260), the appropriate solution concentrations would be as follows:

Equivalent Alkali Content of Portland Cement, %	Storage Solution Strength (Normality)
0.6%	0.49 N
0.8%	0.62 N
1.0%	0.76 N
1.2%	0.90 N
1.4%	1.03 N

If this sort of test was adopted and appropriate expansion limits developed then it could possibly be used in lieu of the longer term, and often unreliable C227 test.

CONCRETE PRISM EXPANSION TEST

As mentioned previously, the current Canadian concrete prism test (CSA A23.2-14A-M94) evolved from one that was originally designed to detect alkali carbonate reactive rocks. This original test is the one on which ASTM C1105 is based. Several researchers in the 1960's and 1970's found that concrete prisms stored moist at either 23°C or 38°C were also effective in detecting some alkali silica reactive aggregates. Concrete testing was also thought to be preferable to mortar bars since coarse aggregates did not have to be crushed to sand sizes as in ASTM C227.

However, it was found that some slowly reactive aggregates such as the greywacke argillites in Northern Ontario did not expand very much unless the alkali loading of the concrete was raised to over 5 kg/m^3 (Magni *et al.* 1987).

Therefore, the 1994 version of the CSA concrete prism test has been substantially changed from the previous 1990 version. The concrete mixture is proportioned with a cement content of 420± 10 kg/m^3 using a normal portland cement with an equivalent alkali content (Na_2O + 0.658 K_2O) of 0.90 ± 0.10%. NaOH is then added to the mix water to provide the equivalent of a 1.25% alkali cement. The alkali loading of the concrete is therefore, 420x1.25% = 5.25 kg/m^3. As can be seen in Fig. 3 (Rogers 1988), this is more than sufficient to cause deleterious expansions in the reactive Spratt quarried siliceous limestone from near Ottawa, and it also causes deleterious expansions in slowly reactive Sudbury gravels containing greater than 15% greywacke-argillites (Fig. 4 (Rogers 1988)).

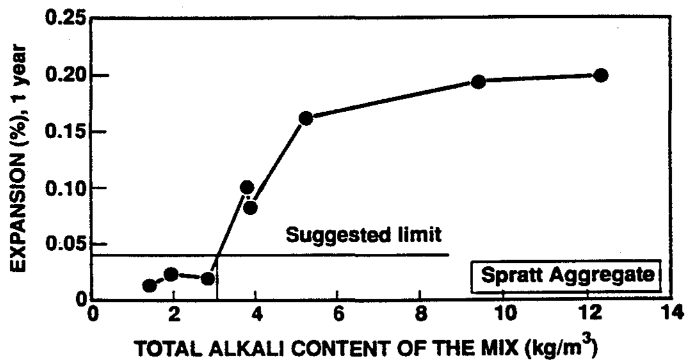


Fig. 3. Concrete prism expansions as a function of alkali loading for reactive Spratt aggregate (Rogers 1988).

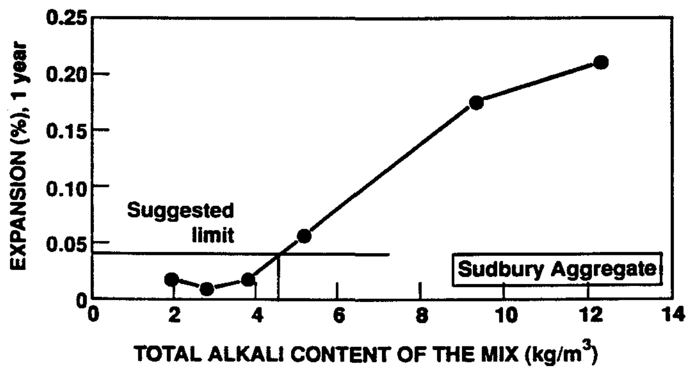


Fig. 4. Concrete prism expansions as a function of alkali loading for slowly reactive Sudbury aggregate (Rogers 1988).

The newly adopted ASTM C1293 test is identical, except for minor editorial issues, to the 1994 version of the CSA concrete prism test method.

The expansion limit used in the CSA standard is 0.04% at one year. This expansion is approximately where cracking and signs of distress are first observed on the prisms. (Mortar bars on the other hand do not exhibit visual damage until approximately 0.10% expansion). It also relates well in terms of observed field performance. France has recently adopted the CSA concrete prism test and has also used a 0.04% limit.

The 12-month time is a concern, but is necessary unless the temperature is raised or other changes are made to accelerate expansion. For a test to be used for acceptance further acceleration of the test may have undesirable side effects.

CONCLUSIONS

The lack of reliability of traditional ASR test methods such as ASTM C289 or C227 when applied to certain aggregate types has led to development of an accelerated mortar bar test (ASTM C1260-94/CSA A23.2-25A-M94) and a concrete prism test (ASTM C1293-95/CSA A23.2-14A-M94). Interpretation of results is not simple and aggregates should not be rejected, but can be accepted, based solely on C1260 expansions. If expansions in C1260 are considered potentially deleterious, then the concrete prism test is suggested to confirm the results before an aggregate is either rejected or limitations are put on its use (for example, a potentially reactive aggregate could be used only if a low alkali cement was used or if a minimum quantity of mineral admixture was used.

While the expansion limits placed on these new test methods, may not be universally acceptable, these tests appear to be far more reliable than the older test methods. In fact, the 1994 CSA standard does not recommend the use of either ASTM C227 or C289.

A guidance document on how to use these new test methods need to be developed by ASTM as was done by the CSA.

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