DEVELOPMENT OF THE NBRI RAPID MORTAR BAR TEST LEADING TO ITS USE IN NORTH AMERICA

R.D.Hooton* and C.A.Rogers**
*Department of Civil Engineering, University of Toronto, Ontario, Canada. **Engineering Materials Office, Ministry of Transportation, Toronto, Ontario, Canada.

After publication of a rapid mortar bar test method by Oberholster and Davies in 1986 for detection of reactive aggregates, international interest was stimulated. In Canada, a draft CSA test method was prepared. The authors also proposed an ASTM method which was successfully balloted as a proposal standard (ASTM P214) in 1989. Evaluation on many U.S. and Canadian aggregates have been positive with the exception of some alkali-reactive aggregates associated with strained quartz. The development of this rapid method in North America is reviewed along with results of interlaboratory testing and suggested expansion limits at alternate ages based on testing of a group of aggregates of known field performance.

INTRODUCTION

Because of the lengthy lead time required to adequately evaluate aggregate sources for potential alkali-aggregate reactivity, there is an urgent need for a reliable rapid test method. While numerous methods have been proposed, most have been found to be deficient or be limited to use with to certain aggregate types. In the 1980's, Oberholster and Davies [1,2] published a new rapid test method for detecting alkali-silica reactive aggregates. It essentially involves fabrication of standard ASTM C 227 mortar bars. However, 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 test is normally terminated. The expansions obtained in this rapid test are comparable or higher than those obtained after one year in the ASTM C 227 test (38°C at 100% humidity) [1,3].

Shortly after publication of this NBRI test method, it was being evaluated internationally and also in Canada by a number of researchers on the CSA A5 Cement-Aggregate Reactivity Subcommittee [3,4,5,6]. A study of several rapid test methods [3] showed that the NBRI method was reliable and reproducible and a CSA draft test method was written by the authors in 1988 and an interlaboratory test was conducted [7]. A similar Proposal Standard for ASTM was also simultaneously developed which was accepted in 1989 and was published as ASTM P214 [8].

This Proposal Standard is now in the process of being adopted as a regular standard by ASTM subcommittee C09.02.02 on Chemical Reactions of Aggregates in Concrete. (This subcommittee is responsible for all test methods related to alkali-aggregate reactivity). Some of the issues and concerns related to adoption of this test method as a standard are discussed below.

CHRONOLOGY OF EVENTS

Dec 1988: A first draft was presented at the ASTM C09.02.02 meeting. The general format and style of the existing ASTM C 227 test method was adopted. An amended draft was prepared for subcommittee ballot.

Feb 1989: Draft #2 submitted to subcommittee letter ballot as a Proposal Standard.

Mar 1989: A CSA interlaboratory study was completed.

Jun 1989: At the ASTM C09.02.02 meeting, all negatives were formally resolved by making minor changes. The full ASTM C09 committee then ratified this acceptance to allow this test to be published as a Proposal.

Sep 1989: ASTM P214 was published. It later appeared in both the 1990 and 1991 Annual Book of ASTM Standards in Vol. 04.02 [8] (Proposal standards are only published for two years).

Sep 1991: Several researchers with experience using P214 were contacted for advise on improving P214 in order to allow it to proceed to ballot as a regular standard.

Dec 1991: Based on suggestions received, P214 revisions were presented to ASTM C09.02.02.

Jan 1992: The revised P214 document was submitted to subcommittee letter ballot.

Mar 1992: Five negative votes were received and are being addressed. Another subcommittee letter ballot will likely be required, followed by a C09 committee letter ballot, and an ASTM society letter ballot, prior to adoption. Providing that negatives are resolved, the earliest possible adoption date will be 1993.

Jun 1992: A joint ASTM and CSA interlaboratory study is planned to develop precision data.

MODIFICATIONS TO ASTM P214

1. Constant W/C.

In ASTM C227, the water to cement ratio (W/C) of the mortar mixtures is varied to achieve a constant range of flow (workability). This was thought to be tedious and often resulted in wasting of test aggregates that had been painstakingly crushed, graded and washed. Therefore, it was decided from the start that the mortar mixtures in ASTM P214 would be mixed at a constant W/C. It was found that in most cases, W/C = 0.50 was a good value for workable mixes with crushed aggregates along with 0.44 for natural sands.

2. Use for Evaluation of Supplementary Cementing Materials.

Because of several negative votes in 1989, all mention of the use of this test for evaluation of the benefits of supplementary cementing materials (SCM) such as ground granulated blast furnace slag, fly ash and silica fume was eliminated. Oberholster and Davies [9] had published a paper showing that while the 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. This work was duplicated in 1988 at the University of Toronto using Canadian fly ash, slag and silica fume and gave almost identical results [10]. However, in the ASTM ballot several negative voters 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 [6], large reductions of the alkalies in the pore solution may result from increased incorporation of alkalies in CSH at lower Ca/Si ratios.

3. Interpretation of Results.

The major difference between ASTM P214 as published and the recently balloted version was the removal of all information on interpretation of test results from the body of the standard. ASTM test methods are not supposed to contain test limits as these are left for material specifications such as ASTM C33 on concrete aggregates (The Appendix to C33 contains the widely quoted test limits for ASTM C 227 and C289).

As an interim measure, an Appendix to P214 has been developed which lists many of the proposed test limits taken from the literature [1,3,5,7,9,11,12]. Much of this information is summarized later in this paper. If test limits are eventually adopted in ASTM C33, then this Appendix would be deleted.

1989 CSA INTERLABORATORY STUDY

Nine laboratories participated [7], testing each of three aggregates (reactive, marginal, and innocuous) with two cements of high (0.92%) and low (0.40%) alkali content. Another set of mixtures was also made with each laboratory receiving a different cement (alkalies varied from 0.34 to 0.98% Na_2O equivalent). The aggregates were described in previous work [3]. Because of obvious errors made by inexperienced laboratory technicians, the results of only six laboratories were considered valid. The average and range of the 14-day expansions along with coefficients of variation are given in Table 1.

The results show excellent coefficients of variation, averaging 10% for both the reactive and marginal aggregates. This is similar to the within laboratory variation found by Davies and Oberholster [11]. The expansions of the innocuous aggregate are so low that coefficients of variation become meaningless.

The alkali content of the portland cement was observed to only have a minor effect on expansion. For the reactive aggregate, an increase in cement alkali content from 0.40 to 0.92% only resulted in an average 8.2% increase in expansion. This confirms that this test is only valid for evaluation of aggregates and cannot be used for cement-aggregate combinations.

These results are presently being evaluated to provide a preliminary precision statement as is now required in all ASTM test methods.

1992 INTERLABORATORY STUDY

A joint ASTM/CSA interlaboratory test involving about 30 laboratories is planned for 1992. The testing will involve two reactive aggregates: the reactive Canadian Spratt aggregate used previously [3,7] and a very reactive sand from Albuquerque, New Mexico, USA. Both a common high-alkali cement and each laboratory's own cement will be used. As well, in one mix, it is planned to compare the use of unwashed, crushed aggregate with the normal, washed aggregate. Washing of each aggregate size fraction after grading as required in ASTM C227 is very tedious and time-consuming and from preliminary results appears to be of little consequence in P214 due to the essentially unlimited source of alkali in the 1N NaOH storage solutions [3].

The results will be used to establish a precision statement and possibly justify removal of the requirement for washing the aggregates after crushing. The CSA subcommittee plans to use the results of this study to qualify the Canadian Spratt aggregate as a laboratory reference material for use in controlling variation of the test results.

EFFECT OF CEMENT ON EXPANSION

In addition to the minor effect of cement alkali content discussed previously and as shown in Table 1, some limited, unpublished work by the Delaware (USA) Department of Transportation [13] has suggested that the autoclave expansion of portland cement for use in P214 mortar bars can have a significant effect on expansions. In one case, the 14 day expansion increased from 0.05% to 0.08% when cement with an autoclave expansion of approximately 0.5% was substituted for one with an autoclave expansion of 0.1%. This implies that the expansive hydration of periclase (MgO) to brucite ($Mg(OH)_2$), which would certainly be accelerated in the 80°C storage conditions, may be contributing to P214 expansions. Therefore, it maybe prudent to select a cement with an autoclave expansion of less than, say 0.10% to minimize this interference.

The cements used in the 1989 CSA interlaboratory study (Table 1) all had autoclave expansions between 0.00 and 0.11% and periclase hydration is not thought to have significantly influenced the expansions.

EXPANSION LIMITS

There is general agreement in the literature that a 14 day (14 days in NaOH solution) expansion of less than 0.10% [1,3,10] or 0.15% [11] is generally indicative of innocuous aggregate. As well, expansions of greater than 0.20% [1,2,11] or 0.25% [10] are regarded as potentially deleterious. Expansions falling between these values have been considered either slowly reactive [1,11] or inconclusive [3,5] and this likely depends on the aggregate type.

In a study of 61 Canadian concrete aggregates [11] of known field performance (19 were deleteriously reactive and 6 were marginal), it was found that limits of 0.15% at 14 days and 0.33% at 28 days were effective in separating deleteriously expansive from non-deleteriously expansive aggregates (Figure 1). The 28 day limit would govern if the 14 day limit was exceeded as it was noted that slowly reactive aggregates continued to expand rapidly beyond 14 days while so-called marginal aggregates containing leached chert but with good field performance histories expanded much less. Another possible secondary limit of 0.48% at 56 days is also shown in Figure 1 but such a long period of test is undesirable. These results contrast with the results of Fournier and Berube [5], who found that for certain siliceous limestones in Quebec, a limit of 0.10% was called for.

Deleteriously reactive granites and gneisses of Grenville age from Maryland and Virginia, USA were found to only expand by 0.08-0.14% at 14 days. It is thought that the reactive component in these aggregates is micro-crystalline quartz associated with strained quartz. Similar aggregates from the eastern seaboard states are known not to expand in ASTM C227 [14] and it is possible that P214 is also not adequate for detecting these types of reactive aggregates.

Regardless of expansions, it is suggested that petrographic analysis should be used to confirm the results. As well in Canada, aggregates showing expansive behaviour may still be used provided that they perform satisfactorily when cast in concrete prisms (using 410 kg/m^3 cement at 1.25% Na_2O equivalent) at 38°C using Canadian Standard, CSA-A23.2-14A.

SUMMARY

The NBRI test has been widely evaluated for use in North America. It has the advantage of being rapid compared to other performance tests for alkali-silica reactivity. Its disadvantage is that it is not suitable for evaluation of cement-aggregate combinations due to its insensitivity to cement alkali content. It also appears unable to distinguish some deleteriously reactive granites and gneisses containing micro-crystalline quartz associated with strained quartz as the only reactive component.

However, it must be remembered that all of the existing standard test methods are also imperfect [15,16]. Because of this, it is not recommended that any one test be used in isolation to evaluate the potential for deleterious reactivity of an aggregate. In this regard, the NBRI test provides a useful addition to the suite of existing test methods. It is anticipated that this test will become commonly used both in Canada and the United States.

REFERENCES

1. Oberholster, R.E., and Davies, G., 1986, Cement and Concrete Research 16, 181.
2. Oberholster, R.E., 1983, "Alkali Reactivity of Siliceous Rock Aggregates: Diagnosis of the Reaction, Testing of Cement and Aggregate and Prescription of Preventative Measures", Alkali in Concrete, Research and Practice Copenhagen, Danish Concrete Association, 419-433.
3. Hooton, R.D., and Rogers, C.A., 1989 "Evaluation of Rapid Test Methods for Detecting Alkali-Reactive Aggregates", Proceedings "8th International Conference on Alkali-Aggregate Reaction", Kyoto, 439.
4. Grattan-Bellew, P.E., 1989, "Test Methods and Criteria for Evaluating the Potential Reactivity of Aggregates", Proceedings "8th International Conference on Alkali-Aggregate Reaction", Kyoto, 279.
5. Fournier, B., and Berube, M.A., 1991, Cement and Concrete Research 21, 1069.
6. Durand, B., Berard, J., Roux, R., and Soles, J.A., 1990, Cement and Concrete Research 20, 419.
7. Hooton, R.D., 1990, "Interlaboratory Study of the NBRI Rapid Test Method and CSA Standardization Process", Proceedings "Canadian Developments in Testing Concrete Aggregates for Alkali-Aggregate Reactivity", Ministry of Transportation, Ontario, Report EM-92, 225-240.
8. ASTM C-9 Proposal P214, "Proposed Test Method for Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction", 1990 Book of Standards, Vol. 04.02, 739-742.
9. Oberholster, R.E., and Davies, G., 1987, Cement and Concrete Research 17, 97.
10. Plaxton, W.L., 1987. BASc Thesis, University of Toronto, Dept. of Geo-Engineering, 63pp.

11.Davies, G., and Oberholster, R.E., 1987, "An Interlaboratory Test Programme on the NBRI Accelerated Test to Determine the Alkali-Reactivity of Aggregates". National Building Research Institute. CSIRO. Special Report BOU 92-1987. Pretoria. RSA.
12.Hooton, R.D., 1991, "New Aggregates Alkali-Reactivity Test Methods", Ministry of Transportation, Ontario, Research Report MAT-91-14.
13.Gaynor, R.D., 1991, Chairman, Mid-Atlantic Regional Technical Commmittee, USA, Personal Communication.
14.Buck, A.D., 1983, Cement, Concrete and Aggregates 5, 131.
15.Rogers, C.A., and Hooton, R.D., 1991, Cement, Concrete and Aggregates 13, 42.
16.Hooton, R.D., 1990, "Case Studies of Ontario Hydro's Experience with Standard Tests for Alkali-Aggregate Reactivity", Proceedings "Canadian Development in Testing Concrete Aggregates for Alkali-Aggregate Reactivity", Published by Ministry of Transportation, Ontario, Report EM-92, 181-189.

TABLE 1 - CSA Interlaboratory Test Results [7] (6 Laboratories)

Aggregate Type	Alkali Content of Cement (%)	14-Day Expansions(%) Range	Average	Std. Dev.	Coefficient of Variation (%)
Reactive (Spratt: siliceous limestone)	0.92	0.349-0.508	0.422	0.0508	12.0
	0.40	0.339-0.432	0.390	0.0361	9.3
	0.34-0.98	0.429-0.508	0.457	0.0316	6.9
Marginal (Paris: cherty sand)	0.92	0.157-0.213	0.181	0.0206	11.4
	0.40	0.126-0.163	0.142	0.0136	9.6
	0.34-0.98	0.156-0.206	0.188	0.0198	10.5
Innocuous (Nelson: dolostone)	0.92	0.007-0.029	0.014	0.0076	53.1
	0.40	0.009-0.016	0.016	0.0073	46.0
	0.34-0.98	0.004-0.014	0.013	0.0079	63.0

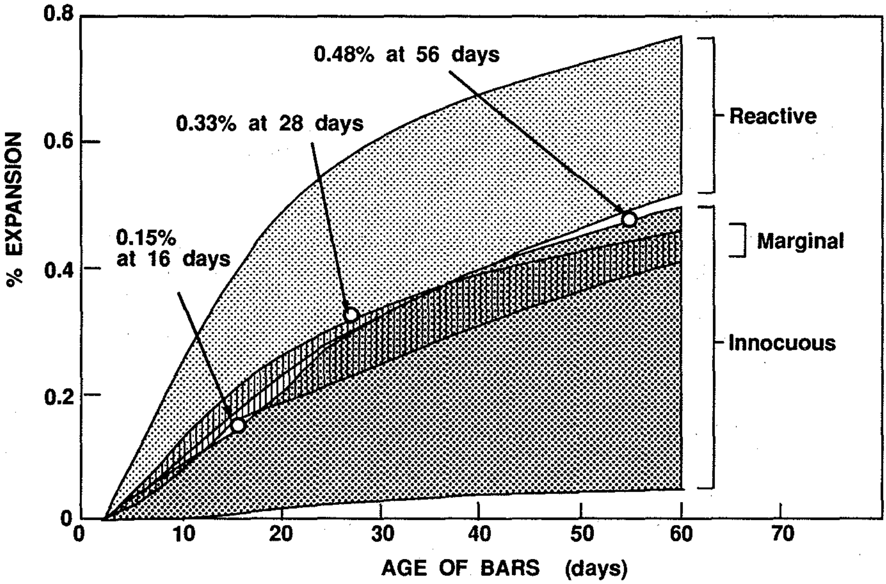

Figure 1 - Suggested NBRI Expansion Limits [12]