NBRI TESTS ON AGGREGATE CONTAINING STRAINED QUARTZ

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ABSTRACT

Instances of distress to concrete structures due to alkali-silica reaction have been diagnosed in India. The reactivity of aggregate has been ascribed to the presence of strained quartz. Standard test methods developed to detect reactivity of classical reactive aggregate, failed to detect potential reactivity of such slowly reactive aggregate, containing quartz with deformed crystal lattice. This paper presents results of evaluation of a number of aggregate samples containing strained quartz by accelerated NBRI mortar-bar test. A critical evaluation of the test method is attempted.
Keywords: accelerated tests, alkali-silica reaction, salt solution, specification, temperature.

INTRODUCTION

Instances of distress to concrete structures in India due to deleterious alkali-silica reaction have been diagnosed about a decade back. The reactivity in such aggregate was ascribed to the presence of strained quartz. Standard test methods, which were developed for aggregate containing metastable silica minerals like opal, chert and chalcedony and volcanic glasses etc. as the reactive component, (hereinafter called 'classical' reactive aggregate) fail to detect potential reactivity of such slowly reactive aggregate containing strained quartz. Appropriate test methods are, therefore, sought to be developed, by modification of the ASTM C-227 mortar bar test.

Need has, simultaneously, been felt for quick and, at the same time, reliable test methods to detect potential alkali-reactivity of aggregate of all types, whether classical reactive aggregate or those containing quartz with deformed crystal lattice, secondary inclusions or microcrystalline quartz etc. The aggregate samples evaluated in the present investigation belong to the latter category. The commonly used mortar bar test as per ASTM C-227 takes about a six month period to show any dependable trend. To cut down the time of evaluation further, the accelerated mortar bar test developed by the National Building Research Institute (NBRI) in South Africa (Oberholster & Davies, 1986) has received much attention the world over. Considerable data has become available on the use of NBRI test on classical reactive aggregate, but data on aggregate containing quartz with deformed crystal lattice is rather limited.

This paper presents the results of an evaluation of a number of aggregate samples containing strained quartz by accelerated NBRI mortar bar test. The results also enable a critical evaluation of the test method and what could be the criterion of potential reactivity.

NBRI ACCELERATED MORTAR BAR TESTS

The procedure consists of preparing mortar-bar samples in the same way as ASTM C-227 i.e. by proportioning 1 part of cement to 2.25 parts of graded aggregate by mass (Oberholster & Davies, 1986). However, a fixed water to cement ratio, i.e. 0.44 for natural fine aggregate and 0.50 for coarse aggregate, is used, instead of water content determination by flow table test, as in the ASTM C-227 method. The samples, after 24 hours of normal curing, are cured in hot water at 80^{o}C for 24 hours. Finally, the specimens are stored in 1N NaOH solution at 80^{o}C. Length change measurements are taken in the hot condition i.e. within 20 seconds from removing the specimens from the solution.

Results of NBRI tests reported in the literature on different aggregate samples - both classical reactive aggregate as well as slowly reactive aggregate containing deformed quartz, show that mortar-bar expansion of the same order are generally obtained in the case of classical reactive aggregate as well as slowly reactive aggregate at 12 to 14 days (Berube et al., 1992, Kerrick & Hooton, 1992). On the other hand, in ASTM C-227 mortar-bar tests at 38^{o}C or at 60^{o}C, slowly reactive aggregate usually show lower orders of expansion upto six months than classical reactive aggregate (Mullick, 1994). In general, it has also been observed that a greater magnitude of expansion is obtained in the NBRI test than in the ASTM C-227 test and there is always a chance that aggregate with satisfactory field performance may be classified as expansive in the NBRI test (Grattan-Bellew, 1989, Berube et al., 1992).

While no firm criteria has yet been established for the evaluation of reactivity of aggregate by the NBRI test, it has generally been suggested (Davies & Oberholster, 1987, ASTM C 1260-94) that:

i) Expansion of less than 0.10 percent is indicative of "innocuous" aggregate;

ii) Expansion of greater than 0.20 percent to 0.25 percent is indicative of "potentially deleterious" aggregate;

iii) Expansions falling between these two limits have been considered either as 'slowly reactive' aggregate or 'inconclusive', and continuation of the test for longer periods is recommended.

EXPERIMENTAL

Twentyfive different types of natural aggregate containing strained quartz (Mullick, 1987, Mullick et al., 1992,) were taken up for investigation. These aggregate samples did not contain metastable silica minerals like opal, chert or chalcedony etc. The aggregate samples included different rock types namely quartzites, granites, greywackes, phyllites, composite samples and samples of natural sand. The angle of undulatory extinction (UE) in different rocks, as measured by the procedure of Dolar-Mantuani, 1983, varied from 10^{o} to 40^{o} and the content of quartz showing strain effect varied from 20 to 90 percent. Characteristics of granitic rocks were similar to aggregates, which have been found to result in deleterious alkali-silica reaction in concrete in service (Mullick, 1994).

ASTM C-227 mortar-bar expansion tests at 38°C and 60°C with ordinary portland cement of total alkali content (as Na_2O eq) more than 1 percent were carried out to check the potential reactivity of these aggregates as per the criteria proposed (Mullick et al., 1992). From the results of mortar bar tests at 38°C as well as 60°C given in Figure 1, it is seen that eleven out of 25 samples of aggregate can be classified as 'innocuous', as the expansion for these samples under the 60°C regime are below the proposed limit of 0.06 percent at 180 days (Mullick, 1994). Most of them satisfy the ASTM C-227 limit at 38°C.

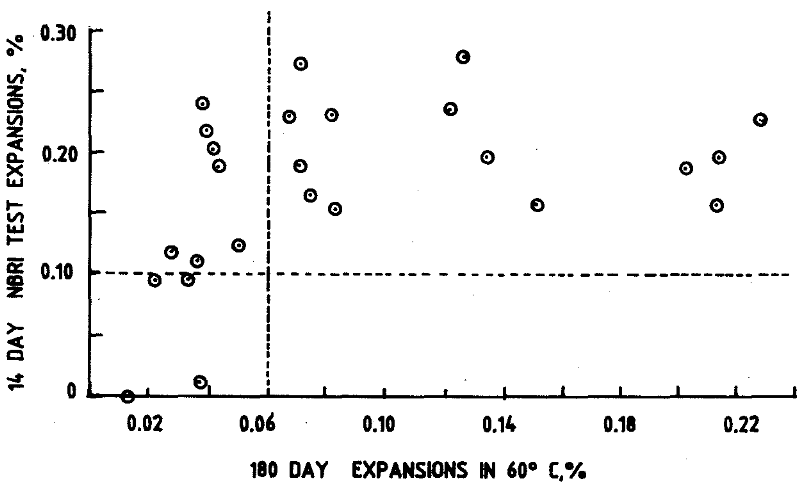

Fig. 1 Results of ASTM C 227 Mortar bar tests at 60°C and NBRI tests on 25 Aggregate Samples

NBRI tests were carried out on the same aggregate samples as per the procedure described above. The same cements as in the 38°C and 60°C tests were used in the NBRI tests. Only such cement samples were used in the present investigation, whose expansion in the autoclave (soundness) test were of the order of 0.1 percent or less, to rule out any possibility of the effect of the unsoundness of cement on the resultant expansion. The use of glass or metal containers for storing the specimens in 1N NaOH solution at 80°C is not recommended as the same get corroded by the test solution. Therefore, plastic containers with airtight covers were used.

The expansion readings were taken periodically upto the required 14 days and also continued upto 56 days in many cases.

In order to evaluate the test procedure, some additional tests were undertaken. These included measurement of total alkali content in mortar bar specimens after periods of exposure, use of cements with different alkali contents, as well as ASTM C-227 mortar bar tests carried out at 27°C, 38°C, 60°C and 80°C.

Discussion of Results

It is seen from Figure 1 that the 14 day NBRI test expansions for the 14 natural aggregate samples, which were classified as potentially reactive on the basis of mortar-bar tests at 60°C regime, are in the range of 0.15 to 0.28 percent. These expansions are comparable to those obtained by other researchers for the classical reactive aggregate. The expansions continued even after 14 days and increased to the order of 0.4 to 0.5 percent at 56 days, (Figure 2). Surface cracking was observed in the specimens at the age of 56 days. Presence of gel in the voids was observed in all the samples. The gel deposits were confined to the periphery of the samples at 14 days and progressed towards the interior after 56 days' exposure.

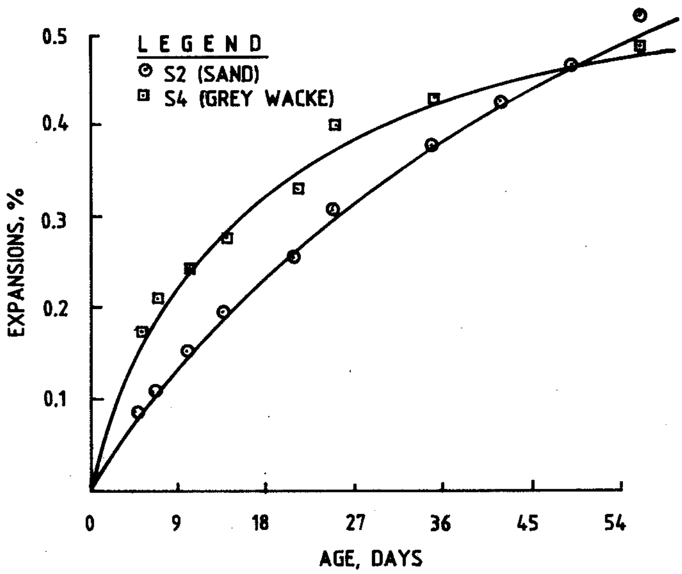

Fig. 2 Typical NBRI Expansions up to 56 days for two Aggregate Samples

No correlation between 14 days NBRI test expansions and 180 days 60°C mortar-bar expansions was apparent (Figure 1). Another eight aggregate samples, classified as 'innocuous' in the 60°C mortar-bar tests gave expansion in the NBRI test above 0.10 percent. Out of a total of 24, there were only three aggregate samples, which could be classified as innocuous in both NBRI test and 60°C mortar bar test (Figure 1).

To study the effect of inherent alkali content in the cement, NBRI tests were carried out on four aggregate samples using three cements of total alkali content 0.70, 0.76 and 1.18 percent. The 14 days expansion data are presented in Figure 3, which show that, in the presence of 1N NaOH solution, the mortar bar expansion was not influenced by the alkali content in the cement.

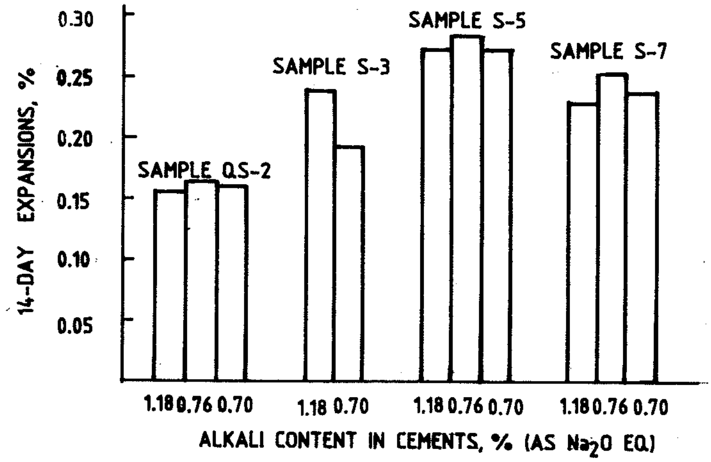

Fig. 3 14-day Expansion in NBRI test with Cements of Different Alkali Contents

Since the results indicated relatively larger expansions in NBRI tests on aggregate containing deformed quartz, which are regarded as slowly reactive, a search was made for possible reasons of acceleration of expansion. Measurement of total alkali content in mortar bar specimens showed that the amount of alkalies continued to increase with time of exposure, especially Na_2O content (Figure 4). Total alkali as Na_2O equivalent of the order of 2.73 percent by mass of mortar was measured after 100 days in the case of one sample. This was much higher than what can ever be encountered in actual constructions.

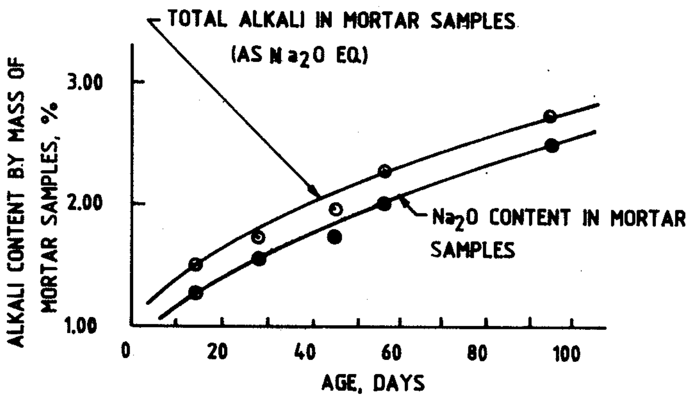

Fig. 4 Alkali Content in Mortar bar Specimens at Different Ages, S-2 Sand

Another possible reason was thermal activation i.e. effect of high temperature. Tests were conducted to study the mortar bar expansion of two aggregate samples at different temperatures. The procedure of ASTM C-227 was followed in the case of all temperatures. The results are presented in Table 1.

Table 1 ASTM C-227 Mortar-bar Expansions at Different Temperatures

Sample	Temperature Regime, °C	Expansions, %, at days						
		14	30	60	120	150	180	210
QS-4	27	0.0040	0.0052	0.0060	0.0100	0.0108	0.0108	0.0108
	38	0.0072	0.0080	0.0100	0.0140	0.0160	0.0198	0.0210
	60	0.0124	0.0144	0.0364	0.0796	0.0920	0.1086	0.1142
	80	0.0380	0.0424	0.0536	*0.0458	0.0538	0.0610	0.0694
QS-5	27	0.0036	0.0048	0.0112	0.0204	0.0228	0.0228	0.0212
	38	0.0068	0.0084	0.0132	0.0432	0.0452	0.0484	0.0500
	60	0.0104	0.0104	0.0120	0.0384	0.0676	0.0812	0.0860
	80	0.0464	0.0516	0.0644	*0.0520	0.0620	0.0720	0.0784

* Warping of specimens was noticed which increased with age.

Warping of specimens occured in tests at 80°C. Expansions increased sharply with temperature, especially above 60°C. The 14-day expansions at 80°C regime was 5 to 6 times, and at 60°C regime was about 1.5 times larger than that at 38°C (Figure 5).

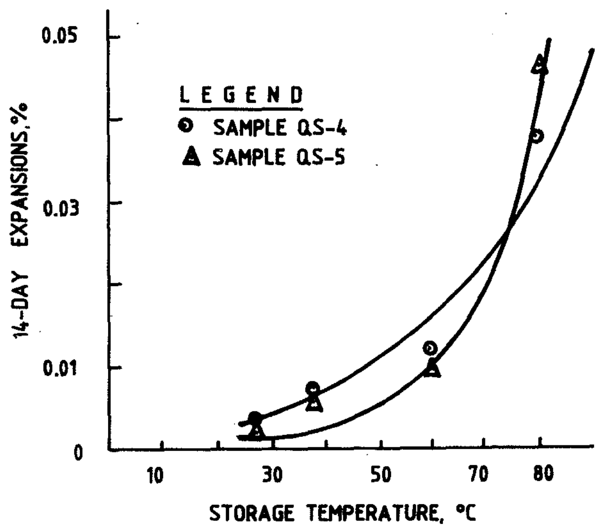

Fig. 5 Effect of Temperature on Mortar bar Expansion

It has been postulated earlier that thermal activation of mortar bar expansion due to higher temperature is more pronounced in case of slowly reactive aggregate containing deformed quartz (Mullick, 1994). The results in Figure 5 indicate a similar trend upto 80°C.

Another interesting comparison is the results of mortar bar expansion as per ASTM C-227 and NBRI test, when both are carried out at 80°C.

Results presented in Table 2 compare expansion in the case of two aggregate samples. It is seen that at comparable exposure time of 14 days , the NBRI test expansions are nearly four times greater. In this case, the acceleration is due to the presence of considerably larger amount of alkalies being available in the NBRI test.

Table 2 Comparison of Expansions in NBRI and ASTM C-227 Tests at same Temperature

Sl No	Aggregate Sample	14-day Expansion, %	
		NBRI Test*	ASTM C-227 Test*
1	QS-4	0.1524	0.0380
2	QS-5	0.1884	0.0464

*Test temperature 80°C in both cases

CONCLUSIONS

NBRI tests resulted in 14-day expansions of the order of 0.15 - 0.28 percent in the case of slowly reactive aggregate containing strained quartz, which were classified as 'potentially reactive' by ASTM C-227 mortar bar expansion tests at 60°C. Expansions in excess of 0.10 percent were obtained in the case of most aggregate samples, which were classified as 'innocuous' in the latter tests. Thus, the NBRI test did not appear to be discerning enough for the slowly reactive aggregate containing deformed quartz. As is to be expected, ASTM C-227 mortar bar test at 38°C failed to detect any potential reactivity of these aggregates. There was no one-to-one correlation between mortar-bar expansion in the NBRI test and ASTM C-227 test at 60°C. Expansions in NBRI tests continued even after 14 days. Expansions of the order of 0.4 to 0.5 percent or more were obtained at 56 days.

The total alkali content in the mortar bar specimens also increased with time of test. There was no relationship between the initial alkali content in cements and the resultant expansions. In general, NBRI tests on slowly reactive aggregate resulted in expansion of the same order of magnitude as reported in the case of classical reactive aggregate containing metastable silica minerals like opal, chert, chalcedony etc., although the former result in much lower expansion in case the of ASTM C-227 mortar bar tests at temperature upto 60°C. Possible reasons are increased thermal activation of expansion at 80°C, as well as effect of continuous intake of alkali solution in the specimens.

In view of these, the NBRI test may not be regarded as complete in itself, but could be a precursor of more detailed investigation, once an aggregate exceeds the threshold mortar-bar expansion, which is recommended to be of the order of 0.15 percent at 14 days.

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