POTENTIAL REACTIVITY OF QUARTZITE AGGREGATES CONTAINING STRAINED QUARTZ

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Results of evaluation of natural aggregates which can be classified as slow/late expanding alkali-silica reactive rocks, are presented. One common feature in these rocks was the presence of strained quartz; on the other hand, metastable silica minerals like opal or chalcedony etc, were not detected. Taking into account past service records, results of mortar-bar tests at 38 and 60°C and rapid chemical tests upto 7 days, revised criteria for assessment of such aggregates are proposed.

INTRODUCTION

Instances of Alkali-Silica Reaction (ASR), attributed as the cause of distress to concrete structures, have evoked considerable attention to this aspect of durability in future concrete constructions in India, [Mullick (1)]. Such structures showing signs of distress were built more than 40 years ago. The natural aggregates used in the constructions escaped from their identification as "potentially reactive" by conventional tests for ASR and would now be classified as being endowed with slow/late expanding alkali-silica reactivity [Grattan-Bellew (2)]. This is distinct from classical alkali-silica reactivity caused by the presence of metastable silica minerals, for which conventional mortar bar (ASTM C-227) and rapid chemical tests (ASTM C-289) were designed.

As a result of evaluation of different varieties of natural aggregates proposed in new constructions in India, substantial data has become available for such potentially slow/late reactive aggregates [Mullick et al (3)]. One common feature of these aggregates is that they contain strained quartz exhibiting undulose extinction (UE) and sometimes alterations of feldspar to clay minerals. Typical rock types include Quartzite, Greywacke, Granite, Biotite-Granite, Biotite-Gneiss, Granite-Gneiss, Phyllite, and Augen-Gneiss. Presence of metastable silica minerals like opal or chalcedony etc were not detected. Results on evaluation of such aggregates as well as performance of concrete structures containing such aggregates have been reported earlier [(3), Rao and Sinha (4), Mullick (5)]. Reactivity of such aggregates being due to the presence of strained quartz were postulated by Gogte (6), Dolar-Mantuani (7) and Buck (8). Such a phenomenon can indeed be supported from a materials science approach, relating to entropy of a disordered system to its chemical reactivity. Instances of deleterious

ASR in concrete due to such aggregates are reported from other countries also [Zampieri et al (9), Tuthill (10)].

On the other hand, it has been held that there is little, if any, correlation between UE angle and the expansivity of quartz-bearing aggregates. It has been suggested that the apparent correlation of undulatory extinction with reactivity may be due to the occurrance of micro-crystalline quartz in aggregates, which result from the rock being subjected to metamorphic conditions, under which silica is frequently mobilised and may recrystallise as micro-crystalline quartz (2).

Pending clarification of these issues, there is a need to evolve methods of assessment for such aggregates for which conventional tests do not hold good. Presence of strained quartz in such aggregates could at least be held as an aid for identification, if not necessarily the cause. Appreciating the need for revised procedures for assessment of such aggregates for their potential reactivity, this paper presents an analysis of results in mortar bar tests at different temperature regimes, rapid chemical tests for durations upto 7 days, and petrographic examination, with a view to suggest modification in the national (IS) specifications for evaluation of aggregates.

AGGREGATE CHARACTERISTICS

Results of evaluation of five samples of coarse aggregates proposed to be used for a hydro-electric project being constructed as a joint Indo-French venture, are presented. These are designated as QS-1, QS-2, QS-3, QS-4, and QS-5. All the coarse aggregates were coarse to medium grained rock with inequigranular texture. Quartz was the most dominating constituent. The accessories included Chlorite, Biotite, Muscovite and Iron Ore. No metastable silica minerals were detected. The Quartz grains varied in size from 0.001 mm to 0.45 mm. 80 to 85 percent quartz grains exhibited a very high strain effect with UE angle varying from 29 to 38° (QS-1), 34 to 39° (QS-2), 32 to 37° (QS-3), 27 to 35° (QS-4), and 30 to 36° (QS-5). In some samples, a few biotite grains showed alterations liberating iron minerals and quartz grains showed high deformation. Taking into account the past service records of aggregates exhibiting strain effect on quartz of such magnitude, these aggregates can be termed as potentially reactive (3, 5).

The evaluation of these aggregates by mortar bar tests at 38°C regime as per ASTM C-227 and 60°C regime were taken up simultaneously in the authors' laboratory in India (designated as Laboratory 1) and another laboratory in France (Laboratory 2). Four cement samples were used for mortar bar expansion tests - (i) Ordinary Portland Cement OPC-1 with total alkali content 1.28%; (ii) OPC-2 with total alkali content 0.42%, (iii) OPC-3 with total alkali content 0.57% and (iv) Portland Pozzolana Cement (PPC) with total alkali content 0.49% - all expressed as Na_2O equivalent. Rapid chemical tests as per ASTM C-289 for extended periods upto 7 days were conducted in Laboratory 1. In the analysis of the results presented herein, data from previous investigations on similar aggregates containing strained quartz have also been used, petrographic details of which have been reported elsewhere (3, 5).

RESULTS AND DISCUSSIONS

Results of mortar bar tests with high alkali cement OPC-1 carried out at 38°C as well as at 60°C in the two Laboratories are summarised in Table 1.

TABLE 1 -- Mortar-Bar Expansion Tests with High Alkali Cement -- OPC-1.

Sample Identification	180 days Expansions, %			
	38° C Regime		60°C Regime	
	Lab-1(India)	Lab-2(France)	Lab-1	Lab-2
QS-1	0.0300	0.04	0.1252	0.20
QS-2	0.0180	0.03	0.1514	0.16
QS-3	0.0224	0.02	0.1080	0.12
QS-4	0.0292	0.01	0.0840	0.11
QS-5	0.0308	0.04	0.0728	0.12

It may be seen that for all the five aggregates, the expansion at 38°C were within the permissible limits as per results in both the Laboratories. At 60°C, however, there were considerable acceleration of expansions which ranged from 0.15 percent in case of QS-2 to 0.07 percent in case of QS-5 in Laboratory 1. From results in Laboratory-2, the expansions were somewhat higher, being 0.2 percent for QS-1 and 0.11 percent for QS-4. Results of expansion under both the temperature regimes carried out with low alkali cements, ie, OPC-2 and OPC-3 as well as PPC, are summarised in Table 2.

TABLE 2 -- Mortar-Bar Expansion Tests with Low Alkali Cements.

Sample Identification	180 days Expansions, %											
	38°C Regime						60°C Regime					
	OPC-2		OPC-3		PPC		OPC-2		OPC-3		PPC	
	Lab-1	Lab-2	Lab-1	Lab-2	Lab-1	Lab-2	Lab-1	Lab-2	Lab-1	Lab-2	Lab-1	Lab-2
QS-1	0.0276	0.03	0.0308	0.03	0.0216	Not Available	0.0568	0.05	0.0580	0.06	0.0568	Not Available
QS-2	0.0164	0.03	0.0148	0.03	0.0124		0.0500	0.05	0.0508	0.05	0.0464	
QS-3	0.0176	0.02	0.0192	0.03	0.0140		0.0516	0.05	0.0492	0.06	0.0440	
QS-4	0.0218	0.03	0.0228	0.03	0.0204		0.0586	0.06	0.0572	0.05	0.0360	
QS-5	0.0172	0.03	0.0200	0.03	0.0172		0.0552	0.05	0.0500	0.05	0.0556	

Here again it will be seen that there was a fairly close agreement between the expansion data reported from the two Laboratories; while the reduction in expansion by use of low alkali cement at 38°C was not much significant, at 60°C tests, the expansions could be brought down considerably, being generally of the order of 0.05 percent at six months, compared to 0.1 to 0.2 percent with OPC-1 (Table 1). The dependence of the amount of expansions at 60°C on the alkali level in the cements is shown in Fig 1, wherein data from Ref 5 are also included. The amount of expansion increased with the alkali content in the cement, showing that such aggregates can expand in presence of alkalis in cement-water system and establishes the reactivity in a classical sense. The results in Fig 1 also show that the amount of expansions can be brought down by reducing the alkali content in the cements. The increase in expansion from low-alkali (upto 0.6 percent) to high-alkali (1 percent or more) level is generally greater than in case of aggregates containing metastable silica minerals.

In describing such aggregates as being slow or late reactive, what is implied is that these are slow expanding only in the laboratory tests, ie, as per ASTM C-227 at 38°C, but not necessarily under service conditions (2). If that be so, adoption of higher temperature regimes to bring out the potential expansion within a relatively shorter period of evaluation of say up to six months, is justified. Fig 2 shows histogram of the ratio of expansion between 38 and 60°C regimes for a large number of aggregates containing strained quartz. The ratio varied from 2 to 4, which is somewhat higher than in case of classical alkali-silica reactive rocks where reactivity is not due to presence of strained quartz. The significance of the fact that mortar bar expansion of these aggregates containing strained quartz are relatively more accelerated by increased alkali level in cement (Fig 1) or increased temperature (Fig 2) has to be further explored. However, if there were a threshold temperature for the reactions to proceed in the presence of alkalis in cement-water system, these revised procedure of tests would be more relevant in tropical countries like India. Therefore, mortar bar tests at a temperature of 60°C with a high-alkali cement (about 1 percent) are proposed (1).

Results of rapid chemical tests as per ASTM C-289 for a number of aggregates tested in the authors' laboratories are shown in Fig 3 to 6. Results in Fig 3 to 5 pertain to aggregates containing strained quartz which are deemed to be 'reactive' at 60°C mortar-bar test and as per the criteria to be elaborated below. In Fig 6 are those aggregates which do not contain strained quartz and which would be non-reactive by the same criteria for mortar-bar tests. In view of the fact that the criteria in the rapid chemical test at 24 hours were evolved on the basis of such aggregates which exhibit potential reactivity at mortar bar test at 38°C (ASTM C-227), it is not surprising that most of these aggregates fall under "innocuous" zone after 24 hours (Fig 3). What is interesting to note is that with longer duration of tests up to 3 days (Fig 4) and 7 days (Fig 5), many of the aggregates containing strained quartz gradually shift to the "potentially deleterious" zone. On the other hand, those aggregates which are branded as non-reactive at 60°C test and with the revised criteria, continue to be in the "innocuous" zone even after 7 days (Fig 6). These results indicate that rapid chemical test can be made applicable to slow/late reactive aggregates containing strained quartz, either by shifting the boundary of "innocuous" and "potentially deleterious" aggregates appropriately to the left, or alternately, by prolonging the test duration to 7 days. Significance of these results are being analysed further.

MODIFIED CRITERIA OF REACTIVITY AND STANDARDIZATION

Indian Standards Specification IS:383-1970 for aggregates from natural sources, specify mortar-bar tests at 38°C similar to ASTM C-227, and rapid chemical test similar to ASTM C-289, for assessment of alkali reactivity of aggregates. No limit of expansion in mortar-bar tests are presently set, presumably because until now little concern was felt. In view of recent experiences and the fact that these methods would not hold good for slow/late expanding aggregates, revised criteria are being proposed (1). For aggregates containing strained quartz and presumably owing their reactivity to it, mortar-bar tests at 60°C are proposed following the reasoning given above. In the investigations of a large number of such aggregates, mortar-bar tests at 60°C with low-alkali cement (not exceeding 0.6% Na_2O equivalent) resulted in expansion seldom exceeding 0.05% at 90 days (Fig 7) or 0.06% at 180 days. On the other hand, with cements of alkali content about 1% Na_2O equivalent, the expansions were always in excess of 0.05% at 90 days (Fig 9) and 0.06% at 180 days (Fig 10). These include aggregates similar to those used in hydraulic structures which have exhibited distress due to ASR (1). Since the well-accepted remedy for use with reactive aggregates is low-alkali cements with alkali content not exceeding 0.06%, expansions recorded with such cements as in Fig 7 and 8 can be considered as acceptable. A limit of acceptable expansion of the order of 0.05% at 3 months or 0.06% at 6 months when tested with higher alkali (about 1%) cement at 60°C is therefore proposed. Use of such aggregates with cements of different alkali contents would enable an evaluation of the cement-aggregate combination for use in a project which is not possible when the alkali content in the system is raised by incorporating additional alkalis or using alkali solutions.

Attempts have been made to set 'prescription'-type limits of UE angle or percentage of quartz grains exhibiting strain effect (6, 7, 8). 'Performance'-type specifications of the nature of limiting expansion in mortar bar tests are preferred. Note that the suggested limits of expansion in mortar-bar tests were reached by quartzite aggregates, in which a minimum of 25% quartz grains showed strain effect with UE angle of 25° or above (3, 5). The limits in the case of granitic aggregates would be somewhat lower, because of the role of alkali feldspars and mica-bearing phases (1). However, specification limits in terms of strain effects on quartz are not contemplated at present, although petrographic tests to detect the presence of strained quartz will be needed in order to identify such aggregates, for which these tests are applicable.

CONCLUSIONS

Service behaviour of concrete structures in India have revealed that natural aggregates, even without the presence of metastable silica minerals like opal, chalcedony etc, can exhibit slow/late expanding type of alkali-silica reaction. Presence of quartz showing strain effect was a common feature in such aggregates, for which conventional tests like ASTM C-227 and C-289 do not hold good. In mortar-bar tests, expansions can be considerably accelerated by raising the temperature to 60°C and when high alkali (about 1%) cement is used. Rapid chemical tests reveal potential reactivity after prolonged storage upto 7 days. On the basis of data obtained on large number of aggregates for different projects, the revised criteria of evaluation are proposed. In mortar-bar tests at 60°C with high alkali (1%) cement, expansions of the order of 0.05% at 90 days or 0.06% at 180 days can be considered as limits. Variability between test results in two different laboratories were within acceptable limits.

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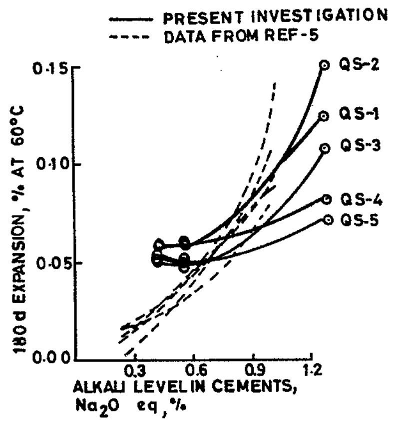

Fig 1 Dependence of mortar bar expansion on the alkali content in cements

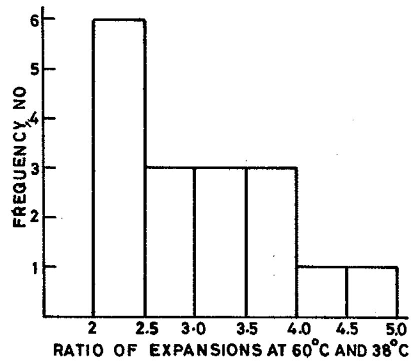

Fig 2 Histogram of Ratio of 180 days mortar bar expansions at 60 °C and 38°C with high alkali cements

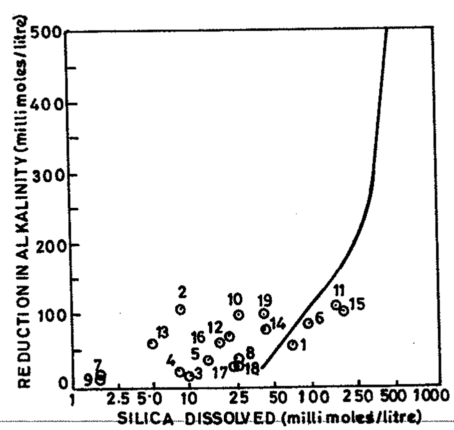

Fig 3 Results of Rapid Chemical Tests for aggregates containing strained quarts (1 day data)

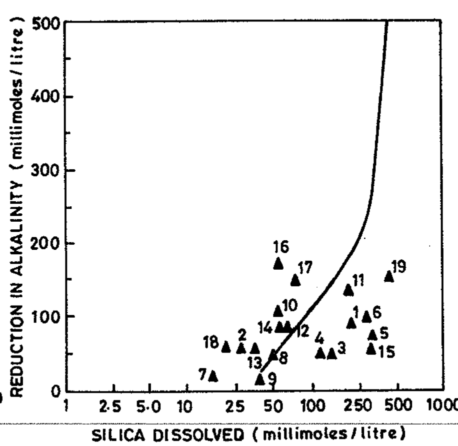

Fig 4 Results of Rapid Chemical Tests for aggregates containing strained quarts (3 days data)

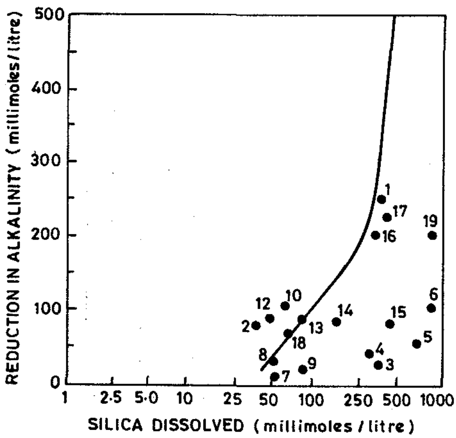

Fig 5 Results of Rapid Chemical tests for aggregates containing strained quarts (7 days data)

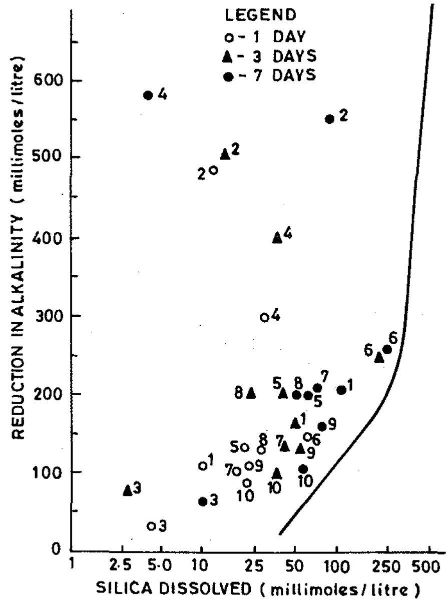

Fig 6 Results of Rapid Chemical Tests upto 7 days for aggregates not containing strained quarts

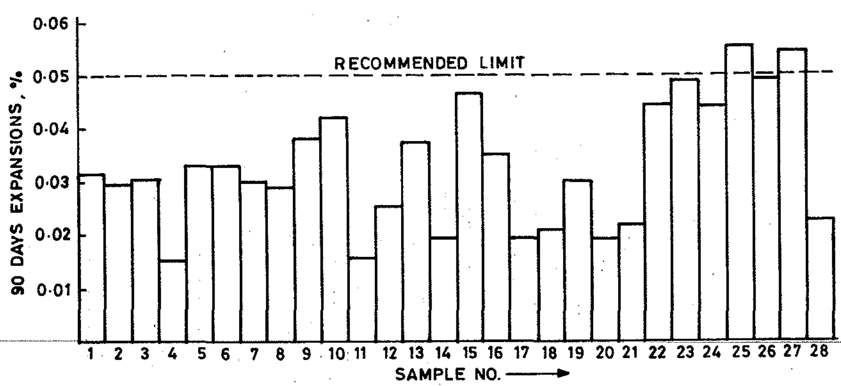

Fig 7 Mortar bar expansions at 90 days with low alkali cements at 60°C

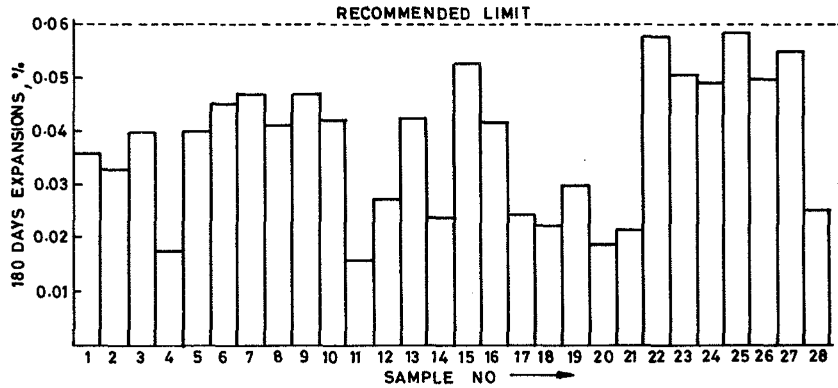

Fig 8 Mortar bar expansions at 180 days with low alkali cements at 60°C

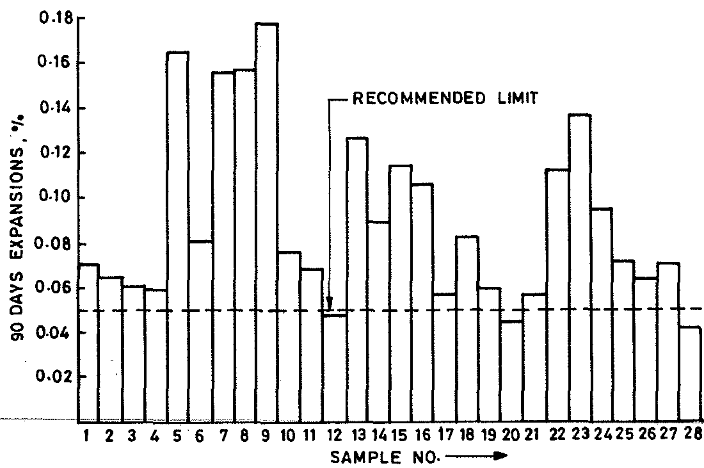

Fig 9 Mortar bar expansions at 90 days with high alkali cements at 60°C

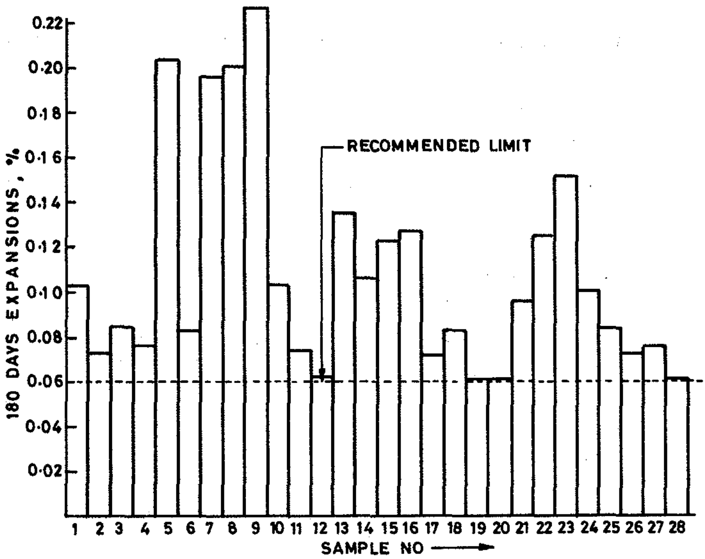

Fig 10 Mortar bar expansions at 180 days with high alkali cements at 60°C