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A comparison of RTA T363 and ASTM C1260 accelerated mortar bar test methods for detecting reactive aggregates

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Abstract

Nowadays, bridge structures are designed for 100 years of service life, and care must be taken to avoid materials that would cause premature deterioration problems in the structures. This requires careful attention to structural design, selection of sound materials and manufacture of components, which would remain durable under the given environmental conditions (exposure and loading). One of the important concrete deterioration problems is the alkali–aggregate reaction (AAR), which can cause cracking and diminished strength properties in concrete, and the best method of avoiding it is to select nonreactive aggregates for the concrete or those that could safely be combined with mineral additives to suppress their reactivity. The purpose of this paper is to compare the expansion results obtained by the two test methods using a number of aggregates with known field performance and to assess the validity of their expansion limits in predicting the field performance of these aggregates. The paper also covers the comparison of the two test methods for the assessment of the effectiveness of fly ash in suppressing AAR expansion.

Keywords: Alkali–aggregate reaction; Accelerated testing; Expansion; Fly ash

1. Introduction

Alkali–aggregate reaction (AAR) has affected a number of RTA bridges, and the degree of damage has been from mild to severe. In the case of mild damage, periodical monitoring of the affected structures and routine maintenance may be adequate for controlling the damage, whereas cases of severe damage have required decisions to replace the affected elements due to serious losses in mechanical properties. For example, prestressed, precast concrete planks, forming the base of bridge decks in some bridges, have partially lost their steel–concrete bond, and their strength properties have significantly deteriorated as described by the authors elsewhere [1].

To avoid such damaging AAR problems in concrete, the best approach is to assess the reactivity of aggregates prior to being used in concrete, either select nonreactive ones or where there are no alternatives to take appropriate precautions. The current state of knowledge enables us to use even reactive types of aggregates in appropriately designed concrete mix formulations when nonreactive alternatives cannot be found.

A number of test methods exist in Australia and overseas for assessing the potential alkali reactivity of aggregates, and considerable data have been accumulated on their performance. These range from rapid chemical tests on aggregates (e.g. ASTM C289 and AS 1141-39) to testing the aggregate in mortar bars over a period of 6 months to 1 year (ASTM C227 and AS 1141-38), a number of concrete tests (ASTM C1293, RTA T364), which also take about 1 year or longer, and more recently developed accelerated mortar bar tests (ASTM C1260 and RTA T363). Australian Guidelines, such as Shayan and Carse [2] and C&CA [3], cover these methods.

Past experience has shown that some of these test methods, such as the chemical tests (ASTM C289, AS 1141-39) and the old mortar bar tests (ASTM C227 and AS 1141-38), are not reliable in detecting the reactivity of the slowly reactive Australian aggregates. The slow nature of the concrete test has necessitated the development of more rapid and more reliable tests, and worldwide efforts in

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the past 10–15 years have resulted in improved techniques of assessment of alkali reactivity of aggregates. Two such methods are the relatively recently introduced accelerated mortar bar tests ASTM C1260 (which is based on the South African NBRI method [4] and the RTA T363 method (based on a paper by Shayan et al. [5]). Both these methods use storage of mortar bars in 1 M NaOH solution at 80°C and measurement of their expansion with time, but they differ in mortar preparation, precuring procedures and more importantly in their expansion limits for classifying reactive aggregates. Recently, VicRoads have also introduced a test method, which is essentially the same as RTA T363 and is also based on Shayan et al. [5]. It has been designated VicRoads Test method RC 376.03. The good correlation between the results of the RTA T363 test and field performance of a number of aggregates was demonstrated by Shayan [6]. Table 1 shows a comparison between the ASTM C1260 and the RTA T363 methods.

It should be noted that the ASTM C1260 procedure is also used in Canada under the designation CSA A 23.2-25A, and recent publications class aggregates causing accelerated mortar bar expansions less than 0.15% as non-reactive and those causing expansions greater than 0.15% as highly reactive [7]. This limit is set at 0.1% for siliceous limestone, and the authors indicate that some other reactive granitic and gneissic aggregates in Canada may expand less than 0.1% in 14 days. Although this comes closer to the RTA T363 limits, still it would class aggregates differently from the latter, which for such slowly reactive aggregates has a limit of 0.1% expansion in 21 days.

In Australia, despite 15 years of experience with the accelerated mortar bar test mentioned above, no standardised form of it exists as yet. Recently, RTA, NSW and the Concrete industry in a joint research project have started collecting data on aggregates using ASTM C1260 and RTA T363 test methods with the aim of preparing a test method as an Australian standard. This project is still at early stages.

The main purpose of the work reported in the present paper is to compare the results of the two test methods for 18 aggregates of known service record and examine the validity of their acceptance limits and classifications for these known aggregates. Another purpose of this work was to examine and compare the applicability of their test limits for assessing the effectiveness of fly ash in suppressing the expansion of alkali reactive aggregates in concrete. A total of 10 out of the 18 aggregates representing a wide range of reactivity were used for this purpose.

2. Materials and procedures

The list of the 18 aggregates and their service records is given in Table 2. All the 18 aggregates were used in the comparison of the two test methods. Those that were also used for additional testing in combination with fly ash (as 25% cement replacement) are also identified in Table 2.

The cement used for the manufacture of mortar bars in both tests was a general purpose Portland cement with the following composition (%): SiO_2 (20.40); Al_2O_3 (4.55); Fe_2O_3 (3.6); CaO (63.3); MgO (1.60); K_2O (0.30); Na_2O (0.40) and SO_3 (2.80), Na_2O equivalent = 0.60. Other analyses gave equivalent alkali contents ($Na_2O + 0.658\ K_2O$) averaging at 0.63%, which was adopted as the alkali content of the cement.

The fly ash used was from Eraring Power Station and of low calcium (Type F) and low alkali (1.32% Na_2O equivalent), with the following composition (%): SiO_2 (69.2); Al_2O_3 (22.8); Fe_2O_3 (2.97); CaO (1.0); Na_2O (0.53); and K_2O (1.2).

3. Procedures

For each test, the mortar bars were made according to the relevant accelerated test method as summarised earlier. When fly ash was used, it replaced 25% of the cement by mass. After the data for each aggregate were obtained, the aggregates or the aggregate–cement combinations were

Table 1
Comparison of the two accelerated methods

Test method	Mortar preparation	Precuring		Period in water at 80°C for zero reading	Subsequent storage	Test limits	
		Demould	Moist curing			Period of test	Limit
ASTM C 1260	fixed water to cement ratio of 0.47	24 h	None. Place in cold water for heating to 80°C	24 h	1 M NaOH, 80°C	16 days: 2 days precuring, 14 days in 1 M NaOH	< 0.1% nonreactive, 0.1–0.2% uncertain/slowly reactive, > 0.2% reactive
RTA T 363	flow table	24 h	48 h then place in cold water for heating to 80°C	4 h	1 M NaOH, 80°C	24 days: 3 days precuring, 21 days in 1 M NaOH	< 0.1% in 10 days nonreactive, >0.1% in 10 days reactive, < 0.1% in 10 days but > 0.1% in 21 days slowly reactive

Table 2
List of aggregates

No.	Aggregate designation	Field reactivity	Source of aggregate	Structure affected several bridges	Extent of cracking	Accelerated mortar bar tests conducted	
						Without fly ash	With fly ash
1	Gordonvale basalt	No	Queensland	–	–	Yes	Yes
2	EXL sand	No[a]	Victoria	–	–	Yes	Yes
3	TMC gravel	Yes	Victoria	several bridges	large	Yes	Yes
4	TMC sand	Yes	Victoria	several bridges	large	Yes	No
5	CC quartz gravel	Yes	Victoria	dam and bridge	moderate	Yes	Yes
6	PM quartz gravel	Yes	Victoria	dam and bridge	large	Yes	No
7	KS quartz gravel	Yes	Victoria	dam and bridge	moderate	Yes	No
8	BGT gneissic granite	Yes	Victoria	two dams	moderate/large	Yes	Yes
9	CNN gneissic granite	Yes	WA	dam	large	Yes	No
10	MKR gneissic granite	Yes[b]	WA	railway sleepers	small/large	Yes	No
11	MRD rhyodacite	Yes	Victoria	dam	moderate/large	Yes	No
12	UPY SAN	Yes[c]	Victoria	dam	moderate/large	Yes	Yes
13	UPY SLT	Yes[c]	Victoria	dam	moderate/large	Yes	Yes
14	Japanese andesite	Yes	Japan	many structures	large	Yes	Yes
15	South African metagreywacke	Yes	South Africa	many structures	large	Yes	Yes
16	NSW metagreywacke	Yes	NSW	bridge	moderate/large	Yes	Yes
17	French coarse	Yes[d]	France	dam	depends on pessimum properties	Yes	No
18	French fine	Yes	France	dam	depends on pessimum properties	Yes	No

[a] The sand contains a small number of reactive strained quartz particles but does not cause deleterious expansion.
[b] The sample collected is ballast from the railway track and could be different from the aggregate that had reacted in the AAR-affected elements.
[c] Samples from the same general site as for the aggregate in the structure, but the locations could be different.
[d] Aggregate shows pessimum effect.

classified according to the expansion limits of the test concerned and then the classification results of the two methods were compared, keeping in mind the field performance of the aggregates.

4. Results and discussion

The results of accelerated mortar bar testing of the 18 aggregates by the two test methods are given in Figs. 1–6, and the results for the 10 aggregates used in combination with fly ash are given in Figs. 7–10. These results are discussed separately below.

4.1. Performance of the two test methods in aggregate classification

The results of the accelerated tests by the two methods can be grouped into two categories: those in which the RTA T363 method gave lower results than the ASTM C1260 method and those in which the two test methods gave very similar results. This difference in behaviour appears to be related to the degree of reactivity of the aggregate. The reactive aggregates exhibit larger expansions in the ASTM method than in the RTA T363, whereas the nonreactive or slowly reactive aggregates give very similar expansions in the two methods. The higher expansion in the ASTM method is related to the high water/cement ratio of 0.47 in this method (compared to values around 0.40–0.42 for the RTA T363 method), which results in higher porosity and allows better access to the aggregate by the NaOH storage solution. The less reactive aggregates may consume less alkali and are not affected by the difference in supply of alkali in the two methods.

Fig. 1 shows the comparison of the two test methods for the nonreactive Excel sand and the two reactive TMC aggregates. Both methods class Excel sand as nonreactive and the two TMC aggregates as reactive.

In Fig. 2, the two methods are seen to have produced identical results for the nonreactive Gordonvale basalt, whereas they have produced different results for the two French aggregates, both of which are rich in flint. The coarse French aggregate is very susceptible to alkali and shows a pessimum effect. The expansion curves shown in Fig. 2 relate to a mixture of 30% French aggregate and 70% nonreactive Excel sand. Based on the 21-day expansion results, the RTA method would class both French coarse and French fine aggregates as slowly reactive (noting the pessimum property), whereas the ASTM method, based on its 14-day limit, places them in the doubtful zone (expansion between 0.1% and 0.2%).

Fig. 3 shows the comparative results for the very slowly reactive gneissic aggregates. The aggregate that caused AAR and cracking in many railway sleepers in Australia

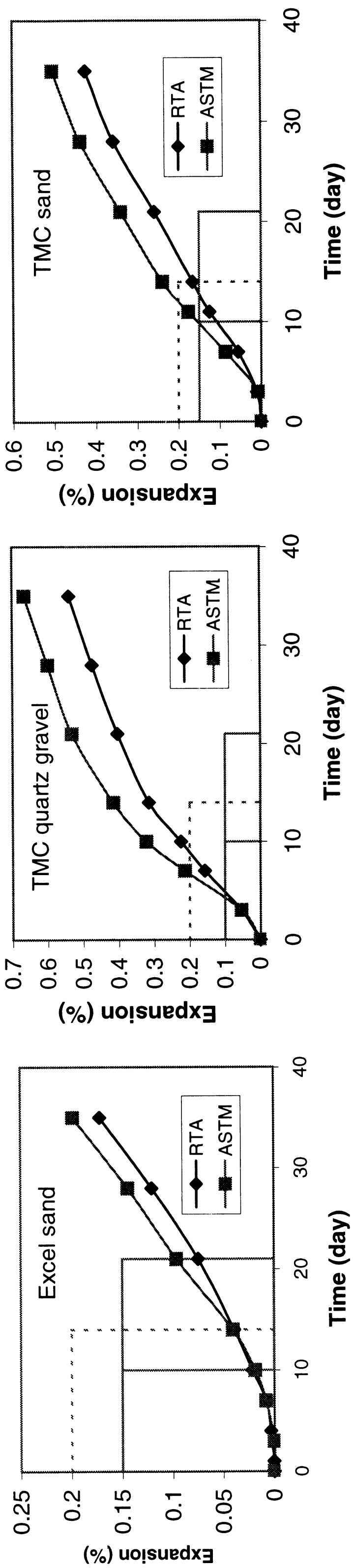

Fig. 1. Accelerated mortar bar test results for the two methods using Excel sand, TMC quartz gravel and TMC sand.

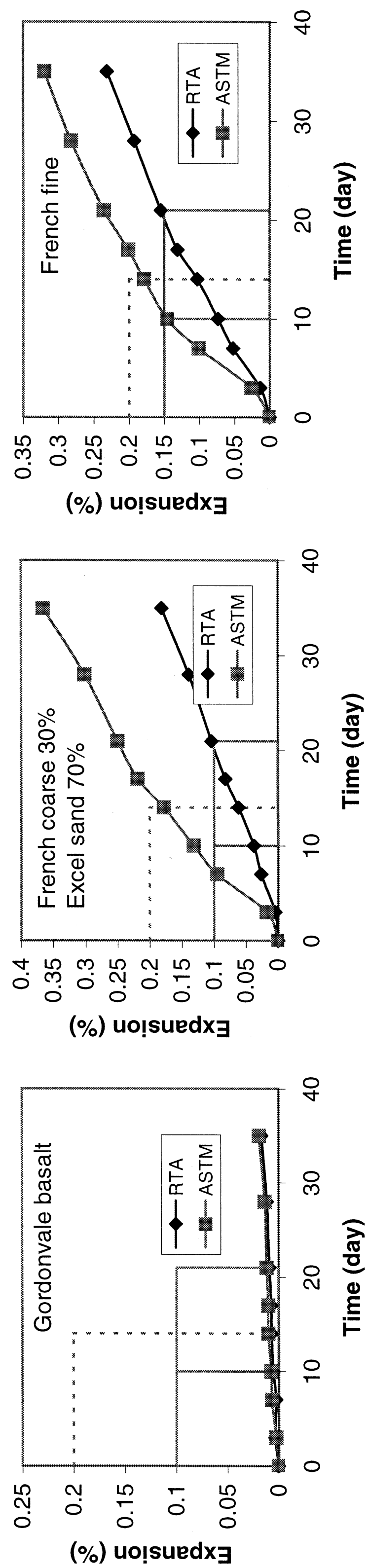

Fig. 2. Accelerated mortar bar test results for the two methods using Gordonvale basalt, French coarse and French fine aggregates.

is from the same region as the MKR gneissic granite. That aggregate originally collected by the author from the quarry gave 0.1% expansion at 21 days and was classed slowly reactive. The current MKR aggregate was sent to us by

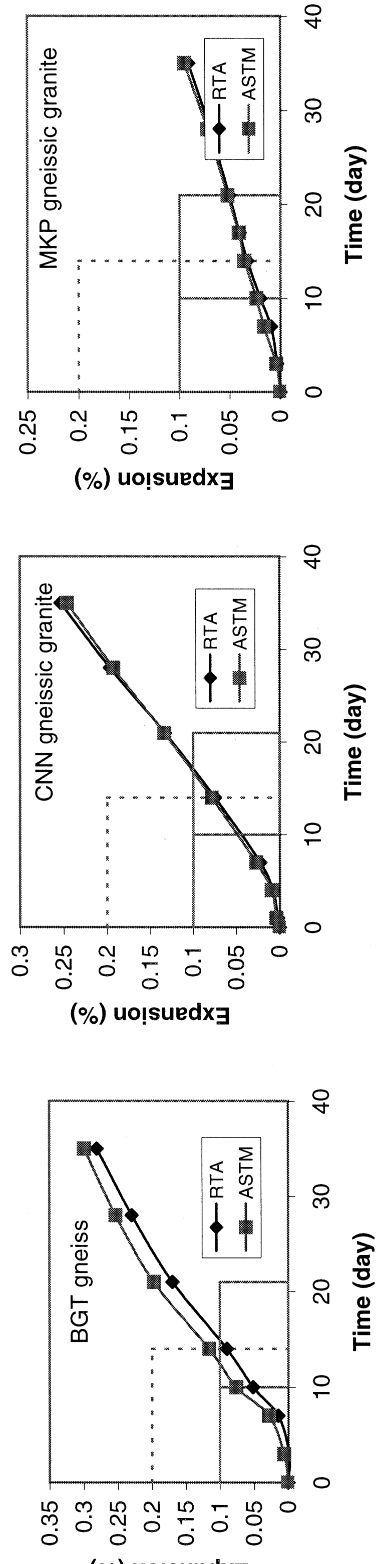

Fig. 3. Accelerated mortar bar test results for the two methods using BGT, CNN and MKR aggregates.

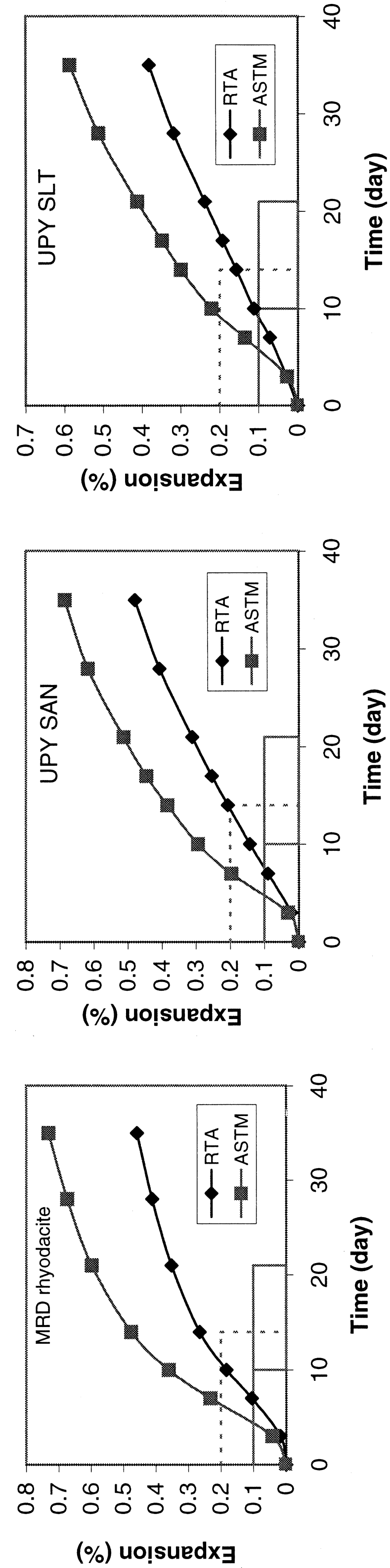

Fig. 4. Accelerated mortar bar test results for the two methods using MRD rhyodacite, UPYSAN and UPYSLT aggregates.

railway workers, who collected it from the track a considerable distance away from the quarry, and may be different from the original aggregate. The current MKR aggregate is classed as nonreactive.

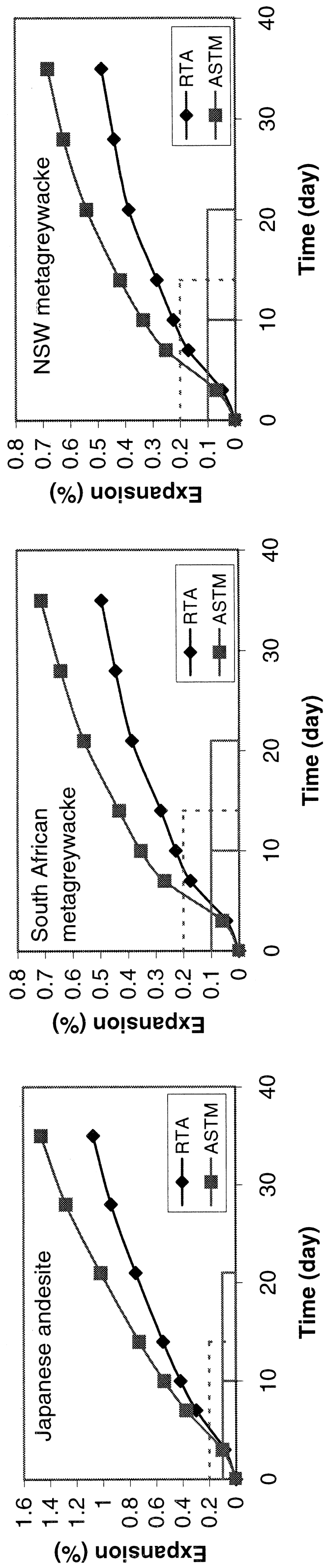

Fig. 5. Accelerated mortar bar test results for the two methods using Japanese andesite, South African and NSW metagreywacke aggregates.

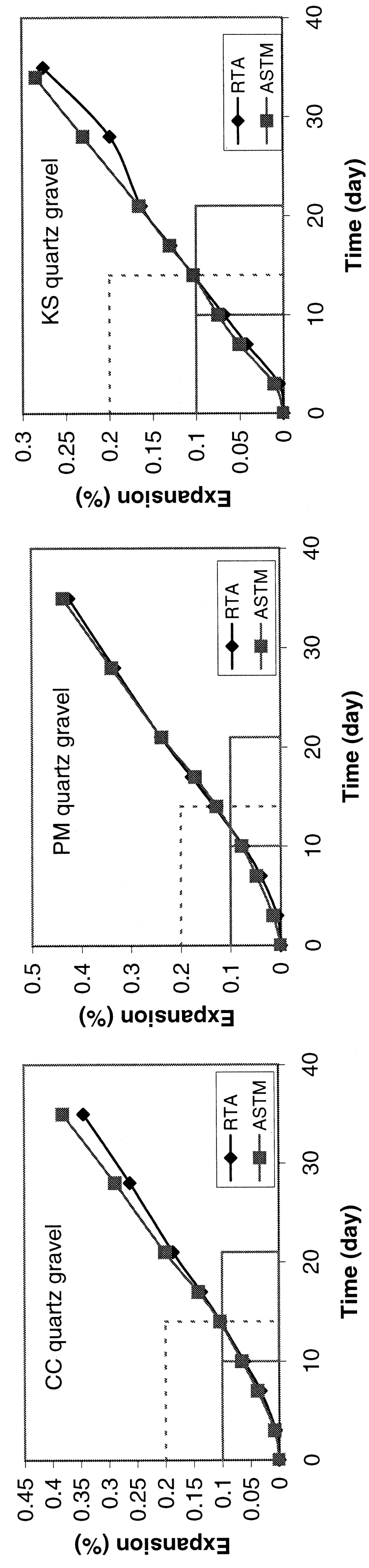

Fig. 6. Accelerated mortar bar test results for the two methods using CC, PM and KS quartz aggregates.

However, the results for the BGT and CNN aggregates, although identical by the two methods, produce different classifications for the aggregates. The RTA method classifies them as slowly reactive based on the 10-day expansion values of less than 0.1% and 21-day expansion values of greater than 0.1%. The ASTM method classifies these two aggregates,

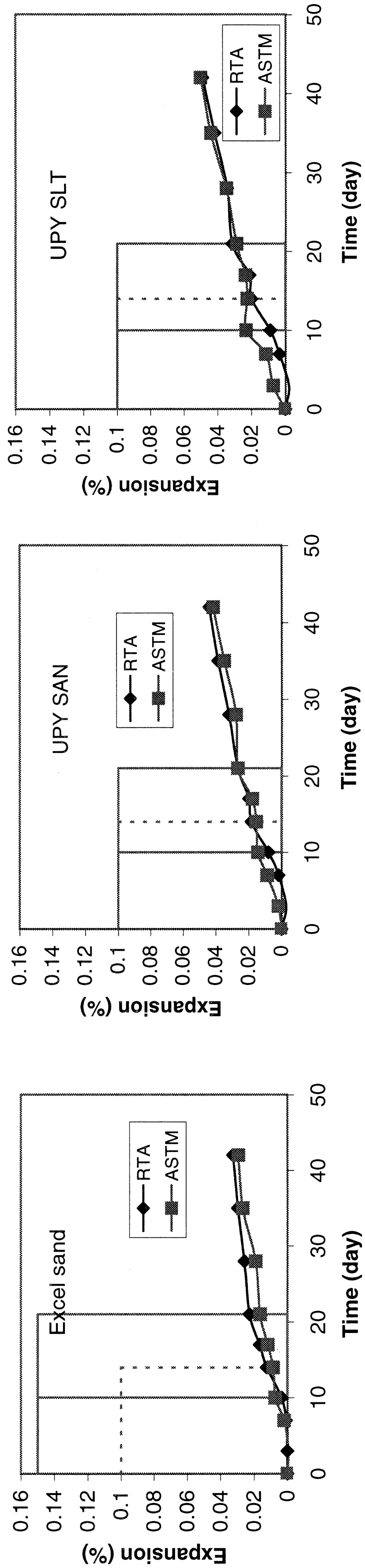

Fig. 7. Accelerated mortar bar test results for the two methods using Excel sand, UPYSAN and UPYSLT aggregates in combination with fly ash.

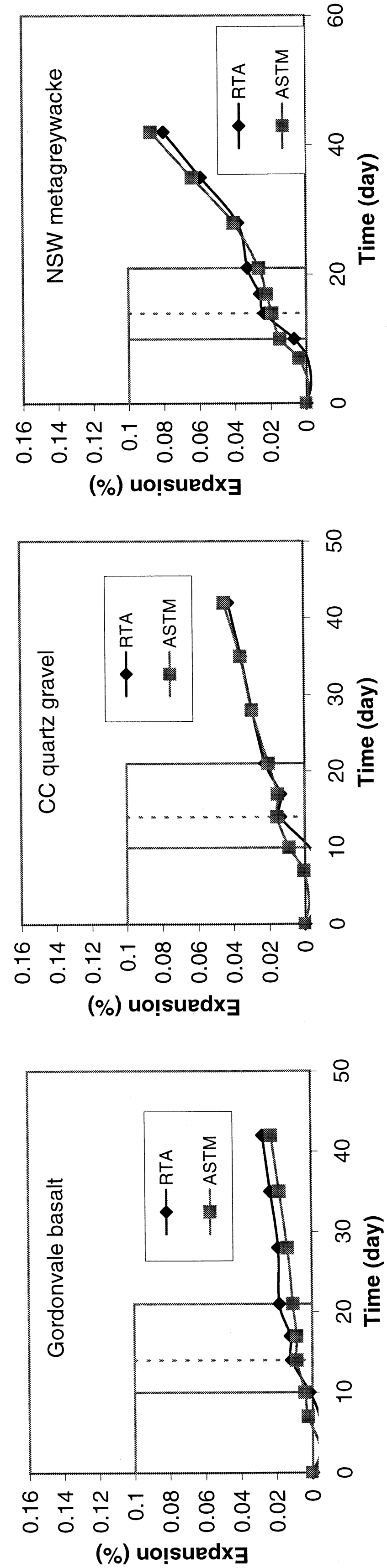

Fig. 8. Accelerated mortar bar test results for the two methods using Gordonvale basalt, CC quartz gravel and NSW meta-greywacke in combination with fly ash.

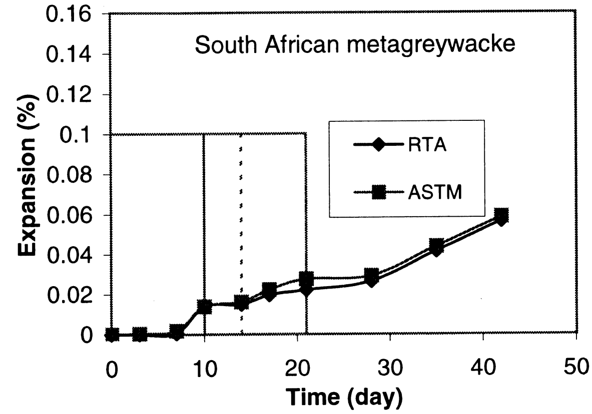

Fig. 10. Accelerated mortar bar test results for the two methods using South African metagreywacke in combination with fly ash.

particularly the CNN aggregate (which has caused serious damage to a dam) as nonreactive because of the low expansion (< 0.1%) at 14 days. Nonmandatory information in the appendix to the ASTM C1260 indicates that some reactive granitic gneisses may produce expansions below 0.1% at 16 days after casting (14 days immersion). Clearly, the use of the RTA limits has an advantage for these aggregates.

The more reactive aggregates (Figs. 4 and 5) are correctly classified as reactive by both test methods, and it is not important which one is used. The fact that much larger expansion values are achieved by the ASTM method does not affect the classification when the respective expansion criteria are applied to the data from each method.

In contrast, three quartz gravel aggregates (Fig. 6), which are slowly reactive and have caused damage to dam and bridge structures, produce identical results by the two test methods. Again, the RTA method classifies these aggregates as reactive, whereas the ASTM (and the Canadian) method classifies them as nonreactive to doubtful. Clearly, the field performance of this type of aggregate is better predicted by the RTA expansion criteria.

The results for the slowly reactive aggregates indicate that it is not important which procedure is adopted for testing the aggregate (as almost identical expansion curves are obtained), but it is essential that the RTA limits are used for predicting the reactivity of the aggregate and its likely field performance.

4.1.1. Conclusion 1

With respect to the choice of test method, it can be concluded that:

1. either of the test methods and their corresponding expansion limits can be used for assessing the alkali reactivity of nonreactive or very reactive aggregates;

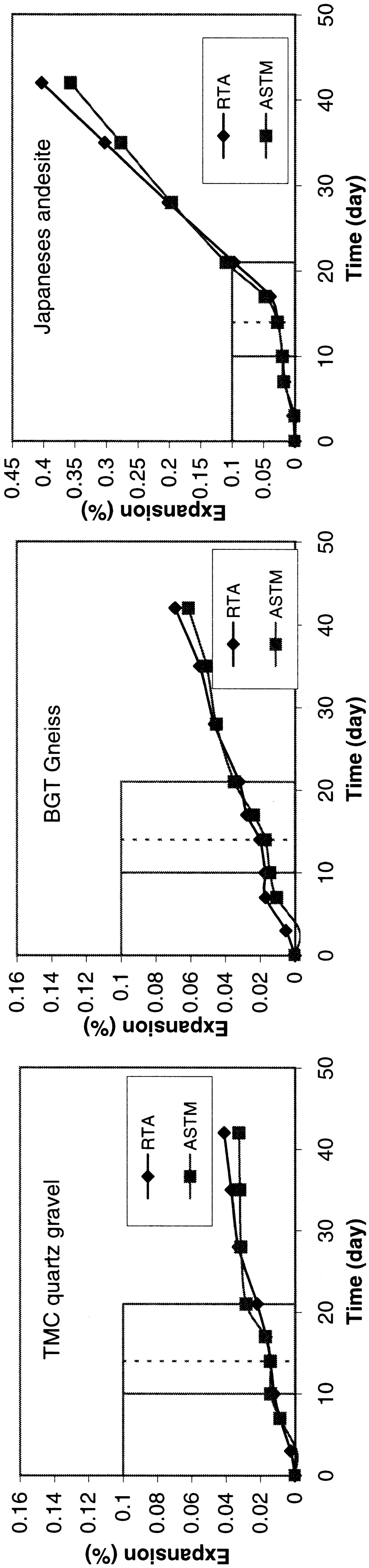

Fig. 9. Accelerated mortar bar test results for the two methods using TMC quartz gravel, BGT gneiss and Japaneses andesite in combination with fly ash.

2. either of the physical test procedures can be used to obtain expansion curves for the slowly reactive aggregates, but regardless of the procedure used, the RTA expansion limits should be used to interpret the reactivity of the aggregate.

4.2. Performance of the two test methods in assessing the effectiveness of fly ash in suppressing AAR expansion

The expansion curves in Figs. 7–10 show that, like the case of the nonreactive aggregates, the two methods have produced almost identical results and both methods show the effectiveness of the fly ash in controlling the AAR expansion (compare with corresponding expansion curves for mortar bars without fly ash). In this respect, the two methods are identical in their performance but with the one exception detailed below.

Fig. 9 shows that late expansion has taken place in mortar bars containing the very reactive Japanese andesite in combination with 25% fly ash. Using the 14-day test limit of the ASTM method, the combination would be classed as nonexpansive, whereas using the RTA test limit of 0.1% expansion at 21 days, the combination would be classed as slowly reactive. It appears that, in the case of the Japanese andesite, the 25% fly ash may not be sufficient to suppress the AAR expansion, whereas the ASTM method would evaluate it as adequate for this purpose. The mortar bars containing the Japanese aggregate and 25% fly ash and tested by both methods have shown cracking. This supports the outcome of the RTA T363 that the 25% fly ash replacement was not adequate for suppressing the AAR expansion. Consequently, the RTA T363 limits are judged more appropriate for predicting the effectiveness of fly ash in suppressing AAR expansion in the case of very reactive aggregates.

4.2.1. Conclusion 2

It can be concluded that, except for very reactive aggregates, the two test methods would produce similar assessments for the effectiveness of fly ash in controlling AAR expansion. For the very reactive aggregates, although either method could be used to obtain expansion curves (which are identical), the use of the RTA limits is recommended for the interpretation of the adequacy of the amount of fly ash used in controlling the expansion.

5. Suggested changes to ASTM C1260 limits

In view of the known service performance of the aggregates used in this work and the results obtained for the two test methods employed, it appears that the limits of ASTM C1260 method need to be adjusted for the slowly reactive aggregates. These aggregates are largely of gneissic sources or are quartz gravels derived from such origins, although with time, we may encounter other sources that would behave similarly. A limit of either 0.1% in 21 days or 0.08% in 14 days of immersion is suggested for the ASTM method to distinguish reactive from nonreactive aggregates of such origins.

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