Long-Term Mortar-Bar Expansion Tests for Potential Alkali-Aggregate Reactivity

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ABSTRACT

ASTM C 227 mortar-bar tests have been extended for up to 5 years with several aggregates and low to high alkali cements. These tests illustrate several areas of concern in the use of such tests to identify potentially reactive aggregates. In several instances cements with alkali contents just below the traditional 0.6% limit developed high levels of expansion. Often cement-aggregate combinations developed expansion slowly so that they met the C 33 limits at 3 and 6 months, but developed very significant expansions between 6 months and 4 or 5 years. In at least two instances, the aggregates with later-age expansion produced deleterious expansion in service. With one aggregate, the replacement of 7.5% cement with Class F fly ash reduced expansion at 6 months sufficient to meet current C 33 limits but large expansions developed at later ages. In this instance 15% fly ash prevented the development of significant expansion through 4 years.

INTRODUCTION

Because of the concern over the significance of long-term expansion from alkali-silica reaction in the ASTM C 227 mortar-bar tests, observations have been extended for periods of up to 5 years. The principal variables studied include source and amount of reactive material, alkali content of the cement and the effectiveness of fly ash in reducing expansion.

The studies demonstrate some of the difficulties of interpreting the results of C 227 tests, particularly when the development of significant expansion is delayed beyond the normal 1 year observation period and when significant expansions develop with cement which has alkali contents slightly below or at the traditional 0.6% limit for low alkali cements.

TEST PROCEDURES

Mortars: The proportioning and mixing of mortars was in accordance with ASTM C 227. When coarse aggregates were tested, the particles were crushed to sand size, sieved, and recombined to meet the C 227 gradation. Cement with three levels of total alkali content, 1.1%, 0.8% and less than 0.6% equivalent Na_2O, were used. Two different low alkali cements were used.

Table 1. Analysis of Alkali in Low Alkali Cements.

	% by Weight of Sample					
	Total Alkali			Water Soluble Alkali		
Cement	Na_2O	K_2O	Equiv. Na_2O	Na_2O	K_2O	Equiv. Na_2O
B	0.26	0.43	0.54	0.04	0.20	0.17
D	0.23	0.53	0.58	0.04	0.27	0.22

In one series, a Class F fly ash was used as a partial replacement of cement. Specific combinations of materials are discussed below.

Storage Containers: Cylindrical containers were constructed of plexiglas and could accommodate 21 bars. When fewer test specimens were being stored, dummy bars were used to fill the remaining spaces. The inside surface of the containers was lined with blotting paper for wicking. Sealed containers were stored in a room at 38°C.

Measurements: At the indicated ages, specimens were removed from the containers and their lengths and weights measured. Reported values of expansion are generally the averages of readings on two bars from each of two batches of mortar.

TEST RESULTS

Series 1: The aggregates tested in this series were chert particles hand picked from a gravel that had reacted when it was used in a lock and dam structure in Alabama many years ago and a quartz sand from Maryland. Previous tests of the quartz sand had indicated that it is not reactive. Mortars were mixed using the high (1.1%) and the medium (0.8%) alkali cements. Expansion curves are shown in Figure 1. Expansion of the quartz sand bars remained below 0.025% with both cements as did the chert bars with the medium alkali cement. Chert bars with the high alkali cement have expanded slowly to 0.06% after five years. Three and 6 month expansions were 0.024 and 0.036% which are well below the limits recommended in C 33 of 0.05% and 0.10% respectively. At 2 years the expansion of 0.04% equals the value at which cracking of mortar bars frequently occurs (Grattan-Bellew, 1983) and the limit set by the Canadian Standards Association (CSA). The CSA expansion limit of 0.04% at any age was established to identify slowly expanding aggregates.

Series 2: The aggregates used in this series are from river deposits in New Mexico containing andesite and rhyolite fragments. Tests were run on both sand and gravel to see if reactive components were contained in both. Mortars were made with high (1.1%), medium (0.8%), and low (0.54%) alkali cements. The results appear in Figure 2. Lower alkali content delays but does not prevent deleterious expansion. All combinations of materials except the sand and low alkali cement combination would be considered potentially reactive at six months.

Series 3: This series was designed to determine whether replacement of low (0.54%) alkali cement with fly ash would prevent expansion of bars made with the New Mexico sands tested in Series 2. Mortars were made using a 50-50 blend of washed sand and unwashed sand. Replacement of the low alkali cement with a Class F fly ash was made at the following percentages: 0, 7.5, 15, and 20. The replacement of 15 to 20% of the cement with fly ash effectively prevented expansion of the test specimens through 4 years (Fig 3). These findings concur with those of Stark (1978) for similar materials.

Series 4: This series was designed to test the effect of varying the amount of reactive rock in an aggregate on the expansion of test specimens. Crushed opaline rock from west Texas was tested in this series as well as Beltane opal (Diamond, 1978). The Texas rock and a non-reactive Maryland quartz sand were blended to produce sands containing 6.7, 20, 41, and 100%

Texas opal for use in C 227 mortars.

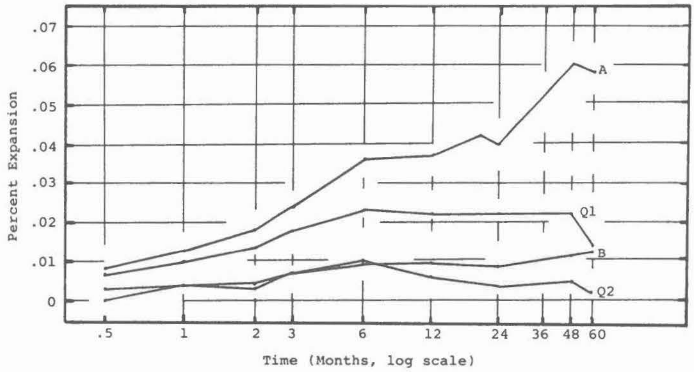

Figure 1. Expansion of C 227 bars in Series 1.
A - chert gravel; .58w/c; 1.1% equiv. Na_2O
B - chert gravel; .58w/c; .8% equiv. Na_2O
Q1 - quartz sand; .51w/c; 1.1% equiv. Na_2O
Q2 - quartz sand; .50w/c; .8% equiv. Na_2O

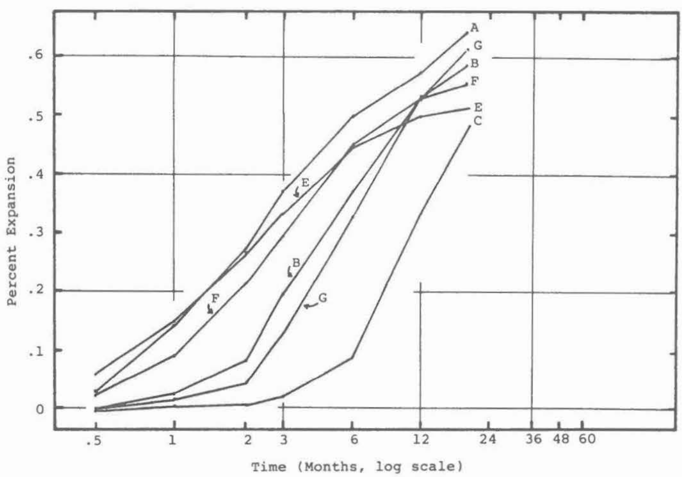

Figure 2. Expansion of C 227 bars, Series 2.
A - New Mexico sand; .51w/c; 1.1% equiv. Na_2O
B - N.M. sand; .50 w/c; .8% equiv. Na_2O
C - N.M. sand; .53w/c; .54% equiv. Na_2O
E - N.M. gravel; .57w/c; 1.1% equiv. Na_2O
F - N.M. gravel; .57w/c; .8% equiv. Na_2O
G - N.M. gravel; .62w/c; .54% equiv. Na_2O

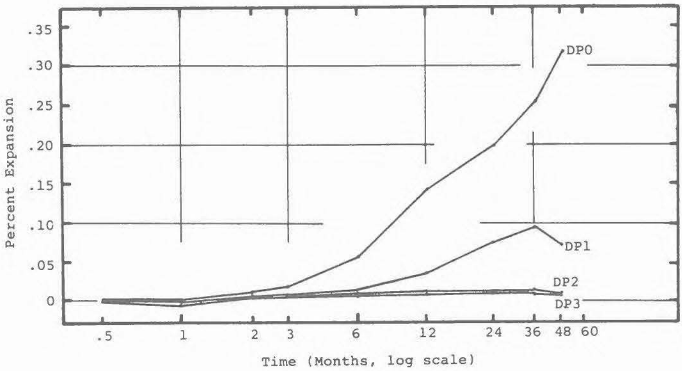

Figure 3. Expansion of C 227 bars, Series 3.
DPO - N.M. sand; .55w/c; .54% equiv. Na_2O; 0% fly ash
DP1 - N.M. sand; .55w/c; .54% equiv. Na_2O; 7.5% fly ash
DP2 - N.M. sand; .52w/c; .54% equiv. Na_2O; 15% fly ash
DP3 - N.M. sand; .49w/c; .54% equiv. Na_2O; 20% fly ash

The distribution of the reactive materials in the blended sands are outlined in Table 2.

Table 2. Percentage of Reactive Aggregate in Sand.

A non-reactive Maryland quartz sand was blended to give C 227 grading.

Sieve	% Texas Rock in Total Sand				Beltane
Fractions	6.7	20	41	100	Opal
No. 4 - No. 8	0	2	10	10	0
No. 8 - No. 16	0	5	25	25	0
No. 16 - No. 30	0	5	2.5	25	0
No. 30 - No. 50	0	5	2.5	25	0
No. 50 - No. 100	6.7	2	1.5	15	6.7
Total	6.7	20	41.5	100	6.7

The cements used with each blend are outlined in Figure 4. When used at 6.7% both the Texas and Beltane opal are highly reactive, but there are some interesting differences. The Texas material developed very high expansion at 14 days. With Beltane opal expansion occurred somewhat more slowly, particularly with the medium alkali cement. With both aggregates the expansion with the high alkali cement slowed down and greater final expansion was obtained with the medium alkali cement. When the Texas rock was used as 20% of the sand, it greatly exceeded the "pessimum" amount. Although the 14 day expansion was high, relatively little additional expansion developed until an age of 2 years when expansion resumed. When either 41 or 100% Texas material was used, expansions were below the C 33 limits. With these high percentages of opaline materials no significant expansion occurred with the 0.54% alkali cement.

Series 5: The aggregates studied in this series are sands and gravels from the Santa Clara River in California. These aggregates contain igneous and sedimentary rock fragments, chert, and opaline shale. The sand size fractions were incorporated into mortars with low (0.58%) and medium (0.8%) alkali cements. One inch (25.4mm) gravel was crushed and mixed with the low alkali cement as was a 50-50 mixture of 1-in.(25.4mm) and 1½-in.(38.1mm) gravel. Additional specimens were composed of 6.7% Beltane opal - 93.3% quartz sand and 100% quartz sand with the medium alkali cement. As expected, the Santa Clara sands and Beltane opal expanded rapidly when they were used with the medium (0.8%) alkali cement. With low (0.58%) alkali cement the Santa Clara sand and both gravel sizes were just under the traditional expansion limits in C 33 of 0.05% and 0.10% at 3 and 6 months respectively. However, all three aggregates continued to expand and at 3 years the expansion of the sand with the low alkali cement equaled that with the medium alkali cement. It would appear that all three Santa Clara materials should be considered potentially reactive. The delayed expansion of the sand with a low alkali cement suggests that deleterious reactions may occur even when low alkali cements are used.

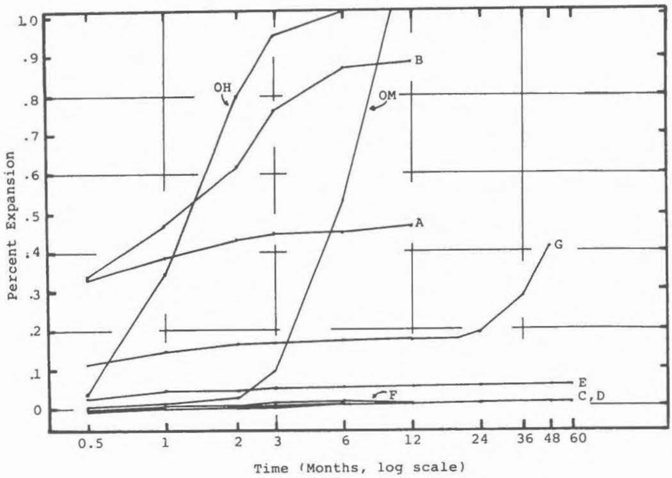

Figure 4. Expansion of C 227 bars, Series 4.
A - 6.7% Tx*; .50w/c; 1.1% eqv. Na_2O; B - 6.7% Tx; .50w/c; 0.8% eqv. Na_2O
C - 100% Tx; .60w/c; 0.8% eqv. Na_2O; D - 100% Tx; .67w/c; .54% eqv. Na_2O
E - 41% Tx; .54w/c; 0.8% eqv. Na_2O; F - 41% Tx; .57w/c; .54% eqv. Na_2O
G - 20% Tx; .54w/c; 0.8% eqv. Na_2O; OH - 6.7% B.O.; .52w/c; 1.1% eqv. Na_2O
OM - 6.7% B.O.; .52w/c; 0.8% eqv. Na_2O; * Tx - Texas Aggregate

CONCLUSION

1. A chert gravel that produced long term expansion in service did not expand significantly with 0.8% alkali cement, but with 1.1% alkali cement expansions were 0.04% at 6 months and 0.06% at 5 years. Application of the C 33 criteria would not rate this aggregate as potentially reactive. Criteria used in Canada would rate it as reactive.

2. Use of a reactive gravel and sand with cements with alkali contents of 0.54, 0.8 and 1.1% demonstrates that large expansions developed with all combinations, but that expansion was delayed with lower alkali content. At 2 years the ultimate expansions were not greatly different. The crushed sand mortar had larger early expansion that is likely the result of a higher water ratio mortar than that made with the natural sand.

3. In a study of the effectiveness of Type F fly ash in reducing expansion a 7.5% replacement reduced expansion and 15 or 20% eliminated expansion for a period of 4 years. The basic aggregate produced expansions well below the 0.10% expansion limits at 6 months, but significant expansions developed between 6 months and 4 years. The 7.5% replacement condition did show evidence of slow later age expansion between 6 months and 4 years although final expansions were still less than 0.1%.

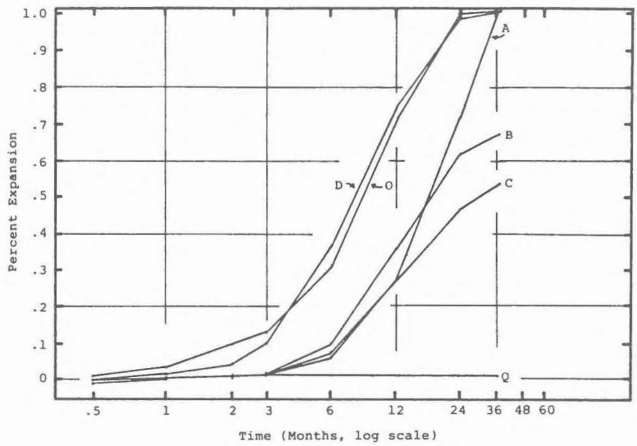

Figure 5. Expansion of C 227 bars in Series 5.
A - Santa Clara sand; .53w/c; .58% equiv. Na_2O
B - Santa Clara 1-in. gravel; .58w/c; .58% equiv. Na_2O
C - Santa Clara 1½-in. gravel; .59w/c; .58% equiv. Na_2O
D - Santa Clara sand; .51w/c; 0.8% equiv. Na_2O
O - Beltane opal; .52w/c; 0.8% equiv. Na_2O
Q - Maryland quartz sand; .50w/c; 0.8% equiv. Na_2O

4. When highly reactive opaline materials were used as 6.7 to 100% of the sand very large expansions developed at 6.7% since as expected the pessimum amount is quite low. When either 40 or 100% were used no significant expansion developed. With these materials no significant expansion occurred with the 0.54 alkali cement and the relative amounts of expansion developed with 0.8 and 1.1% alkali cements depended upon the amount of opaline material and whether that amount was above or below the pessimum. Although the data are not extensive enough to define the effect it appears that expansion developed more rapidly if the reactive ingredient was concentrated in the finer sizes of the sand.

5. When a highly reactive sand and gravel which contains opaline shale was used with 0.8 alkali cement it expanded very rapidly and performed similarly to Beltane opal. When these materials were used with a 0.58% alkali cement expansions were less than the 0.10% limit in C 33. However, expansions developed rapidly between 6 months and a year and continued through 3 years.

REFERENCES

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