Pergamon

Cement and Concrete Research 32 (2002) 1981–1987

CEMENT AND CONCRETE RESEARCH

Communication

Evaluation of modified ASTM C 1260 accelerated mortar bar test for alkali–silica reactivity

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Received 13 June 2001; accepted 31 May 2002

Abstract

Among the numerous tests prescribed for assessing alkali–silica reactivity, ASTM C 1260 has become the preferred test method because of rapidity of the test procedure. However, a general concern about this method is the severity of the test conditions. The authors have evaluated the functionality of the method after modifying some of the important test parameters such as water–cement ratio, normality of test solution, length of test period, and curing. Combinations of high- and low-alkali cement with and without Classes C and F fly ash were included in the test program. The results are presented in this paper.

Keywords: Alkali–silica reactivity; Classes C and F fly ash; Modified ASTM C 1260 test

1. Introduction

The undesirable expansion of concrete due to reaction between cement alkalis and certain types of reactive siliceous aggregates continues to be a cause for major concern [1].

Tests performed by researchers have shown that use of fly ash can effectively reduce expansion due to alkali–silica reaction (ASR) [2]. This has been demonstrated through a number of accelerated tests performed on concrete and mortar bars made with known reactive aggregate [3].

Among the different test methods available, ASTM C 1260—Accelerated Mortar Bar Test [4] is considered to be one of the most commonly used methods because test results can be obtained within as little as 16 days. However, a general criticism about this test method is the severity of test condition. As a result, aggregates with good field track record and no history of ASR can test as reactive [5].

The authors have modified some of the test parameters to determine if improvements in this method can be achieved, even at the expense of a somewhat longer testing period. Both Classes F and C fly ash were included in this program. The modifications that were evaluated were: (i) a lower water–cementitious materials ratio (W/CM), (ii) a different curing condition, (iii) effect of high- and low-alkali cement, (iv) rate of fly ash replacement, and (v) effect of normality of the alkaline solution. This report presents the results obtained to date.

2. Materials and mixture characteristics

2.1. Materials

Mortar bars meeting ASTM C 1260 specifications were prepared with high- and low-alkali ASTM Type I Portland cement. The chemical and physical properties of the cementitious materials are given in Table 1. Potentially reactive fine aggregate (siliceous sand) from Murphy Pit (Victoria, TX) was used for this study. Since its expansion is claimed to be between 0.10% and 0.20% at 14 days [6], it is considered ‘potentially reactive.’ For preparing the low W/CM mortar bars, a lignosulfonate-based water-reducing admixture (WRA) was used.

2.2. Mixture characteristics

Fly ash replacement levels selected were 20% and 35% fly ash by mass of high- and low-alkali cement. Mortars were prepared at W/CM of 0.35 and 0.47. The lower W/CM

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PII: S0008-8846(02)00903-1

Table 1
Physical properties and chemical analyses of cementitious materials

Composition	Cement (% by mass)		Fly ash (% by mass)	
	Low alkali	High alkali	Class F	Class C
SiO_2	20.98	20.1	47.73	35.20
Al_2O_3	4.85	5.4	19.95	21.60
Fe_2O_3	1.8	3.2	4.32	5.40
CaO	65.38	65.4	15.45	25.90
MgO	1.43	0.7	2.54	4.80
SO_3	3.17	3.3	0.78	1.40
Na_2O equivalent	0.51	0.58	0.32	1.20
Loss on ignition	1.09	0.9	0.05	0.30
Fineness (passing 45 μm)	92.7	95.3	20.09	15.00
Specific gravity	3.14	3.11	2.48	2.67
Initial set (min)	183	150	–	–
Final set (min)	303	270	–	–

of 0.35 was an arbitrary selection, based on the fact that when fly ash is used in concrete, its W/CM is reduced in order to obtain a reasonably high early strength, which otherwise cannot be achieved at high W/CM. The dosage of WRA in the low W/CM mixtures was adjusted to obtain proper workability. The mixture proportions are presented in Table 2.

3. Test procedures

The standard ASTM C 1260 method was used for evaluating potential reactivity of the aggregate in different cementitious mixtures. Additionally, the procedure was modified to include a different curing regime, a high- and a low-alkali cement, a lower W/CM, and alkali hydroxide solutions of lower normality. The objective was to study the expansion characteristics of these mixtures when subjected to conditions different from traditional testing condition prescribed for C 1260, but would be more representative of exposure conditions for field concrete. Recently, Shayan and Morris [7] reported test results of a comparative study of ASTM C 1260 and RTA T363 methods. Though both these methods are essentially the same, the RTA T363 method uses a different mortar preparation technique, i.e., longer (up to 48 h) moist curing followed by 21 days of immersion in 1 N NaOH solution.

Six mortar bars, each 25 × 25 × 225 mm in size, were cast from mortar mixtures whose compositions are given in Table 2. Immediately after casting, the molds were covered and placed in a moist curing room at 23 °C. One set of three mortar bars was moist cured for a period of 24 ± 2 h, while a second set was moist cured at 23 °C for 28 days. The rationale for a longer curing period was to enable the fly ash to start hydrating. It is well known that Class F fly ash does not hydrate as fast as cement. In fact, only nominal hydration takes place until about 28 days [8]. Therefore, subjecting highly immature test bars containing up to 35% fly ash to an elevated temperature and simultaneously exposing these bars to a strong (1 N) alkaline solution within 2 days of casting cannot be representative of actual conditions prevailing in the field. Actually, these test conditions were adopted solely for the purpose of obtaining rapid results.

Both sets of mortar bars were preconditioned for 24 h in water maintained at 80 ± 2 °C. The length of mortar bars was measured, and then the bars were immediately transferred to storage containers filled with 1, 0.5, and 0.25 N NaOH solutions maintained at 80 °C. The containers were then placed in an oven at 80 °C. Lengths of mortar bars were periodically measured over a 28-day period instead of the normal 14-day period recommended in ASTM C 1260 procedure.

4. Results and discussion

4.1. Control mortars

The comparative evaluation of expansion results for mortars containing only plain cement is given in Table 3 and Figs. 1 and 2. Low-alkali cement generally appears to produce slightly lower expansion than its high-alkali counterpart cement, irrespective of curing regime and W/CM, although difference in Na_2O_{eq} between the two cements is not very remarkable. The results indicate that

Table 2
Mortar mixture proportions

Mixture	W/CM	Unit weight (g)						WRA (ml)
		Water	Cement		Fly ash		Fine aggregate	
			High alkali	Low alkali	Class F	Class C		
Control	0.35	154	440	440	–	–	990	3
FA20			352	352	88	88	990	3
FA35			286	286	154	154	990	3
Control	0.47	207	440	440	–	–	990	–
FA20			352	352	88	88	990	–
FA35			286	286	154	154	990	–

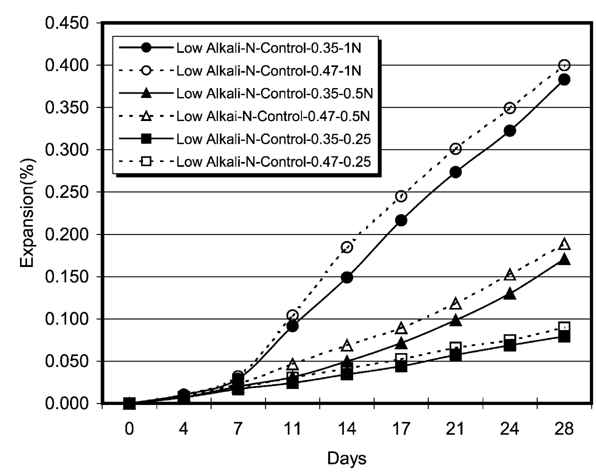
Control: Plain cement mortar mixture containing high- and low-alkali cement. FA20 and FA35 = percentage of fly ash in mortar.

Table 3
Expansion of control mortars at 14 and 28 days

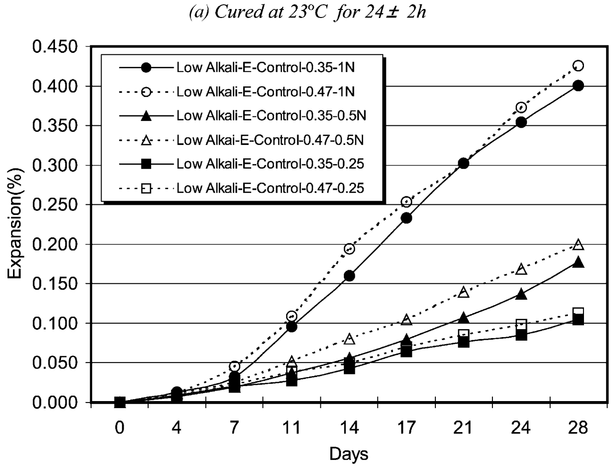
Mixture (cement–curing–W/CM)	Expansion (% at 0.25 N solution)		Expansion (% at 0.5 N solution)		Expansion (% at 1 N solution)	
	14 days	28 days	14 days	28 days	14 days	28 days
High alkali–N–0.35	0.054	0.127	0.062	0.180	0.168	0.496
Low alkali–N–0.35	0.034	0.079	0.050	0.171	0.149	0.383
High alkali–N–0.47	0.066	0.164	0.088	0.226	0.203	0.568
Low alkali–N–0.47	0.041	0.090	0.069	0.189	0.185	0.400
High alkali–E–0.35	0.061	0.146	0.088	0.218	0.174	0.509
Low alkali–E–0.35	0.043	0.105	0.056	0.178	0.160	0.401
High alkali–E–0.47	0.080	0.183	0.109	0.255	0.210	0.582
Low alkali–E–0.47	0.050	0.113	0.080	0.200	0.194	0.426

Curing: N = normal, in accordance with ASTM C 1260; E = extended moist curing for 28 days.

at the higher W/CM (0.47) and in higher-normality NaOH solution (1 N), expansion of mortar bars is also higher. Furthermore, prolonged moist curing does not have any major impact on the amount of expansion either at 14 or 28 days. When the test period is extended to 28 days, a significant amount of expansion is seen to occur between 14 and 28 days under both curing regimes, especially for mortar bars kept in 1 N solution. Expansion of mortar bars immersed in 0.5 N NaOH solution at 28 days is comparable to, and possibly nominally higher than, that of mortar bars in 1 N NaOH solution at 14 days. Up to 14 days, however, there is very little expansion of mortar bars in 0.5 N NaOH solution. Very little expansion of mortar bars takes place, even at 28 days, when placed in 0.25 N NaOH solution. From these results, it emerges that for plain cement mortars, normality of the alkali hydroxide solution governs the expansion characteristics. Decreasing the W/CM from 0.47 to 0.35 marginally affects the expansion rate, while

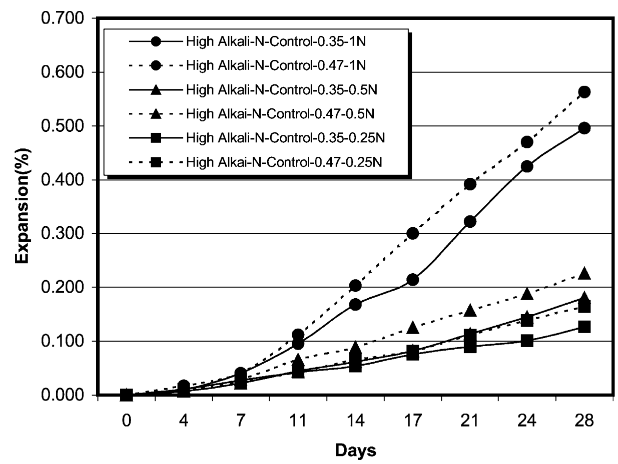


(a) Cured at 23°C for 24 ± 2h

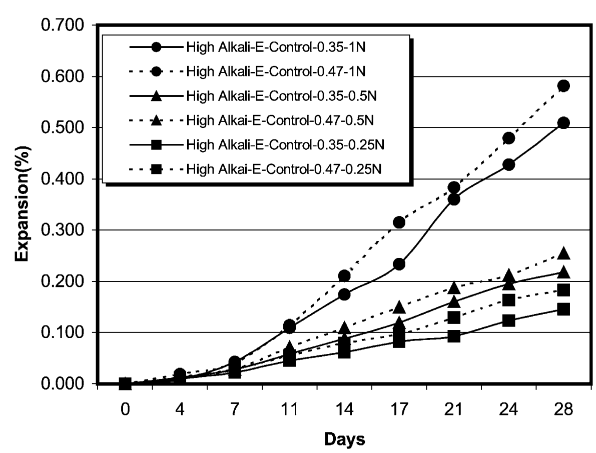


(b) Cured at 23°C for 28 days

Fig. 1. Expansion curves for control mortar bars.



(a) Cured at 23°C for 24 ± 2h



(b) Cured at 23°C for 28 days

Fig. 2. Expansion curves for control mortar bars.

extended moist curing has still less effect. To test expansion of mortar bars at the lowest normality of 0.25, it is necessary to continue the test for a much longer period of time. Currently, this test is in progress.

Although at 14 days aggregate expansion barely meets the 'potentially reactive' criterion for aggregates, a drastic change in expansion characteristics occurs between 14 and 28 days [9]. Expansion far exceeds the 'reactive' aggregate criterion at 28 days. This reflects the sensitive nature of the test. However, when normality of the test solution is reduced to 0.5 N, expansion at 28 days is seen to remain close to the 0.20% mark, which is considered to be upper limit of expansion for 'potentially reactive' aggregate; in the case of high-alkali cement, expansion is marginally in excess of 0.20%, whereas it is marginally lower than 0.20% in the low-alkali cement mortar.

4.2. Mortars containing fly ash

The results for mortar mixtures containing 20% and 35% Classes C and F fly ash by mass of cement are summarized in Table 4 and Figs. 3 and 4. Expansion of mortars bars containing 20% and 35% Class F fly ash was below 0.10% at 14 days, but at 28 days of expansion of mortar bars incorporating 20% fly ash—irrespective of cement alkali level, curing condition, or W/CM—exceeded 0.10%, whereas with 35% Class F fly ash replacement, expansion was lower than 0.10% at both W/CM and curing conditions. These results support the previous data [10–12] that a minimum of 30% Class F fly ash is generally required to control deleterious expansion with reactive aggregates.

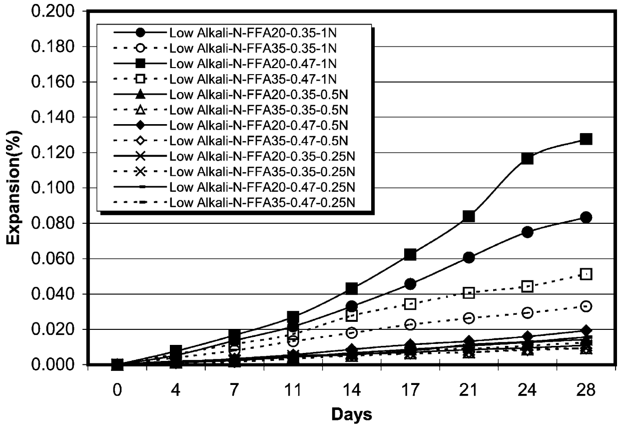
Owing to the nonresponsiveness of mortar bars to 0.25 N NaOH solution, only a limited number of samples were tested at this low-normality solution. The expansion was measured to be negligible even at 28 days for both Classes F and C fly ashes (Fig. 5).

The results show that, generally, a distinct reduction in expansion occurs in the presence of fly ash compared to plain cement mortar bars. Only those mortars containing 20% Class C fly ash and low-alkali cement at W/CM = 0.47 recorded an expansion greater than 0.10% at 14 days. However, in the counterpart mortar bars containing 35%

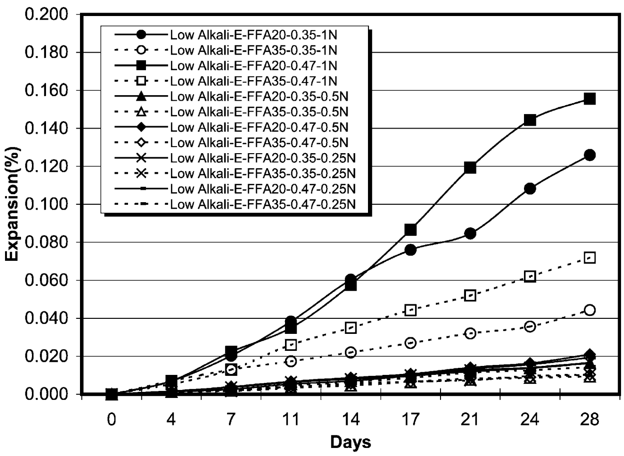
Table 4
Expansion of mortar mixtures incorporating fly ash at 14 and 28 days

Mixture (cement–curing–FA–W/CM)	Expansion (% at 0.25 N solution)		Expansion (% at 0.5 N solution)		Expansion (% at 1 N solution)	
	14 days	28 days	14 days	28 days	14 days	28 days
High alkali–N–FFA20–0.35	0.005	0.010	0.018	0.033	0.054	0.120
High alkali–N–FFA35–0.35	0.004	0.009	0.009	0.011	0.021	0.042
High alkali–N–FFA20–0.47	0.008	0.015	0.022	0.034	0.071	0.147
High alkali–N–FFA35–0.47	0.006	0.011	0.009	0.014	0.019	0.049
High alkali–E–FFA20–0.35	0.006	0.013	0.022	0.043	0.070	0.145
High alkali–E–FFA35–0.35	0.006	0.012	0.009	0.020	0.022	0.051
High alkali–E–FFA20–0.47	0.009	0.017	0.023	0.051	0.060	0.196
High alkali–E–FFA35–0.47	0.007	0.015	0.018	0.034	0.035	0.065
Low alkali–N–FFA20–0.35	0.006	0.011	0.007	0.014	0.033	0.083
Low alkali–N–FFA35–0.35	0.005	0.009	0.005	0.009	0.018	0.033
Low alkali–N–FFA20–0.47	0.006	0.016	0.009	0.019	0.043	0.128
Low alkali–N–FFA35–0.47	0.006	0.013	0.005	0.009	0.017	0.051
Low alkali–E–FFA20–0.35	0.008	0.017	0.007	0.016	0.060	0.126
Low alkali–E–FFA35–0.35	0.005	0.010	0.004	0.009	0.022	0.044
Low alkali–E–FFA20–0.47	0.009	0.019	0.009	0.021	0.058	0.156
Low alkali–E–FFA35–0.47	0.006	0.014	0.006	0.010	0.035	0.072
High alkali–N–CFA20–0.35	0.006	0.013	0.030	0.070	0.054	0.120
High alkali–N–CFA35–0.35	0.005	0.010	0.017	0.027	0.021	0.042
High alkali–N–CFA20–0.47	0.008	0.017	0.028	0.085	0.071	0.147
High alkali–N–CFA35–0.47	0.006	0.012	0.021	0.040	0.019	0.049
High alkali–E–CFA20–0.35	0.006	0.016	0.040	0.088	0.087	0.218
High alkali–E–CFA35–0.35	0.006	0.013	0.024	0.043	0.032	0.056
High alkali–E–CFA20–0.47	0.010	0.020	0.055	0.103	0.117	0.279
High alkali–E–CFA35–0.47	0.006	0.015	0.035	0.064	0.036	0.071
Low alkali–N–CFA20–0.35	0.005	0.012	0.017	0.036	0.064	0.184
Low alkali–N–CFA35–0.35	0.005	0.010	0.008	0.019	0.027	0.048
Low alkali–N–CFA20–0.47	0.006	0.016	0.023	0.057	0.116	0.257
Low alkali–N–CFA35–0.47	0.005	0.012	0.011	0.025	0.032	0.064
Low alkali–E–CFA20–0.35	0.006	0.016	0.021	0.041	0.070	0.145
Low alkali–E–CFA35–0.35	0.005	0.011	0.009	0.024	0.022	0.051
Low alkali–E–CFA20–0.47	0.008	0.017	0.029	0.069	0.060	0.196
Low alkali–E–CFA35–0.47	0.007	0.014	0.018	0.034	0.035	0.065

Curing: N = normal, in accordance with ASTM C 1260; E = extended moist curing for 28 days.



(a) Cured at 23°C for 24 ± 2h



(b) Cured at 23°C for 28 days

Fig. 3. Expansion curves for mortar bars containing Class F fly ash and low-alkali cement.

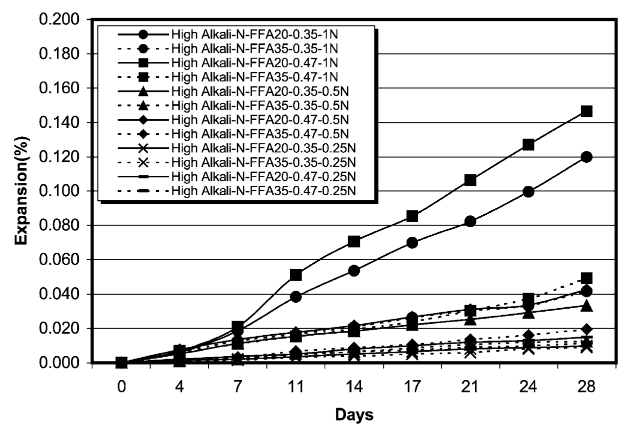
Class C fly ash at the same W/CM, expansion was 50% lower at 14 days. Expansion in the corresponding mortar bars with high-alkali cement measured less than 0.07%. The reason for such an abnormal expansion in one set of mortars cannot be fully explained at this stage. The fact, that in all the other mortar bars containing 20% Classes F and C fly ash expansion is less than 0.10% at 14 days, but at 28 days most of them record expansions in excess of 0.10%, implies that the trend of expansion is very similar to that of plain cement mortar bars. This can be expected, since the amount of fly ash replacement is quite low.

Interestingly, with the exception of mortar bars with 20% fly ash in them, dependence of expansion of all the other fly ash mortar bars on the normality of sodium hydroxide solution does not appear to be as critical as in plain cement mortar bars. Instead, the amount of fly ash replacement and W/CM play a more dominant role. Unlike plain cement mortar bars, those containing fly ash that were moist-cured for an extended period of 28 days exhibit higher expansion than counterpart bars that were cured in accordance with C 1260 method, i.e., moist-cured for 24 h. This observation is remarkable, in the sense that it is representative of the slower rate of microstructural development in fly ash concrete under normal conditions that can be expected to be found in the field.

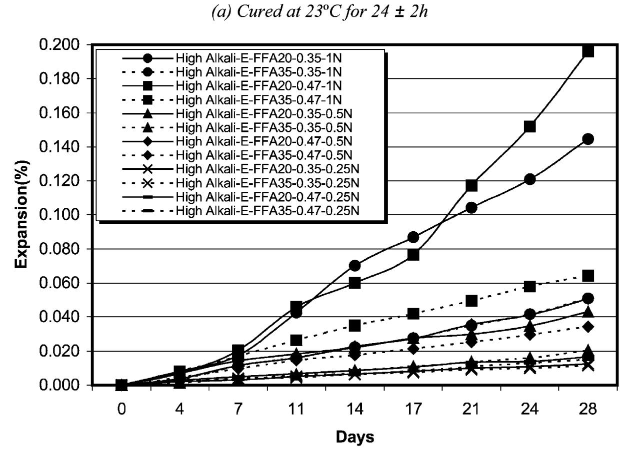
4.3. Strength development of concrete

To validate the influence of microstructural development of a cementitious system on the test procedure, concrete specimens with and without fly ash were prepared. Class F fly ash was used. Fly ash replacements were 20% and 35% by mass of cement. Mixture proportions of concretes that were tested are presented in Table 5. One set of specimens was water-cured at ambient temperature, whereas another set was water-cured at 80 °C.

The strength development patterns of these concretes are presented in Fig. 6. It is evident that curing at an elevated temperature tends to increase the early strength [13]. However, the plain cement concrete cured at 80 °C develops marginally higher 3-day strength compared to the one cured at ambient temperature. Although early age strength of fly ash concretes is lower than that of plain cement concrete, at this age, the relative increase in strength of concrete containing fly ash cured at an elevated temperature is higher

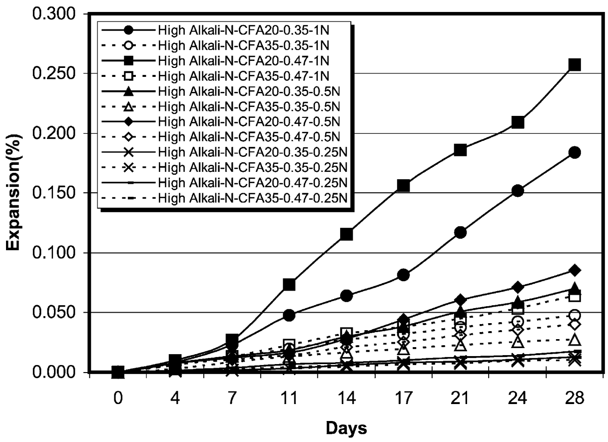


(a) Cured at 23°C for 24 ± 2h

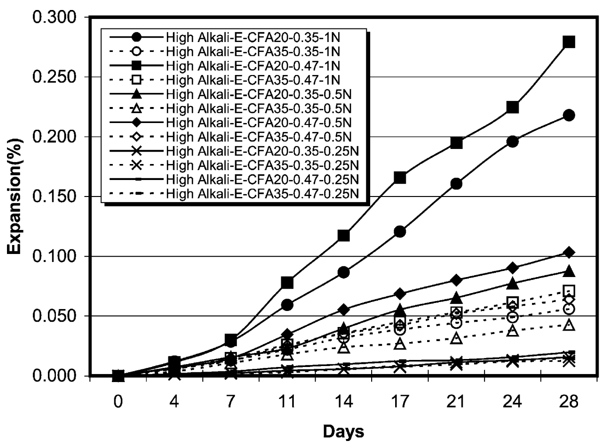


(b) Cured at 23°C for 28 days

Fig. 4. Expansion curves of mortar bars containing Class F fly ash and high-alkali cement.



(a) Cured at 23ºC for24 ± 2h



(b) Cured 23°C for 28 days

Fig. 5. Expansion curves of mortar bars containing Class C fly ash and high-alkali cement.

than that of the corresponding plain cement concrete, implying a greater change in pore structure and mineralogy. Paul and Glasser [14] have reported that a series of mineralogical changes can occur from prolonged warm moist curing of Portland cement paste.

5. Conclusions

The results suggest that, despite nominal difference in alkali content of high- and low-alkali cement, there is recognizable effect on the rate and amount of expansion of mortar bars under most of the experimental conditions that were considered.

Mortar bars with higher W/CM, and kept in stronger alkaline solution, do produce greater expansion, irrespective of the class of fly ash used. Generally, expansion is lower in mortar bars containing fly ash, but 20% fly ash replacement may not be adequate for lowering expansion at W/CM = 0.47. Tests confirm that incorporation of Class F fly ash produces greater reduction in expansion than with Class C fly ash. However, when the replacement amount was increased to 35% by mass of cement, then even the Class C fly ash was quite effective in reducing expansion at W/CM = 0.47. Mortar bars containing 20% Class C fly ash appear to be totally ineffective in reducing expansion in the presence of high-alkali cement at a W/CM = 0.47.

Interestingly, extended moist curing for 28 days increases the amount of expansion, regardless of the cement alkali content, class of fly ash, and amount of fly ash replaced. Expansion of mortar bars at 28 days in 0.5 N NaOH solution is comparable or slightly higher than that at 14 days in 1 N NaOH. The potentially reactive aggregate used in this study demonstrates nearly 2.5 times expansion between 14 and 28 days than the expansion that occurs at 14 days. Thus, it may be more appropriate to extend the testing period to 28 days in order to obtain a more reproducible expansion figure. At the same time, reducing the normality of the NaOH test solution to 0.5 N will closely approximate field conditions.

Table 5
Concrete mixture proportions

Mixture	W/CM	Unit weight (kg/m^3)					WRA (ml)
		Water	Cement	Fly ash	Coarse aggregate	Fine aggregate	
Control	0.35	175	500	–	1088	611.4	4.0
FA20		175	400	100	1088	606.5	3.5
FA35		175	325	175	1088	586.6	3.0

Control: Plain concrete mixture containing high-alkali cement. FA20 and FA35 = percentage of fly ash in concrete.

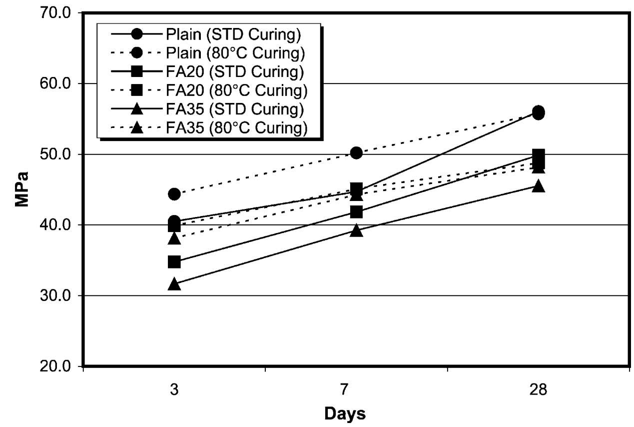


Fig. 6. Compressive strength of concrete moist-cured under two different conditions.

Acknowledgements

This study was jointly sponsored by Boral Material Technologies, ISG Resources, Reliant Energy, Williams Brothers, Fordyce Aggregates, Capitol Aggregates, and Alamo Cement. We wish to acknowledge their support, both financial and in kind.

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