Pergamon

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Cement and Concrete Research 33 (2003) 1539–1542

CEMENT AND CONCRETE RESEARCH

Use of ground clay brick as a pozzolanic material to reduce the alkali–silica reaction

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Received 6 December 2001; accepted 24 March 2003

Abstract

The objective of this experimental study was to use ground clay brick (GCB) as a pozzolanic material to minimize the alkali–silica reaction expansion. Two different types of clay bricks were finely ground and their activity indices were determined. ASTM accelerated mortar bar tests were performed to investigate the effect of GCB when used to replace cement mass. The microstructure of the mortar was investigated using scanning electron microscopy (SEM). The results showed that the GCBs meet the strength activity requirements of ASTM. In addition, the GCBs were found to be effective in suppressing the alkali–silica reaction expansion. The expansion decreased as the amount of GCBs in the mortar increased.

Keywords: Ground clay brick; Alkali–aggregate reaction; Pozzolan

1. Introduction

The use of pozzolanic materials such as fly ash, silica fume, slag, rice husk ash, and natural pozzolans is an effective way to control deleterious alkali–silica reaction. Effectiveness of the pozzolanic materials in suppressing the alkali–silica reaction is attributed to refined pore structure thus reducing ionic mobility, consumption of calcium hydroxide, and entrapment of alkalis in silica rich hydration products.

It is possible to obtain pozzolanic materials when clays are thermally treated. By heat treatment, the crystal structure of the clay minerals is destroyed and an amorphous or disordered alumino silicate structure is formed, developing pozzolanic property [1]. Thermally treated kaolinite clays have shown good performance in suppressing the expansion caused by the alkali–silica reaction [2–5].

Clayey soil is widely used as raw material in brick production. Firing is the essential process to produce structural bricks. In a previous study, it was shown that the optimum clay firing temperature to give maximum pozzolanic activity is around 1000 °C, which is the approximate firing temperature for brick production [6]. Thus, it is possible to obtain a pozzolanic material when clay bricks are ground to adequate fineness. It was found that ground clay brick (GCB) not only refines the pore structure but also increases the resistance to various chemical attacks [3–10].

The present study aims to evaluate the effect of GCB on the alkali–silica reaction when used to partially replace cement. Microstructural studies were also carried out on polished sections using scanning electron microscopy (SEM) equipped with energy disperse X-ray (EDX).

2. Materials

The cement used in the study was an ASTM Type I cement having moderate alkali content. The physical and the chemical properties of the cement are given in Table 1. Two types of bricks were pulverized: bricks for slabs (SB) and for wall construction (WB). The main difference in manufacturing process of SB and WB is the firing temperature; 800–900 °C for the wall brick and 1000–1100 °C for the slab brick. Since energy requirement constitutes 40% of the total cost, WB has a higher cost of approximately 70% per kg.

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0008-8846/03/$ – see front matter
doi:10.1016/S0008-8846(03)00101-7

Table 1
Physical and chemical properties of the cement and the ground bricks

	Cement	SB	WB
Specific gravity (g/cm^3)	3.12	2.70	2.67
Blaine fineness (cm^2/g)	3421	4260	5059
Chemical analysis (%)			
SiO_2	21.33	66.94	64.54
Al_2O_3	4.99	16.28	16.88
Fe_2O_3	3.65	5.44	6.62
CaO	62.48	4.92	4.24
SO_3	2.60	0.21	0.46
MgO	1.16	3.00	2.73
Na_2O	0.38	1.82	1.03
K_2O	0.65	2.65	2.41
Na_2O_{eq}	0.81	3.56	2.62
LOI[a]	2.70	0.86	1.80

[a] Loss on ignition.

The bricks were reduced by an impact crusher. Then, the particles retained on #20 sieve were discarded in order to get a homogenous batch for the pulverization. The particles passing #20 sieve were ground in a ball mill for 60 min. Weight ratio of the brick to the steel balls was 1:7. The physical and the chemical properties of GCBs are given in Table 1.

In the alkali–silica reaction tests, river aggregate with known alkali–silica reactivity was used. Petrographical results showed that the aggregate was made up of moderate to well-rounded mineral and rock grains that range between 0.2 and 2 mm in size. The aggregate contained 2% serpentine, 3% pyroxene, 5% calcite, 1% hornblende (green prismatic actinolites), 1% opaque minerals, 4% aragonite as mineral grains, and 10% sandstone with quartz, 19% granite with fresh quartz, 8% andesite, 11% limestone, 8% quartz-mica schist with strained quartz, 22% basalt, 3% radiolarite, 2% opal as rock fragments. Opal, radiolarite, and strained quartz were the main constituents causing the expansive alkali–silica reaction.

3. Experimental work

The strength activity indices of the ground bricks were determined in accordance with ASTM C311 for 7 and 28 days. A control batch was prepared with standard sand and cement alone. Two additional batches, in which 20% of the cement mass was replaced by SB and WB, respectively, were also prepared. For each batch, six cubes of 5 cm were

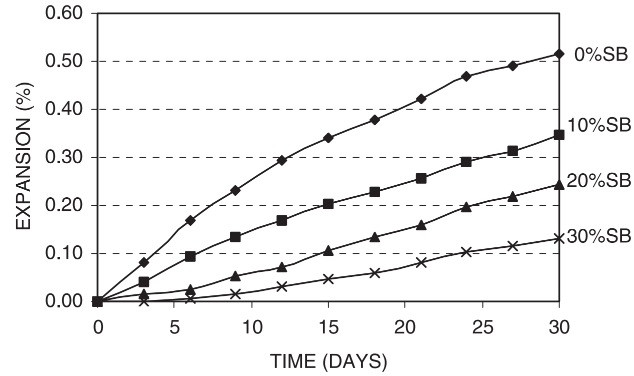

Fig. 1. Expansion curves of the specimens containing various amounts of SB.

cast in accordance with ASTM C109. Then, compressive strengths were determined at 7 and 28 days for each batch as the average of three cubes.

In the next step of the experimental program, mortar bars were cast in accordance with ASTM C1260 except that the water binder ratio was 0.50 in order to obtain sufficient workability. Seven sets, each containing three mortar bars, were prepared. First set was the control sample with no GCB addition. In the remaining six sets, the cement was partially replaced by SB and WB individually in quantities of 10%, 20%, and 30%. The mortar bars were demoulded after 24 h and cured in water at 80 °C for another 24 h. After initial reading of the lengths, the mortar bars were immersed in 1 N NaOH solution at 80 °C. The expansions of the mortar bars were recorded up to 30 days.

Representative samples were cut from the control specimen and the specimens containing the maximum amounts (30%) of each GCB type. The samples were impregnated with epoxy resin. The surfaces of the samples were polished and coated with gold. The micro observations were done by means of SEM with secondary electron images and semi-quantitative chemical analyses were performed with EDX.

4. Results and discussion

4.1. Strength activity index test

Compressive strength values of GCBs and the control specimen at 7 and 28 days are given in Table 2. Strength activity indices of the two GCBs, both at 7 and 28 days, met

Table 2
Results of the strength activity index test

	Compressive strengths (MPa)		Strength activity index (%)		Water requirement (%)
	7 days	28 days	7 days	28 days	
Control	42.7	53.8	–	–	–
SB	34.5	46.4	81	86	103
WB	32.0	41.7	75	78	106

Table 3
Expansions of the mortar bars

Replacement (%)	0		10		20		30	
Age (days)	14	30	14	30	14	30	14	30
Expansion (%)								
SB	0.33	0.52	0.19	0.35	0.10	0.24	0.04	0.13
WB	0.33	0.52	0.21	0.36	0.10	0.23	0.06	0.16

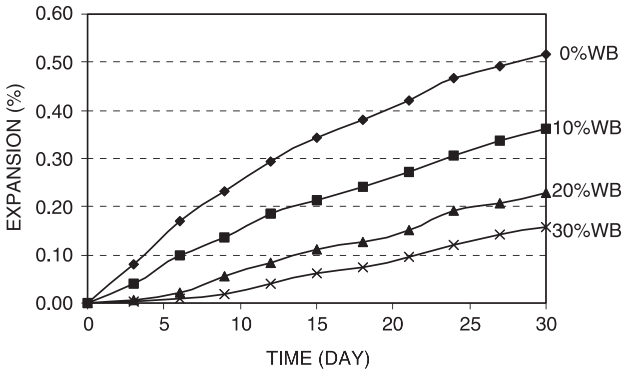

Fig. 2. Expansion curves of the specimens containing various amounts of WB.

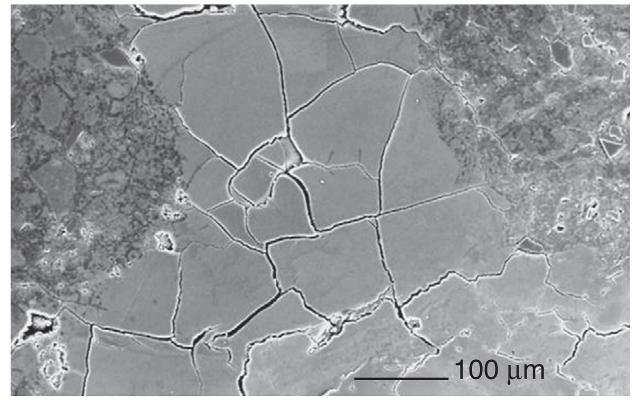

Fig. 4. Drying shrinkage cracks on massive alkali–silica gel.

the 75% limit proposed by ASTM C618 (Table 2). It is apparent from the table that SB is better than WB. Probably, this is due to differences in mineralogy of the raw material. Wild et al. [10] established that the glass content of the ground brick is the most important factor influencing strength development in ground brick mortars. It is worth to note that strength activity indices of both GCBs were improved at 28 days. This shows that formation of pozzolanic C-S-H increases at later ages.

Water requirement for natural pozzolans and calcined clays is limited to 115% in ASTM C618. The water requirements for the ground bricks, 103% and 106% for SB and WB, respectively, met the criterion.

4.2. Accelerated mortar bar test

Fig. 1 shows the expansion curves of the mortar bars containing 0%, 10%, 20%, and 30% SB as replacement of the cement mass. It is obvious from the graph that as the amount of SB increased, the expansion decreased. Expansion values at 14 and 30 days are given in Table 3. The values at 14 days were calculated by linear interpolation. At 14 days, the average expansion of the control bars was 0.33%, which is above the safe limit proposed by ASTM C1260. However, the expansion was kept at 0.04% with 30% SB addition, which means 88% reduction in expansion. Similarly, 75% reduction in expansion was achieved at 30 days.

The expansion curves of the mortar bars containing 0%, 10%, 20%, and 30% WB are given in Fig. 2 and the expansion values are given in Table 2, in which 14 day values were calculated by linear interpolation. Similar to SB, the expansion caused by the alkali–silica reaction decreased as WB content of the mortar increased. The highest reduction with WB was achieved at 30% replacement level. The expansion was 0.06% at 14 days and 0.16% at 30 days. As compared to the control sample, the expansion decreases were 82% and 69% at 14 and 30 days, respectively.

The performances of two GCBs were nearly the same except at 30% replacement level where the SB was marginally better than WB. However, the values are close to each other that retesting for this level may be useful to understand the behavior. For both GCB, there was a delay in the start of the expansion. However, it is obvious that the expansion rate increased at later ages with a decrease in the effectiveness of the material. Wild et al. [6] observed that ground brick mortars exposed to sulfate attack only start to expand when the reaction products fill up the available pore space. Similarly, the delay of ASR expansion, observed in the present work, can also be attributed to the initial filling up of the pore space.

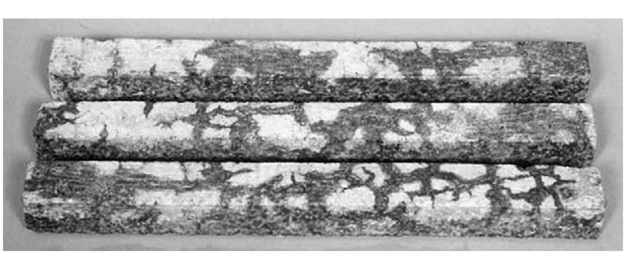

Fig. 3. Map cracks on the surface of the control specimens.

Fig. 5. Crystallized products having rosette morphology.

4.3. Microstructural study

At the end of the testing period, bending and cracking of the control bars could be observed by visual inspection. There were cracks at the surface running through the whole length of the specimens (Fig. 3). Typical map cracking caused by the alkali–silica reaction was monitored by visual inspection. In addition, there were cavities at the surface from which some parts were spalled off due expansive forces of the reaction. Similar observations were done at the specimens containing GCBs. The degree of cracking was low compared to that of the control specimens.

The microstructure of the mortars and the morphology of the alkali–silica gel were studied by SEM. Observations of the control sample revealed the severe internal cracking. The cracks were generally interconnected, covering the sample surface. Expectably, inner deterioration of the samples containing GCBs was not high. Unlike the control sample, discrete cracking, which was generally localised around the reaction sites, was abundant in the samples containing GCBs. The alkali–silica reaction gel was identifiable in the pores close to the reactive aggregates. The gel not only accumulated in the pores but also diffused in to the cement matrix through the cracks. The amount of gel monitored in GCB samples was less compared to that of the control sample. The gel was generally present in massive form and there were large drying cracks on the surface (Fig. 4). Calcium-rich crystallised products of the alkali–silica reaction gel having rosette morphology were also observed (Fig. 5).

5. Conclusion

The experimental study showed that as a pozzolanic material, GCB has the potential, when used to partially replace the cement, to suppress expansion due to the alkali–silica reaction. The results are in good agreement with previous work on ground brick mortar and on other pozzolanic materials, in that as the level of GCB replacement increases, the expansion decreases.

References

[1] V.S. Ramachandran (Ed.), Concrete Admixtures Handbook, Properties, Science, and Technology, 2nd ed., Noyes Publications, New Jersey, USA, 1995.

[2] T. Ramlochan, M. Thomas, K.A. Gruber, The effect of metakaolin on alkali–silica reaction, Cem. Concr. Res. 30 (2000) 339–344.

[3] G.V. Waters, T.R. Jones, Effect of metakaolin on ASR in concrete manufactured with reactive aggregates, in: V.M. Malhotra (Ed.), Proceedings of the 2nd International Conference on the Durability of Concrete, Am. Concr. Inst., vol. 2, 1992, pp. 941–947.

[4] T. Jones, G.V. Walters, J.A. Kostuch, A role of metakaolin in suppressing ASR in concrete exposed to saturated NaCl solution, Proceedings of the 9th International Conference on Alkali–Aggregate Reaction in Concrete, Vol. 1, The Concrete Society, Slough, London, 1992, pp. 485–496.

[5] J.A. Kostuch, V. Walters, T.R. Jones, High performance concretes incorporating metakaolin: A review, in: R.K. Dhir, M.R. Jones (Eds.), Concrete 2000, Vol. 2, E&FN Spon, London, 1993, pp. 1799–1811.

[6] S. Wild, J.M. Khatib, M. O'Farrell, Sulphate resistance of mortar, containing ground brick clay calcined at different temperatures, Cem. Concr. Res. 27 (5) (1997) 697–709.

[7] M. O'Farrell, S. Wild, B.B. Sabir, Pore size distribution and compressive strength of waste clay brick mortar, Cem. Concr. Compos. 23 (2001) 81–91.

[8] M. O'Farrell, S. Wild, B.B. Sabir, Resistance to chemical attack of ground brick-PC mortar Part I. Sodium sulphate solution, Cem. Concr. Res. 29 (1999) 1781–1790.

[9] M. O'Farrell, S. Wild, B.B. Sabir, Resistance to chemical attack of ground brick-PC mortar Part II. Synthetic seawater, Cem. Concr. Res. 30 (2000) 757–767.

[10] S. Wild, A. Gailius, H. Hansen, J. Szwabowski, Waste clay brick—A European study of its effectiveness as a cement replacement material, in: T.G. Jappy (Ed.), Int. Congr. Creating with Concrete, Thomas Telford, 1999, Theme 2: Alternative options.