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Use of Ground Clay Bricks to Suppress Deterioration due to Potassium-Acetate Deicer

Fatih Bektas[1] and Kejin Wang[2]

[1]*RFM 424, Texas State University, San Marcos, Texas, USA 78666. E-mail: <fbektas@txstate.edu>*
[2]*492 Town Engineering, Iowa State University, Ames, Iowa, USA 50011. E-mail: <kejinw@iastate.edu>*

ABSTRACT

A recent survey including 100 airports in the US showed that potassium acetate based deicers are widely used for snow and ice control of airfield pavements. There are concerns with the use of these deicers on concrete pavements since they appear to promote and/or accelerate alkali-silica reaction (ASR). The deterioration mechanism is not fully known yet. This study aims to investigate the effectiveness of ground recycled/reclaimed clay brick to control the deterioration in concrete exposed to potassium acetate deicers. Performance of ground clay brick in comparison with fly ash was evaluated. Mortar specimens with and without pozzolan were prepared: cement mass replacement up to 25% was employed. The specimens were stored in a commercial potassium acetate deicer solution at 80^{o}C and tested for length change (expansion), compressive and flexural strengths. The results showed that the ground clay brick, when used as cement replacement, has potential to control the potassium-acetate based deterioration.

INTRODUCTION

Sodium chloride and calcium chloride have been effectively used as an economical solution to fight against snow and ice on highways. However, these salts are known to lead durability problems on concrete bridge decks and pavements (e.g., corrosion) and draw criticism as not being environmental friendly. There had been a search for alternate deicers and in early 1990s new formulations based on alkali acetate and alkali formate (e.g., potassium acetate, sodium acetate, sodium formate, calcium magnesium acetate) have been introduced to the service. Among these deicers, potassium acetate based solutions have gained popularity. A recent survey including 100 airports in the US showed that potassium acetate and sand are the most widely used materials for snow and ice control of airfield pavements [ACRP 2008]. In addition to their effectiveness potassium acetate based deicers are known to be environmental friendly. Furthermore, potassium acetate deicers are more preferable in corrosion sensitive operations such as deicing of airfield runway and taxiway pavements. Due to their high deicing efficiency and low degree of damage to concrete material, these deicing chemicals are increasingly considered by transportation agencies too. For instance, potassium acetate based liquid anti-icers are being considered for fixed automated sprayed technology systems used on bridge decks. However, recently, there are concerns arising with the use of potassium acetate based deicers on concrete pavements. Recent investigation by the Federal

Aviation Administration (FAA) through the Innovative Pavements Research Foundation (IPRF) has demonstrated that the alkali-based deicing chemicals (e.g., potassium-acetate, sodium-acetate) promote and/or accelerate concrete deterioration in presence of certain aggregates. The deterioration appears associated with alkali-silica reaction (ASR), however, the mechanism has not been fully understood yet. In addition to well-known alkali-silica gel, secondary deleterious products which may cause deterioration have been identified [Rangaraju 2007].

Finely ground clay brick, which is obtained from recycled/reclaimed fired clay products, has proven to possess pozzolanic property and to suppress conventional ASR effectively [O'Farrell et al. 2001; Turanli et al. 2003]. This study aims to investigate the effectiveness of ground recycled/reclaimed clay brick in controlling the deterioration of concrete that is exposed to potassium acetate deicers. The ground clay brick was used as a cement mass replacement and its performance was evaluated in comparison with ASTM Class F and C fly ashes.

MATERIALS

A high-alkali ASTM Type I portland cement was used in the study. The chemical composition is given in Table 1. The clay brick used in the study was obtained from a local source that stated the material had been reclaimed from demolished masonry. The brick was reduced to pass 4.75-mm sieve (ASTM No. 4) and ground in a laboratory-type ball mill which utilizes steel balls as the grinding medium. The chemical composition of the finely ground brick is given in Table 1. Its specific gravity was 2.68 and fineness was $370 m^2/kg$ (Blaine). The 45-micron sieve (ASTM No. 325) residue was measured as 10.2%. One ASTM Class F fly ash and one Class C fly ash, whose chemical compositions are given in Table 1, are also used in the study. The fly ashes will be referred as F ash and C ash hereafter.

Alkali-reactive sand, which contains volcanic glass (4%) and chert (2%), was used in mortars. 14-day expansion of the sand according to ASTM 1260— Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method) is 0.87%. The mix proportion used in the study was identical as given in ASTM 1260. However, the aggregate gradation was not followed but used as in-place gradation.

Table 1. Chemical Composition of the Cementititous Materials

Chemical Composition (%)	Portland Cement	Ground Brick	Class F Ash	Class C Ash
CaO	62.5	0.81	3.78	24.27
SiO_2	20.19	69.90	45.05	35.27
Al_2O_3	5.57	15.38	23.71	19.28
Fe_2O_3	2.33	6.78	16.43	7.93
MgO	2.40	1.58	0.88	5.02
SO_3	4.4	0.04	0.68	2.29
K_2O	1.15	2.78	1.46	0.44
Na_2O	0.23	1.02	0.8	1.54
Loss on ignition	0.69	0.16	5.39	0.21

EXPERIMENTAL METHODS

The experimental program was carried out progressively, depending on the results of each stage, to investigate the effectiveness of different fly ashes as well as ground recycled/reclaimed clay brick in control of the deterioration of mortars exposed to potassium acetate deicers. Initially, 25×25×285 mm^3 mortar bars were cast employing a 25% cement mass replacement for each supplementary cementitious material (i.e., ground brick, F ash, and C ash). In addition, a control set with only portland cement was cast. After the results were obtained a 15% replacement level was also tested for ground brick and F ash. Three mortar bars were cast and cured according to ASTM C 1260 except that not sodium hydroxide but potassium acetate was used as curing solution. The bars were stored in a commercially available potassium acetate deicer (50% solution) at 80^{o}C and length change (expansion) was measured up to 56 days. In the next stage, employing the same mixture proportions, three 50-mm cubes and three 40×40×160 mm^3 prisms were prepared for compressive strength and flexural strength testing, respectively. Center point loading was applied for flexural testing. Two different curing regimes were applied—moist curing for 28 days and potassium acetate solution soaking at 80^{o}C for 14 days. The last stage includes casting of mini mortar slabs with a 100×150 mm^2 surface area and a 25mm depth. These slabs were subjected to a ponding test in which an approximately 5mm-deep potassium acetate solution was ponded on the surface. An impervious sealant was applied to form high sides to pond the solution (See Fig. 1). The specimens, then, were stored at 80^{o}C for 14 days. The surface was covered in order to limit evaporation.

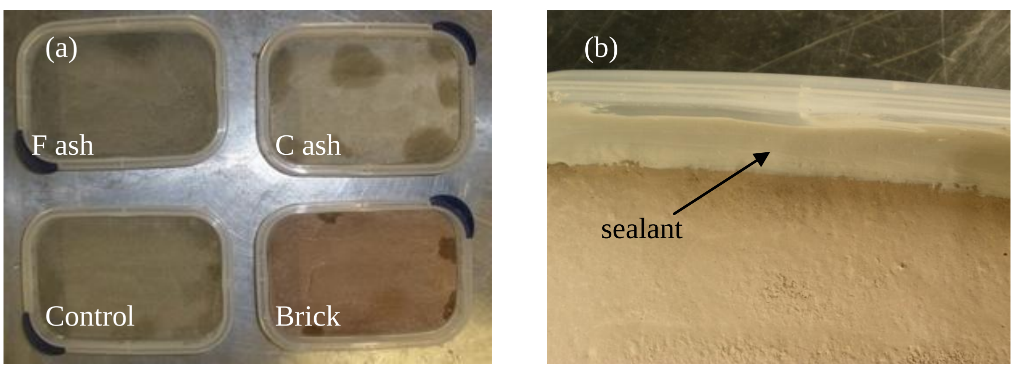

Fig. 1. (a) Mini Mortar Slabs for Potassium Acetate Ponding; (b) Sealant to Raise the Sides and Pond the Solution on the Surface

RESULTS AND DISCUSSION

Mortar Bar Expansion

The results of the mortar bar expansion test are plotted in Fig. 2. The first letter in mix designation indicates the type of supplementary cementitious material used—B is for ground clay brick, F for F ash and C for C ash. The following letter indicates the replacement level. Control-1260 belongs to the expansion curve for the control mix in 1N sodium hydroxide utilized by ASTM C1260. The data is taken from an unpublished study.

Visual examination of the mortar bars indicated the extensive cracking on the control bars and the bars containing 25% C ash. On the other hand, no surface cracking was observed in the bars containing 25% of either ground brick or F ash, even at 56 days.

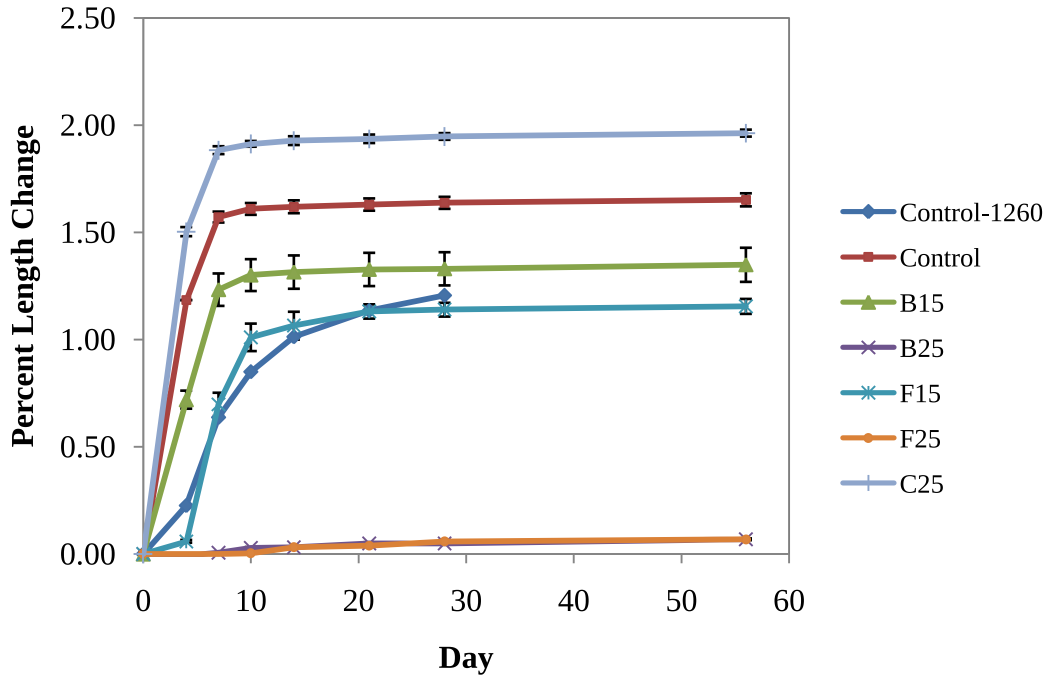

Fig. 2. Expansion of the Mortar Bars Stored in Potassium Acetate Solution

It is evident that the potassium acetate solution accelerates the ultimate expansion and also the rate of expansion when compared to 1N sodium hydroxide solution, which shows that the potassium acetate deicer could lead to severe concrete deterioration. It is highly probable that ASR has involvement in the potassium acetate deicer disruption. In the first stage of the study 25% replacement levels were tested and Fig. 2 demonstrates that the C ash exacerbates the expansion, mortar bars reaching higher expansions compared to the control. On the other hand, 25% ground clay brick and fly ash shows superior performance limiting the expansion at %0.03. Based on the 0.10% expansion limit which is the limit for innocuous mixtures in ASTM 1567— ASTM C 1567 Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method), 25% ground clay brick is sufficient to limit the deleterious expansion. In the next stage, a lower replacement level, namely 15%, was tested for the ground brick and the F ash. Although both of them have achieved lower expansions compared to the control, neither ground brick nor F ash could limit the expansion at 0.10%. Also note that, 15% F ash showed lower expansions compared to 15% ground brick.

Strength Tests

Mortar cubes and mortar prisms were used to determine compressive strength and flexural strength, respectively. A control set with only portland cement and 25% replacement of ground brick, F and C ashes were tested. As mentioned above, in addition to standard 28 days moist curing, potassium acetate soaking was also tested in order to evaluate the degree of deterioration on strength and the effect of ground brick. Tables 2 and 3 summarize the compressive strength and flexural strength results, respectively.

Table 2. Compressive Strength of Mortar Cubes

	Compressive Strength, MPa (Coefficient of Variation)	
	Moist Curing - 28 days	Potassium Acetate Immersion - 14 days
Control	51.6 (0.04)	18.8 (0.06)
B25	42.7 (0.02)	35.2 (0.10)
F25	48.8 (0.02)	41.1 (0.09)
C25	48.7 (0.01)	15.9 (0.02)

Table 3. Compressive Strength of Mortar Cubes

	Flexural Strength, MPa (Coefficient of Variation)	
	Moist Curing - 28 days	Potassium Acetate Immersion - 14 days
Control	6.5 (0.03)	1.1 (0.08)
B25	6.1 (0.08)	7.7 (0.04)
F25	6.5 (0.04)	7.6 (0.03)
C25	6.3 (0.05)	0.9 (0.07)

Strength test results are well aligned. The control and C ash mortar that were stored in the potassium acetate solution experienced significant strength reductions both in compression and flexure. The reduction in compressive strength is 64% and 67% for the control and the C ash specimens, respectively. Similarly, the reduction in flexural strength is 83% and 85% for the control and the C ash specimens, respectively. On the other hand, the ground brick and the F ash used in the study were successful to limit the strength loss in compression: the reductions are 18% and 16% for the ground clay brick and F ash incorporated mortar. The flexural strength of the ground brick and F ash specimens stored in the potassium solution showed an increase compared to moist curing specimens. This result is unexpected, however, the same phenomenon was observed in the study of Bektas et al. [2007], particularly for short period of exposures. The mechanism is unknown.

Potassium Acetate Ponding on Mini Mortar Slabs

The mini slab test was designed to simulate real/field conditions. Again 25% replacement level was used for the supplementary cementitious materials. Deicing application is topical in the field. It was anticipated that the cracking might not be severe if the specimen was subjected to the potassium acetate from the surface but not totally immersed in the solution. Fig. 3 shows the mini slabs after 14 days of ponding. No quantitative measurement was done. However, the visual observation confirmed the findings of the previous testing. The control and C ash experienced extensive cracking from top to bottom. The cracks on the surface were wider compared to the control. It was observed that the cracking started between 3 and 5 days for both slabs. On the other hand, at the end of the 14^{th} day, the ground brick slab was intact as the F ash slab was too.

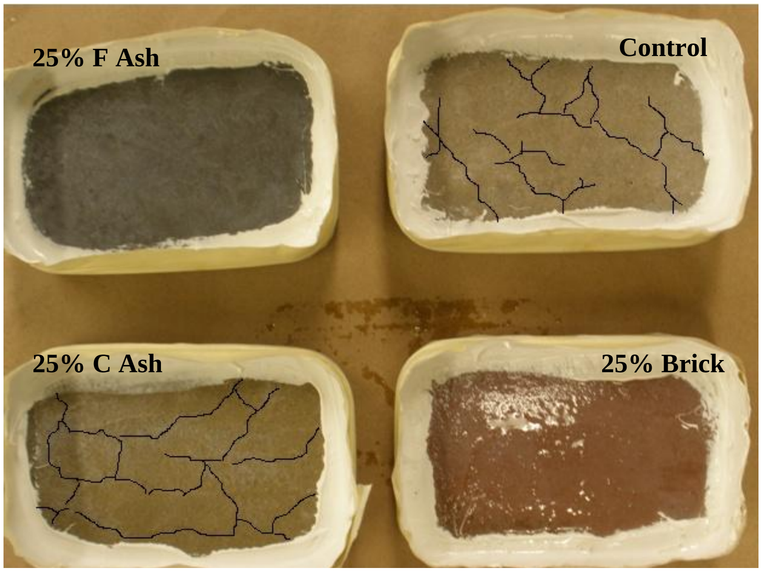

Fig. 3. Mini Mortar Slabs After Potassium Acetate Ponding.

Use of waste materials as a cementitious substitution for portland cement has been being practiced for almost 90 years. However, it is the last decade that the cement/concrete industry has been pressured to implement more sustainable and green approaches. Waste clay brick has potential to be used as a pozzolanic material in concrete. There is a significant amount of discarded/reject clay brick that do not confirm to the standards as being overburned, underburned or distorted: reject units could be as high as 15% of the total stock depending on the technology used in the brick manufacturing plant. A small portion of these reject products return to manufacturing process as raw material and some percentage is used for landscaping purposes. However, the majority remains unused or waste and is dumped landfills. Besides, demolished masonry may also generate significant amounts of waste clay brick. These materials could be recycled/reclaimed as a pozzolanic material in concrete. This study showed that the ground clay brick has potential to prevent or limit potassium acetate associated deterioration in concrete.

CONCLUSION

An experimental study was undertaken to investigate the effectiveness of ground clay brick in suppressing the deterioration due to potassium acetate deicer. Performance of ground clay brick was evaluated in comparison to ASTM Class F and C fly ashes. It was found that the expansion in mortar bars, strength loss in cubes and prisms, and surface cracking in slabs can be effectively limited if not eliminated using ground clay brick when used as portland cement replacement. Performance of the ground brick used in the study was superior to C ash and comparable to F ash.

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