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Use of perlite powder to suppress the alkali–silica reaction

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Abstract

Reported below are the results from a study aimed at mitigating the deleterious alkali–silica reaction by using perlite powder as an admixture. The expansion of mortar bars containing various amounts of silica fume (SF), expanded perlite, and natural perlite was studied. Two kinds of reactive aggregates were used in the study: highly reactive river aggregate containing opal and marginally reactive monzo-diorite aggregate. Expanded perlite and silica fume were tested with both aggregate, separately; on the other hand, natural perlite was tested only with monzo-diorite aggregate. The bars were cast in accordance with ASTM C1260, accelerated mortar bar method, and were stored in NaOH solution for 30 days. Length changes were measured and reported. The results showed that both expanded and natural perlite powder (NPP) have potential to suppress the deleterious alkali–silica expansion.

Keywords: Alkali-aggregate reaction; Mortar bars; Perlite powder

1. Introduction

Perlite, a hydrated volcanic glass, commonly has a pearly, vitreous luster characterized by concentric onion-skin fractures. A relatively high water content of 2% to 5% distinguishes perlite from other hydrous volcanic glasses, such as obsidian, hydrated volcanic ash, and pumicite. Upon rapid heating, perlite transforms into a cellular material of low bulk-density. As the chemical water held within the perlite boils, generally at temperatures in the range of 900–1100 °C, the resultant steam forms bubbles within the softened rock to produce a frothy-like structure. The formation of these bubbles allows perlite to expand up to 15–20 times of its original volume [1]. This new material is referred to as "expanded perlite" (commercially, the term perlite can denote either natural or expanded perlite). Because of its favorable physical and chemical characteristics, expanded perlite finds diverse utilization in various applications: for use as a lightweight aggregate in the construction industry; as a rooting medium and soil conditioner in horticulture; as a bleaching agent in the textile industry; as an adsorbent in the chemical industry; and as filter aid and as filler in miscellaneous processes [2].

Nearly 65% of the perlite produced today is consumed by the construction industry. Its lightness, thermal, and acoustic insulation properties make expanded perlite an excellent candidate to be used as lightweight aggregate in concrete production. For insulation purposes, expanded perlite powder (EPP) is utilized as filler material in hollow bricks or as an additive in plasters. Studies to date have generally focused on the lightness and insulation properties of expanded perlite.

This study examines the efficacy of perlite powder in suppressing alkali–silica expansion. The experimental program included the production of mortar bars incorporated with alkali-reactive aggregate and certain amounts of perlite powder (both expanded and natural) and silica fume (SF), and the determination of length changes of mortar bars immersed in alkaline solution.

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2. Materials

Two different reactive aggregates were used in the study: marginally reactive monzo-diorite aggregate containing 20% quartz as reactive constituent and river aggregate containing 2% highly reactive opal. Ordinary portland cement, corresponding to ASTM Type I, was used to construct the concrete specimens. Expanded perlite in a powdered form was purchased from Etibank General Administration which produces expanded perlite in Cumaovasi, Izmir. The natural perlite was purchased in 0.6–1.2 mm sieved sizes and then ground to mineral admixture fineness using a laboratory-type grinding mill. After 2 h of grinding with 70 kg steel cylinders, 10 kg material was fined to 330 kg/m^2 as measured with Blaine apparatus. Chemical compositions of the materials are given in Table 1.

3. Experimental procedure

The experimental program was conducted in two series of tests. In the first series, the mortar bars containing either silica fume (SF) or expanded perlite powder (EPP) were tested for alkali–silica reaction resistance. Preliminary studies had shown that as a cement replacement EPP could be used in small quantities due to its high water absorption capacity. SF, a well-known mineral admixture used to mitigate alkali–silica expansion, was chosen as a baseline for comparison purpose since it can be applied in similar ranges to EPP. In the second series, natural perlite powder (NPP) was tested for alkali–silica reaction resistance. In the experimental program, the mineral fines were added to mortar as mass replacement of the ordinary portland cement.

Mortar bars were cast in accordance with ASTM C1260 except that the water binder ratio utilized was 0.5. In addition, 2% solid plasticizer by weight of binder was used to provide adequate workability for the bars containing admixtures. For control purpose, mortar bars containing only ordinary portland cement were cast. The mineral admixtures, SF and EPP, were introduced into the mortars as cement mass replacement in quantities of 4%, 8%, 12%, and 16%. EPP and SF were tested both with the river aggregate and with the monzo-diorite separately. The bars were demoulded after 24 h, immersed in water bath at room temperature which gradually increased to 80 °C, then cured for another 24 h, their length measured, and then were immersed again into an 80 °C, 1 M NaOH solution. The mortar bars were measured every 3 days up to 30 days.

Table 1
Percent chemical composition of the fine materials

	OPC	EPP	NPP	SF
CaO	63.18	1.52	1.72	1.42
SiO_2	19.27	73.56	70.96	96.14
Al_2O_3	5.59	14.98	13.40	–
Fe_2O_3	2.52	1.06	1.16	–
MgO	2.77	0.37	0.28	1.05
SO_3	3.00	–	–	0.39
Na_2O	0.24	2.85	3.20	0.75
K_2O	1.10	4.90	4.65	0.65
Na_2O_{eq}	0.96	6.07	6.26	1.18
LoI[a]	1.59	1.59	3.27	1.51

[a] Loss on ignition.

In the second series of experiments, natural perlite was tested as mineral admixture to compare its performance with expanded perlite. NPP was tested only using monzo-diorite aggregate. Because of its low water requirement, probably due to reduced surface area compared to EPP, NPP was utilized relatively at higher levels of 8%, 16%, 24%, and 32%, and no plasticizing agent was used. Testing and length measurement procedures adopted were the same as in the first series of the experimental program.

4. Results and discussion

Fig. 1 shows the expansive behavior of the mortar bars made with reactive river aggregate and various amounts of SF. As expected, the control sample showed the highest expansion, with a decreasing trend in the expansion with increased SF content (except in the case of mortar bars containing 8% and 12% SF where the expansion rate was nearly the same). ASTM C1260 proposes a 0.10% expansion limit at 14 days for innocuous aggregates. In this experiment, only mortar bars containing 16% SF met this criterion; however, the expansion at 30 days was 0.25% for the same level.

Fig. 2 shows the expansion curves of the same river aggregate cast with EPP. Mortar bars containing 4% EPP did little to inhibit expansion; however, increasing levels decreased the expansion. Mortar bars containing 16% EPP performed very well, achieving expansions of 0.04% and 0.10% at 14 and 30 days, respectively. Comparing the performances of mortar bars containing SF and EPP demonstrates that mortar bars containing low replacement levels (4% and 8%) of SF mitigated expansion more successfully than mortar bars containing EPP; however, mortar bars containing higher replacement levels of EPP (12% and 16%) performed better than mortar bars containing similar levels of SF. It should be noted that 16% EPP satisfied the criteria of 0.10% even at 30 days.

Expansion curves of the mortar bars cast with monzo-diorite aggregate are given in Figs. 3 and 4 for SF and EPP, respectively. Expansion rates were almost identical for SF and EPP for all replacement levels. For both mineral admixtures, expansion decreased as the amount of replacement increased. At 30 days, the expansion was the same, being 0.08%, for both SF and EPP at 12% replacement level; and 0.07% and 0.05% for SF and EPP, respectively, at the 16% replacement level. Clearly, a 12% replacement level of either SF or EPP limited expansion at a very safe limit for the reactive monzo-diorite aggregate.

The effectiveness of SF in reducing alkali–silica expansion has been demonstrated by numerous researchers. The

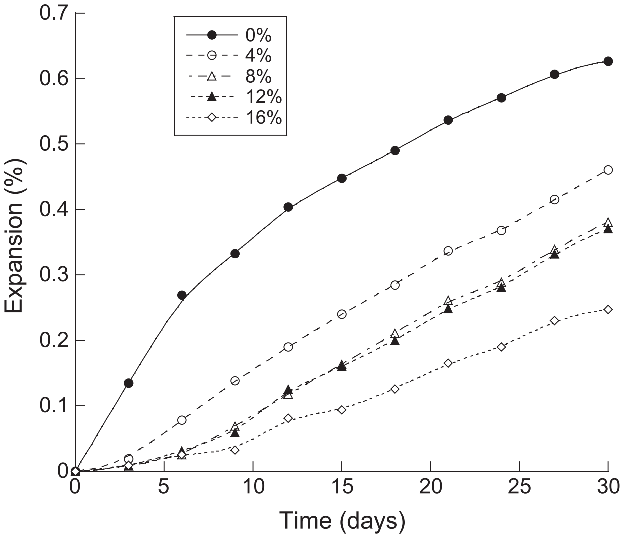

Fig. 1. Silica fume with river aggregate.

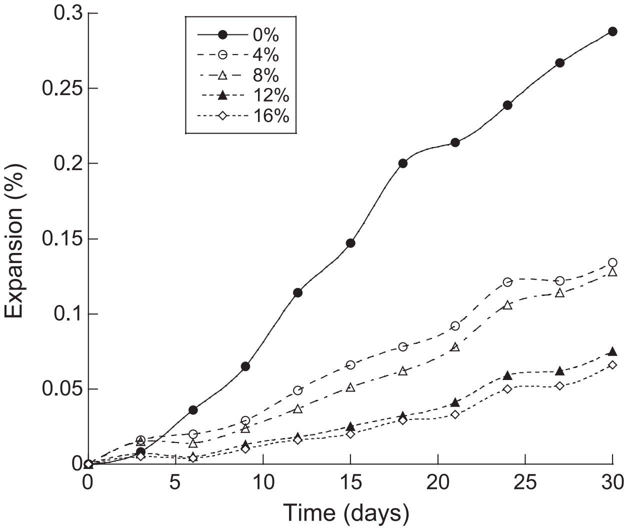

Fig. 3. Silica fume with monzo-diorite.

reduction is attributed to SF's high pozzolanic activity. The pozzolanic effect in suppressing the alkali–silica reaction is based on one or a combination of more than one of the following factors: consumption of calcium hydroxide, reduced ionic mobility due to refined pore structure, and/or binding of alkalis into pozzolanic calcium silicate hydrates. Similarly, the effectiveness of EPP in suppressing the deleterious alkali–silica reaction can be attributed to pozzolanic activity possessed by the material. It is known that the lightweight aggregate–cement interface is generally favored by a chemical interaction in the form of a pozzolanic reaction [11]. Urhan [4] postulated that the enhancement of bond strength between lightweight expanded perlite aggregate and cement matrix is due to the pozzolanic activity of perlite [3]. Recently, Demirboğa et al. [5] attributed the strength improvement of expanded perlite aggregate concrete to both the self-curing property and pozzolanicity of the perlite. This pozzolanicity may be due to the binding of alkalis onto perlite. Yilmaz and Yücel [6] produced synthetic silicate from perlite treated with NaOH. Similarly, Christidis et al. [7] reported zeolitisation of perlite fines upon NaOH treatment. Clearly, perlite is capable of sodium adsorption or possesses some alkali binding property that provides a basis for its pozzolanic activity.

Another possible explanation is that the highly porous nature of expanded perlite provides a closely distributed air bubble system that accommodates expansive alkali–silica gel in concrete. Previous researches demonstrated that air-entraining agents significantly reduce the expansion caused by alkali–silica reaction [7,8], i.e., alkali–silica gel fills the entrained air voids thus relieving potential pressure. Collins and Bareham [9] used porous aggregate, both natural and synthetic, to reduce disruptive expansion due to alkali–silica reaction. Reduction in expansion was based on gel entrapment in the voids and alkali ion dilution by water absorbed in the aggregate and/or by the aggregate itself being

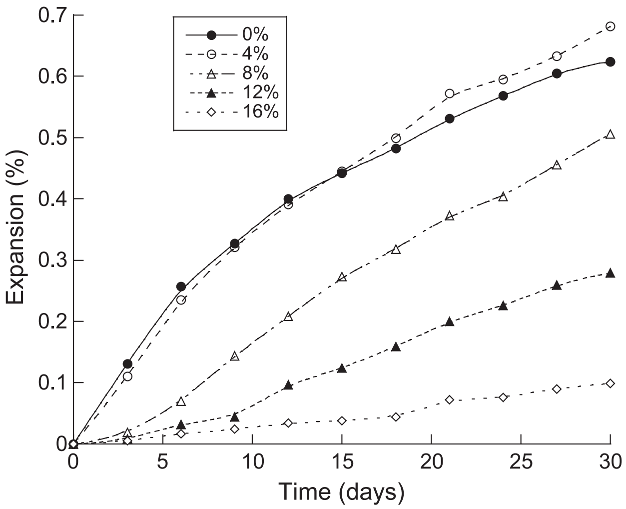

Fig. 2. Expanded perlite powder with river aggregate.

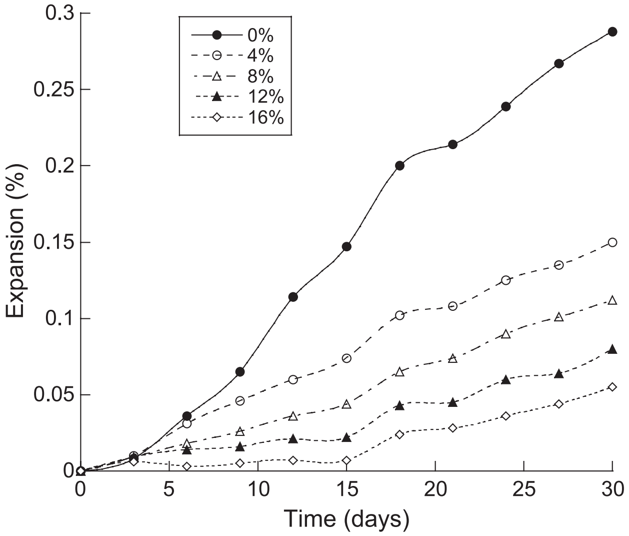

Fig. 4. Expanded perlite powder with monzo-diorite.

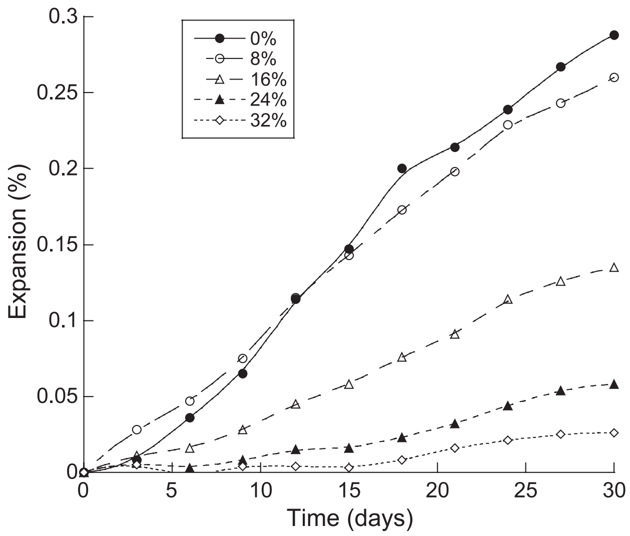

Fig. 5. Natural perlite powder with monzo-diorite.

susceptible to alkali–silica reaction. Ducman et al. [10] recently reported that a highly reactive, laboratory-produced lightweight aggregate did not cause expansion and related cracking in the mortar bars. This was attributed to the porous structure of the aggregate that accommodated the large amount of gel produced.

Expansion curves of the mortar bars cast with NPP and monzo-diorite aggregate are given in Fig. 5. Although 8% levels of NPP did not suppress the alkali–silica reaction, increasing amounts did achieve significant reduction in expansion. The expansion was almost eliminated with 32% replacement level. The mitigation achieved by NPP is attributed to its pozzolanic property. Its volcanic origin, hydrous nature, and high silica and alumina content support the assumption that natural perlite is highly pozzolanic in nature. This is also documented in a study by Yu et al. [10] who demonstrated that natural perlite has a significant pozzolanic effect and is an effective active mineral admixture when finely ground.

Based on the results of the above experiments, the levels of NPP needed to attenuate the alkali–silica reaction is on the same order as those values proposed for natural pozzolans (literature [12–14] suggests that 20–30% natural pozzolan replacement is satisfactory). Although 8% replacement levels of NPP did not significantly reduce expansion in the mortar bars, higher replacement levels reduced expansion dramatically. Mortar bars containing 24% and 32% NPP showed 30-day expansions of only 0.06% and 0.03%, respectively. A comparison between mortar bars containing EPP and NPP at a replacement level of 16% reveals that mortar bars with EPP performed better than mortar bars containing NPP. The expansion rates experienced at 30 days were 0.05% and 0.13% for EPP and NPP, respectively. As it is discussed before, the porous nature of EPP may play an important role in expansion reduction. In addition, increased surface area of EPP provides advantage over NPP in chemical reactions either pozzolanic or ion adsorbing. Perlite needs further study to fully understand its suppression mechanism of alkali–silica expansion.

5. Conclusions

The study shows that when incorporated into concrete mortar bars, perlite powder, in both its natural and expanded configuration, can effectively suppress expansion induced by alkali–silica reaction. Although both forms of perlite ameliorated the alkali–silica reaction through pozzolanic characteristics, expanded perlite was more effective. Relatively low levels of expanded perlite were needed to control deleterious expansion when compared to natural perlite. It is assumed that the effectiveness of expanded perlite is based both on pozzolanic activity and on the space provided for the gel accommodation due to its porous nature. Currently, there is no available data in the literature to compare the findings of this study, and further investigation is needed to determine the exact suppression mechanism.

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