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Use of binary and ternary cementitious blends of F-Class fly-ash and limestone powder to mitigate alkali-silica reaction risk

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HIGHLIGHTS

- The mortar containing the binary blends of 30% LSP was the best one among all binary and ternary blends on the suppression of ASR.
- The mortar containing the ternary blends of 20% FA/LSP became more effective than the use of binary blends of %20 FA and 20% LSP.

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ABSTRACT

The aim of this paper was to investigate the effects of binary and ternary cementitious systems including Portland Cement (PC), F-Class fly ash (FA) and limestone powder (LSP) to suppress expansion caused by alkali-silica reaction (ASR). Mortar prisms were prepared with potentially deleterious aggregates and tested by using Mortar-Bar Method according to ASTM C 1260. To evaluate the effect of FA and LSP on the suppression of ASR in mortar, ten different types of mortar were cast with combination of different dosages of FA and LSP as binary and ternary blend systems (partial replacement of PC) while the control mortar consisted of only PC as binder. Moreover, the Scanning Electron Microscopy (SEM) was carried out to interpret the microstructure. It was found that the reduction of ASR expansion rate due to increase in LSP content was more prominent compared to the increase of FA content in the binary blends system. Finally, the mixture containing ternary blends of 20% FA/LSP were in general more effective to mitigate the ASR risk for 14 days compared to all mortars.

1. Introduction

Alkali-silica reaction (ASR) occurs between the reactive amorphous silica existing in aggregates and alkalies (Na_2O, K_2O) in the pore solution. Alkali ions in the cement paste and mixing water dissolve into the pore solution and increases its hydroxyl ion concentration. The OH^- ions dissolve the amorphous silica and thus, alkali-silica gel forms [1]. In the development of reaction, the presence of moisture, type of cement, porosity of concrete and the presence of mineral additives play important role. The gel caused by ASR lead to expansion in concrete and, thus, it results in cracking of the concrete due to the tensile stress induced by the volume expansion. Therefore, the studies related with ASR must be taken into consideration in the aspect of both chemical and structural [2].

Many studies have been carried out to protect concrete from the expansion due to ASR and in accordance with this purpose, some strategies have been suggested. First one is to avoid the use of aggregates that consist of amorphous silica [3]. Second one is the application of low-alkali content of PC. According to ASTM C 150, the alkali content of PC must be equal or lower than %0.6 ($Na_2O + 0.658\ K_2O \le$ %0.6). Third way to mitigate the ASR expansion is to use mineral additive materials such as fly ash [4], silica fume [5], slag [6] and meta-kaolin [7]. The use of pozzolans is one of the most successful way to inhibit ASR expansion because of their advantages like decreasing the alkali content in concrete due to using as a replacement of PC, providing better alkali binding and higher strength because of increasing the formation of C-S-H gels and reducing the silica dissolution rate from aggregate [8]. Many studies have been carried out about the replacement of cement by pozzolans to control the expansion due to ASR. Thomas [9] found that the addition of F-Class FA as a replacement of 20–30% PC by weight, controlled the ASR at late ages. Also, it was reported that higher dosages of FA with high calcium content needed to limit the ASR expansion compared to FA including low calcium [10,11]. According to the study of Shehata et al. [12] in ternary

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blend of silica fume and fly ash with low calcium, at early ages, silica fume reduced the alkalinity while FA was very effective in the strength development of the hardened concrete at late ages. Moreover, it was stated that most fly ashes decreased the water demand of concrete and it increased ionic diffusion and fluid flow resistance. These beneficial effects of FA become visible in maturity of concrete which consists of especially low calcium FA [13] Besides, it was reported that the ternary blends of 3–5% silica fume and 20–30% fly ash with high calcium content showed satisfactory performance in limiting ASR expansion [14]. Hicks [15] used C-Class FA, high alkali content of PC and highly reactive aggregates in the study and the results showed that the use of C-Class FA over 35 percent was needed to mitigate ASR expansion. Chen and Yang [16] investigated the effect of LSP on the mitigation of ASR expansion. They found that LSP addition suppressed the ASR expansion of the mortar bar. However, the addition of 10% LSP was suggested as an optimum ratio to reduce the expansion regardless of water-cement ratios. Also, it was emphasized that the effects of 15% LSP or more replaced by cement on the expansion was so close to that of the use of 10% LSP at 14 days. According to the study of Gudissa and Dinku [17], the replacement of PC from 5% to 10% and 15% to 20% by weight with LSP satisfied the standard high early (42.5 N) and ordinary early compressive strength (32.5) of cement, respectively. Nevertheless, the use of 25%–30% LSP as a replace of PC caused lesser standard compressive strength (in 28 day).

The use of pozzolans in the mitigation of ASR expansion has already been proven by the previous researchers. In this study, besides using FA, by LSP addition, ASR was tried to be suppressed. Because, in the production of PC, LSP is used as a raw material. Due to its stable properties, the addition of LSP is supposed to inhibit the ASR. Thus, this study aimed to evaluate the effects of combinations of FA and LSP on controlling ASR expansion. To evaluate the potential of FA and LSP to suppress ASR expansion, the mortar prisms were prepared by using potentially deleterious aggregates. Moreover, SEM was also carried out to interpret the microstructure.

2. Expansion test methods for ASR

To measure the expansion rate caused by ASR, there are some applicable test methods which are suggested by ASTM C 1260 [18] and ASTM C 227 [19]. ASTM C 1260 has been used for potential reactivity of aggregates using mortar-bar samples while ASTM C 227 has been used for the potential alkali reactivity of a composite form including cement and aggregates. The measurement condition and expanding criteria are different for these two methods, however, there are also some similarities such as fixed amount of aggregates and 2.25 of sand-cement ratios. The samples are subjected to 1 N NaOH solution for 80 °C in terms of measurement condition in ASTM C 1260 while the measurement condition is 100% dependant moisture for 38 °C for ASTM C 227. In the view of expanding criteria, if 14-day expansion is bigger than 0.2%, it is accepted as harmful in ASTM C 1260 but ASTM C 227 limits 1-year expansion as 0.1%. Testing duration time of ASTM C 227 is too long and providing same test environment is compulsory. Therefore, ASTM C 1260 is more suitable due to being faster method.

In this study, ASTM C 1260 standard was used to investigate the effect of binary and ternary cementititous blends of FA and LSP on ASR as a most proper method. This test method determines whether the reactivity potential of aggregate used in concrete causes the harmful internal expansions because of ASR or not. This process is in general influential for aggregates that exhibit late expansion in ASR reaction. The content of alkali in cement for expansion is not a crucial factor because the samples have already been exposed to NaOH solution. If the potential reactivity of aggregates increase risk of ASR, some precautions can be taken such as using mineral additive materials and PC with low content of alkali as suggested by the standard. However, in this research, the use of PC with high alkali content (%1.06) caused to increase the expansion ratios.

In order to determine the potential reactivity of aggregate, three 25 g. portions of aggregate samples which were grinded in the range of 150–300 μm, were submerged into alkali solution (1 N sodium hydroxide) at 80 °C for a day. After 24 h, the filtration procedure had carried out and then the concentration of silica in NaOH solution filtered from the aggregate and the reduction of alkalinity were measured in conformity with ASTM C 289 [20]. According to the results, the concentration of silica and reduction in alkalinity were identified as 700 mmol/L and 350 mmol/L, respectively. It showed us that the aggregate was potentially detrimental in the aspect of alkali-aggregate reactivity as presented in Fig. 1.

3. Experimental methods

3.1. Materials

In the study, standard CEM II 32.5R high alkali (Na_2O + 0.658 K_2O = 1.06%) Portland Cement that was manufactured by LİMAK Şanlıurfa Çimento was used for all mixtures. As mineral admixture, F-Class FA and reactive LSP having approximately 150 μm grain diameter were added into the mixtures. The chemical properties of PC, FA and LSP were presented in Table 1. To prepare testing mortars, granulated aggregates having the potential reactivity were obtained from aggregate quarry of Gevye-Sakarya River in Turkey and the particle size distribution was prepared according to ASTM C 1260 as shown in Table 2.

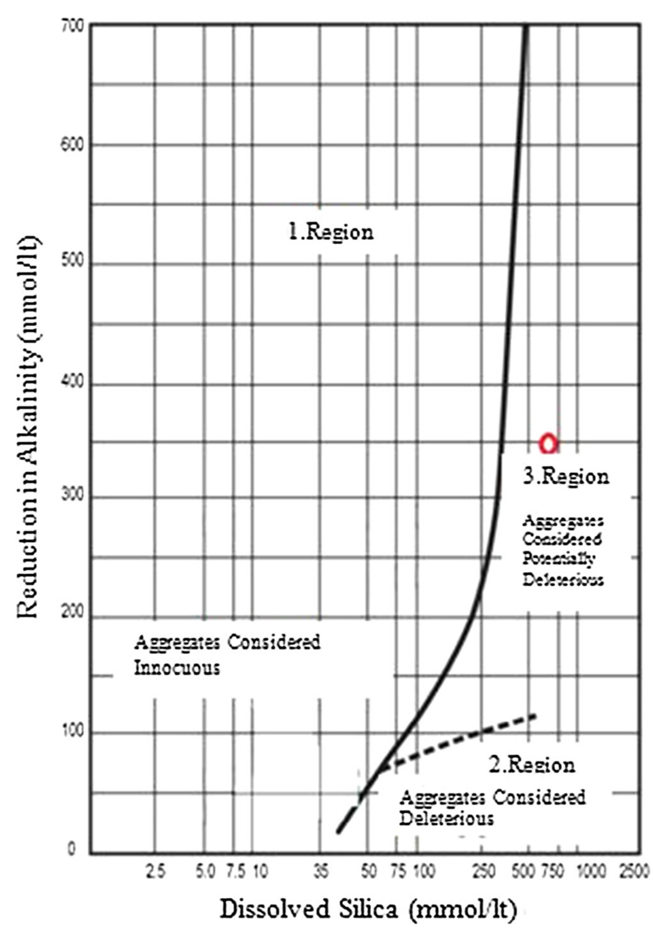

Fig. 1. Potential alkali-silica reactivity of aggregate.