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Improvement of the performance of alkali activated blast furnace slag mortars with very finely ground pumice

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HIGHLIGHTS

- Very finely ground pumice was added to AAS mortars at certain rates.
- The strength, durability and drying shrinkage of reference specimens were compared.
- Experimental tests, SEM and EDX were performed.
- Better durability values were obtained with the AAS + pumice samples.

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ABSTRACT

This work investigates the strength and durability of alkali activated blast furnace slag mortars (AAS) with very finely ground pumice (P) at certain rates. BFS was used instead of cement at the rate of 60% and 80%. Sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) alkalis were added as solution into the mixture. First stage Na_2O 6, 7 and 8 wt% of the BFS was added. Better results were obtained from the strength values of the sample containing 8% Na_2O. Because of this result, in the second stage, pumice was used instead of 5% and 10% of the BFS. However, silicate modules ($M_S = SiO_2/Na_2O$) in both experimental studies were calculated as 0.5, 0.75 and 1.00. The durability values of the AAS + P samples were better than those of the reference samples.

1. Introduction

The industrial manufacturing process of cements based on the alkaline activation of blast furnace slag (AAS) started in Ukraine between 1960 and 1964 [1]. In studies to date, fly ash, metakaolin, blast furnace slag, kaolinitic clays, rice husk, silica fume and red mud were used with AAS concretes. Cementitious materials, which focus on the development of binding systems and are based on compositions in the $MeO–Me_2O_3–SiO_2$ system, consist of the high calcium content minerals C_3S, C_2S, C_3A and C_4AF. These systems serve their purpose well but have some drawbacks. The synthesis of high CaO minerals involves large fuel and energy consumption. Because Portland cement and the concrete derived from it constitute the largest volume manufactured material in the world, it is a significant source of carbon dioxide. This is the result of the decarbonation of limestone in the kiln during manufacturing and the use of fossil fuel in the kiln.

$$5CaCO_3 + 2SiO_2 \rightarrow 3CaO \cdot SiO_2 + 5CO_2$$

The production of 1 ton of Portland cement accounts for 1 ton of CO_2 [2]. This slag produced from industrial by-products requires less production energy than ordinary Portland cement. Many valuable research results on this material have been reported. Alkali activated slag concrete (AASC) has been found to have some superior properties compared to ordinary Portland cement concrete (OPCC), namely, a high early strength and excellent durability in an aggressive environment (exposed to acid, sulfate or seawater). Many alkali activated slag properties have been explored [3–6]. For example, Collins and Sanjayan reported that micro cracks in AAS concrete increased from the lack of curing moisture. A survey of the published literature showed that this is new binder system has some serious problems such as rapid setting and high drying shrinkage [7–9]. Phosphoric and malic acid were used as retarders in previous studies [10,11].

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It was reported that the strength development of AASC depends on the type of activator and concretion. As a result, sodium silicate and sodium hydroxide were found to have the best strength development performance [12,13].

Collins and Sanjayan [14] examined the effects of internal curing of alkali-activated slag concrete (AAS) by replacing normal weight coarse aggregate (AAS-Basalt) with fully saturated blast furnace slag (AAS-BFS) coarse aggregate. After 7 days of exposure to 23 °C and 50% RH, AAS-BFS concrete shows significantly less drying shrinkage than AAS-Basalt. At ages beyond 1 day, under drying condition of 50% RH and 23 °C, AAS-BFS demonstrates higher compressive strength than AAS-Basalt and OPC-Basalt.

In the literature, there exist some studies in which pumice was used as porous aggregates. However, high water absorption of lightweight porous aggregates (pumice) causes decreasing of the AAS strength [15]. In the present study, drying shrinkage and durability of ASS mortars with pumice in case of very finely ground were investigated under sulfate conditions. Three different Na_2O rates were studied to obtain AAS mortars. Better results were obtained from the strength values of the sample containing 8% Na_2O. Very finely ground pumice was added to this rate at the percentages of 5% and 10% of the BFS. The flexural and compressive strength, durability and drying shrinkage values of the produced specimens were compared with reference specimens.

2. Experimental program

2.1. Materials

Pumice that occurs as a result of volcanic activity is a porous and lightweight material. Turkey has extensive deposits of pumice. One seventh of the pumice stone reserves in the world are in Turkey. Pumice is a light material, can float in water for a long time and has low permeability and high insulation characteristics. Silica content of up to 75% can be found in the chemical composition of pumice. The SiO_2 ratio contained in the rock gives them their abrasive property, and the Al_2O_3 composition makes it heat and fire resistant [16]. Pumice is divided into two groups, acidic and basic. Acidic pumice is common in nature. It is white or oyster white in color, whereas basic pumice is brown or black in color. Acidic pumice was used in this study. The most important reason for using pumice concrete is that it has a high pozzolanic activity. Pumice added to a cement mixture increases durability. If the amount of pumice in a mixture increases, the volume of the cement decreases.

Ground granulated blast furnace slag (GGBFS) has been used for many years as a supplementary cementitious material in concrete technology. The slag is a by-product material obtained from the manufacturing of pig iron in the blast furnace and is formed by a combination of the earthy constituents of iron ore with limestone flux. Granulated blast furnace slag, which contains a large amount of silica and alumina and has an amorphous structure, shows pozzolanic properties when it is ground to a very fine grain size. There are various uses of ground granulated blast furnace slag as a binding material, and it can be used as a mineral admixture in concrete production. Factors such as flexibility in the preparation of concrete mixtures makes it advantageous to grind granulated blast furnace slag separately when using it as a concrete admixture [17].

The alkaline activators sodium hydroxide and sodium silicate with $M_s = 0.5$, 0.75 and1.00 were used for this study. The amount of Na_2O was 8 wt% of the slag (BFS). Mortars with a binder:sand ratio of 1:3 and a water/binder ratio of 1:2 were used. Blast furnace slag (BFS) was used instead of cement at 60 wt% and 80 wt%. In the second stage, pumice was added instead of BFS 5 wt% and 10 wt%. Produced specimens were cured at 7, 28 and 90 days, and their flexural and strength values were examined (see Figs. 1–5).

The chemical composition of the slag and pumice used are tabulated in Table 1. Mortar specimen rates are also given in Tables 2–4 and 6.

2.2. Mortar preparation

AAS mortars, which were prepared with OPC, pumice and standard sand, were determined by Turkish standard (TS EN 196-1) [18].

Prismatic specimens (40 × 40 × 160 mm) from each mixture underwent a flexural strength test according to the Turkish standard. The specimens were loaded from their mid-span. The compressive strength tests were conducted following the flexural tests on the two broken pieces according to Turkish standard (TS EN 196-1) [18].

The compressive strengths of the specimens were measured after 7, 28 and 90 days, as specified in Turkish standard (TS EN 196-1) [18].

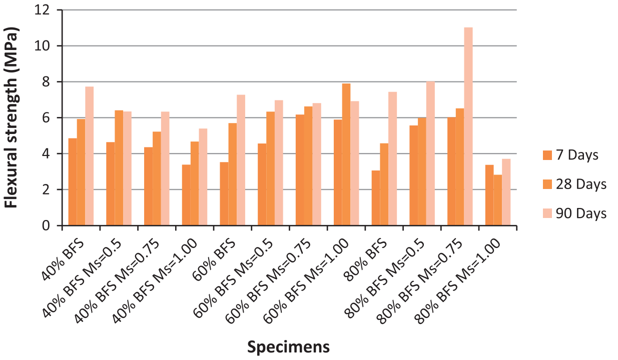

Fig. 1. A graph of the flexural strength of the 8% Na_2O content specimens at 7, 28 and 90 days.

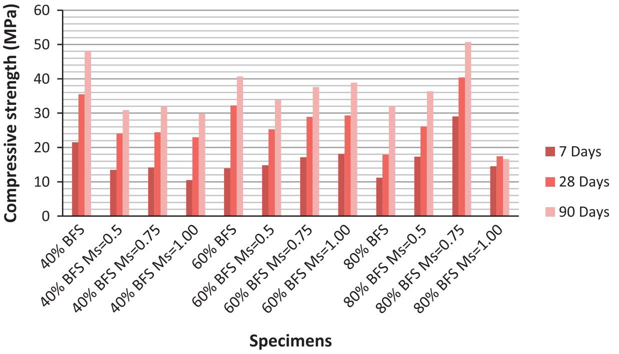

Fig. 2. A graph of the compressive strength of the 8% Na_2O content specimens at 7, 28 and 90 days.

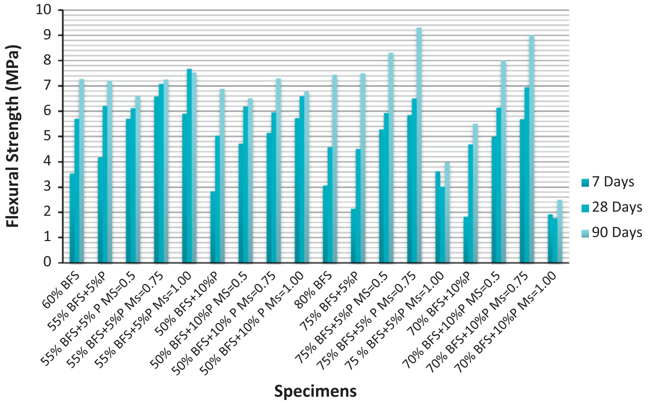

Fig. 3. A graph of the flexural strength of the AAS+P content specimens at 7, 28 and 90 days.

2.3. Methods

2.3.1. Durability test

The ASTM C1012 test method for the length change of hydraulic cement mortars exposed to a sulfate solution [19] was used as a basis for the mortar sulfate resistance test. After the AAS mortars were kept in a water bath for 28 days, the mortar specimens were immersed in two solutions containing approximately 10% Na_2SO_4 and 10% $MgSO_4$. The compressive strength was measured periodically for 90 and 180 days.

2.3.2. Water absorption

Water absorption was performed in accordance with ASTM C642 [20]. For the water absorption test, the cubes were first kept in an oven at 105 ± 5 °C for 24 h and weighed (W_d). They were then immersed in water for 24 h and weighed again (W_S). W_S was taken as the saturated weight. The water absorption (WA) was then calculated by the following formula. The results of this test were determined to be 20% of the water absorption rate of pumice.