



A method for improving the early strength of pumice concrete blocks by using alkyl alkoxy silane (AAS)

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ABSTRACT

In this study, the effects of coarse pumice aggregate (CPA) treatment with alkyl alkoxy silane (AAS) and direct addition of AAS as an admixture at different dosages on workability, water requirement, early strength development and water absorption of pumice concrete blocks have been investigated. The AAS treatment greatly enhanced the workability in an indirect way; the need for extra mixing water was significantly decreased. The performance of external silane addition was not as effective as in the case of surface treatment method. AAS treatment reduced the impregnation of water into the CPA and let the free water to increase the consistency as a lubricating agent between aggregates and paste matrix. Additionally, AAS treated CPA incorporating mixtures showed excellent behavior both in obtaining better workability and achieving higher early strengths compared to control mixture. The effectiveness of AAS surface treatment on reducing the water/cement ratio also causes an increase in ultimate strength of pumice concrete blocks. SEM micrographs and MIP analysis of AAS treated and untreated CPA incorporated concretes showed that, the matrix phase of AAS treated CPA incorporated pumice block was denser than untreated ones. Coarser porosity of matrix phase of untreated CPA can be attributed to the quick water absorption of CPA, which reduced the consistency of matrix to obtain sufficient compaction.

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1. Introduction

Lightweight concrete has been widely used in buildings as masonry blocks, wall panels, roof decks and precast concrete units. Reduction in weight by the use of lightweight aggregate concrete is preferred, especially for structures built in seismic zones. Lightweight concrete manufactured either from natural or from artificial aggregate is classified by the ACI Committee 213 into three categories according to its strength and density [1]. The first category is termed low strength, corresponding to low density and is mostly used for insulation purposes. The second category is moderate strength and is used for filling and block concrete. The third category is structural lightweight concrete and is used for reinforced concrete. Pumice concrete blocks, which are being manufactured and used in Interior Anatolian Region of Turkey, can be classified in second category. Pumice is principally an aluminosilicate of volcanic origin, which is produced from the rapid cooling of molten lava. It is a natural lightweight aggregate with a sponge-like structure and found in granulated form [2].

The positive benefits of incorporating pumice aggregate in cementitious composites from the viewpoint of insulation such as low density, low thermal conductivity were reported in detail by researchers [2–6]. Pumice aggregate concrete mixture design has special characteristics from the viewpoint of mixing water con-

tent. In general, the water/cement ratio of a mixture reported considering the aggregates as saturated surface dry. However, due to high water absorption capacity of pumice aggregates, the total mixing water requirement of pumice concrete mixture can be extremely high. This effect result with low early strengths. The loss of strength at early ages can be attributed to the high water demand of pumice aggregates due to their porosity. Highly porous aggregate structure may absorb a significant portion of mixing water which reduces the workability of fresh concrete to a great extent [6]. To avoid this, the aggregate can be pre-wetted and made saturated surface dry before casting of concrete. However, this process will also cause an increase in W/C ratio and results with strength loss and increase in the fresh density of concrete block.

Silane treatment or silane incorporation as an admixture can be alternative solutions of the above-mentioned problems related with water absorption of pumice aggregate. Silane treatment has been widely used for surface treatment of cementitious materials and served as a high performance hydrophobic surface preparation material [7]. The applications of silane mainly divided into two groups – surface treatment of ingredients with silane or – use as an admixture. Previous studies focused on surface treatment of silica fume, steel, carbon fibers with silane. The effects of silane treatment on strength and durability, and dimensional stability properties of cementitious composites have also been investigated [7–15].

In this study as another applications of silane, coarse pumice aggregate treatment and direct addition of silane as an admixture

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at different dosages have been studied. The effect of silane treatment or addition on workability, water requirement, early strength development, water absorption and pore structure of pumice blocks were investigated.

2. Experimental

2.1. Materials

An ordinary Portland cement (CEM I 42.5) conforming the EN 196-1 standard requirements was used throughout this research. The chemical composition, physical and mechanical properties of the cement are given in Table 1.

Pumice aggregates were supplied from a quarry in Nevşehir Region, Centre Anatolian of Turkey. The pumice aggregates in these regions are generally composed of amorphous silica and quartz [16,17]. The chemical composition and physical properties of pumice aggregate are given in Tables 2 and 3. Pumice aggregates obtained from the quarries were screened into 0–3 mm as fine pumice aggregate (FPA) and 3–7 mm size fractions as coarse pumice aggregate (CPA).

Alkyl alkoxy silane (AAS) was used in silane treatment and addition. It is a low viscosity colourless neutral water-based chemical, which is used for the water repellent impregnation of exterior mineral building materials. The specific gravity and solid content of the AAS solution were 1.03% and 2.5% by weight respectively. In this study, two different processes are used. In the first process, AAS used as an external admixture at different dosages blended with mixing water before the preparation of concrete. The second process is the surface treatment of CPA before the preparation of concrete mix. Surface treatment of oven dried CPA was performed by immersing them into the silane solution, heating to 75 °C while stirring and holding at 75 °C for 1 h. After this process, the CPA was dried in a furnace at 110 °C for 12 h. Due to high porosity and low particle density of CPAs; they tend to flow over the solution. For this reason immersion process was performed in a cage bucket, which provides full immersion of lightweight aggregates into the AAS solution. The time dependent water absorption of AAS treated and untreated coarse pumice aggregates in a bottle of water were illustrated in Fig. 1. After one week of waiting period, the amount of aggregates sunk into the water was significantly higher for untreated aggregates. There was a significant water absorption difference between the normal and treated CPAs. The water absorption values of both aggregates were measured in a 1 l container equipped with a cage that forces lightweight aggregates to sink under the water level. The water absorption data have been collected at 5, 10, 30 and 60 min respectively (Fig. 2). For each measurement, aggregates have been surface dried by using a towel.

2.2. Mixture proportions and testing procedure

Seven different mixtures were prepared by using the above mentioned silane treatment processes. The mix proportions of concretes are given in Table 4. The first mix is the "control mixture (C)" without any silane addition. Mixtures notated by CS contains silane treated CPA. CS-I incorporate the same amount of mixing water as of control mixture. On the other hand, 10% water reduction has been performed in the case of CS-II.

The silane added to fresh concrete mixture as an external admixture was blended with the same amount of mixing water as of control mixture and labeled with as "A" series. The addition amounts of silane into mixtures were 0.5%, 1%, 2% and 5% of cement by weight respectively. These mixtures have been labeled as A-0.5, A-1, A-2 and A-5 respectively.

Due to low W/C ratio of control mixture, the consistency of mixtures can be termed as dry and measured with Ve-be consistometer apparatus. Method-A described in ASTM C 1170 standard was used [18]. After the completion of Ve-be test, concrete mixtures were cast in cubic molds of 100 mm by compaction and vibration. Compaction was performed by using a wide field mallet. 25 compaction strokes have been performed at two levels. Three cubes have been prepared for each mixture. The Ve-be times and fresh unit weights of mixtures are presented

Table 1
The chemical composition, physical and mechanical properties of the cement.

Chemical composition (%)	Physical and mechanical properties		
CaO	64.01	Comp. str. 2 days (MPa)	23.8
SiO ₂	20.15	Comp. str. 7 days (MPa)	39.8
Al ₂ O ₃	5.95	Comp. str. 28 days (MPa)	48.5
Fe ₂ O ₃	2.57		
MgO	0.95	Specific gravity	3.12
Na ₂ O	0.25	Initial setting time (min.)	135
K ₂ O	0.84	Final setting time (min.)	185
SO ₃	2.63	Volume stability (mm)	2
Cl	0.011	Blaine value (m ² /kg)	3680
LOI	2.90	90 μm passing (%)	99.5
Free CaO	1.35	32 μm passing (%)	88.5

in Table 4. Samples were demolded 1 day after casting and cured at laboratory until the day of testing. The 1, 7 and 28 days compressive strength were determined. After 28 days, specimens were dried and capillary water absorption test was performed by immersing the specimen's base into constant water level. As the water absorbed by the specimen, additional water added into the system to maintain the constant immersion height of specimen. The increase in weight after a period of 24 h was measured.

The cracked particles of specimens after compression test of pumice concrete blocks were used in SEM analysis. It was realized that specimens prepared with AAS treated CPA; the cracking was occurred directly from aggregate. This may be due to the high strength of matrix phase of AAS treated CPA containing concrete blocks. However, the cracking of specimens with untreated pumice aggregate was usually near the surface of aggregate. This may be due to the low bond strength between untreated CPA and matrix with insufficient consistency. The samples were gold coated before SEM observation. The interfacial zones and matrix phase near the pumice coarse aggregates were observed.

In order to analyse and compare the micro porosity and pore size distribution of mortar phases of pumice blocks, mercury intrusion porosimetry (MIP) tests have been performed on three selected samples. The control mixture block (C) without any modification, block prepared with AAS pre-treated pumice aggregates (CS-II, 10% water reduced mixture) and block prepared with direct addition of 5% of silane into fresh mixture have been selected respectively. At least 10–15 mortar particles detached from the surface of these blocks have been used in MIP. The total volume of these samples was approximately 0.5–0.6 cm³. MIP analyses were performed with Quantachrome Poremaster 60 which generates pressure to 55,000 psi for pore size analysis from 10 μm to 0.004 μm pore diameter. The mercury porosimeter is based upon the physical principle that a non-reactive, non-wetting liquid will not penetrate fine pores until sufficient pressure is applied to force its entry. The relationship between the applied pressure and the pore diameter into which mercury will intrude can be calculated by the Washburn equation [17]. The surface tension of the mercury (480 dyn cm⁻¹) and θ is the contact angle between mercury and the pore wall, assumes as 140°. By increasing the external pressure, mercury successively invades pore-chamber volumes as an inverse function of their pore-throat radii [19]. It should be noted that mercury intrusion at high pressures may cause some modifications in pore structure [20].

3. Test results and discussion

Fig. 3 illustrates the relationship between fresh unit weight and Ve-be times of plain and externally AAS incorporated mixes (Group C–A) and mixes containing AAS treated CPA (Group CS). As can easily be seen from the figure, lower Ve-be times were obtained by using AAS treated CPA (even at lower W/C ratios) when compared with plain control mix. It can be concluded that AAS treated CPA incorporated mixes showed better performance when compared with control or external AAS incorporated mixtures from the viewpoint of consistency. For example while the Ve-be time of plain control mix (W/C = 0.34) was 32 s, Ve-be time of mix incorporating AAS treated CPA even at lower water content (W/C = 0.30) was only 11 s which can be accepted as more workable. This may be attributed to the hydrophobic nature of AAS treated CPA by the cover of silane molecules. Because the silane treatment greatly enhanced the workability in an indirect way, the need for extra mixing water was much decreased. In fact, a water-reduction as high as 10% was obtained when AAS treated CPA was used. The silane molecules on the surface of aggregates served as a lubricating agent at mixing stage. The performance of externally silane addition was not as effective as surface treatment of AAS. It may be due to the loss of mixing water when poured into the dry CPA incorporating mixture. In this case, the effectiveness of AAS reduced by absorption of CPA, which caused a consistency loss and increase the extra water requirement to compact the mixture.

Another important finding derived from Fig. 3 was the fresh compacted unit weight difference of mixes. Lighter pumice blocks with higher compressive strengths were obtained by using silane treated CPA (Fig. 4). AAS treatment reduced the impregnation of water into the CPA and let the free water to increase the consistency as a lubricating agent between aggregates. Again the lower performance of AAS in external addition is due to the high porosity and high initial absorption rate of untreated CPA. Fresh unit weights lower than 1250 kg/m³ can be obtained with 1-day compressive strengths up to 4.0 MPa. As a practical consideration, this

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