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Effect of prewetting methods on some fresh and hardened properties of concrete with pumice aggregate

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ABSTRACT

One of the major problems in lightweight aggregate concrete production is the high water absorption characteristic of the aggregates due to their porous structure. This problem is usually overcome by prewetting the lightweight aggregates or increasing the amount of mixing water. Since aggregate prewetting methods significantly affect fresh and hardened lightweight concrete properties, it is important to take this into account before the concrete production process.

This study is focused on the effects of three prewetting methods on some fresh and hardened properties of pumice lightweight concrete. Pre-soaking, water-soaking and vacuum-soaking methods were applied to pumice lightweight aggregate prior to mixing. Test results showed that fresh and hardened properties of concretes with vacuum-soaked and water-soaked lightweight aggregate were significantly better than that of concretes with pre-soaked lightweight aggregate. Vacuum-soaking and water-soaking of pumice aggregate improved workability, compressive strength and drying shrinkage of pumice lightweight concrete.

1. Introduction

Lightweight concrete (LWC) is usually defined as a concrete with an oven dry density of no greater than 2000 kg/m^3 [1]. However there are variations in certain parts of the world about the definition for LWC. For example, in the USA, LWC is defined as a concrete with an equilibrium density between 1440 and 1840 kg/m^3 [2]. In Japan, no density values are specified for LWC and properties are only provided for concrete made with lightweight coarse and fine aggregates [3]. In Europe, LWC is classified according to density and compressive strength [4]. According to RILEM/CEB, LWC is classified by its properties such as compressive strength, thermal conductivity and density as; structural, structural/insulating and insulating [3]. In ACI 213R [5], structural LWC is defined as a concrete with a minimum 28 day compressive strength of 17 MPa and an equilibrium density between 1120 and 1920 kg/m^3.

The history of the use of LWC for structural purposes dates from the earliest calcareous binders in Ancient Rome where volcanic rocks were used in lieu of regular dense aggregate to lighten the structural loads and the burden for those doing the work [6]. The use of LWC can be traced to as early as 3000 BC. In Europe, earlier use of LWC occurred about 2000 years ago when the Romans built the Pantheon, the aqueducts, and the Colosseum [7]. At present, LWC is widely used in buildings as masonry blocks, wall panels, lightweight floor fills, roof decks and precast concrete units [8,9].

The use of LWC reduces self-weight of structures, cross-sectional areas of structural elements, construction costs and also provides better thermal insulation [1,10–14]. The lightweight aggregate (LWA) itself and its gradation plays an important role in providing the necessary strength and density of hardened concrete and the workability of fresh concrete [8].

All aggregates, whether natural or artificial, absorb water at a rate which diminishes with time. Such absorption in aggregates is important because it may influence such properties of fresh concrete as workability, pumpability and density and also may affect such hardened properties as density, thermal insulation, fire resistance and freeze/thaw resistance [3].

Water absorption of the LWA is usually higher than that of normal aggregates. Due to the inner voids and light weight, LWA can easily absorb the mix water or float during the mixing and in both cases the workability of the mixture can deteriorate unless the LWA is adequately prewetted and the mixture is properly proportioned [15,16]. The high absorption of water by LWAs in the initial stages of mixing can also cause balling up of cement and loss of slump [9].

LWC characteristics depend on the aggregate water content prior to mixing. Excessive water content of the aggregates, if not taken into consideration in concrete production, will cause an increase in the amount of total water and thus may cause lack of adherence between the aggregate and mortar. On the other hand,

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low aggregate water content may cause the aggregate to absorb part of the mix water. Both cases may result in lower resistance characteristics than when the aggregates are moderately soaked prior to concrete preparation [9].

In ACI 213R it is indicated that the absorptive nature of the LWA requires prewetting to as uniform a moisture content as possible before adding the other ingredients of the concrete. It is also noted that prewetting minimizes the mixing water being absorbed by the aggregate, therefore minimizing the slump loss during pumping.

It is obvious that extra care should be paid in LWC production because of the porous structure and higher water absorption of the LWAs. This difficulty is usually overcome by prewetting or saturating the aggregates or increasing the amount of mixing water according to the LWA's water absorption ratio [15–20].

The aim of this research work was to determine the effects of LWA prewetting methods on some fresh and hardened LWC properties and in particular to compare a vacuum-soaking method with other methods generally used in LWC production. Thus, three prewetting methods were applied on LWAs; pre-soaking, water-soaking and vacuum-soaking. Cement dosage was 350 and 500 kg/m^3 and effective water to cement ratio was constant at 0.55. A total of six different concrete series were obtained. In each series, slump, vebe time and density were determined in fresh concrete; density, drying shrinkage and compressive strength were determined in hardened concrete.

2. Experimental study

2.1. Materials used in the research

The materials used in this research include pumice aggregate (PA) as lightweight aggregate, crushed stone sand, cement and chemical admixture. PA with a maximum particle size of 8 mm was obtained from Nevşehir, Turkey. Physical properties of PA are given in Table 1. Crushed stone sand with a maximum particle size of 2 mm was in saturated surface dry (SSD) conditions and its bulk unit weight and particle density were 1750 and 2670 kg/m^3, respectively. Particle size distribution of the aggregates is given in Table 2.

The cement used in all concretes was an ASTM Type I (42.5 MPa), from one source and is commercially available in all regions of Turkey. The chemical composition of the cement is given in Table 3. A commercially available naphthalene sulfonate-based superplasticizer was also used.

2.2. Prewetting of LWAs

PA was in as received conditions with a moisture content of about 2% and kept in the laboratory until the prewetting procedure. PA was prewetted by three different methods before mixing.

In the first method, pre-soaked water content of the PA was determined using the 1 h water absorption [21]. The PA was then placed in the mixer and the pre-soak water was sprayed on the PA and kept for 30 min. The PA was mixed three times for homogenization during this period and the batching procedure proceeded after this period. During the batching procedure and casting, PA was considered to continue to absorb mix water for another 30 min and thus completely absorb the determined pre-soak water. This type of concrete was coded by "P".

In the second method, PA was soaked in water for 24 h and concretes containing this type of PA were coded by "S".

In the third method, PA was vacuum-soaked [5] and this type of concrete was coded by "V". In this group, PA was placed in a 15 dm^3 transparent container made of plexiglas. The air in the container was evacuated and the pressure in the container was decreased to -650 ± 10 mm Hg by a vacuum pump. The container was then filled with water and returned to atmospheric pressure. PA was kept for 10 min in this condition [1].

Prior to mixing, the water-soaked and vacuum-soaked PA was spread on sieves to provide the evaporation of the excess water and to obtain surface dry conditions [22].

After the prewetting process, particle density of each group of PA was determined, as shown in Table 1.

Table 1
Physical properties of pumice aggregate.

Bulk unit weight (kg/m^3)	Particle density (kg/m^3)			Water absorption, % by dry weight	
	P	S	V	60 min	24 h
635	1510	1560	1650	12.0	16.0

Table 2
Particle size distribution of aggregates.

Sieve opening (mm)	Cumulative passing (%)	
	Pumice aggregate	Crushed stone sand
8	100	100
4	76	100
2	41	100
1	24	70
0.5	7	46
0.25	3	31

Table 3
Chemical, physical and mechanical properties of cement.

Chemical properties (%)		Physical properties	
Insoluble residue	–	Specific gravity (g/cm^3)	3.2
SiO_2	20.73	Unit weight (g/cm^3)	1.1
Al_2O_3	3.96	Setting time (start, min)	230
Fe_2O_3	3.98	Setting time (end, min)	336
CaO	64.38	Volume expansion (mm)	2
MgO	0.97	Specific surface (cm^2/g)	3006
SO_3	2.29		
K_2O	0.57		
Na_2O	–	Compressive strength	
Cl^-	–	28 days (MPa)	50.2
Loss of ignition	2.24		
CaO (free)	1.09		

2.3. Specimen preparation and curing

Six different concrete series with a constant aggregate gradation were prepared. Each concrete series consisted of two different cement dosages; 350 and 500 kg/m^3 and coded by 35 and 50, respectively. The mixture design is presented in Table 4. The mass of PA given in Table 4 is determined according to the prewetted conditions of the PA. Mixing was performed in a 45 l capacity pan mixer with a vertical rotation axis and fresh concrete properties were determined immediately after the mixing. After applying each prewetting method, the materials, adjusted in accordance with the mixture proportions were placed in the mixer and mixed in the following sequence:

Aggregates were added to the mixer and the mixer was started. After 1 min, half of the required water and superplasticizer was added. After 2 min, the cement was added simultaneously with the remainder of the water and superplasticizer. Mixing continued for three more minutes.

After the mixing procedure, for each mixture, three 150 × 150 × 150 mm cube and three 40 × 40 × 160 mm prism

Table 4
Mixture proportions.

Series	Pumice aggregate (kg/m^3)	Pre-soak water (kg/m^3)	Crushed stone sand (kg/m^3)	Cement (kg/m^3)	Water (kg/m^3)	Cement paste volume (m^3)	Total aggregate volume (m^3)	Super plasticizer (kg/m^3)
P35	856	87	270	350	192.5	0.302	0.668	7.7
P50	696	70	218	500	275	0.431	0.543	5.0
S35	874	–	270	350	192.5	0.302	0.661	5.6
S50	714	–	217	500	275	0.431	0.539	–
V35	930	–	271	350	192.5	0.302	0.665	5.6
V50	745	–	218	500	275	0.431	0.533	–

specimens were cast. Cube specimens were cured according to TS 3234 as follows. The specimens were demoulded 24 h after the production, water-cured for six days and then stored in laboratory conditions for eighteen days at an average temperature and relative humidity of 20 ± 5 °C and 55 ± 10%, respectively. The specimens were then dried in an oven at 60 ± 3 °C for three days and stored in laboratory conditions to cool to room temperature. After the curing procedure, compression tests were conducted in accordance with EN 12390-3. Drying shrinkage of each concrete mixture was determined on 40 × 40 × 160 mm prisms. These specimens were stored in laboratory conditions at 20 ± 5 °C and 55 ± 10% R.H for the shrinkage measurements.

2.4. Test procedure

The performance of the three prewetting methods applied on PA was evaluated by determining the following properties; workability, oven dry density, drying shrinkage and compressive strength.

2.4.1. Tests on fresh concrete

Workability of fresh concrete was determined immediately after the mixing by slump and vebe tests according to EN 12350-2 and EN 12350-3 respectively. In each concrete series, fresh density was also determined according to EN 12350-6. Table 5 summarizes the test results of fresh concrete.

2.4.2. Tests on hardened concrete

In each concrete series, density of hardened concrete was determined according to EN 12390-7, compression tests were applied on 150 mm cube specimens at 28 days and drying shrinkage of each concrete mixture was determined at 7, 28, 56, 91 and 189 days. Test results of hardened concrete properties are presented in Table 5.

3. Results and discussion

3.1. Workability

The slump and vebe time of the mixtures varied between 50–210 mm and 1–5 s respectively. As seen in Table 5, concrete mixes with water-soaked and vacuum-soaked PA had higher slump values than those of concretes with pre-soaked PA. The effect of PA prewetting on slump was more evident especially in concretes with 350 kg/m^3 cement dosage; the increase in slump was 100% and 160% in the conditions of using water-soaked and vacuum-soaked PA. Hossain [23] reported that the lighter the mix, the less is the slump. The results of this study also confirm this statement as slump values increased with an increase in cement paste volume and fresh density. Vebe time of concretes with water-soaked and vacuum-soaked PA was lower than those of concretes with pre-soaked PA. Among all series, P35 had the highest vebe time of 5 s and S50 and V50 had the lowest (1 s). According to the visual observations during concrete production, and the test results, we can say that prewetting PA whether by water-soaking or vacuum-soaking improved workability more than pre-soaking.

3.2. Fresh density

The fresh density of concrete mixtures with water-soaked and vacuum-soaked PA was higher than that with pre-soaked PA. Concretes with vacuum-soaked PA had the highest fresh densities of 1773 and 1826 kg/m^3 for 350 and 500 kg/m^3 cement dosages, respectively. The prewetting of aggregates either by water-soaking or vacuum-soaking increased the fresh density of the concrete. While the fresh densities of S35 and V35 were about 5.1% and 8.2% higher than P35, the fresh densities of S50 and V50 were about 4.9% and 7.4% higher than P50.

3.3. Oven dry density

The oven dry density of all mixtures increased with an increase in the cement paste volume. As explained by Şahin et al. [24], one reason for this is that the specific gravity of cement is higher than that of other ingredients. The other reason can be attributed to the higher workability obtained by a higher cement paste volume. Among all series, P35 had the lowest and V50 had the highest oven dry density of 1412 and 1593 kg/m^3, respectively. Different prewetting methods affected the concrete densities, especially of the series with 350 kg/m^3 cement dosage. The increase in density was about 8% in S35 and V35 when compared with P35. When we consider the mixtures with 500 kg/m^3 cement dosage, the densities of S50 and V50 were about 4% higher than that of P50.

3.4. Compressive strength

The results demonstrate that the more saturated the LWA, the higher was the strength. The concretes possessed 28 days compressive strengths of 21.0–29.4 MPa with a corresponding oven dry density of 1412–1593 kg/m^3 which falls within the requirements for structural LWC suggested by RILEM and ACI.

The compressive strength was significantly affected by aggregate prewetting methods especially in the mixtures with 350 kg/m^3 cement dosage. While the compressive strengths of S35 and V35 series were approximately 22% higher than that of P35, they were just 4% and 7% higher in S50 and V50 when compared with P50. The reason for this can be attributed to the lower PA volume content. For each cement dosage, the concrete series with vacuum-soaked PA had the highest compressive strength. Lo et al. [15,18] reported that prewetting of LWAs results in an increase in compressive strength. Considering the test results of this study, water-soaking and vacuum-soaking have improved compressive strength more than pre-soaking, especially in the series with 350 kg/m^3 cement dosage.

Fig. 1 shows the relationship between the oven dry density and the compressive strength of the concrete series at 28 days. It was clearly seen that the compressive strength increased with increasing

Table 5
Fresh and hardened concrete properties.

Series	Slump (mm)	Vebe time (s)	Aggregate prewetting time	Density (kg/m^3)		Compressive strength (MPa)	Drying shrinkage at 189 days (microstrain)
				Fresh	Oven dry		
P35	50	5	30 min	1638	1412	21.0	719
P50	170	2	30 min	1700	1527	27.6	794
S35	100	4	24 h	1722	1532	25.6	696
S50	210	1	24 h	1783	1590	28.6	740
V35	130	3	10 min	1773	1530	25.7	687
V50	210	1	10 min	1826	1593	29.4	729

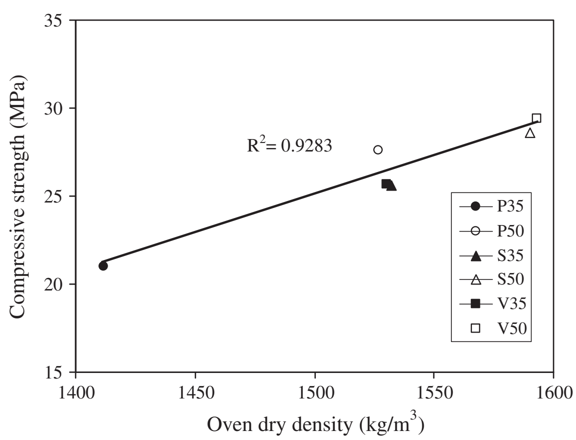

Fig. 1. Relationship between oven dry density and compressive strength.

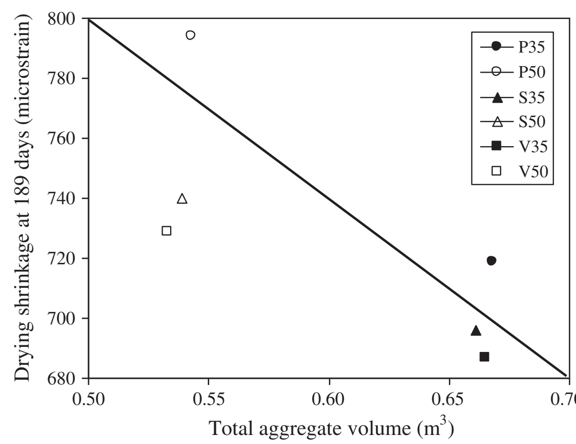

Fig. 3. Effect of total aggregate volume on drying shrinkage.

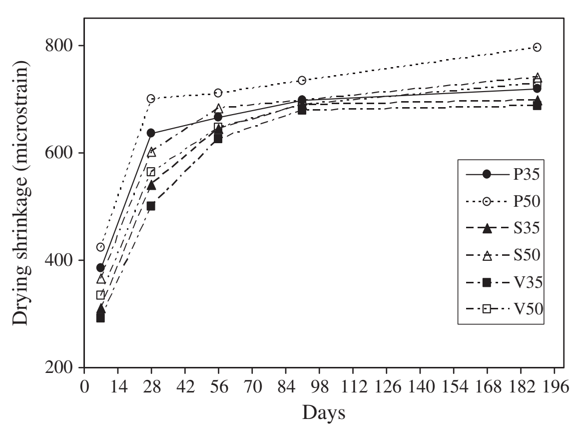

Fig. 2. Drying shrinkage of lightweight aggregate concrete.

concrete density. This is typical for LWC and is reported by several researchers [18,25].

3.5. Drying shrinkage

Drying shrinkage is a long lasting process that depends on several factors such as; water to cement ratio, degree of hydration, curing temperature, relative humidity, duration of drying, aggregate properties, type and amount of admixture and cement composition. Hossain [23] reported that aggregates with high absorption properties are associated with high shrinkage in concrete. Neville [26] indicated that LWA usually results in higher shrinkage values in concrete mainly because of the lower modulus of elasticity of the aggregate.

Fig. 2 shows the development of drying shrinkage of the concrete mixtures with drying time. The shrinkage rate is reduced gradually with elapsed time for all mixtures. As seen in Table 5, P50 possessed the highest shrinkage value of 794 microstrain at the age of 189 days. Concretes with water-soaked and vacuum-soaked PA showed less drying shrinkage values at all times when compared with concretes with pre-soaked aggregates. This might be due to the higher saturation conditions of the PA. It was reported that porous lightweight aggregates when used in saturated conditions can be used as water reservoirs for internal curing of concrete [17,27–29]. Thus, the lower drying shrinkage values of concretes with water-soaked and vacuum-soaked PA can be attributed to the better internal curing provided by more saturated aggregates. The increase in cement paste volume and thus the decrease in the total aggregate volume resulted in an increase in drying shrinkage of all mixtures (Fig. 3) while concretes with vacuum-soaked PA possessed the lowest shrinkage values for each cement dosage at 189 days.

4. Conclusions

Based on the test results of this study, the following conclusions may be drawn:

(1) Prewetting of lightweight aggregates prior to mixing had an important effect on workability. Workability of the concretes with water-soaked and vacuum-soaked pumice aggregate was found to be higher than that of concretes with pre-soaked (30 min) pumice aggregate.
(2) The highest compressive strengths at 28 days were 25.7 and 29.4 MPa in concretes with vacuum-soaked pumice aggregate for 350 and 500 kg/m^3 cement dosages respectively.
(3) Although fresh and hardened properties of concretes with water-soaked and vacuum-soaked pumice aggregate were similar for 500 kg/m^3 cement dosage, vacuum-soaking had the advantage of a shorter application time of 10 min. On

the other hand, it should also be taken into consideration that vacuum-soaking of aggregates will increase both the labor load and cost of the construction.

(4) Drying shrinkage of concretes with pre-soaked pumice aggregate had the highest values at the age of 189 days. However, concretes with water-soaked and vacuum-soaked pumice aggregate possessed lower drying shrinkage values.

(5) It is important to take the prewetting process of lightweight aggregates into consideration since it has a significant effect on fresh and hardened concrete properties. Throughout the study, the overall performance of the concretes with vacuum-soaked pumice aggregate was observed to be better than those with water-soaked and pre-soaked aggregates.

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