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The effects of gradation and admixture on the pumice lightweight aggregate concrete

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Abstract

The usage of lightweight concrete, which has some advantage over ordinary concrete, has increased to a remarkable level in recent years. Many researchers have investigated the possible uses of lightweight concrete in terms of its strength, density and other mechanical and physical properties. The desired quality for lightweight concrete can be obtained through the proper selection of admixtures and proper grading of the lightweight aggregate.

In this article, an experimental investigation on the production of moderate-strength lightweight concrete with pumice, according to the ACI standard, is presented. The gradation curves' (which fall within A16–C16 gradation curves, Turkish Standard Code, TS706) performances were investigated in terms of strength and density. The addition of superplasticizer and air-entraining admixtures improved the strength-to-density ratio of the hardened concrete and the workability of fresh concrete. As a result of this study, lightweight concrete blocks having a minimum compressive strength of 6.56 N/mm^2 and a density of 1300 kg/m^3 were obtained.
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Keywords: Lightweight aggregate; Pumice; Superplasticizer; Air-entraining admixture

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. The spectrum of lightweight concrete, according to strength and density, is given in Fig. 1.

The lightweight aggregate gradation plays an important role in providing the necessary strength and density of hardened concrete and the workability of fresh concrete. The way of obtaining a good-quality lightweight aggregate concrete is to combine fine and coarse aggregates to produce an optimum grading [2].

The properties of lightweight concrete can be improved by the addition of proper superplasticizer and air-entraining admixtures to the concrete mix. Superplasticizer admixtures are micromolecular organic agents and are used to reduce the amount of mixing water requirement of concrete at a constant consistency. Air-entraining admixtures are also organic materials, which are used to introduce and control the quantity of air into the fresh concrete. They improve the properties of the hardened concrete and decreases the segregation and bleeding in fresh concrete [3,4].

Pumice is principally an alumino-silicate 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. It is found abundantly in Mediterranean countries like Turkey, Italy, Spain and Greece. Although it has been used for structural elements in ancient times, it is currently being used mainly for nonstructural elements. Because Turkey is subject to considerable earthquake activities due to the presence of the North Ana-

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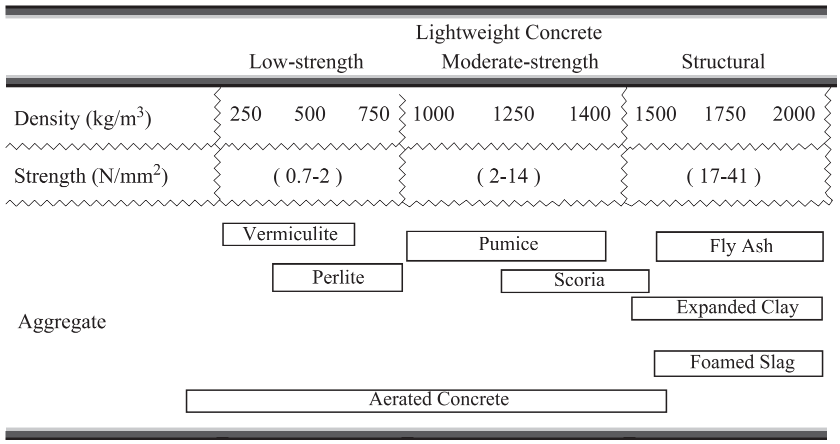

Fig. 1. Spectrum of lightweight concrete [1].

tolian Fault Zone, research on the possible uses of pumice for lightweight concrete increased during the last decades.

This paper presents a part of a research program on the usage of the pumice of Isparta, Turkey, for a lightweight aggregate concrete [5,6]. It was aimed to obtain a lightweight aggregate concrete with an optimum strength for a minimum density by introducing convenient admixtures and a proper grading.

2. Materials used

2.1. Aggregate and cement

The aggregate used in this research is obtained from Isparta province, Turkey. It is characterized with a maximum particle size of 15 mm. The density of the aggregate for different particle size distributions is given in Table 1. The blended cement (KC 32,5) was used for all concrete mixtures. The chemical compositions and physical properties of the used cement and pumice are given in Table 2.

2.2. Admixture

Two types of commercially available admixtures were used in this research. These are the superplasticizer, Sikament (FF-N), and the air-entraining agent Sika Light Crete (SL). The dosages used during the specimens' preparation (3% superplasticizer and 1.5% air-entraining agent by weight of cement) were determined considering the range recommended by the manufacturer and the optimum dosage that had been found in a previous study [7].

2.3. Gradation

To define the optimal mix proportions and to obtain satisfactory mechanical properties, the pumice aggregate was divided into three different size ranges: smaller than 4 mm, 4 to 8 mm and 8 to 16 mm. The aggregates in these size ranges were combined in different proportions to obtain three grading curves, Grade 1, Grade 2 and Grade 3, which fall within the grading curves A16 and C16 in TS706 (Turkish Standard Code [8]). The grading data for

Table 1
Density of the pumice for different particle size distributions

Sieve size (mm)	Bulk density (kg/m^3)		
	Natural	Dry	Saturated
+0.00–0.20	1049	1011	1563
+0.20–0.50	1024	944	1462
+0.50–1.18	904	834	1415
+1.18–2.36	879	779	1250
+2.36–4.75	789	751	1039
+4.75–8.00	760	727	985
+8.00–15.0	719	678	781
Average	875	817	1214

Table 2
Physical and chemical properties of pumice and cement

		Cement	Pumice
Physical properties	Specific surface (cm^2/g)	3050	–
	Specific gravity	3.01	2.11
	Retained on 200-μm sieve (%)	0.80	–
	Setting time, start (min)	165	–
	Setting time, end (min)	255	–
Chemical composition (%)	SiO_2	30.01	59.79
	Al_2O_3	5.67	17.01
	Fe_2O_3	3.92	1.98
	CaO (total)	51.26	4.03
	MgO	1.42	1.09
	SO_3	2.52	0.37
	Na_2O	0.93	5.19
	K_2O	0.20	6.20
	CaO (free)	0.90	–
	Insoluble residue	15.55	–
	LOI	2.06	–
	Others	–	2.59

Table 3
Cumulative passing for three aggregate grades and for A16–C16 TS706 code

Sieve size (mm)	Cumulative passing (%)				
	A16	Grade 1	Grade 2	Grade 3	C16
16	100	100	100	100	100
8	60	65	70	75	88
4	36	40	42	45	74
2	21	22	24	28	62
1	12	15	17	19	49
0.5	8	10	12	14	33
0.25	3	5	7	10	18

the three gradings and for A16–C16, TS706 are given in Table 3.

3. Preparation of the specimens

The concrete mixes were proportioned by absolute volume method. The absolute volume occupied by each ingredient of the mixture was calculated as;

$$V_{\mathrm{I}} = \frac{W_{\mathrm{I}}}{\mathrm{SG}_{\mathrm{I}} x \delta_{\mathrm{w}}} \quad (1)$$

where, V_{I} is the bulk volume of the ingredient (m^3), W_{I} is the weight of the ingredient (kg), SG_{I} is the bulk specific gravity of the ingredient and δ_{w} is the density of water (kg/m^3).

The specimens with superplasticizer and air-entraining admixture and the control specimens without admixture were prepared for each grade. All the mixtures were designed to have a slump of 70 to 100 mm after trial–error batches by adjusting the mixing water, keeping the cement dosage constant at 250 kg/m^3. All the parameters, except the aggregate proportions, were kept constant during the preparation of the mixtures. In the experimental study, 20 dm^3 mixtures were prepared at a time both for the control and the admixture-added specimens. The mixture proportions by weight and volume are given in Table 4. The materials, adjusted in accordance with the mixture proportions given in Table 4, were placed in a conventional rotary drum mixer and mixed in the following sequence:

- Blended pumice aggregates were added to the mixer and the mixer was started.
- After 5 min, two thirds of the required water (and admixtures for admixture-added concrete mix) was added.
- After 2 min, the cement was added simultaneously with the remainder of the water and admixtures.
- Mixing continued for 3 min, then stopped for a minute and then continued for 2 min more.

After the mixing procedure, the concrete was placed to a vibration machine operating at a frequency of 3000 rpm and was compacted by 15–20% of its loose bulk volume. Nine cube specimens (150 × 150 × 150 mm) were pre-

Table 4
Mixture proportions of control and admixtures-added mixes

Specimens			Cement	Pumice size (mm)			Water	Admixture	W/C	Total
				0–4	4–8	8–16				
Control	S1 (Grade1)	m^3	0.08	0.34	0.15	0.27	0.15	0	0.61	0.99
		kg/ m^3	250.0	489.8	155.6	209.4	152.1	0		1256.9
	S2 (Grade2)	m^3	0.08	0.34	0.27	0.15	0.15	0	0.61	0.99
		kg/ m^3	250.0	489.8	271.1	120.2	152.1	0		1283.2
	S3 (Grade3)	m^3	0.08	0.38	0.19	0.19	0.15	0	0.61	0.99
		kg/ m^3	250.0	544.9	193.8	149.6	152.1	0		1290.4
With superplasticizer	S4 (Grade1)	m^3	0.08	0.36	0.16	0.28	0.12	0.01	0.48	1.01
		kg/ m^3	250.0	505.5	160.6	216.1	120.2	7.5		1259.9
	S5 (Grade2)	m^3	0.08	0.36	0.28	0.16	0.12	0.01	0.48	1.01
		kg/ m^3	250.0	505.5	279.8	124.0	120.2	7.5		1287
	S6 (Grade3)	m^3	0.08	0.4	0.2	0.2	0.12	0.01	0.48	1.01
		kg/ m^3	250.0	562.3	200.0	154.4	120.2	7.5		1294.4
With air-entraining admixture	S7 (Grade1)	m^3	0.08	0.35	0.16	0.27	0.13	0.01	0.53	1.00
		kg/ m^3	250.0	498.1	158.2	212.9	131.4	3.8		1254.4
	S8 (Grade2)	m^3	0.08	0.35	0.27	0.16	0.13	0.01	0.53	1.00
		kg/ m^3	250.0	498.1	275.6	122.2	131.4	3.8		1281.1
	S9 (Grade3)	m^3	0.08	0.39	0.2	0.2	0.13	0.01	0.53	1.01
		kg/ m^3	250.0	554.0	197.0	152.2	131.4	3.8		1288.4

Table 5
The test results of all grades for 28-day curing

	Specimens								
	Control			With superplasticizer			With air-entraining admixture		
	S1	S2	S3	S4	S5	S6	S7	S8	S9
E_d (N/mm^2)	10390	10470	8960	9940	10620	10190	10700	11440	11140
Ultrasonic velocity (m/s)	2778	2776	2606	2671	2688	2674	2793	2908	2814
Water absorption (%)	22.21	19.59	20.58	21.54	20.28	20.14	20.40	19.13	19.89

pared at a time from this procedure. The specimens were cured at a temperature of 20–25 °C and a relative humidity of 50–55%.

4. Results and interpretations

Samples randomly selected among the cured specimens were used for the determination of the physical and mechanical properties of the hardened concrete. The uniaxial compressive strength (UCS) and density tests were carried out at the 28th and 56th days of curing. Water absorption test was conducted at the 28th day. The dynamic (sonic) modulus of elasticity was determined from ultrasonic pulse velocity (P wave) measurements at the age of 28 days. The dynamic modulus of elasticity, E_d, was calculated using the relation,

$$E_d = \left[\frac{v^2 x\delta}{g}\right] \times 10^{-5} \tag{2}$$

where E_d is the dynamic modulus of elasticity (N/mm^2), δ is the density (kg/m^3), v is the P wave velocity (m/s) and g is the gravitational acceleration (9.81 m/s^2).

The water absorption, ultrasonic velocity and dynamic modulus of elasticity are given in Table 5.

4.1. Influence of the gradation

The control samples' test results were interpretated, and the effects of gradation on the strength and density for the ages of 28 and 56 days were graphically illustrated in Figs. 2 and 3. The gradation of aggregate has a positive effect on the strength. The strength increases with increasing fine-to-coarse ratio up to the second-grade level, then, it begins to decline. As it can be seen from Fig. 2, regardless of age and admixture, the highest compressive strength was obtained with Grade 2. The strength of Grade 2 is 8.4% higher than the strength of Grade 1 and 28.8% higher than the strength of Grade 3 at the end of the 28th day of curing. At the end of 56th day, the strength of Grade 2 is 9.7% higher than the strength of Grade 1 and 9.9% higher than the strength of Grade 3. On the other hand, the gradation does not have a positive effect on the density at all ages. At the end of 56-day period, the density of Grade 2 is 0.8% higher than the density of Grade 1 and 2.7% higher than the density of Grade 3 (see the control concrete curves in Fig. 3). The density of Grade 1 has increased 3.0% and that of Grade 2 has increased 4.0% between the 28th and the 56th day of the curing period, while the other grade shows almost no change. The test results indicate that the water absorption of Grade 2 is less than of the others and has the highest dynamic modulus of elasticity (Table 5). To examine the overall effect of gradation, a new constant—quality con-

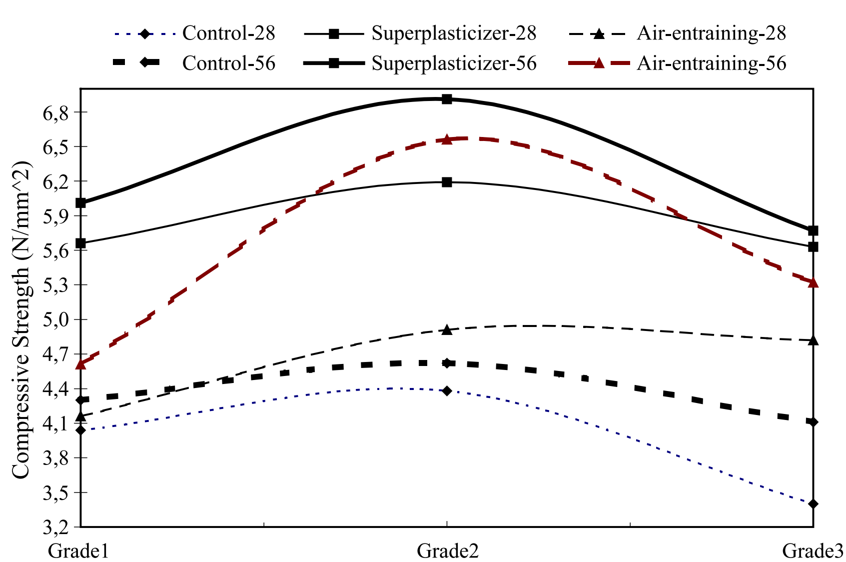

Fig. 2. The compressive strength of all grades for 28- and 56-day curing.

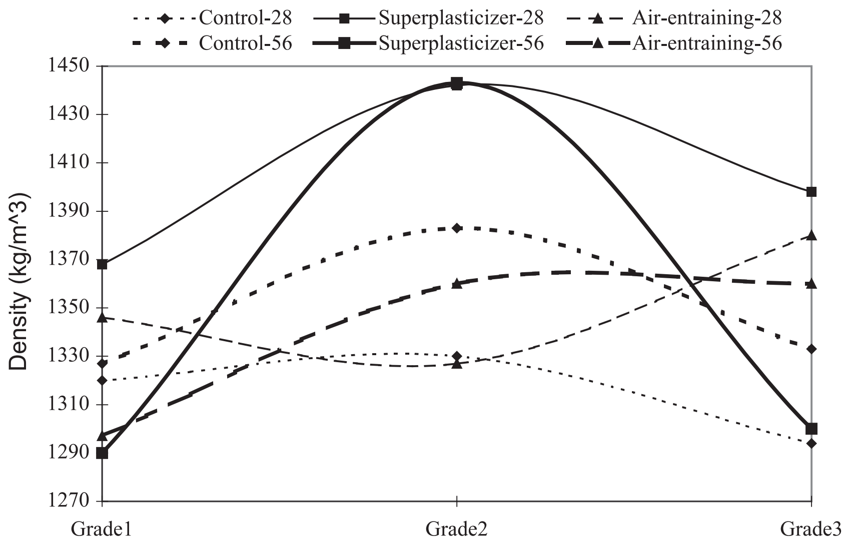

Fig. 3. The density of all grades for 28- and 56-day curing.

stant—has been introduced. Quality constant is defined as the ratio of compressive strength to density multiplied by a hundred. The quality constants for the control samples, at the 28th and 56th days of curing, are shown in Fig. 4.

4.2. Influence of superplasticizer

From the test results, it is clearly seen that the superplasticizer is highly effective on the strength of all gradation samples; but it is highly effective on Grade 2 as compared with the other grades (see Fig. 2). The behavior of the strength of all grades is similar with the strength behavior of the control samples. The age effect is only observed at Grade 2; the strength value obtained after 56-day curing is 12.0% higher than the strength of the specimen tested at the 28th day. On the other hand, the addition of superplasticizer made all the grades denser than the control concrete at the end of the 28th day (Fig. 3). The density of Grade 2 was higher compared with other grades of the control and air-entraining-added concrete at the end of the 56th day. An age effect on Grade 2 was not observed in terms of density. The water absorption of Grade 2 is higher than that of the control sample, but the water absorption for Grades 1 and 3 is lower compared with the control samples. The addition of superplasticizer has a positive effect on the dynamic elastic modulus of Grades 2 and 3, whereas the dynamic elastic modulus of Grade 1 is adversely affected (Table 5). The quality constant of each grade was calculated to examine the overall effect of superplasticizer on the density and strength. The overall quality constants obtained from this concrete for Grades 1, 2 and 3 are 4.1, 4.3 and 4.0 for the age of 28 days and 4.7, 4.8 and 4.4 for the age of 56 days,

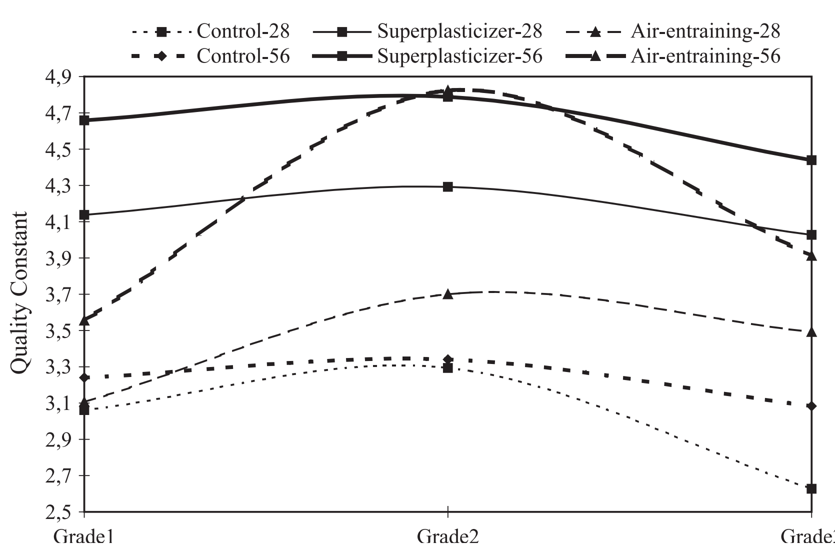

Fig. 4. Quality constant for all grades at 28- and 56-day curing.

Table 6
The correlation between the test results for all concretes

Specimens		UCS	Density	E_d	Water absorption
Control	UCS	1			
	Density	0.36	1		
	E_d	0.98	0.55	1	
	Water absorption	− 0.60	0.96	− 0.75	1
With air-entraining admixture	UCS	1			
	Density	0.05	1		
	E_d	0.95	− 0.25	1	
	Water absorption	− 0.87	0.46	− 0.97	1
With Superplasticizer	UCS	1			
	Density	0.89	1		
	E_d	0.91	1.00	1	
	Water absorption	− 0.38	− 0.75	− 0.72	1

respectively. Grade 2 has the best overall quality for all ages (see Fig. 4).

4.3. Influence of air-entraining admixture

Air-entraining admixture affected the fresh concrete in a positive manner by altering its rheology. Besides, the beneficial effect of this admixture was seen for all grades, especially on Grade 2 (Fig. 2). The strength of Grade 2 is 7.5% higher than that of Grade 1 and 9.9% higher than that of Grade 3. After the 56-day curing, the strength of Grade 2 is 42.3% higher than that of Grade 1 and 23.2% higher than that of Grade 3. At the end of 56-day period, the strength of Grade 2 was 13.0% higher compared with its strength on the 28th day. In addition, the strengths of both Grades 1 and 3 have increased by 10.0% between the 28th and 56th days. Although the strength of Grade 2 is higher than that of the control concrete, it is less than the strength of the superplasticizer-added concrete. The density of Grade 2 is a little bit less than that of the control concrete for the age of 28 days, but the other grades' densities are higher than of the control concrete samples (Fig. 3). The densities of Grades 1 and 2 decrease, while the density of Grade 3 increases (higher than the control concrete samples' densities), at the end of 56-day period. The water absorption values of all grades are lower compared with the control and superplasticizer-added concrete samples Grade 2 has the highest dynamic modulus of elasticity, and it is followed by Grades 3 and 1 (Table 5). The overall quality constants obtained from this concrete for Grades 1, 2 and 3 are 3.1, 3.7 and 3.5 for the age of 28 days and 3.5, 4.8 and 3.9 for the age of 56 days, respectively. From this result, it is seen that the best quality constant is obtained for Grade 2 (see Fig. 4).

4.4. Statistical analyses

Statistical analysis is performed for all the concrete types, and the correlation constant of each investigated parameter is calculated. A positive value approaching 1 represents a high positive correlation between two compared parameters and a negative value approaching − 1 represents a negative correlation. In other words, as one of the compared parameters increases, the other one decreases. A zero correlation constant (or a value approaching zero) means that there is no significant correlation between two compared parameters. A positive correlation between the modulus of elasticity and compressive strength is observed for all types of concrete. Control and superplasticizer-added specimens have high a positive correlation between density and water absorption. All concretes have negative correlation between compressive strength (UCS) and water absorption. Negative correlation is observed between the modulus of elasticity and water absorption for all types of concrete. The correlation constants of each investigated parameter are given in Table 6.

5. Conclusions

In this study, the effects of gradation of aggregates and admixtures on the pumice lightweight concrete were investigated. Three kinds of grading size distributions between A16 and C16 in TS706 were used to get the most suitable grading for the pumice lightweight aggregate concrete. On the other hand, to improve the engineering properties of the gradations (the strength-to-density ratio), superplasticizer and air-entraining admixtures were added to the concrete mix. It was revealed from this study that the usage of both admixtures was beneficial on the properties of fresh and hardened concrete for all grades. The following conclusions can also be deducted from this study:

1. Investigated parameters, which are optimum granulometry and admixture addition to the lightweight aggregate concrete mix, have significant influence on the strength and density of lightweight pumice concrete.
2. The addition of superplasticizer and air-entraining admixture improves the strength and workability of pumice concrete for all gradation curves, especially for the Grade 2.
3. The minimum compressive strength requirement of pumice block (above 5 N/mm^2 and below 1400 kg/m^3) was achieved by using both admixtures.
4. The best moderate-strength, lightweight concrete was obtained with the grading curve (Grade 2) between A16 and C16 in TS706 at a water/cement ratio of 0.48 from the superplasticizer-added mix, among the others.
5. Optimum gradation of Isparta pumice for the block production was obtained with the proper usage of admixtures and dosage amount.
6. If this optimum gradation can be used, the pumice aggregate will be efficiently used, and there will not be any fine stocks; this will serve beneficial and economical effects to the civil engineering sector in Turkey.

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