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The effects of different cement dosages, slumps and pumice aggregate ratios on the compressive strength and densities of concrete

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Abstract

Compressive strengths of concretes made up of mixtures of pumice aggregate (PA) and normal aggregate were measured. To determine the effect of PA ratio, different cement dosage and slumps on the compressive strength of concrete, (1) 25%, 50%, 75% and 100% pumice ratios were used instead of normal aggregate by volume, (2) 200, 250, 350, 400 and 500 kg/m^3 cement dosages were used and (3) 3 ± 1, 5 ± 1 and 7 ± 1 cm slumps were also used in this study.

The analysis of the test results leads to the conclusion that PA decreased the density of concretes up to 41.5% and reductions occurred due to the increase of the PA ratio in the mixes. With the increase of cement dosage in the mixes, both density and compressive strength of concretes increased up to 3.2% and 265%, respectively, when compared to the control sample that contain 200 kg/m^3 cement dosage. The effect of the slump on the density and compressive strength was varied. Elasticity moduli were decreased with an increase of PA ratio and increased with an increase of cement dosage. Water absorption improved with an increase of cement content.

Keywords: Pumice aggregate; Lightweight aggregate concrete; Compressive strength; Density

1. Introduction

Although structural lightweight concrete is usually defined as a concrete with an oven-dry density of no greater than 2000 kg/m^3 [1–4], there are variations in certain parts of the world. For example, in the USA [5], structural lightweight aggregate concrete is considered to be a concrete with an air-dry density of less than 1810 kg/m^3. In Japan [6], lightweight concretes do not specify any density values, and properties are only provided for concrete made with lightweight coarse and fine aggregates. In Europe [7], lightweight concrete is classified according to density.

For lightweight aggregate concrete, it is more relevant for mix design purpose to relate strength to cement content [8]. Although the increase in strength for a given increase in cement content depends on the type of aggregate used and the cement content itself, on average, for lightweight aggregate, a 10% higher cement dosage will give approximately a 5% higher strength [9].

Factors influencing the density and compressive strength of aerated concrete made with fly ash and lime/cement ratio have also been reported by Ramamurty and Narayanan [10]. They concluded that the compressive strength was a function of density of concrete, with an increase of density resulting in higher compressive strength.

2. Experimental study

Portland cement (PC) from Aşkale, Erzurum in Turkey was used throughout this study. Pumice aggregate (PA) and natural aggregate were obtained from the Kocapınar region in Van-Erciş and the Aras River in Erzurum, respectively, in Turkey. The chemical composition and physical properties of the materials used in this study are summarized in Table 1 and 2.

ASTM D-75 and ASTM C-136 and C-29 were used for sampling, grading, unit weight and fineness modulus of aggregates. Maximum aggregate size was 16 mm. The cement content was 200, 250, 350, 400 and 500 kg/m^3 for

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Table 1
Chemical analysis of PC and PA

Component	PC (%)	PA (%)
SiO_2	17.69	71.35
Fe_2O_3	3.59	1.54
Al_2O_3	5.89	13.20
CaO	57.69	1.84
MgO	3.39	0.01
SO_3	2.57	0.04
K_2O	0.3	5.00
Na_2O	–	3.40
TiO_2	0.2	0.25
Sulfide (S^{-2})	0.17	–
(Cl^-)	0.04	–
Undetermined	0.55	–
Free CaO	0.96	–
LOI	2.50	–

a constant 25% PA + 75% normal aggregate and 3 ± 1 cm slump for the evaluation of the effect of cement dosage on the density and compressive strength. In addition, when the cement dosage was constant at 300 kg/m^3, 25%, 50%, 75% and 100% PA ratios were used instead of normal aggregate to determine the effect of PA on the mixtures density and compressive strength for 3 ± 1, 5 ± 1 and 7 ± 1 cm slumps, respectively. Hence, 20 different mixes were obtained and cast (see Table 3). The concrete mixes were prepared in a laboratory countercurrent mixer for a total of 5 min. Hand compaction was used. Precautions were taken to ensure homogeneity and full compaction. For each mixture, three samples of 150 × 300 were prepared and cured for 7 and 28 days in lime-saturated water at 20 ± 3 °C until the time of the testing. At 7 and 28 days, samples were tested for compressive strength in accordance with ASTM C-192 and results were compared to the control samples.

3. Results and discussion

3.1. Effect of cement dosages on the density, compressive strength, elasticity modulus and water absorption

It can be seen from Table 4 that the density of concrete increases with an increase in cement dosage (keeping the slump constant at 3 ± 1 cm). The reason for this is that the specific gravity of PC is higher than that of other ingredients.

Table 4 shows the variation in compressive strength with cement dosage. When cement dosage increased from 200 to 250, 300, 350, 400 and 500 kg/m^3, compressive strength increased 68%, 113%, 164%, 232% and 265%, respectively. For lightweight aggregate concrete, it is more relevant for mix design purpose to relate strength to cement content [8]. Although the increase in the strength for a given increase in the cement content depends on the type of aggregate used and the cement content itself, on average, for lightweight aggregate, a 10% higher cement will give approximately a 5% higher strength [9].

Factors influencing the density and compressive strength of aerated concrete made up of fly ash and lime/cement ratio have also been reported by Ramamurty and Narayanan [10]. They concluded that the compressive strength was a function of density of concrete and with an increase of density resulting in higher compressive strength. Concrete made up of 25% PA replacement for natural aggregate and 350 kg/m^3 cement dosage higher is needed to supply compressive strength required for structural lightweight aggregate concrete [14].

Water absorption of concretes decreased from 5.8% to 3% with an increase of cement content. Results are shown in Table 4. This may be due to the reduction of porosity because of increasing fine cement particles in mixes and decreasing water/cement ratio.

Table 4 also shows the variation in elasticity modulus with cement dosage. When cement dosage increased from 200 to 250, 350, 400 and 500 kg/m^3, elasticity modulus increased 21%, 64%, 89% and 112%, respectively.

The modulus of elasticity of mixes depends on the type of aggregates, the effective water binder ratio and the volume of cement. The water/cement ratio controls the elasticity modulus of the cement paste, which ranges from about 12 to 26 GPa. Furthermore, the lower value can be reduced by air entraining agents. The influence of the aggregate on the elasticity changes with the type of aggregate. The stiffness of the mixes increases with increasing density of concrete due to natural stiffness aggregate [13]. Figs. 2–4 shows relationship between stress and strain and their slope shows the elasticity modulus of concretes. Elasticity moduli are the function of compressive strength, and with increasing compressive strength, they also increase. Indeed, compressive strength increases with an increase of cement dosage and increasing cement dosage results in higher elasticity moduli (see Fig. 1).

3.2. Effect of different PA ratios on the density, compressive strength, elasticity modulus and water absorption

Table 4 shows that the density of concrete decreases with an increase in PA ratios (keeping slump at 3 ± 1, 5 ± 1 and

Table 2
Mechanical and physical properties of PC

Specific gravity (g/cm^3)		3.03
Specific surface (cm^2/g)		3613
Remainder on 200 μm sieve (%)		0.1
Remainder on 90 μm sieve (%)		3.1
Setting time, initial (min)		270
Setting time, final (min)		320
Volume expansion (Le Chatelier, mm)		3
Compressive strength (MPa)	2 days	12.5
	7 days	24.8
	28 days	36.5

Table 3
Mix proportions

			Different PA ratios (%)					Different dosages (kg/m^3)				
			0	25	50	75	100	200	250	350	400	500
Lightweight aggregate (kg/m^3)	Sieve sizes (mm)	Specific gravity (g/cm^3)										
	0–2	1.65	–	80.9	154.6	221.6	336.4	87.1	85.7	82.7	79.9	73
	2–4	1.04	–	17.0	32.5	46.5	58.8	16.9	16.6	16	15.5	14.2
	4–8	0.93	–	38.0	72.6	103.9	120.2	40.1	39.4	38.1	36.8	33.6
	8–16	0.82	–	46.9	86.6	128.3	159.1	51.4	50.5	48.8	47.2	43.1
Normal aggregate (kg/m^3)	0–2	2.44	455	338	215.4	102.8	–	348.1	342.5	330.7	319.5	291.9
	2–4		151	112.1	71.4	34.1	–	116	114.1	110.2	106.5	97.3
	4–8	2.62	406	301.1	191.9	91.6	–	311.9	306.8	296.3	286.3	261.6
	8–16		570	421.4	268.6	128.1	–	436.7	429.6	414	400	365.4
Cement dosage (kg/m^3)			300	300	300	300	300	200	250	350	400	500
Water			189	217.7	246.4	275	295	229	225	215.8	219.6	236.8
Slump (cm)			3 ± 0.5	3 ± 0.5	3 ± 0.5	3 ± 0.5	3 ± 0.5	3 ± 0.5	3 ± 0.5	3 ± 0.5	3 ± 0.5	3 ± 0.5
Fresh unit weight (kg/m^3)			2310	1985	1952	1451	1330	1973	1981	1999	2024	2057

7 ± 1 cm and cement content constant at 300 kg/m^3, respectively). While the control sample's density was 2182 kg/m^3 at 3 ± 1 cm slump, the density of concretes of those made up of 25%, 50%, 75% and 100% PA replacement for normal aggregate was 1977, 1638, 1454 and 1167 kg/m^3, respectively. Reduction in the density due to the PA was 10%, 25%, 50% and 87% for 25%, 50%, 75% and 100% PA replacements, respectively. While the control sample's density was 2143 kg/m^3 at 5 ± 1 cm slump, the density of concretes of those made up of 25%, 50%, 75% and 100% PA replacement for normal aggregate was 1878, 1647, 1402 and 1278 kg/m^3, respectively. Reduction in the density due to PA was 14%, 30%, 53% and 67.7% for 25%, 50%, 75% and 100% PA replacements, respectively. The reduction in the density due to the PA at 5 ± 1 cm slumps was 15%, 24%, 51% and 86% for 25%, 50%, 75% and 100% PA replacements, respectively. This is probably due to the porous structure of PA. Table 4 shows the variation in compressive strength with PA ratios. The reductions induced by 0%, 25%, 50%, 75% and 100% PA replacement for normal aggregate by volume, on the compressive strength, were around 41%, 67.6%, 123% and 157.3% at 3 ± 1 cm slump, 38.6%, 85.8%, 90% and 106.6% at 5 ± 1 cm slump and 36.9%, 48%, 46.3% and 94% at 7 ± 1 cm slump, respectively. This can be explained as follows. Compressive strength is a function of density. Gül et al. [11] reported that the compressive

Table 4
Hardened concrete properties for different PA ratios and cement dosages

Groups	Properties	Different PA ratios (%)					Different cement dosage (kg/m^3)				
		0	25	50	75	100	200	250	350	400	500
Slump = 3 ± 1 cm	Density (kg/m^3)	2182	1977	1638	1454	1167	1864	1874	1896	1936	1943
	Compressive strength (MPa)	23.11	16.39	13.79	10.34	8.98	7.7	12.96	20.32	25.58	28.14
	Elasticity modulus (GPa)	14.4613	10.608	9.9525	6.1228	4.4214	6.9200	8.3760	11.368	13.088	14.657
	Water absorption (%)	3.7	4.8	6.6	9.9	16.7	5.8	5.2	4.4	3.3	3
Slump = 5 ± 1 cm	Density (kg/m^3)	2143	1878	1647	1402	1278	–	–	–	–	–
	Compressive strength (MPa)	22.31	16.10	12.01	11.74	10.80	–	–	–	–	–
	Elasticity modulus (GPa)	13.27000	9.3649	7.9559	5.8919	5.4874	–	–	–	–	–
	Water absorption (%)	4.146	6.1	8.3	9.0	–	–	–	–	–	–
Slump = 7 ± 1 cm	Density (kg/m^3)	2191	1855	1664	1448	1181	–	–	–	–	–
	Compressive strength (MPa)	17.84	13.03	12.05	12.19	9.19	–	–	–	–	–
	Elasticity modulus (GPa)	13.2532	9.3649	6.3686	4.5482	4.0819	–	–	–	–	–
	Water absorption (%)	4.8	6.6	9.1	12	15.2	–	–	–	–	–

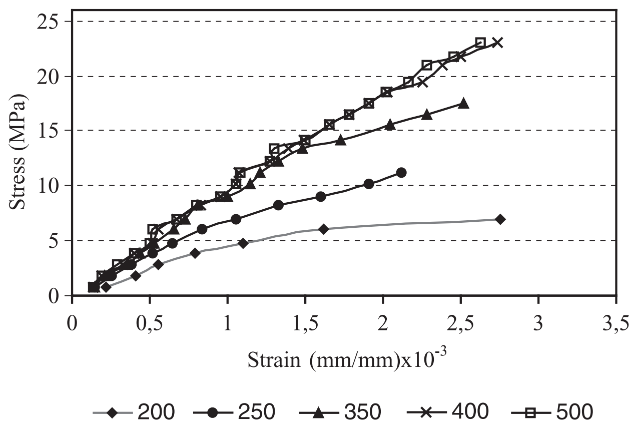

Fig. 1. Stress–strain relationship for different cement dosages (slump 3 ± 1 cm).

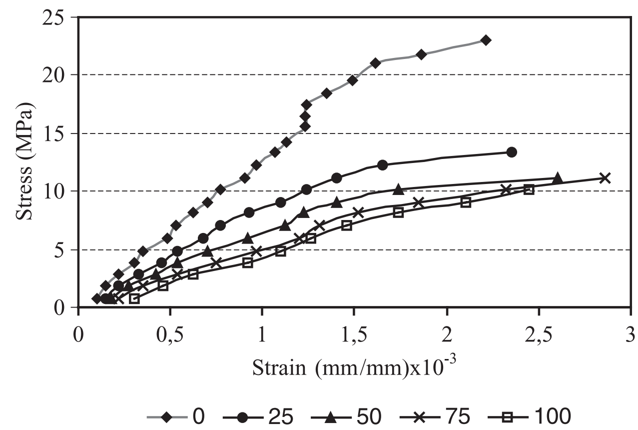

Fig. 3. Stress–strain relationship for different PA ratio (slump 5 ± 1 cm).

strength decreased because the density decreased with increasing PA ratio instead of the normal aggregate. Akman and Taşdemir [12] concluded that compressive strength decreased because the density decreased with increasing lightweight aggregate ratio instead of the tradition aggregate. Faust [13] reported that the replacement of natural sand by lightweight fine aggregate reduces the compressive strength. The loss of strength was more pronounced with decreasing density of mixes (see Table 4). It can be concluded that there is a consensus [8–12] on the relation between compressive strength of lightweight concrete and density.

Water absorption of concretes was increased with increasing PA ratio. The maximum absorption value was found to be as 16.7% at 100% PA ratio. The same result was obtained for all slumps (see Table 4).

Most lightweight aggregates exhibit significantly higher water absorptions than normal aggregates. This results in lightweight aggregate concretes having higher absorptions than traditional concretes on a mass base although the difference is not as large as expected since the aggregate particles in lightweight concrete are surrounded by a high-quality matrix [15].

As it mentioned before that the influence of the aggregate on the elasticity also changes with the type of aggregate, the stiffness of the mixes increases with increasing density of concrete due to natural stiffness aggregate [13]. It can be seen from Figs. 2–4 that with increasing PA ratio the slope of stress–strain curves decreased drastically at all slumps. This means that when PA contents increased in mixtures the stiffness of the composite decreased. This is because of the PA porous structures.

3.3. Effect of different slumps on the density, compressive strength, elasticity modulus and water absorption

The influence of the different slumps (± 1 cm) on the density of concrete is shown in Fig. 1 for different pumice ratios. It can be seen from Fig. 1 that the density of concrete fluctuated with an increase in slumps (keeping the cement dosage constant at 300 kg/m^3). PA replacement caused drastic reduction in density. Fig. 5 shows the variation due to the different slumps and PA ratios. Since the compressive

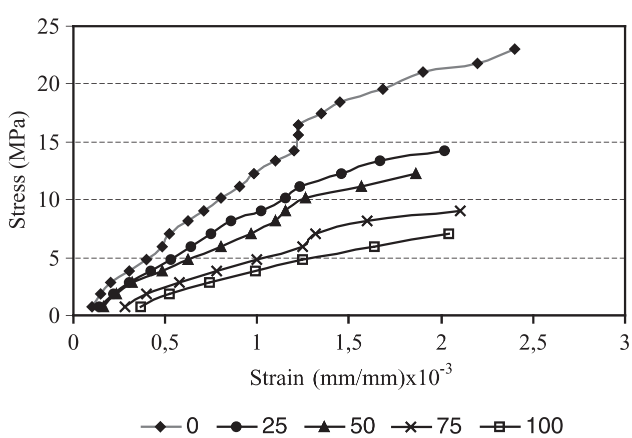

Fig. 2. Stress–strain relationship for different PA ratio (slump 3 ± 1 cm).

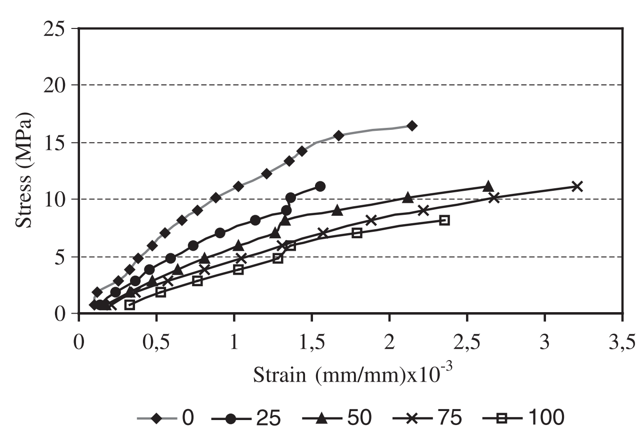

Fig. 4. Stress–strain relationship for different PA ratio (slump 7 ± 1 cm).

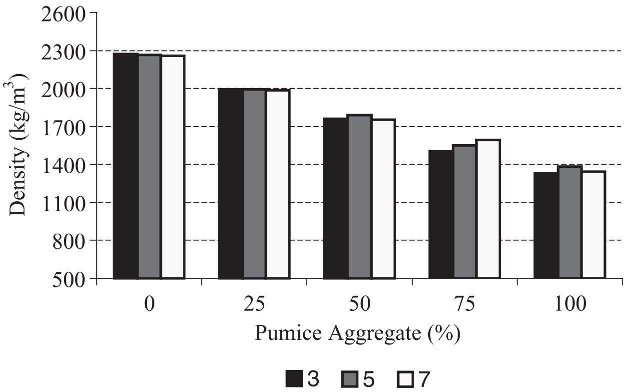

Fig. 5. Relation between PA ratio and density (±0.02) for different slumps (±1).

strength is related to the density and the density fluctuated as described above, then the compressive strength also fluctuated.

4. Conclusions

The analysis of the test results leads to the conclusion that PA decreased the density of concretes up to 41.5% and reductions occurred due to the increasing PA ratios in the mixes. With the increasing of cement dosage in the mixes, both density and compressive strength of concretes increased up to 3.2% and 265% respectively, when compared to the control sample that contain 200 kg/m^3 cement dosage. The effect of the slump on the density and compressive strength was varied. Elasticity moduli were decreased with an increase of PA ratio and increased with an increase of cement dosage. Water absorption improved with an increase of cement content. PA decreased the density, compressive strength and elasticity moduli of concretes. The effects of the different slumps on the density and compressive strength were varied.

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