Computers and Concrete, Vol. 3, No. 2/3 (2006) 163-175
DOI: http://dx.doi.org/10.12989/cac.2006.3.2/3.163

The effects of different cement dosages, slumps and pumice aggregate ratios on the freezing and thawing of concrete

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(Received April 4, 2006, Accepted June 19, 2006)

Abstract. This research was conducted to determine effect of pumice aggregate ratio, cement dosage and slumps on freeze-thaw resistance, density, water absorption and elasticity of concrete. In the first batch, 300 kg/m^3 cement dosage were kept constant and pumice ratios were changed as 25%, 50%, 75% and 100% of replacement for normal aggregate by volume for 3±1 cm, 5±1 cm and 7±1 cm slumps. Other batches were prepared with 200 kg/m^3, 250 kg/m^3, 350 kg/m^3, 400 kg/m^3 and 500 kg/m^3 cement dosages and 25% pumice aggregate +75% normal aggregate at a constant slump. Test results showed that when pumice-aggregate ratio decreased the density and freeze-thaw resistance of concretes increased. With increasing of cement dosage in the mixtures, density of the concretes increased, however, freeze-thaw resistance of concretes decreased. Water absorption of the concrete decreased with increasing cement dosage but increased with the pumice ratio. Water absorption of the concrete also decreased after freeze-thaw cycles. Freeze-thaw resistance of concretes was decreased with increasing the slumps.

Keywords: pumice aggregate, concrete, freezing thawing resistance, density

1. Introduction

With the deterioration of existing structures, durability of concrete is of great concern (Cai, *et al.* 1998). For structures in cold areas, freeze-thaw resistance of concrete is especially important. Concrete exposed to temperature cycles, where water freezes to ice and ice melts to water in winter, is deteriorated due to freezing and thawing. As the temperature lowered, the water held in the capillary pores freezes and expansion of the void occurs. Thus, repeated cycles of freezing and thawing deteriorate concrete rapidly (Detwiler, *et al.* 1989, Aavik and Chandra 1995). It is well established that the microstructure, porosity and permeability properties of lightweight aggregate concrete are different from those of normal concrete (Zhou 1994). Obviously it has economical and technical advantages over ordinary concrete, such as construction saving due to reduction of dead weight, thermal isolation, freeze-thaw resistance, and lower handling cost and fire protection but have disadvantage of having low mechanical properties (Bingöl and Gül 2004). During the freezing process, to reach a protective air void, a spacing factor, which is represented by the average

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maximum distance from any point in the paste to the edge of a void, is the critical parameter. According to ASTM C 457, the spacing factor should not exceed 0.2 mm to ensure adequate protection. The smaller the spacing factor is, the more durable concrete becomes. The smaller the bubble size is, the smaller the spacing becomes at a given air content. Furthermore, small voids remain as discrete isolated bubbles, and are not readily filled with water even when the concrete is kept saturated (Erdoğan 1997).

Like the cement paste, aggregate particles may be subjected to internal hydraulic pressure. Aggregate saturated must accommodate the expansion of freeze water either by expelling the excess water or expanding. Very porous aggregate such as lightweight aggregate has such a high permeability that water can escape during freezing without major aggregate damage (Detwiler, *et al.* 2989). Consequently lightweight aggregate is more durable than normal aggregate (Chandra, *et al.* 1982). Soroushian, *et al.* also reported that the increase in lightweight aggregate content up to a certain limit increases the freeze-thaw durability of lightweight carbon fiber reinforced cement composite. Higher aggregate contents, in contrast, negatively affect freeze-thaw durability of the composite (Soroushian, *et al.* 1992).

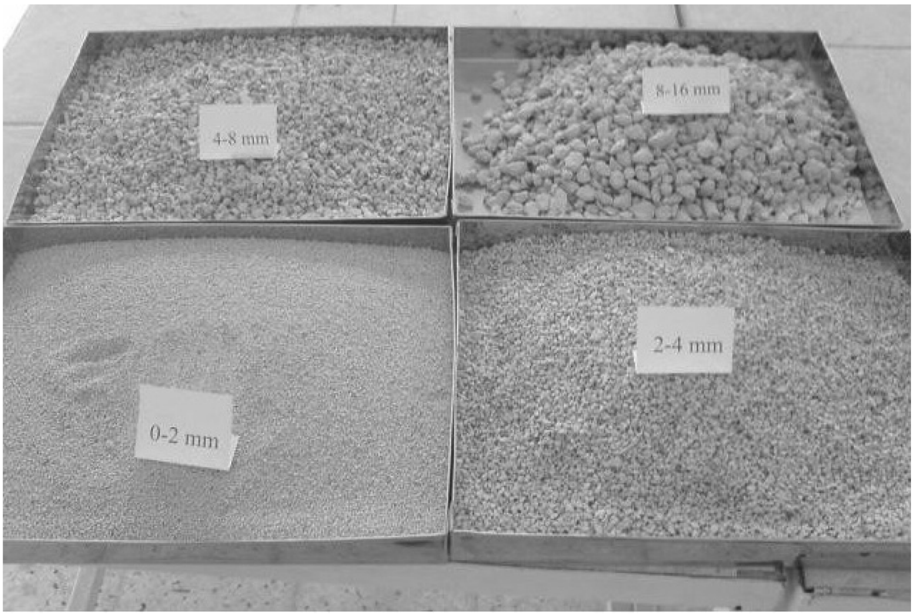
The most popular way of Lightweight concrete (LWC) production is by using lightweight aggregate (LWA) (Bingöl and Gül 2004). LWC mixes are generally of low water/cement-mineral (w/cm) to compensate for the aggregate weakness. There are a number of methods to produce LWC. In one method, the fine portion of the total concrete aggregate is omitted, which is called 'no-fines'. Another way of producing LWC is to introduce stable air bubbles inside concrete by using chemical admixtures and mechanical foaming. This type of concrete is known as aerated, cellular or gas concrete. The most popular way of LWC production is use lightweight aggregate (Demirboğa, *et al.* 2001). In recent years, LWC with high strength or high workability have been widely developed (Wasserman Bentur 1996).

Structural lightweight concrete is usually defined as a concrete with an oven-dry density of no greater than 2000 kg/m^3 (Euro 1991, CEB/FIB 1978, Euro 1992, Terminology Definition 1975), but there are variations in certain parts of the world. For example, in the USA (ACI 1989), structural lightweight aggregate concrete is considered to be a concrete with an air-dry density of less than 1810 kg/m^3. In Europe (ENV 1989), 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 (Lydon 1982). In Japan (JASS 1982), lightweight concretes do not specify any density values, and properties are only provided for concrete made with lightweight coarse and fine aggregates. 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 (Clarke 1993).

A laboratory investigation was carried out in order to evaluate the quality of concrete with different combination of pumice aggregate ratio, cement dosages and slumps. Several properties related to durability were determined, and particular attention was put on the resistance of the concrete mixes to the freezing and thawing cycles based on ASTM C 666. The main objective was focused on the effect of PA ratios, different slumps and dosages on the freeze-thaw resistance of lightweight aggregate concrete.

2. Materials and methods

Portland cement (PC), from Aşkale, Erzurum in Turkey was used throughout this study. Pumice aggregate (PA) (see Picture 1) and normal aggregate were obtained from Kocapinar region in Van-Erciş, and Aras River in Erzurum in Turkey, respectively. The chemical composition and physical



Picture 1 Pumice aggregates

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
Sulphide (S^{-2})	0.17	-
(Cl^-)	0.04	-
Undetermined	0.55	
Free CaO	0.96	
LOI	2.50	

Table 2 Mechanical and physical properties of PC

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

Table 3 Mix proportions

			Different Pumice Ratios (%)					Different Dosages (kg/m^3)				
			0	25	50	75	100	200	250	350	400	500
Lightweight Aggregate (kg/m^3)	Sieve Sizes (mm)	Density (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
Cément 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
Wet Unit weight (kg/m^3)			2310		1952		1330	1973	1981	1999	2024	2057

properties of the materials used in this study are summarized in Table 1 and Table 2. The ASTM D 75, ASTM C 136 and C 29 were used for sampling, grading, unit weight and fineness modulus of aggregates, respectively. Maximum aggregate size was 16 mm. The cement content was varied as 200 kg/m^3, 250 kg/m^3, 350 kg/m^3, 400 kg/m^3 and 500 kg/m^3 for a constant 25% PA +75% normal aggregate. 3 ± 1 cm slump was applied to evaluation of the effect of cement dosage on density and freeze-thaw resistance. In addition, when the cement dosage was constant at 300 kg/m^3, 25%, 50%, 75% and 100% PA ratios was used instead of normal aggregate to determine the effect of PA on the mixtures density and freeze-thaw resistance for 3 ± 1 cm, 5 ± 1 cm and 7 ± 1 cm slumps, respectively. The mix proportions of the materials used in this study are summarized in Table 3. Hence, 20 different mixes were obtained and cast. The concrete mixes were prepared in a laboratory by a mixer for a total of 5 minutes. Hand compaction was used. Precaution was taken to ensure homogeneity and full compaction. For each mix, three specimens of 150 diameter and 300 mm height were prepared and cured in lime saturated water at 20 ± 3°C until 14 day. Then, they were exposed to 14 cycles

Table 4 Density and freeze-thaw resistance of different pumice aggregate ratios

Groups	Properties	Different pumice aggregate ratio (%)									
		0		25		50		75		100	
		Water curing	Freeze-thaw	Water curing	Freeze-thaw	Water curing	Freeze-thaw	Water curing	Freeze-thaw	Water curing	Freeze-thaw
Slump: 3 ± 1 cm	Dry unit weight at 28 day (kg/m^3)	2182	2170	1977	1968	1638	1631	1454	1448	1167	1160
	Reduction (–) or Increment (+) (%)	-0.54		-0.45		-0.42		-0.41		-0.59	
	Compressive Strength (MPa)	23.11	22.23	16.39	15.87	13.79	13.36	10.34	10.15	8.98	8.86
	Reduction (–) or Increment (+) (%)	-4.24		-3.17		-3.11		-1.85		-1.33	
	Elasticity Module (GPa)	14.46	13.87	10.61	10.29	9.99	9.64	6.12	5.94	4.42	4.31
	Reduction (–) or Increment (+) (%)	-4.07		-3.92		-3.12		-2.95		-2.49	
Slump: 5 ± 1 cm	Dry unit weight at 28 day (kg/m^3)	2143	2126	1878	1865	1647	1636	1462	1394	1278	1271
	Reduction (–) or Increment (+) (%)	-0.79		-0.69		-0.66		-0.57		-0.54	
	Compressive Strength (MPa)	22.31	21.22	16.1	15.47	12.01	11.69	11.74	11.42	10.8	10.6
	Reduction (–) or Increment (+) (%)	-4.88		-3.93		-2.67		-2.72		-1.85	
	Elasticity Module (GPa)	13.27	12.43	9.36	8.85	7.96	7.58	5.89	5.68	5.48	5.30
	Reduction (–) or Increment (+) (%)	-6.32		-5.45		-4.69		-3.56		-3.39	
Slump: 7 ± 1 cm	Dry unit weight at 28 day (kg/m^3)	2291	2173	1855	1842	1664	1653	1448	1439	1181	1174
	Reduction (–) or Increment (+) (%)	-0.82		-0.70		-0.66		-0.62		-0.50	
	Compressive Strength (MPa)	17.8	16.8	13.03	12.37	12.05	11.52	12.19	11.69	9.19	8.84
	Reduction (–) or Increment (+) (%)	-5.58		-5.06		-4.39		-4.06		-3.77	
	Elasticity Module (GPa)	13.25	12.32	9.36	8.75	6.36	5.97	4.55	4.32	4.09	3.88
	Reduction (–) or Increment (+) (%)	-7.04		-6.56		-6.13		-4.99		-4.90	

samples were tested on the compressive strength in accordance with ASTM C 192. Results were compared to the control samples that stayed in lime-saturated water until 28 day.

3. Results and discussion

3.1. Effect of different cement dosages on the unit weight, compressive strength and elasticity module of concrete before and after freeze-thaw

It can be seen from Table 5 that the unit weight of concrete increases with an increase in cement dosage (slump was kept constant at 3 ± 1 cm). The maximum increment was 4 percent at 500 kg/ m^3. The reason for this is that the specific gravity of PC is higher than that of other ingredients.

Fig. 3 and Table 5 shows the variation in compressive strength with cement dosage. When cement dosage was 200, 250, 300, 350, 400 and 500 kg/m^3, compressive strength was 7.70, 12.96, 20.32,

Table 5 Effect of different cement dosage on the freeze-thaw resistance of concretes

Cement Dosage (kg/m^3)	200	250	350	400	500
Dry unit weight at 28 day (kg/m^3)	1864	1874	1896	1936	1943
Dry Unit Weight After Freeze-Thaw cycles (kg/m^3)	1852	1860	1978	1921	1931
Lost Weight (%) (±0.02)	0.64	0.74	0.95	0.77	0.61
28 day Comp. Strength (MPa)	7.7	12.96	20.32	25.58	28.14
Comp. Str. After Freeze-Thaw Cycles (MPa)	6.42	11.76	19.54	24.76	27.08
Reduction (–) or Increment (+) (%)	-16.62	-9.25	-3.83	-3.2	-3.76
Elasticity Module (GPa) at 28 day	6.92	8.38	11.37	13.09	14.62
Elasticity Module (GPa) After Freeze-Thaw Cycles	6.51	7.76	10.47	11.66	13.75
Reduction (–) or Increment (+) (%)	-5.92	-7.35	-7.88	-10.92	-5.91

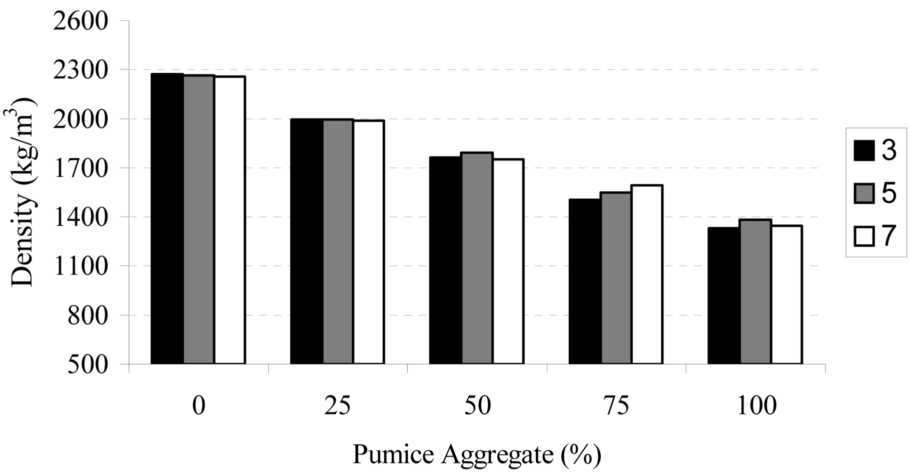


Fig. 1 Relation between pumice aggregate ratio and density (±0.02) for different slumps (±1)

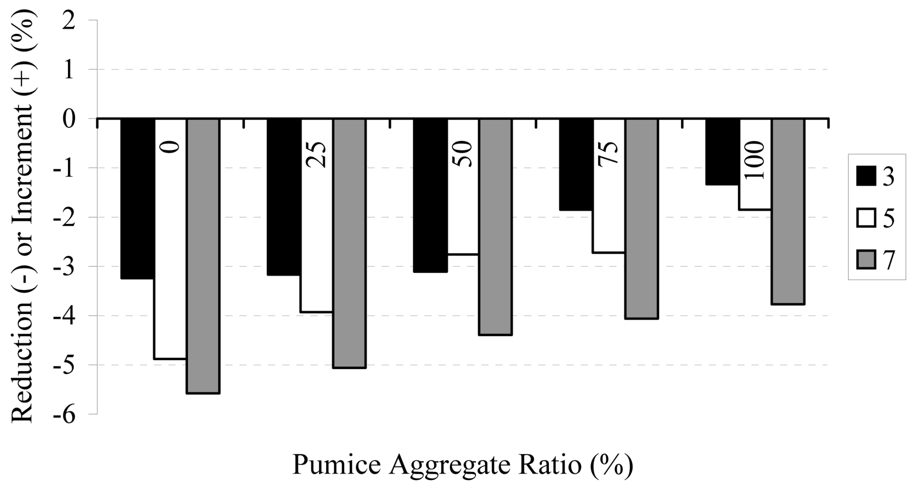


Fig. 2 Relation between pumice aggregate ratio and reduction or increment (%) in compressive strength for different slumps (±1)

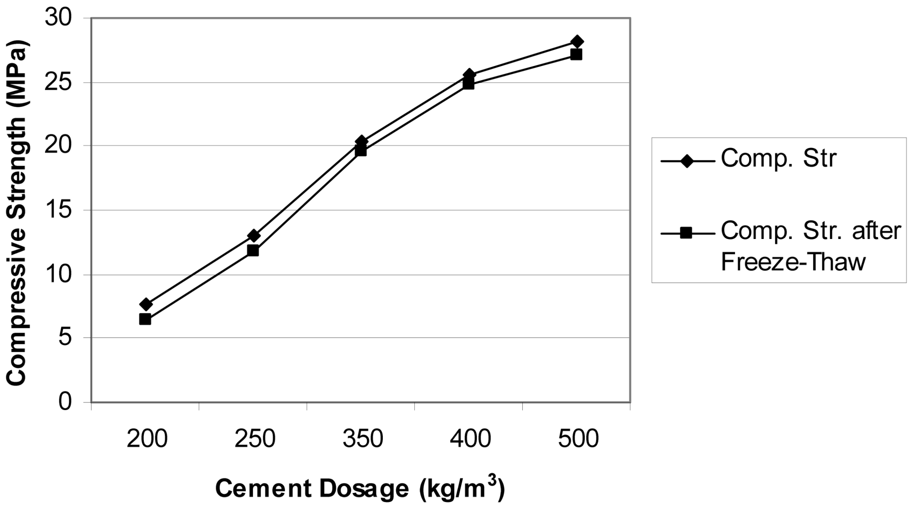


Fig. 3 Relationship between compressive strength and cement dosage both normal conditions and after freeze-thaw for 28-day

25.58, and 28.14, respectively. For lightweight aggregate concrete, it is more relevant for mix design purpose to relate strength to cement content (Lydon 1982).

Compressive strength of concrete made up of 25% PA replacement of normal aggregate and 350 kg/m^3 cement dosage was adequate to supply compressive strength required for structural lightweight aggregate concrete (BS 1982).

As it can be seen from Fig. 4 that elasticity modulus of concrete before freeze-thaw cycles increased with increasing cement dosage. It ranges from 12 to 16 GPa and the maximum dosage value was obtained at 500 kg/m^3. The modulus of elasticity of mixes depends on the type of aggregates, effective water binder ratio and volume of cement. The influence of the aggregate on

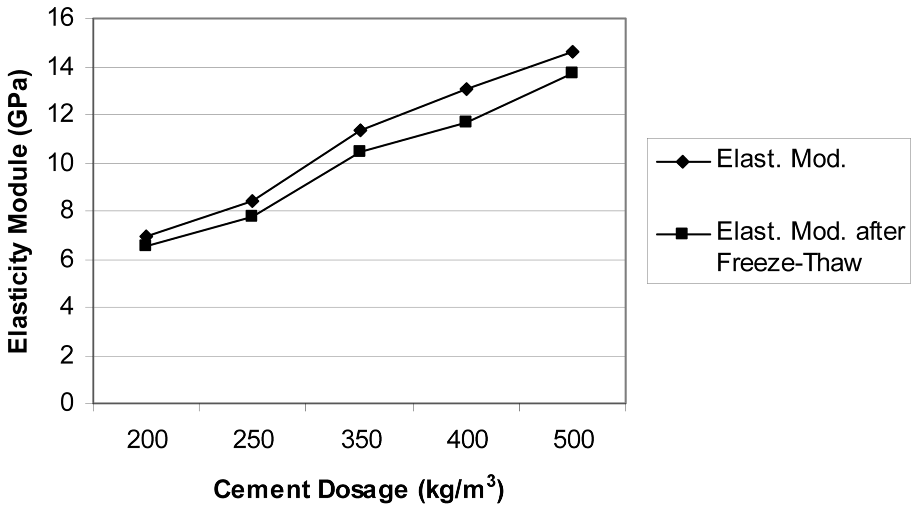


Fig. 4 Relationship between elasticity module and cement dosage both normal conditions and after freeze-thaw for 28-day

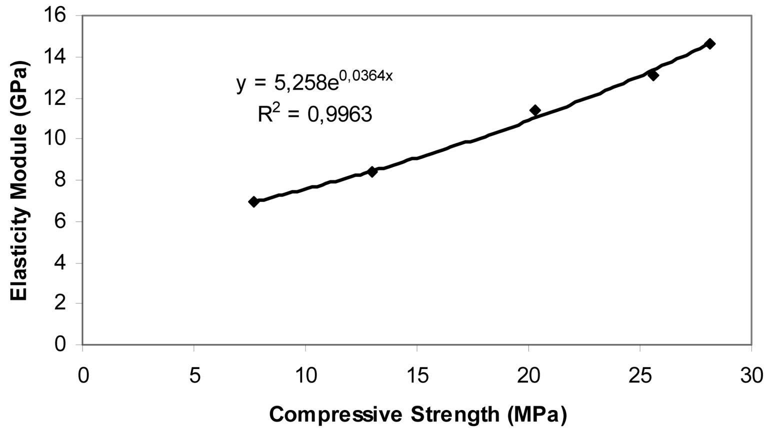


Fig. 5 Relationship between elasticity module and compressive strength for 28-day

the elasticity changes with the type of aggregate. The stiffness of the mixes increases with increasing density of concrete due to natural stiffness of aggregate (Faust 2000). There was a very good exponential relationship between elasticity module and compressive strength. Since R^2=0.996, we can say that 99.6% of the variation in the values of elasticity module is accounted for by exponential relationship with compressive strength (See Fig. 5). Determination coefficient of the model was 0.998.

After freeze-thaw cycles, it can be seen from Table 5 that the unit weight of concrete increases with the increase in cement dosage (keeping the slump constant at 3 cm ±1). However, reductions were occurred in unit weights after freeze-thaw cycles when compared to the samples that were not exposed to the freeze-thaw cycles. They were 0.64 percent, 0.74 percent, 0.95 percent, 0.77 percent and 0.61 percent for 200 kg/m^3, 250 kg/m^3, 350 kg/m^3, 400 kg/m^3 and 500 kg/m^3 cement dosage,

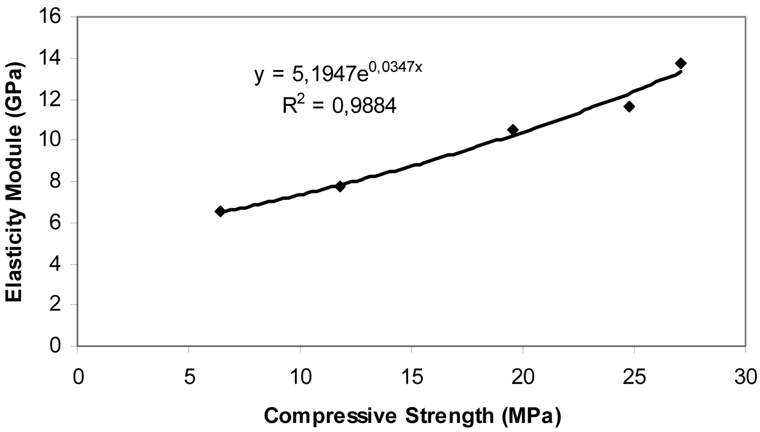


Fig. 6 Relationship between elasticity module and compressive strength after freeze-thaw for 28-day

respectively. Turgutalp and Örüng (1992) reported that the increase in cement dosage up to a certain limit increases reduction of the unit weight of lightweight aggregate concrete. Higher cement contents, however, positively affect reduction of the unit weight of lightweight aggregate concrete (Turgutalp and Örüng 1992). Reductions were increased up to 0.95 percent for 350 kg/m^3, and over 350 kg/m^3 cement dosage, reduction was diminished with increasing cement dosage. Reductions due to freeze-thaw were negligible among these dosages. The same results were reported by previous studies (Demirboğa and Gül 2004, Sahin, *et al.* 2003, Ramamurty and Narayanan 2000).

Elasticity modules and compressive strength were also reduced after freeze-thaw cycles. Reductions in compressive strength were 17, 9, 4, 3, and 4 percent for 200 kg/m^3, 250 kg/m^3, 350 kg/m^3, 400 kg/m^3 and 500 kg/m^3 cement dosage after freeze-thaw cycles when compared to the samples that were not exposed, respectively. While the maximum reduction in compressive strength was occurred at the 200 kg/m^3 cement dosage, it showed the fluctuation for elasticity module and it changed between 6 and 11 percent (see Fig. 4 and Table 4). There was also a very good exponential relationship between elasticity module and compressive strength after freeze-thaw cycles. Since R^2 is 0.988, we can say that 98.8% of the variation in the values of elasticity module is accounted for by exponential relationship with compressive strength (See Fig. 6). Determination coefficient of the model was 0.994.

3.2. Effect of different pumice aggregate ratios on the unit weight, compressive strength and elasticity module of concrete before and after freeze-thaw

Table 5 and Fig. 1 shows that the density of concrete decreases with an increase in PA ratios (keeping slump at 3 ± 1, 5 ± 1 and 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 decreased 9, 25, 33, and 47 percent, 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 decreased 12, 23, 35, and 40 percent, respectively. This is probably due to the porous structure of PA. Fig. 2 shows the variation in compressive strength with PA ratios. The

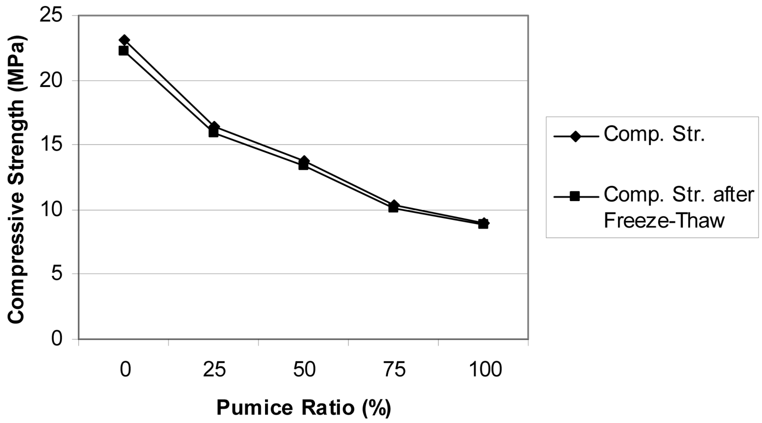


Fig. 7 Relationship between compressive strength and pumice ratio both normal conditions and after freeze-thaw for slump (3±1 cm) and 28-day

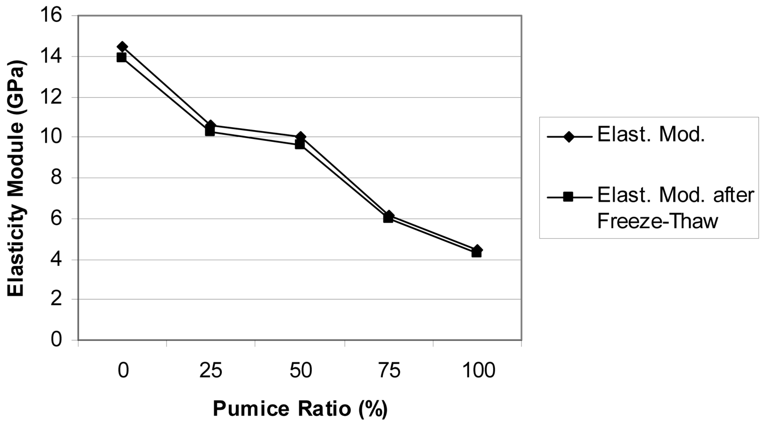


Fig. 8 Relationship between elasticity module and pumice ratio both normal conditions and after freeze-thaw for slump (3±1 cm) and 28-day

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, respectively, and this is the maximum reductions due to the PA ratio when compared to the other slumps (see Fig. 2). This is because of the weak structure of the PA. Compressive strength is a function of density. Many investigators (Demirboğa and Gül 2004, Sahin, *et al.* 1003, Faust 2000) reported that the compressive strength decrease with the reduction of the density. Fig 7 and 8 show the variation in compressive strength and Elasticity module with PA ratios before and after freeze-thaw.

The reductions induced by 0%, 25%, 50%, 75% and 100% PA replacement for normal aggregate by volume, on the elasticity module, were around 27, 31, 58, and 69 percent at 3 ± 1 cm slump, respectively. The modulus of elasticity of the lightweight concrete varied from 4 to 14.46 GPa before freezing and thawing cycles, which was very much lower than that of normal weight concrete.

After freeze-thaw cycles, it can be seen from Figs. 1-2 that the density of concrete decreases with the increase in pumice aggregate ratios (keeping the slump and cement content constant at 3±1 cm and 300 kg/m^3, respectively). While the control sample's density was 2170 kg/m^3, the density of concretes those made up of 25%, 50%, 75% and 100% pumice aggregate replacement for normal aggregate was 1968, 1631, 1448 and 1160 kg/m^3, respectively. Reduction in the density due to pumice aggregate was 9.3, 24.8, 33, and 46.5 percent for 25%, 50%, 75% and 100% pumice aggregate replacement, respectively. The same reduction value was occurred for both before and after freeze-thaw cycles. However, when we compare the same percentage of PA replacement with each other for before and after freeze-thaw cycle's negligible reductions were occurred after cycles. Uysal, *et al.* (2004) and Sahin, *et al*. (2003) reported similar results in their studies related to thermal conductivity and compressive strength. This may be due to the porous structure of pumice aggregate, which is the main cause of lightness.

Table 5 shows the variation in compressive strength after freeze-thaw cycles with pumice aggregate ratios. The effect of freeze-thaw cycles on the compressive strength reduction was around 4.24, 3.17, 3.11, 1.85 and 1.33 percent for 25%, 50%, 75% and 100% pumice aggregate replacement, respectively. Elasticity module is also reduced around 3 and 4 percent after freeze- thaw cycles of concrete.

3.3. Effect of Different Slumps on the unit weight, compressive strength and elasticity module before and after freeze-thaw:

The influence of the 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 the increase in slumps (keeping the cement dosage constant at 300 kg/m^3). The reason for this is that the difference among the slumps is so low, that the increment or reductions due to the 3 cm, 5 cm and 7 cm are as negligible as low or high. Pumice aggregate replacement caused reduction in density drastically. When pumice aggregate increased from 0% to 25%, 50%, 75% and 100% in the mixes at 3 (±1) cm slump value, density decreased 9, 25, 33 and 47 percent before freeze-thaw cycles, respectively. It can be seen from Table 4 that, the density of samples after freeze-thaw cycles for 3, 5 and 7 cm slumps decreased approximately 0.5, 0.8 and 0.8; 0.5, 0.7 and 0.7; 0.4, 0.7 and 0.7; 0.4, 0.6 and 0.6; 0.6, 0.5 and 0.5 percent at 0%, 25%, 50%, 75% and 100% PA replacement of normal aggregate, respectively. Fig. 2 shows the variation in the compressive strength due to the different slumps and pumice aggregate ratios. As it can be seen from Table 4 and Fig. 2 that increased of both PA ratio and slump decreased compressive strength. Reduction of compressive strength due to the PA ratio was much higher than that of slumps. Maximum reduction due to the PA ratio in compressive strength was 61, 52 and 48 percent at 3, 5 and 7 cm slumps, respectively.

As it can be seen from Table 4 that increased of both PA ratio and slump decreased elasticity module. Reduction of elasticity module due to the PA ratio was much higher than that of slumps. Maximum reduction due to the PA ratio in elasticity module was 69, 59 and 69 percent at 3, 5 and 7 cm slumps, respectively. The elasticity module of samples after freeze-thaw cycles for 3, 5 and 7 cm slumps decreased approximately 0.4, 0.6 and 0.7; 0.4, 0.5 and 0.7; 0.3, 0.5 and 0.6; 0.3, 0.4 and 0.5; 0.2, 0.3 and 0.5 percent at 0%, 25%, 50%, 75% and 100% PA replacement of normal aggregate, respectively. Compressive strength and elasticity modules reductions due to the slump are increased with an increase of the slump. Reductions due to slumps are decreased with the increase of pumice aggregate ratios (see Fig. 2). However, reductions due to the slumps are very low.

4. Conclusions

The density of the concrete increased with increase in cement dosage (keeping the slump constant at 3 ± 1 cm) and decreased with increase in pumice aggregate ratios. Density, compressive strength and elasticity module of the concrete decreased after freeze- thaw cycles. The effect of freeze-thaw cycles on the compressive strength of the tested concrete decreased with increase of pumice aggregate in the mixtures. Reduction in elasticity module was decreased with increase of cement dosage. Increasing of slump also causes the increase in reduction of compressive strength after freeze- thaw cycles. Reductions of compressive strength due to slump after freeze-thaw cycles is decreased with an increase of pumice aggregate ratio.

References

Aavik, J., and Chandra, S. (1995), "Influence of organic admixtures and testing method on freeze-thaw resistance of concrete", *ACI Mater. J.*, **92**, 10-14.

ACI 318-89: (1989), "Requirements for reinforced concrete", *ACI Mater. J.*, Detroit. Architectural Institute of Japan, Tokyo.

Bingöl, A. F. and Gül, R. (2004), "Compressive strength of lightweight aggregate concrete exposed to high temperatures", *Indian Journal of Engineering and Materials Sciences*, **11**, 68-72.

BS 8110: (1985), "Structural use of concrete: Part 1, Code for Practice for Design And Construction; Part 2, Code for Special Circumstances", British Standards Institution, London.

Cai, H. and Liu X. (1998), "Freeze-thaw durability of concrete: Ice Formation Process in Pores", *Cement Conc. Res.*, **20**(9), 1281-1287.

CEB/FIB (1978), *Model Code for Concrete Structures*, Vol. II, 3rd ed., *CEB,* Paris

Chandra, S., Aavik, J. and Berntsson, L. (1982), "Influence of polymer micro particles on freeze thaw resistance of structural lightweight aggregate concrete", *The International Journal of Cement Composites and Lightweight Concrete*, **4**(2).

Clarke, J.L. (1993), "Structural lightweight aggregate concrete", *Blackie Academic And Professional*, Glasgow, pp. 25-26.

Demirboga, R. and Gül, R. (2004), "Durability of mineral admixtured lightweight aggregate concrete", *Indian Journal of Engineering and Materials Science*, **11**, June, 201-206.

Demirboğa, R, Örüng, Y & Gül, R. (2001), "Effects of expanded perlite aggregate and mineral admixtures on the compressive strength of low-density concretes", *Cement Conc. Res.*, **31**, 1627-1632.

Detwiler, R.J., Dalgleish B.J., and Williamson R.B. (1989), "Assessing the durability of concrete in freezing and thawing", *ACI Mater. J.*, **86**, 29-35.

ENV 206: (1989), "Concrete-performance, production, placing and compliance criteria", *Final Draft*, February.

Erdoğan, T.Y. (1997), *Admixtures for Concrete*, Middle East Technical University Press, Ankara, TURKEY, 22, 89.

Eurocode No: (1991), "Design of concrete structures", Part 1: General Rules and Rules For Buildings, *Final Text*, October, EEC.

Eurocode No. 2, Part 1-4: (1992), "The use of lightweight aggregate concrete with closed structure", Draft, June, EEC.

Faust, T. (2000), "Properties of different matrix and LWAs their influences on the behavior of structural LWAC", *Second International Symposium on Structural Lightweight Aggregate Concrete*, 18-22 June. Kristiansand, Norway, pp. 502-511.

JASS 5 (1982): "Japanese Architectural standard for reinforced concrete"

Lydon, F.W. (1982), *Concrete Mix design*, 2nd ed., Applied Science, London.

Ramamurty, K. and Narayanan, N. (2000), "Factors influencing the density and compressive strength of aerated concrete", *Mag. Conc. Res.*, **52**(3), 163-167.

RILEM, (1975), *Terminology and definition of lightweight concrete*, Recommendation LC1, 1st ed., Brussels.

Sahin, R., Demirboğa, R., Uysal, H. and Gül, R., (2003), "The effects of different cement dosages, slumps, and pumice aggregate ratios on the compressive strength and densities of concrete", *Cement Conc. Res.*, **33**, 1245-1249.

Soroushian, P., Nagi, M., and Okwuegbu, A. (1992), "Freeze-thaw durability of lightweight carbon fiber reinforced cement composites", *ACI Mater. J.*, **89**(5).

Turgutalp, U. and Örüng, İ. (1992), "Effect of freezing and thawing on some properties of lightweight concretes", *Atatürk University Agriculture Faculty Journal*, **23**(2).

Türkmen, İ. and Kantarci, A. (2006), "Effects of expanded perlite aggregate and different curing conditions on the drying shrinkage of self-compacting concretes" *Indian Journal of Engineering and Materials Sciences*, **13**, 253-258.

Uysal, H., Demirboğa, R., Sahin, R. and Gül, R. (2004), "The effects of different Cement dosages, slumps, and pumice aggregate ratios on the thermal conductivity and density of concrete", *Cement Conc. Res.*, **34**, 845-848.

Wasserman, R. and Bentur, A. (1996), "Interfacial interactions in lightweight aggregate concretes and their influence on the concrete strength", *Cement Conc. Compo.*, **18**, 67-76.

Zhou, Y., Cohen, M. and Dolch, W.L. (1994), "Effect of external loads on the frost resistance properties of mortar with and without silica fume", *ACI Mater. J.*, **91**, 595-601.

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