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The effects of different cement dosages, slumps, and pumice aggregate ratios on the thermal conductivity and density of concrete

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Abstract

Thermal conductivity coefficients 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 thermal conductivity of concrete, 25%, 50%, 75%, and 100% pumice ratios were used in place of normal aggregate by volume, 200-, 250-, 350-, 400-, and 500-kg/m^3 cement dosages, and 3 ± 1-, 5 ± 1-, and 7 ± 1-cm slumps were used in this study. The analysis of the test results leads to the conclusion that PA decreased the density and thermal conductivity of concretes up to 40% and 46%, respectively. Increasing the cement dosage in the mixtures caused both density and thermal conductivity of the concrete to increase. The effect of slump on the density and thermal conductivity fluctuated.

Keywords: Pumice aggregate; Concrete; Thermal conductivity; Density

1. Introduction

Concrete of low thermal conductivity is useful for the thermal isolation of buildings [1]. Thermal conductivity of concrete increases with increasing cement content [2] and thermal conductivity of aggregate [3,4]. Bouguerra et al. [5] reported that the thermal conductivity of lightweight concrete changes considerably with porosity.

Steiger and Hurd [6] reported that when unit weight of concrete increased 1% due to the water absorption, the thermal conductivity of these specimens increases 5%. Thermal behavior of concrete is relevant to any use of concrete, especially in relation to structures where it is desirable to have low thermal conductivity, dimensional stability, high specific heat, and little or no decrease of stiffness upon heating. Although much work has been done on the effect of admixture and the mechanical properties of concrete, relatively little work has been done on the thermal conductivity [2,7–9].

Differences in the apparent density and the effective thermal conductivity of concretes arise from differences in their porosity. In other words, voids filled with air contribute nothing to the weight of concrete, while the overall conductivity of a porous concrete is the result of the thermal conductivity of the silicate structure and that of the air contained in it. It is for this reason that the thermal conductivity of concrete is related to its density [10]. Thermal conductivity of concrete increases with increasing moisture content. Since water has conductivity about 25 times that of air, it is clear that when the air in the pores has been partially displaced by water or moisture, the concrete must have greater conductivity [3,4,10–12].

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 Kocapınar region in Van-Erciş and Aras River in Erzurum in Turkey, respectively. The chemical composition and mechanical and physical properties of the materials used in this study are summarized in Tables 1 and 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 200, 250, 350, 400, and 500 kg/m^3 for a constant 25% PA + 75% normal aggregate and

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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	

3 ± 1 cm slump for evaluating the effect of cement dosage on the density and thermal conductivity. 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 for to determine the effect of PA on the mixtures density and thermal conductivity for 3 ± 1, 5 ± 1, and 7 ± 1 cm slumps, respectively. Hence, 20 different mixes were prepared and cast.

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 110 × 160 × 40-mm^3 prisms were prepared and moist-cured for 7 days and then removed from the moist room and stored in lime-saturated water at 20 ± 3 °C until the time of the testing. The specimens were dried at the age of 28 days in an oven at 110 ± 10 °C and weighed at 24-h intervals until the loss in weight did not exceed 1% in a 24-h (ASTM C 332). The specimens' surfaces were sandpapered before measuring their thermal conductivities.

A quick thermal conductivity meter based on ASTM C 1113-90 hot-wire method was used [13]. Variac (power supply) was used to supply constant electrical current to the resistance.

QTM 500 device is a product of Kyoto Electronics Manufacturing, Japan. Measurement range is 0.0116–6 W/mK. Measurement precision is ± 5% of reading value per reference plate. Reproducibility is ± 3% of reading value per reference plate. Measurement temperature is − 100 to 1000 °C (external bath or electric furnace for temperature other than room). Sample size required is two pieces of 100 × 80 × 40 mm thick or more ($W \times L \times H$). Measuring time is standard 100–120 s.

This method has wide applications [14–16] in determining thermal conductivity of refractory materials where, instead of measuring heat flow, the temperature variation with time at certain locations is measured. Being transient in nature, this method takes only a few minutes in contrast to the earlier methods involving steady-state conditions.

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
Density and thermal conductivity of different cement dosage

Cement dosage (kg/m^3)	200	250	350	400	500
Density (kg/m^3) (± 0.02)	1970	1990	2020	2030	2040
Thermal conductivity (W/mK) (± 0.05)	1.163	1.203	1.223	1.272	1.461

3. Results and discussion

3.1. Effect of cement dosages on the density and thermal conductivity

The influence of the cement dosage on the density of concrete is shown in Table 3. It can be seen from Table 3 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, thus increasing the cement dosage results in an increase in density.

Table 3 shows the variation in thermal conductivity with cement dosage. When cement dosage was increased from 200 to 250, 350, 400, and 500 kg/m^3, thermal conductivity increased 3.4%, 5.2%, 9.4%, and 25.6%, respectively. The thermal conductivity of concrete increases with increasing cement content [2]. Lu-shu et al. [17] experimentally formulated a correlation between the density and thermal conductivity and reported that the thermal conductivity increased with increasing density. Akman and Taş demir [18] and Blanco et al. [19] also reported that the thermal conductivity decreased due to the density decreasing of concrete (see Table 3).

Table 4
Density and thermal conductivity of different PA ratios

PA ratios (%)	0	25	50	75	100
Density (kg/m^3) (± 0.02)	2270	1990	1761	1504	1329
Thermal conductivity (W/mK) (± 0.05)	1.458	1.349	1.170	1.053	0.776

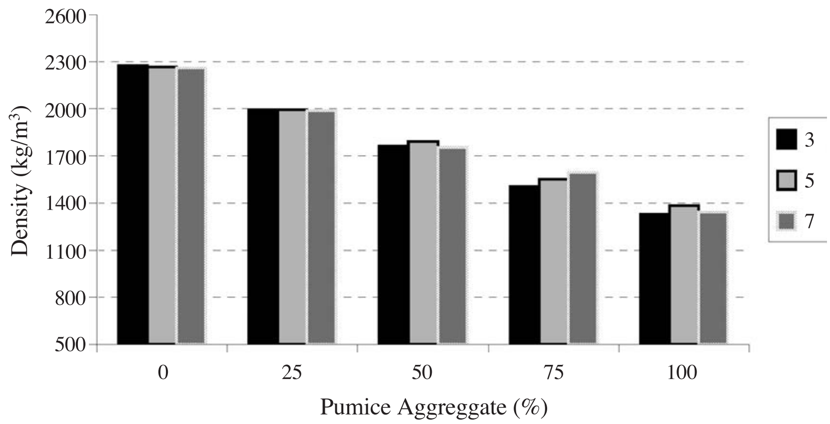

Fig. 1. Relation between PA ratio and density (± 0.02) for different slumps (± 1).

3.2. Effect of different PA ratios on the density and thermal conductivity

It can be seen from Table 4 that the density of concrete decreases with an increase in PA 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 2270 kg/m^3, the density of concretes that is made up of 25%, 50%, 75%, and 100% PA replacement for normal aggregate was 1990, 1761, 1504, and 1329 kg/m^3, respectively. Reduction in the density due to PA was 12.3%, 22.42%, 33.74%, and 41.5% for 25%, 50%, 75%, and 100% PA replacements, respectively. This is due to the porous structure of PA, which results in lightness.

Table 4 shows the variation in thermal conductivity with PA ratios. The effect of PA that replaced normal aggregate at 0%, 25%, 50%, 75%, and 100% by volume on thermal conductivity is approximately 7.5%, 19.8%, 27.8%, and 46.8%, respectively. This is explained as follows. The thermal conductivity is a function of density. Lu-shu et al. [17] reported the relationship between thermal conductivity and the density of lightweight concrete. They derived a correlation between the density and thermal conductivity for lightweight concrete experimentally and also reported that the thermal conductivity increased with increasing density. The lower density of lightweight concrete due to silica fume (SF) and fly ash (FA) is probably related to the higher air content that results in less density [7] and partly to the amorphous structure of SF and FA, as indicated in Ref. [8]. Additionally, Demirboğa [21,22], Akman and Taş demir [18], and Blanco et al. [19] also reported that the thermal conductivity decreased due to decreasing density of concrete, which results in an increase void content.

Demirboğa and Gül [23] reported that the thermal conductivity decreased because the density decreased with increasing FA and SF content instead of PC. Akman and Taş demir [18] concluded that the thermal conductivity decreased because the density decreased with increasing lightweight aggregate ratio instead of the traditional aggregate. Lu-shu et al. [17] experimentally formulated a correlation between the density and thermal conductivity and reported that the thermal conductivity increased with increasing density (see Table 2). Fu and Chung [7,20] also reported that latex (20–30% by weight of cement), methylcellulose (0.4–0.8% by weight of cement), and SF (15% by weight of cement) decreased the density of the cement paste and the reduction of the thermal conductivity of cement paste occurred due to the reduction of the density

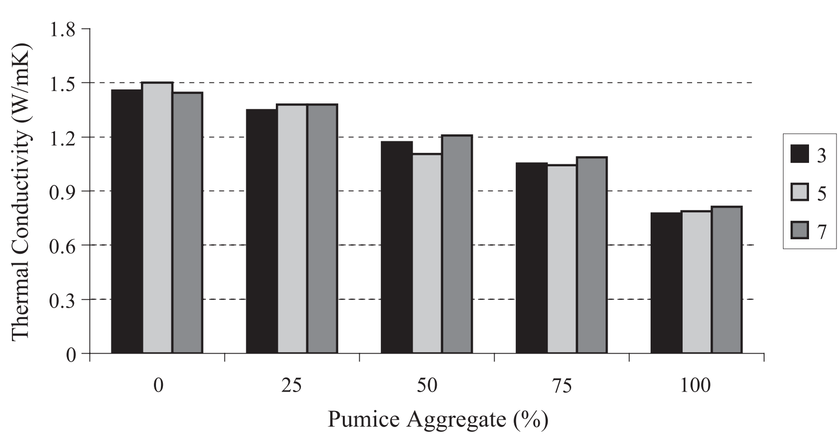

Fig. 2. Relation between PA ratio and thermal conductivity (± 0.05) for different slumps (± 1).

up to 46%. In our study, PA decreased thermal conductivity up to 46.8% due to the reduction of the density of concrete [5,18,19].

3.3. Effect of different slumps on the density and thermal conductivity

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). The reason for this is that the difference between the slumps is very low. In addition, the incremental reductions due to the 3-, 5-, and 7-cm slumps are negligible. PA replacement caused reductions in density drastically. Fig. 2 shows the variation due to the different slumps and PA ratios. Since the thermal conductivity is related to the density and the density fluctuated as described above, then the thermal conductivity also fluctuated.

4. Conclusion

The density of concrete increased with an increase in cement dosage (keeping the slump constant at 3 ± 1 cm). When cement dosage increased from 200 to 250 kg/m^3, 350, 400, and 500 kg/m^3, thermal conductivity was increased 3.4%, 5.2%, 9.4%, and 25.6%, respectively. PA decreased the density and thermal conductivity of concretes up to 40% and 46%, respectively. The effects of the different slumps on the density and thermal conductivity fluctuated.

References

[1] Y. Xu, D.D.L. Chung, Improving silica fume by using silane, Cem. Concr. Res. 30 (2000) 1305.

[2] R. Gül, H. Uysal, R. Demirboğa, Kocapınar Pomzası ile Üretilen Hafif Betonların ısı Ýletkenliklerinin Araştırılması (Investigation of the thermal conductivity of lightweight concrete made with Kocapınar's pumice aggregate), Advances in Civil Engineering: III. Technical Congress, vol. 2, METU, Ankara, Turkey, 1997, pp. 553–562 (in Turkish).

[3] T. Ashworth, E. Ashworth, Insulation Materials: Testing and Applications, in: R.S. Graves, D.C. Wysocki (Eds.), ASTM Special Technical Publication, vol. 1116, ASTM, Philadelphia, PA, 1991, pp. 415–429.

[4] FIP State of Art Report, Principles of Thermal Insulation with Respect to Lightweight Concrete, FIP/8/1, C and CA, Slought, England (1978).

[5] A. Bouguerra, A. Ledhem, F. de Barquin, R.M. Dheilly, M. Queneudec, Effect of microstructure on the mechanical and thermal properties of lightweight concrete prepared from clay, cement, and wood aggregate, Cem. Concr. Res. 28 (8) (1998) 1179–1190.

[6] R.W. Steiger, M.K. Hurd, Lightweight insulating concrete for floors and roof decks, Concr. Constr. 23 (7) (1978) 411–422.

[7] X. Fu, D.D.L. Chung, Effects of silica fume, latex, methylcellulose, and carbon fibers on the thermal conductivity and specific heat of cement paste, Cem. Concr. Res. 27 (1997) 1799–1804.

[8] K. Onaran, Malzeme Bilimi (Materials Science), Science Technical Press, İstanbul, Turkey, 1993, p. 174 (in Turkish).

[9] P. Chen, D.D.L. Chung, Effect of polymer addition on thermal stability and thermal expansion of cement, Cem. Concr. Res. 25 (1995) 465.

[10] A. Short, W. Kinniburg, Lightweight Concrete, Great Britain, Galliard, Great Yormouth, 1978.

[11] U. Schnider, Behavior of Concrete at High Temperatures Heft 337, Deutscher Aussehuss für stahlbeton, Berlin, 1982.

[12] P. Morabito, Measurement of thermal properties of different concretes, High Temp., High Press. 21 (1) (1989) 51–59.

[13] ASTM C 1113-90, Test Method for Thermal Conductivity of Refractories by Hot Wire (Platinum Resistance Thermometer Technique).

[14] W.R. Daire, A. Downs, The hot wire test—a critical review and comparison with B 1902 panel test, Trans. Br. Ceram. Soc. 79 (1980) 44.

[15] J.C. Willshee, Comparison of thermal conductivity methods, Proc. Br. Ceram. Soc. 29.

[16] K. Sengupta, R. Das, G. Banerjee, Measurement of thermal conductivity of refractory bricks by the nonsteady state hot-wire method using differential platinum resistance thermometry, J. Test. Eval., JTEVA 29 (6) (1992) 455–459.

[17] K. Lu-shu, S. Man-qing, S. Xing-Sheng, L. Yun-xiu, Research on several physico-mechanical properties of lightweight aggregate concrete, Int. J. Lightweight Concr. 2 (4) (1980) 185–191.

[18] M.S. Akman, M.A. Taşdemir, Taşiyici Malzeme Olarak Perlit Betonu (Perlite Concrete as a Structural Material), 1st National Perlite Congress, Ankara, Turkey.

[19] F. Blanco, P. Garcia, P. Mateos, J. Ayala, Characteristics and properties of lightweight concrete manufactured with cenospheres, Cem. Concr. Res. 30 (2000) 1715–1722.

[20] X. Fu, D.D.L. Chung, Effect of admixtures on the thermal and thermomechanical behavior of cement paste, ACI Mater. J. 96 (4) (1999) 455–461.

[21] R. Demirboğa, Influence of mineral admixtures on thermal conductivity and compressive strength of mortar, Energy Build. 35 (2) (2003) 189–192.

[22] R. Demirboğa, Thermo-mechanical properties of sand and high volume mineral admixtures, Energy Build. 35 (5) (2003) 435–439.

[23] R. Demirboğa, R. Gül, The effects of expanded perlite aggregate, silica fume and fly ash on the thermal conductivity of lightweight concrete, Cem. Concr. Res. 33 (5) (2003) 723–727.