МОДЕЛИРАНЕ НА ДИНАМИЧНОТО ПОВЕДЕНИЕ НА МНОГОМАСОВИ КОНСТРУКЦИИ С ПОМОЩТА НА КРАЙНИ ЕЛЕМЕНТИ

EFFECT OF ATMOSPHERIC PRESSURE STEAM CURING UPON MECANICAL PROPERTIES OF LIGHTWEIGHT CONCRETE PRODUCED WITH ERZURUM √ PASİNLER PUMICE

ВЛИЯНИЕ АТМОСФЕРНОГО ДАВЛЕНИЯ ПАРА ОТВЕРДИТЕЛЕМ К МЕХАНИЧЕСКИЕ СВОЙСТВА ЛЕГКИХ БЕТОНОВ СОЗДАН ПРИ ERZURUM – PASİNLER ПЕМЗА

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Abstract: *In this study, some physical and mechanical properties of lightweight aggregate concrete (LWAC) produced with pumice aggregate and cured in atmospheric pressure steam were investigated. For this purpose, concrete specimens with 400 kg/m^3 constant dosage and 3±1 cm constant slump were produced by using pumice at 100%, obtained from Pasinler region in Erzurum/Turkey. Standard water curing and air curing for duration of 7, 14, and 28 days, and steam curing for duration of 8, 12 and 16 hours at temperature of 60, 70 and 80^{o}C after delay period of 4 hours were applied to specimens. As a result, unit weight, compressive strength, flexural strength, and ultrasonic pulse velocity values of LWAC increased when curing period increased for the air and water curing. Increases were observed at these properties of steam curing specimens as increased curing temperatures and periods for the very shorter time. Moreover, an exponential relationship was determined between the unit weight and thermal conductivity of LWAC.*
Keywords: LIGHTWEIGHT CONCRETE, PUMICE, ATMOSPHERIC PRESSURE STEAM CURING, COMPRESSIVE STRENGTH, FLEXURAL STRENGTH, ULTRASONIC PULSE VELOCITY, THERMAL CONDUCTIVITY

1. Introduction

Lightweight aggregates, such as natural (pumice, diatomite, and from volcanic source) or artificial (expanded perlite, shale, slate), are available in many parts of the world and can be used in producing concrete in a wide range of unit weights and suitable strength values for different fields of applications such as internal and external walls, inert leaves of external cavity walls, in the fill panels, and isolation of roof decks and floors [1,2].

Pumice is a natural material of volcanic origin produced by the release of gases during the solidification of lava and it has been used as aggregate in the production of lightweight concrete in many countries of the world. So far, the use of pumice was dependent on the availability and limited to the countries where it is locally available or easily imported [3,4]. Approximately, 7.4 billion m^3 (40%) of the total 18 billion m^3 of pumice reserve is located in Turkey. Besides, the other reserves are located in Italy, Greece, Germany, USA, Mexico, France, Iceland, China, Canada, New Zealand and Indonesia [5]. Besides, masonry blocks from pumice lightweight aggregate have been produced in Turkey and these blocks are cured in air at least until 7 d to gain the required strength [6]. In this study, it was aimed to present in least time the service of LWC produced with PA by steam curing.

The hardening process and strength-gaining rate of concrete under normal conditions are slow; they affect the production rate of concrete plants. Therefore, it is beneficial to provide a desired strength level for concrete in a short time by accelerating its hardening process using various methods. Heat treatment is among the methods widely used for this purpose [7]. Thus, precast concrete elements are used increasingly in construction to improve the quality of concrete production and to reduce the construction time various techniques can be employed for heating concrete with low pressure steam curing being commonly used in practice despite heat curing being used widely in the precast industry to speed up production investigations on heat-cured products focused mainly on their strength development. Research on durability of heat-cured products, particularly on mixes incorporating mineral admixtures, is somewhat limited [8].

The term “curing” is frequently used to describe the process by which hydraulic cement concrete matures and develops hardened properties overtime as a result of the continued hydration of the cement in the presence of sufficient water and heat. While all concrete cures to varying levels of maturity with time, the rate at which this development takes place depend on the natural environment surrounding the concrete, and the measures taken to modify this environment by limiting the loss of the water, heat or both from the concrete or by externally providing moisture and heat. The word “curing” is also used to describe the action taken to maintain moisture and temperature conditions in a freshly placed cementitious mixture to allow hydraulic- cement hydration and if applicable pozzolanic reactions to occur so that the potential properties of the mixture may develop. There are many methods that can be used for curing of concrete. These can be divided into three main groups namely, air curing; which includes sealed curing fogging, etc., water curing and steam curing; which includes atmospheric (low pressure) steam curing and autoclave (high pressure) steam curing [8]. The steam curing will be used as atmospheric or low pressure steam curing throughout this paper.

Steam curing is widely used in the production of pre-cast concrete members because it accelerates the rate of strength development. Some pre-cast concrete plants apply steam curing immediately after casting the elements in the formwork in order to speed up the production rate [9]. Steam curing is a heat treatment which has been used for many years to accelerate the strength development of concrete products. Because the hydration rate of cement increases with the increase in temperature, the gain of strength can be speeded up by curing concrete in steam. For compressive strength development of concrete, duration of steam curing is also an important parameter as well as temperature [10,11].

Maximum curing temperatures may be anywhere in the range of 40 to 100^{o}C. However, the optimum temperature has been found in the range of 65 to 85^{o}C. The curing temperature will be a compromise between rate of strength gain and ultimate strength, because the higher the curing temperature, the lower the ultimate strength [8,10].

There is wealth information in literature related to effect of steam curing on variable type of concretes except for pumice aggregate lightweight concrete. The results of this study may be useful to investigate the utilization of steam curing in lightweight and prefabricated concrete technology.

2. Materials and experimental study

The ASTM D 75, ASTM C 136 and ASTM C 29 were used for sampling, grading, unit weight and fineness modulus of aggregates, respectively. Maximum size of pumice aggregate (PA) was 16 mm. The general properties of PAs in Turkey and some properties of PA used in this study are given Table 1 and 2, respectively. Portland cement (PC), CEM II 42.5 from Aşkale; Erzurum in Turkey was used in this study. A melamine sulphonate polymer based water reducing plasticizing agent is used as super plasticizer (SP) for workability in all concrete mixes. The chemical, physical and mechanical properties of PC are given in Table 3 and 4.

Table 1. General properties of PAs in Turkey

Chemical Properties	%
SiO_2	52 – 75
Al_2O_3	11 – 17
Fe_2O_3	0.5 – 5.0
CaO	1 – 8
MgO	0.5 – 3.0
$Na_2O + K_2O$	3 – 9
TiO_2	< 1
SO_3	< 1
Ignition loss	1 – 3
Physical and Mechanical Properties	
Porosity (n) (%)	45 – 70
Hardness (MOHS)	5.5 – 6,0
Water absorption (%)	30 – 70
Bulk density (g/cm^3)	0.32 – 0.97
Specific gravity (ρ) (g/cm^3)	1.90 – 2.65
Thermal conductivity (λ) (k.cal/m.h.°C)	0.12 – 0.20
Sound insulation (R) (dB)	40 – 55
Steam diffusion (η)	5 – 10
Compressive strength (σ) (kg/cm^2)	16 – 30

Table 2. Some properties of PA used in this study

Properties	Grain size (mm)				
	0 – 2	2 – 4	4 – 8	8 – 16	0 – 16
Bulk density (kg/m^3)	667	547	509	453	605
Specific gravity (g/cm^3)	1.46	1.02	0.88	0.84	–
Specific gravity factor (wet situation, 10 min)	1.73	1.39	1.07	0.95	–
Water absorption (%)	17	29	33	30	–
Natural moisture (%)	2.73	4.71	3.56	1.02	–
Natural grading (%)	31	15	35	17	98
Regulated grading (%)	25	25	25	25	100

Table 3. Chemical properties of PC (%)

SiO_2	20.56
Al_2O_3	5.01
Fe_2O_3	2.25
CaO	56.38
MgO	3.01
SO_3	2.28
Na_2O	0.39
K_2O	0.59
Cl	0.0169
Free CaO	1.21
Additive (%)	26.91

Table 4. Physical and mechanical properties of PC

Physical Properties		
Fineness (> 0,09 mm, %)		0.4
Specific gravity (g/cm^3)		2.99
Specific surface (cm^2/g)		4406
Initial set (hour – minute)		2 – 48
Final set (hour – minute)		3 – 48
Volume expansion (mm)		1
Water necessity (%)		29.6
Mechanical Properties		
Compressive Strength (MPa)	2th day	20.8
	7th day	31.7
	28th day	47.7
Flexural Strength (MPa)	2th day	3.9
	7th day	5.8
	28th day	7.3

The concrete specimens were prepared with 400 Kg/m^3 constant dosage and 3±1 cm constant slump using 100% of PA. The amounts of materials in concrete mix and some fresh properties are summarized in Table 5. Three series of specimens were prepared for water, air and steam curing. At the end of curing treatment, the water and air curing specimens are tested at 7, 14 and 28th day. Also, the steam curing specimens are tested after steam curing treatment for delay period of 4 h and curing period of 8, 12 and 16 h at maximum temperature of 60, 70 and 80^{o}C. Thus, totally 33 specimen series were prepared as 3 numbers for water curing, 3 numbers for air curing and 27 numbers for steam curing.

Table 5. Proportion of concrete mixture for volume of 1 m^3

Component and properties of fresh concrete		Volume quantity (dm^3)	Weight quantity (kg)
Dosage of PC (CEM II/B–M 42.5 N)		137	413
Water content		160	160
Air content		30	–
Super plasticizer admixture (1,5% of cement dosage)		5.083	6.198
Pumice aggregate (natural moisture)	0 – 2 mm	167	288
	2 – 4 mm	167	231
	4 – 8 mm	167	178
	8 – 16 mm	167	158
Total		1000	1434

During the delay period, the specimens were covered with a wet cloth and kept at 20±2 ^{o}C. At the end of the delay period, the temperature within the curing chamber was increased to maximum temperature at a rate of approximately 20±5 ^{o}C/h and the specimens were subjected to steam curing at constant temperature for steaming period. Then, they were allowed to cool down to the ambient temperature (20±2 ^{o}C) at a rate of approximately 20±5 ^{o}C/h. Details of curing treatment applied to steam curing specimens are summarized in Table 6.

Table 6. The cycle characteristics of steam curing

Max. curing Temp. (^{o}C)	Delay period		Heating period		Steaming period		Cooling period		Total time (h)
	Temp (^{o}C)	Time (h)	Temp (^{o}C)	Time (h)	Temp (^{o}C)	Time (h)	Temp (^{o}C)	Time (h)	
60	20±2	4	60±2 ↑ 20±2	2	60±2	8	60±2 ↓ 20±2	2	16
						12			20
						16			24
70	20±2	4	70±2 ↑ 20±2	2,5	70±2	8	70±2 ↓ 20±2	2,5	17
						12			21
						16			25
80	20±2	4	80±2 ↑ 20±2	3	80±2	8	80±2 ↓ 20±2	3	18
						12			22
						16			26

In this study, the concrete specimens were used in Ø100 x 200 mm for unit weight, compressive strength, UPV tests, and beam specimens were prepared in 70 x 70 x 280 mm prismatic shape for flexural strength and thermal conductivity. The steam curing treatment was applied to specimens appropriately schematic representation of the heat treatment procedure. That procedure is shown Figure 1.

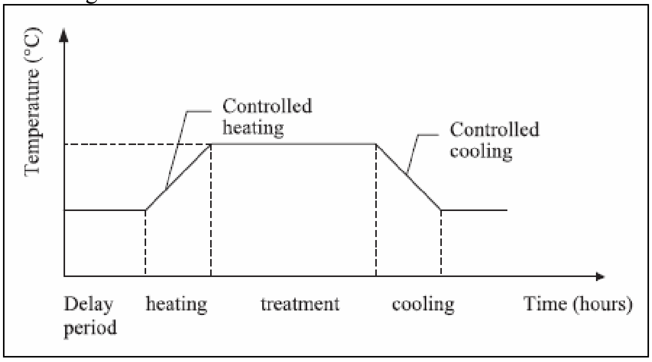

Fig.1. Schematic representation of the heat treatment procedure [10]

3. Results and discussion

The test results of specimens for unit weight, compressive strength, flexural strength, UPV and thermal conductivity after the treatment of water, air and steam curing are presented in Table 7, totally.

Table 7. Test results of concrete specimens after the treatment of water, air and steam curing

Curing Type		Symbol (°C-h)	Unit Wight (kg/m^3)	Compressive Strength (Mpa)	Flexural Strength (Mpa)	UPV (m/s)	Thermal Conductivity (W/mK)
Steam Curing at temp. of	60 °C	60-8	1087	15.6	4.75	2817	0.3014
		60-12	1111	17.8	5.40	3162	0.3226
		60-16	1130	20.1	5.92	3293	0.3410
	70 °C	70-8	1092	16.0	4.89	2872	0.2997
		70-12	1122	18.5	5.70	3331	0.3307
		70-16	1146	21.0	6.38	3512	0.3554
	80 °C	80-8	1102	16.3	4.92	2953	0.3085
		80-12	1135	19.2	5.81	3544	0.3424
		80-16	1160	21.9	6.40	3783	0.3639
Water Curing		W-7	1104	17.4	5.19	3147	0.3392
		W-14	1206	21.3	6.48	3864	0.3736
		W-28	1272	23.8	7.17	4265	0.4192
Air Curing		A-7	1039	13.1	3.96	2589	0.2824
		A-14	1094	16.2	4.83	3056	0.3201
		A-28	1136	18.1	5.41	3342	0.3484

According to results obtained from experiments, the unit weight of specimens was changed between 1039 and 1272 kg/m^3. Likewise, minor and major values of compressive strength, flexural strength, UPV, thermal conductivity of specimens were measured as 13.1 and 23.8 MPa, 3.96 and 7.17 MPa, 2589 and 4265 m/s, 0.2824 and 0.4192 W/mK at air curing for 7 days and water curing for 28 days, respectively.

The results showed that; when curing period increased for water and air curing, unit weight, UPV, thermal conductivity, compressive and flexural strength values increased. The relationship between compressive strength and curing period for water and air curing is shown in Figure 2.

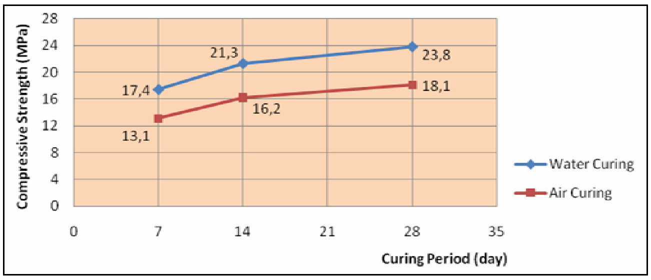

Fig.2. The relationship between compressive strength and curing period for water and air curing

According to ACI 213R and ASTM C330; the LWCs are accepted as structural LWC, had unit weight of 1840 kg/m^3 and compressive strength of 17 MPa [12]. In this study, LWC produced with pumice aggregate may be also accepted as structural LWC, since the lower compressive strength and unit weight values were obtained as 23.8 MPa and 1272 kg/m^3 at water curing for 28 ages, respectively.

Test results indicate that maximum values of unit weight, UPV, thermal conductivity, compressive and flexural strength were obtained from water curing for 28 ages. The major values of these properties at steam curing were obtained at maximum temperature of 80^{o}C and steaming period of 16 h. Besides, these values were higher from that obtained at air curing for 7, 14 and 28 ages.

The results of specimens exposed to steam curing showed that; when maximum temperature and steaming period increased, values of unit weight, UPV, thermal conductivity, compressive and flexural strength increased. Besides, the higher values for these properties were obtained at steam curing for all curing temperatures and periods than at air curing for 7 ages. But, either values of compressive strength or other properties of specimens exposed to steam curing were lower than properties of specimens exposed to water curing for duration of 28 d. This determination may be explained with; during the heating stage, the differences in the thermal expansion coefficient of the concrete ingredients can lead to micro-cracking and increased porosity [9].

The improving of compressive strength for water, air and steam curing showed in Figure 3.

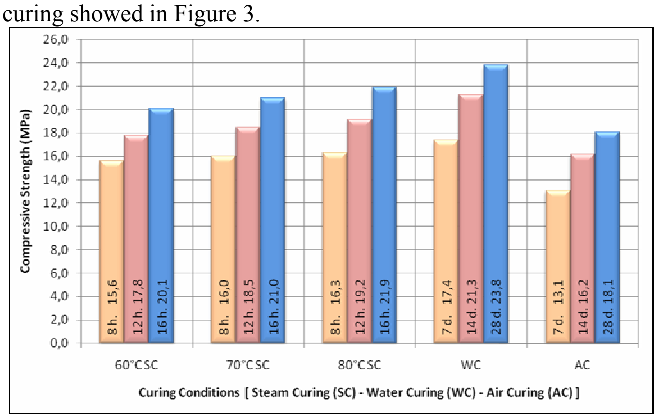

Fig.3. The improving of compressive strength for steam, water and air curing conditions

In this study, finally; an exponential relationship was determined between the unit weight and thermal conductivity of LWAC, exposed to water curing for 28 ages. For this relationship, ACI Committee 213R-03 [14] has recommended an equation to obtain thermal conductivity (**λ**) of structural LWC related with its dry unit weight (**w**) as follows:

(1) $$\lambda = 0.08640\, e^{0.00125\, w}$$

The curves were obtained for experimental and ACI 213R-03 depending on unit weight and thermal conductivity. They are shown in Figure 4.

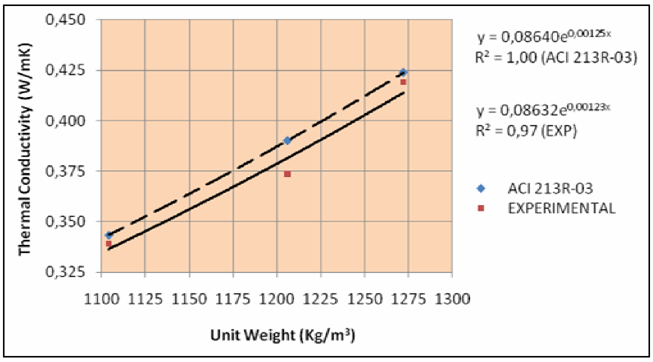

Fig.4. Relationship between unit weight and thermal conductivity of LWC

As seen from Figure 4, there is a little difference between both the curves. The exponential curve for experimental remained under of the exponential curve for ACI 213R-03. Nevertheless, may be said that; there was a good relationship between thermal conductivity (**λ**) and unit weight (**w**) in experimental results (R = 0.97). For the moderate strength LWC, the following equation can be proposed:

(2) $$\boldsymbol{\lambda = 0.08632\ e^{0.00123\ w}}$$

4. Conclusion

The compressive strengths obtained from specimen series of 60–16, 70–16, 80–12 and 80–16 for steam curing reached to 84.5, 88.2, 80.7 and 92% of compressive strength obtained from water curing for 28 ages. In also air curing for 28 ages, this percentage was 121% as maximum. Such that, compressive strength of concrete must be reached to 50% of strength at water curing for 28 ages to take out cast and 80% of that to transport and montage [13]. And the masonry blocks from pumice lightweight aggregate have been produced in Turkey and these blocks are cured in air at least until 7 days to gain the required strength [6]. When these determinations consider, steam curing treatment for this temperatures and periods may be useful and economic on account of time saving.

5. References

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