Available online at www.sciencedirect.com
ScienceDirect
Building and Environment 42 (2007) 4108–4116
BUILDING AND ENVIRONMENT
www.elsevier.com/locate/buildenv

Properties of autoclaved lightweight aggregate concrete

İlker Bekir Topçu[a], Tayfun Uygunoğlu[b,*]

[a]Department of Civil Engineering, Engineering Faculty, Eskişehir Osmangazi University, 26480 Eskişehir, Turkey
[b]Construction Department, Technical Education Faculty, Afyon Kocatepe University, 03200 Afyonkarahisar, Turkey

Received 16 September 2005; received in revised form 8 November 2006; accepted 30 November 2006

Abstract

Many researches have been carried out on production and properties of pre-cast concretes. Currently, most of them have focused on normal concrete, and are unable to completely represent the behavior of lightweight concrete (LWC). In this study, physical and mechanical properties of LWC produced with diatomite and pumice lightweight aggregates after autoclave curing were investigated. In the production of LWC, 0–4 mm maximum sizes of aggregates were used. Cement content and water/cement ratio were kept at 300 kg/m^3 and 0.20, respectively. The specimens were prepared in $\varnothing 50 \times 100$ mm cylindrical shape, and after 24 h of demoulding exposed to autoclave curing for 2, 4, 6, 8 and 10 h. Besides, two different cures were applied on the specimens as in water and in air at 20 °C ± 2, respectively. At the end of autoclaving and environmental cure, compressive strength in 7, 28 and 590 d, unit weight, specific porosity, thermal conductivity and water absorption were tested. Also, microstructures of LWC produced with diatomite and pumice aggregate were investigated. As a result, it is concluded that by autoclaving of specimens in 8–10 h, especially, compressive strength of specimens have increased 75% of strength of 28 aged specimens cured in water.
© 2007 Elsevier Ltd. All rights reserved.

Keywords: Pumice; Diatomite; Aggregate; Lightweight concrete; Autoclaving

1. Introduction

High temperature has significant effect on ultimate strength of concrete, and curing at moderately high temperature increases early strength of concrete. The temperature of curing and the duration of moist curing are the key factors for proper curing of concrete. The loss of moisture in the capillary pores due to evaporation or dissipated hydration may cause reduction in hydration resulting in lower strength. The moist cured samples give higher compressive strength than dry cured samples of concrete [1–3].

Strength development of concrete at early age is often inadequate for prefabrication purposes since the hardening process and strength-gaining rate of concrete under normal curing conditions are rather slow. Keeping track of mould rotation as fast as possible is of great importance, particularly for the prefabrication industry in order to maintain low-cost production by accelerating the hardening and strength-gaining process of concrete [4]. With the aim of satisfying increasing accommodation demands economically and in a short period of time, various methods have been developed to accelerate the strength gain of lightweight concrete (LWC). Factors such as material properties, concrete composition, concrete replacement and compaction factor, and geometric dimensions of building element, cure cycle and curing conditions affect early-strength gain along with the heat-treatment applications [5–7].

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 [8]. 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

*Corresponding author. Tel.: +90 272 2281312/228; fax: +90 272 2281319.
E-mail address: uygunoglu@aku.edu.tr (T. Uygunoğlu).

0360-1323/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.buildenv.2006.11.024

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 [9–11].

The production of lightweight aggregate concrete (LWC) has been expanding, and now includes all types—from no-fines concrete of low density, mainly for block production with densities from 300 to 1200 kg/m^3, to structural concrete with densities from 1000 to 2000 kg/m^3 and compressive strengths from 1 to 100 MPa. The production of all types of concrete is closely connected to the availability of lightweight aggregate, and economics dictate the use of LWC in place of normal weight concrete. LWCs are of various types, depending upon the composition of the mortar matrix and the aggregates used. The properties of the aggregates also vary significantly depending upon the raw materials used for making them and the technique adopted to produce them [7,12].

Lightweight aggregates, (LWA) 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 [13,14]. The essential characteristic of LWA is its high internal porosity, which results in a low apparent specific gravity. Since the lightweight particles of coarse aggregate are relatively weak, their strength may be the limiting factor affecting concrete strength [15].

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 LWC in many countries in 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 [16]. Similar to pumice, diatomite is used in the production of low-strength LWC for thermal insulation [17]. Diatomite is a siliceous sedimentary rock, which consists principally of fossilized skeletal remains of diatoms, unicellular aquatic plants related to algae. These microscopic plants have the unique capability of extracting silica from water to produce their skeletal structure. Diatomite is commonly found in volcanic environments, with the deposits forming in lakes in volcanically active areas. It is very finely porous and very low in density. There are a large number of diatomaceous deposits in Afyonkarahisar/Turkey [18,19].

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. In this study, it was aimed to present in least time the service of LWC produced with pumice and diatomite by curing in autoclave.

2. Experimental program

2.1. Materials

The diatomite was supplied from Seydiler—Afyon region in Turkey, and volcanic pumice from Isparta/Turkey region was used for this study. Particle density and bulk density of pumice and diatomite were 2.2 and 2.45, 910 and 540 kg/m^3, respectively. Ordinary Portland cement (CEM I 42.5R) was used for the production of the LWC mortars. Surface area by Blaine, specific gravity and 28 d compressive strength of cement were 386 m^2/kg, 3.07 and 48.5 MPa, respectively. The chemical analyses of materials used in this study were determined in Acme Analytical Laboratories Ltd. in Canada and results are given in Table 1. The size of the diatomite and pumice aggregates used was 0–4 mm. Sieve analyses of diatomite and pumice aggregates are given in Table 2. Autoclave which can supply 0.15 MPa pressure and 127 °C heat in 25 min was used for curing of the specimens (Fig. 1).

2.2. Mix proportions and test program

The mixtures, in the production of the samples, were designed at 300 kg/m^3 cement content. The actual water/cement ratio of mixtures was kept at 0.20 and the diatomite and pumice aggregates were absorbed in water in 30 min before adding the mix because of high porosity of aggregates [20]. The aggregates were added in the mix by compacted saturated bulk density (CSBD). The CSBD of pumice and diatomite were 930 and 580 kg/m^3, respectively. In the mixes, superplasticizer was used in 1%. Solid content and density of admixture were 22% and 1.1, respectively. The prepared mortar as damped was filled in $\varnothing 50 \times 100$ mm cylindrical moulds by tamping in 20% compression ratio. The specimens immediately demoulded and a part of them were exposed to autoclaving at 2, 4, 6, 8 and 10 h after 24 h. Details of a satisfactory cycle of autoclaving would consist of the following: pre-waiting period of 24 h, heating at the rate of 25 min to a maximum temperature of 127 °C, then storage at maximum temperature (treatment), and finally a cooling period. Later, the

Table 1
Chemical analyses of cement, diatomite and pumice

Component (%)	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	SO_3	K_2O	A.K.
Diatomite	67.20	10.09	2.74	0.63	1.36	0.36	—	0.67	8
Pumice	59	16.6	4.8	1.8	1.8	5.2	—	5.4	1.6
Cement (CEM I 42.5R)	19.3	5.57	3.46	0.86	63.56	0.13	2.91	0.80	2.78

Table 2
Sieve Analyses of diatomite and pumice lightweight aggregate

Sieve	4 mm	2 mm	850 μm	425 μm	250 μm	180 μm	150 μm	75 μm
Diatomite, passing (%)	100	72.88	46.19	27.74	21.55	16.74	10.63	3.77
Pumice, passing (%)	100	40.34	6.2	5.2	5.16	5.03	4.9	4.28

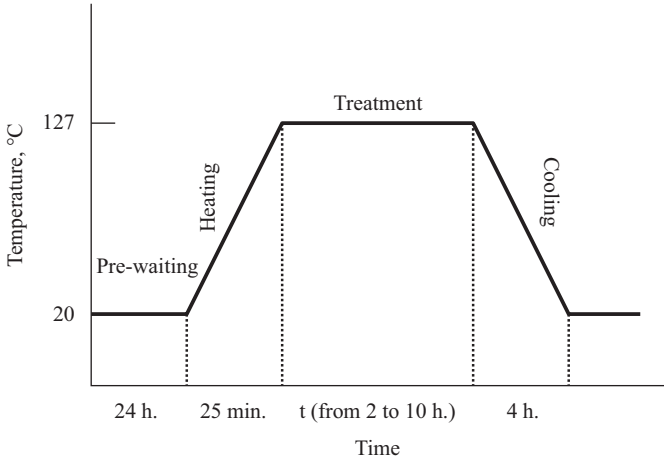


Fig. 1. Heat-treatment cycle of autoclave.

specimens were waited to room temperature. The other part of the specimens was cured in air (A) and in water (W) until 7 and 28 ages, respectively. Then, all the specimens were cured in air until 590 d. On the specimens, compressive strength was defined according to TS EN 12390-3 [21] by 2000 kN compressive machine with a rate of loading controller. The thermal conductivity of specimens was determined by the "hot wire method" according to ASTM C1113 [22] on the autoclaved and aged 28 d specimens cured in A and W. Unit weight (UW), specific porosity (SP) and water absorption (WA) were calculated for 7 and 28 d aged specimens according to Archimedes principle by the weight measurements of saturated specimens in air and in water, and dry weight (oven drying at 105 °C to constant weight). Besides, microstructure of specimens that cured in air until 28 d was investigated by SEM. Freshly fractured surfaces of LWC chips were coated with gold in a vacuum evaporator. They were examined using a LEO VP-1431 scanning electron microscope (SEM) to determine aggregate–cement matrix interfacial zone.

On the other hand, relationship between maturity factor and compressive strength was determined for autoclaved specimens. For determination of maturity factor, classical maturity formulas were used [9,19,23,24].

3. Results and discussion

LWC has very important usage area such as internal and external walls, inner leaves of external cavity walls, fill panels and isolation of roof decks and floors. Also, LWC is produced as masonry blocks in Turkey. Hence, it must be used in the constructions as soon as produced. Because diatomite and pumice have both high pore structure and are lightweight, they are used as lightweight aggregate in the production of LWC for supplying high insulation and reducing the dead weight in the structure [14]. In this study, how to present the service of LWC as soon as produced has been investigated. The physical and mechanical properties of LWC produced with diatomite (DLWC) and pumice (PLWC) are given in Table 3 according to curing time.

As seen in Table 3, SP and WA of PLWC cured in autoclave have decreased by increasing of curing time, and the lowest SP and WA values were obtained in 8 h autoclaving time as 12.1% and 8.1%, respectively. However, the SP and WA values of PLWC cured in environment at 7 and 28 ages have ranged between 26.1–28.3% and 17.8–18.9%, respectively. The SP and WA of PLWC cured in autoclave have lower value than PLWC cured in both water and air at 7 and 28 ages. On the other hand, the lowest SP and WA values of DLWC that cured in autoclave were obtained as 59.9% and 65.5%, respectively. These values were changed between 64% and 74.9% for DLWC cured in both air and water. As well as PLWC, SP and WA of 8 h autoclaved DLWC have lower values than DLWC that cured in environment. Besides, because diatomite aggregates are more porous materials than pumice aggregates (PA), DLWC has higher SP and WA values than PLWC.

Figs. 2 and 3 show the unit weight of PLWC and DLWC specimens related to curing time. As seen in both figures, unit weight of PLWC and DLWC has not changed the increase of curing time. Dry unit weight of PLWC that cured in air, water and autoclave was 1500 kg/m^3. Only, unit weight of 8 h autoclaved specimens has increased a bit, but it was not as much as 1600 kg/m^3. On the other hand, DLWC that cured in air, water and autoclave has 900 kg/m^3 unit weight. The unit weight of DLWC has changed neither curing in both water and air nor autoclaving time in 2–10 h. The density of LWC depends upon the raw material used for making them. Unit weight of PLWC was higher than DLWC because of high porosity of diatomite aggregate. LWCs with intermediate densities varying from 800 to 1350 kg/m^3 are extensively used in precast blocks for load-bearing and heat-insulating walls [6].

As known from the literature, thermal conductivity depends upon the pore structure of the lightweight aggregates, density of concrete and the cement paste matrix. In other words, the thermal conductivity increases with increase of density of concrete. Also, according to Kim et al. [25], aggregate volume fraction and moisture

Table 3
Physical and mechanical properties of LWC cured in different condition

Curing type	Curing time	PLWC			DLWC		
		Specific porosity %	Water absorp. %	Thermal cond. (W/mK)	Specific porosity %	Water absorp. %	Thermal cond. (W/mK)
Autoclaving cure, hours	2	23.3	15.7	0.46	62.5	71.9	0.13
	4	23.3	15.6	0.46	60.6	66.0	0.14
	6	21.8	15.3	0.42	62.4	72.0	0.13
	8	12.1	8.1	0.52	59.9	65.5	0.14
	10	19.7	13.5	0.43	62.3	71.4	0.13
Environment cure, days	7W	26.1	17.8	—	59.3	64.0	—
	28W	28.3	18.9	0.44	65.0	74.9	0.13
	7A	26.4	17.9	—	61.1	68.5	—
	28A	26.4	17.9	0.44	60.5	66.6	0.14

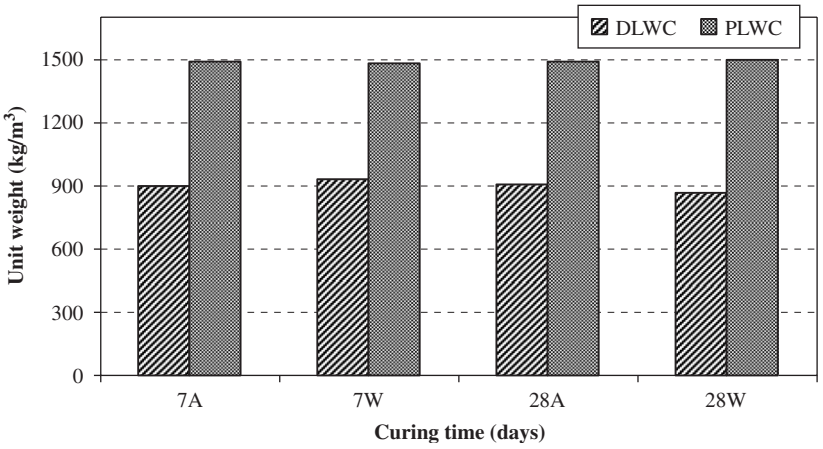


Fig. 2. Unit weight of PLWC and DLWC related to curing time.

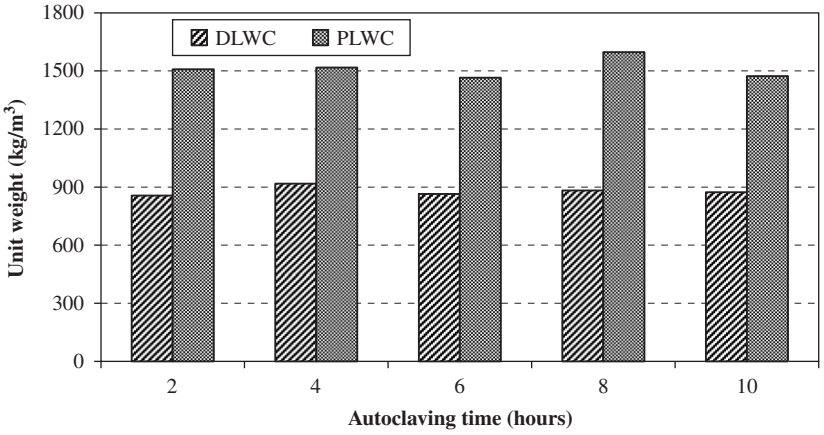


Fig. 3. Unit weight of PLWC and DLWC related to autoclaving time.

condition of concrete are revealed as mainly affecting factors of the thermal conductivity of concrete. Thermal conductivity of PLWC that were autoclaved has changed between 0.42 and 0.52 W/mK in 1500 and 1600 kg/m^3 unit weight. The PLWCs that cured in water and air at 28 d have 0.44 W/mK thermal conductivity in 1500 kg/m^3 unit weight. Whereas DLWC specimens that were 2–10 h autoclaved have 0.13–0.14 W/mK thermal conductivity coefficients in 900 kg/m^3 unit weight. This value was similar for DLWC cured in air and water for 28 d. DLWC have lower thermal conductivity than PLWC due to its lower density depending on aggregate properties. Uysal

et al. [26] has conducted a study on thermal conductivity coefficients of concretes made up of mixtures of PA and normal aggregate, and they reported that when 25%, 50%, 75%, and 100% PA ratios were used in place of normal aggregate by volume, PA decreased the density and thermal conductivity of concretes up to 40% and 46%, respectively. Also, thermal conductivity of the specimens in 300 kg/m^3 cement content and produced with %100 PA was 0.77 W/mK. Thermal conductivity of concrete depends also on curing and compacting condition. Ünal et al. [17] carried out a study on thermal conductivity of low-strength LWC produced with diatomite in different ratios and cement content. The unit weight of specimens was changed between 900 and 119 kg/m^3 in 250–400 kg/m^3 cement content and thermal conductivity of specimens in 300 kg/m^3 cement content was 0.23 W/mK. Autoclaved LWC that was produced with pumice and diatomite has lower thermal conductivity than normal concrete.

ACI Committee 213R-03 [27] has recommended an equation to obtain thermal conductivity (λ) of structural LWC related with its dry unit weight (w) as follows:

$$\lambda = 0.0864\, e^{0.00125\, w}. \quad (1)$$

The curves were obtained for experimental and ACI 213R-03 depending on unit weight and they are shown in Fig. 4. As seen from Fig. 4, there is a little difference between both the curves. These differences may be explained by that natural sand is used in the structural LWC to achieve the strength. The natural sand increases the thermal conductivity of concrete from that produced by outright LWA. There was a good relationship between thermal conductivity (λ) and unit weight (w) in experimental results ($R = 0.99$). For the moderate strength LWC, the following equation can be proposed:

$$\lambda = 0.023\, e^{0.002\, w}.$$

By increasing dry unit weight of DLWC and PLWC from 900 to 1500 kg/m^3, thermal conductivity coefficient has increased from 0.13 to 0.52 W/mK.

Microstructures that show interfacial zone of aggregate–cement matrix of DLWC and PLWC cured in air are given in Figs. 5 and 6, respectively. In Fig. 5, it is seen that

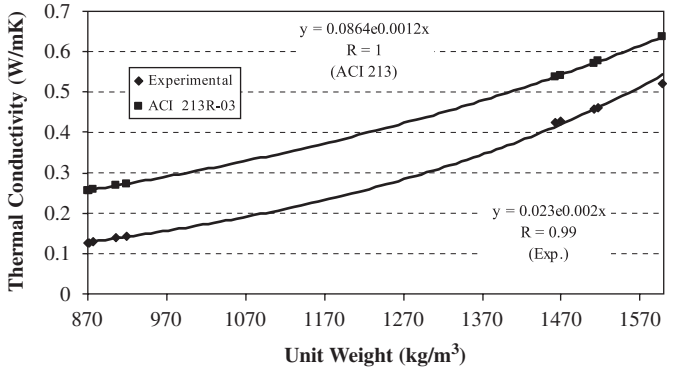


Fig. 4. Relationship between unit weight and thermal conductivity of LWC.

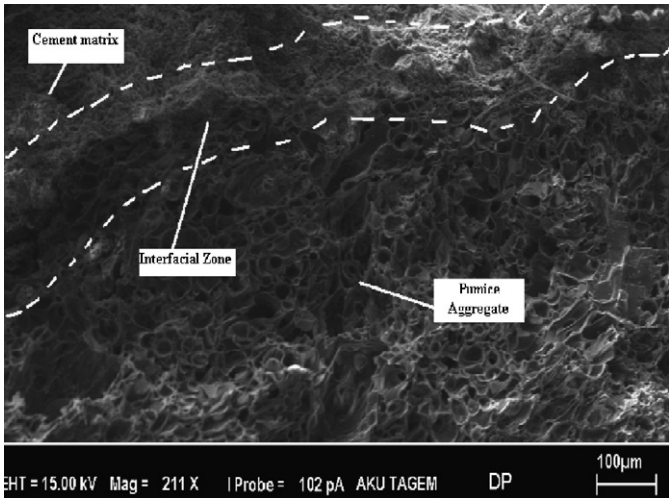


Fig. 5. SEM image of aggregate–cement matrix interfacial zone for PLWC (× 211).

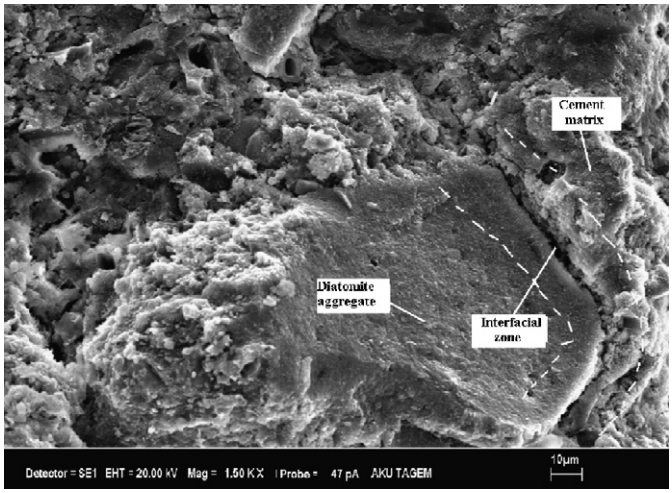


Fig. 6. SEM image of aggregate–cement matrix interfacial zone for DLWC (× 1500).

the boundary between the cement matrix and the pumice LWA is not distinct showing that the LWA bonds tightly and continuously with the cement matrix. The interaction of the paste matrix and the lightweight aggregates is different from that of normal concrete [28]. Also, it is seen that the cement paste has infiltrated the aggregate surface to a certain depth. In other words, the 'wall effect' that appears in the normal weight concrete does not occur on the interfacial zone of PLWC. This was because the porous and rough surface of the pumice LWA provides sites for the cement paste to merge across the interfacial zone and improves the interaction mechanism between the aggregate and the matrix. The well-bonded interfacial zone is characteristic of higher strength development of the LWC [15].

Fig. 6 indicates that interfacial zone of cement paste and aggregate is very weak because the diatomite aggregate surface is not as rough as PA. In other words, a shell

structure has not been at the surface of diatomite aggregate. The presence of a shell structure on the lightweight aggregates as well as its WA rate significantly influences the mechanical properties of the LWC [29]. The surface of diatomite was as smooth as normal concrete and it was concluded that "wall effect" or "surface effect" occurred at the surface of diatomite LWA [28]. WA of the lightweight aggregate is usually higher than that of normal aggregates. Micro-cracking at the interface will easily appear at early hydration due to higher absorption rate. Also, this weakness can be due to the low w/c ratio and the high pore structure of diatomite aggregate. This weakness in interfacial zone of diatomite aggregate and cement paste has negatively affected the strength of LWC.

Compressive strength of PLWC and DLWC were compared in Figs. 7–9 depending on curing type and specimen age. Generally, the specimens cured in water at 7 and 28 ages have higher compressive strength than that cured in air for all ages (Fig. 7). Also, the PLWC specimens have higher compressive strength than the DLWC specimens in all ages. Of course, the strength development in LWC is limited by the inherent strength of aggregate [30]. The compressive strength of PLWC changed between 7–22 and 6.7–18.5 MPa cured in water and in air at 7–590 ages. The compressive strength of DLWC has ranged between 3–6 MPa and 2–3 MPa cured in water and in air at 7–590 ages, respectively. As seen, while the compressive strength of PLWC is significantly developed by the increase of concrete age, compressive strength of DLWC has decreased because of very high porous structure of diatomite and weakness of aggregate–cement paste interfacial zone. Also, the water that was absorbed by diatomite was not released as easily as in PA. This has encouraged both developing of hydration of cement paste and improvement of the strength.

Sari et al. [31] investigated the effects of gradation and admixture on the pumice LAC. The specimens were cured at a temperature of 20–25 °C and a relative humidity of 50–55%. Compressive strength of the specimens was determined as between 3.5 and 7 MPa for 28 and 56 ages. Babu et al. [32] investigated the performance of lightweight EPS aggregate concretes containing fly ash over a wide

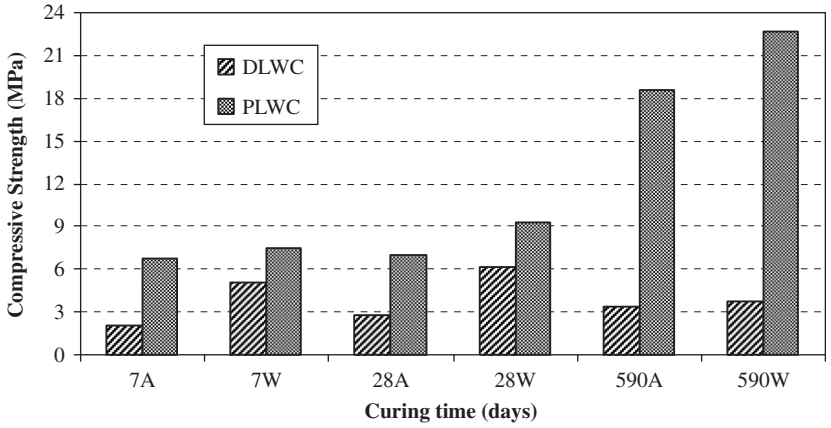


Fig. 7. Compressive strength of PLWC and DLWC related to curing time.

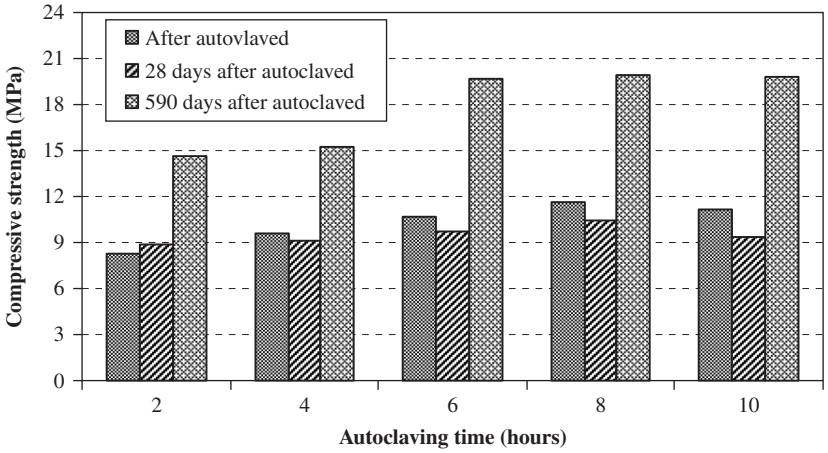


Fig. 8. Compressive strength of PLWC related to autoclaving time.

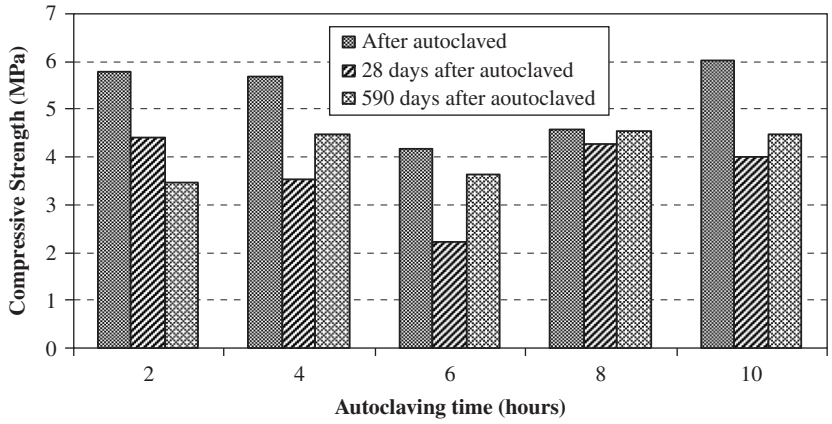


Fig. 9. Compressive strength of DLWC related to autoclaving time.

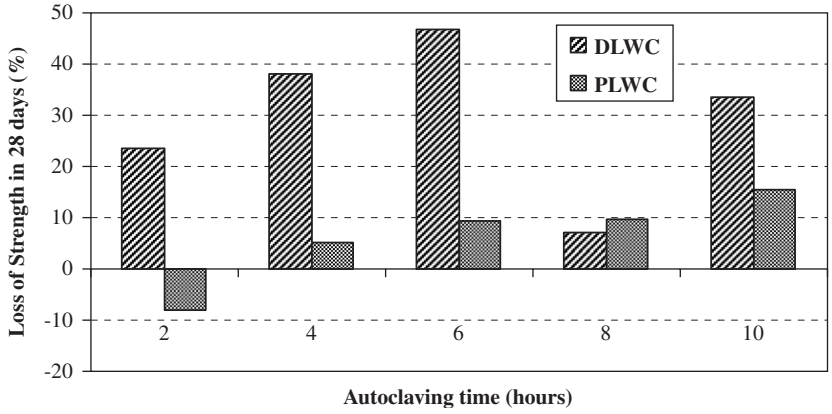


Fig. 10. Loss of strength of PLWC and DLWC in 28 d.

range of concrete densities of 500–2200 kg/m^3. The compressive strengths of the specimens varied between 1.1 and 18.4 MPa for 28 ages.

Al-Jabri et al. [33] studied block element for hot climate region. The blocks were produced from two indigenous materials: vermiculite (VerBlock) and polystyrene beads (PolyBlock1) which were used as lightweight aggregates with different proportions in the mix. The mechanical properties of the two types of blocks were compared and compressive strength of these blocks was changing between 2.2 and 15 MPa.

However, the PLWC specimens that cured in autoclave in 2–8 h have 8–12 MPa compressive strength (Fig. 8). The highest strength was obtained in 8 h autoclaved specimens. In other words, the PLWC specimens that were 24 h pre-waited and then 8 h autoclaved and 5 h cooled (totally in 37 h) have gained 75% higher strength than 28 aged specimens that cured in water. Compressive strength of 10 h autoclaved specimens has decreased a bit due to exposure to high temperature for a long time. Long time high temperature results in the unstable C–S–H gel forms in cement matrix and this instable form negatively affects the strength of concrete [34]. On the other hand, by autoclaving of DLWC specimens in 2–10 h, similar to PLWC, they have higher compressive strength than specimens that cured both in air and in water at 7 and 28 ages (Fig. 9). In autoclaved DLWC, the highest strength was obtained on 10 h autoclaved specimens as 6 MPa. All the autoclaved specimens were waited in air until 28 and 590 d after autoclave. In 28 d, the loss of strength occurred because of some unstable forms in concrete microstructure. This behavior is identical to normal concrete that cured in steam [35]. After 590 d, compressive strength of PLWC that cured in autoclave and environment has increased. This increasing was the highest in PLWC that cured in water at 28 ages. Compressive strength of DLWC cured in autoclave has increased, too. Probably, it was due to that diatomite aggregates in autoclaved DLWC were coated densely with cement matrix under temperature and pressure, and pores of aggregate were plugged. On the other hand, by evaporating or absorbing by aggregate of free water in the DLWC that cured in water and air, compressive strength of DLWC at 590 d has significantly decreased.

In Fig. 10, the loss of strength of PLWC and DLWC in 28 d was presented. In the PLWC, the loss of strength has increased with increase of autoclaving time. The compressive strength of 2 h autoclaved PLWC has raised at 28 ages

because PA has saturated to humidity in 2 h. After autoclave, the hydration forms probably have developed by this humidity. But, on increasing the autoclaving time, irregular distribution of hydrated cement products could occur in the DLWC and PLWC specimens due to the effect of high temperature and pressure in autoclave. The highest loss of compressive strength in DLWC and PLWC was 47% and 15%, respectively. But, again, on increasing LWC age until 590 d, the strength has increased, too. As a result, it can be said that by autoclaving of LWC, it can be presented for service in short time such as in 37 h by when it has gained the desired and adequate strength.

Park et al. [36] studied the effects of processing and material variations on the mechanical properties of lightweight cement composites, and they defined the fabrication techniques for producing lightweight cement composites that can substitute for autoclaved LWC.

To estimate the strength of concrete without the necessity of carrying out physical tests, the concept of concrete maturity has been established (Fig. 11). The maturity method is a technique that accounts for the combined effects of time and temperature on the strength development of a concrete mixture. The maturity method, which can determine the strength of concrete, replaced the one related to heat and time, and the accelerated cure methods, which are based on the determination of 28 d strength by finding the relationship between the early strength that is gained by the concrete generally through heating in order to accelerate the hardening of the concrete, are alternative methods [5,23,24].

The relationship between compressive strength value and maturity factor of autoclaved specimens was investigated for PLWC and DLWC (Fig. 11). There was a good relationship between compressive strength and maturity ($R = 0.99$) in PLWC specimens. For the DLWC, the relationship was not as well as PLWC, but it is in acceptable degree ($R = 0.82$). The maturity of the LWC was conducted as 24 h pre-waiting in 20 °C and autoclaving time in 127 °C temperature. Thus, the maturity of LWC ranged from 990 to 2090 °C h by increasing of autoclaving time from 2 to 10 h.

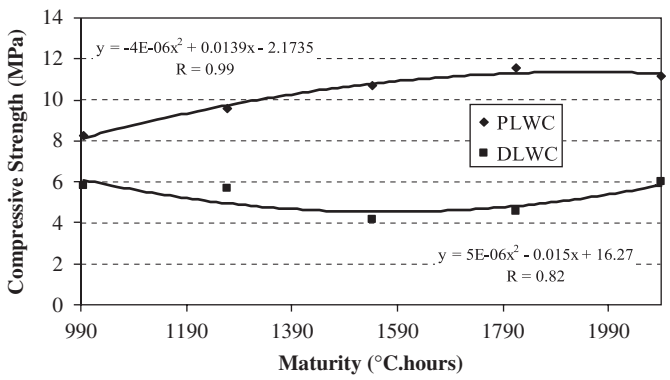


Fig. 11. Relationship between compressive strength and maturity for PLWC and DLWC.

4. Conclusion

Based on the experimental study of the autoclaving of lightweight aggregate concrete, the following conclusions can be drawn:

- The SP and WA of PLWC cured in autoclave have lower value than PLWC cured in both water and air at 7 and 28 ages. Because diatomite aggregates are more porous materials than PAs, DLWC has higher SP and WA values than PLWC.
- Dry unit weight of PLWC and DLWC that cured in air, water and autoclave was 1500 and 900 kg/m^3, respectively. Autoclaving of the LWC has not affected their unit weight.
- The thermal conductivity of the LWC was not changed very much by autoclaving them. A good relationship has been obtained between thermal conductivity and unit weight of LWC.
- In DLWC, interfacial zone was very weak because of wall effect on aggregate surface. Whereas in PLWC, there was a strong bond between aggregate and cement paste.
- In 37 h, strength of LWC has been increased to 75% higher than specimens that cured in water for 28 d by autoclaving it. The highest compressive strength was obtained at 8–10 h autoclaving of the LWC in autoclave curing.

References

[1] Mannan MA, Basri HB, Zain MFM, Islam MN. Effect of curing conditions on the properties of OPS-concrete. Building and Environment 2002;37:1167–71.
[2] Toutanji HA, Bayasi Z. Effect of curing procedures on properties of silica fume concrete. Cement and Concrete Research 1999; 29:497–501.
[3] Aldea CM, Young F, Wang K, Shah SP. Effects of curing conditions on properties of concrete using slag replacement. Cement and Concrete Research 2000;30:465–72.
[4] Erdoğdu Ş, Kurbetci Ş. Influence of cement composition on the early age flexural strength of heat-treated mortar prisms. Cement and Concrete Composites 2005;27:818–22.
[5] Topçu İB, Toprak MU. Fine aggregate and curing temperature effect on concrete maturity. Cement and Concrete Research 2005;35: 758–62.
[6] Chandra S, Berntsson L. Lightweight aggregate concrete: Science, Technology and Applications. New York, USA Norwich: William Andrew Publishing; 2002.
[7] Neville AM, Brooks JJ. Concrete technology. Longman Scientific and Technical; 1987. p.188–349.
[8] Erdem TK, Turanli L, Erdoğan TY. Setting time: an important criterion to determine the length of the delay period before steam curing of concrete. Cement and Concrete Research 2003;33:741–5.
[9] Türkel S, Alabas V. The effect of excessive steam curing on Portland composite cement concrete. Cement and Concrete Research 2005;35: 405–11.
[10] Yang Q, Zhang S, Huang S, He Y. Effect of ground quartz sand on properties of high- strength concrete in the steam-autoclaved curing. Cement and Concrete Research 2000;30:1993–8.

[11] Liu B, Xie Y, Li J. Influence of steam curing on the compressive strength of concrete containing supplementary cementing materials. Cement and Concrete Research 2005;35:994–8.
[12] Elsharief A, Cohen MD, Olek J. Influence of lightweight aggregate on the microstructure and durability of mortar. Cement and Concrete Research 2005;35:1368–76.
[13] Demirboğa R, Örüng İ, Gül R. Effect of expanded perlite aggregate and mineral admixtures on the compressive strength of low-density concretes. Cement and Concrete Research 2001;31:1627–32.
[14] Topçu İB. Semi-lightweight concretes produced by volcanic slags. Cement and Concrete Research 1997;27:15–21.
[15] Chi JM, Huang R, Yang CC, Chang JJ. Effect of aggregate properties on the strength and stiffness of lightweight concrete. Cement and Concrete Composites 2003;25:19–205.
[16] Khandaker Anwar Hossain M. Properties of volcanic pumice based cement and lightweight concrete. Cement and Concrete Research 2004;34:283–91.
[17] Ünal O, Uygunoglu T, Yildiz A. Investigation of properties of low-strength lightweight concrete for thermal insulation. Building and Environment 2007;42:584–90.
[18] Bruvel F. Diatomite., Department of Mines and Energy, Mineral Information Leaflet No 30, (07) 3235; August, 1999.
[19] Uygunoğlu T. Investigation of physical and mechanical properties of block element produced with lightweight aggregate in Afyon and region. MS thesis, Afyon Kocatepe University; 2005 [in Turkish].
[20] Lo TY, Cui HZ, Li ZG. Influence of aggregate pre-wetting and fly ash on mechanical properties of lightweight concrete. Waste Management 2004;24:333–8.
[21] TS EN 12390-3. Testing hardened concrete—Part 3: compressive strength of test specimens.Tukish Standard Institute, Ankara; 2003 [in Turkish].
[22] ASTM C1113-99. Standard test method for thermal conductivity of refractories by hot wire (platinum resistance thermometer technique). American Society for Testing and Materials; 2004.
[23] Topçu İB. Maturity in fresh concrete and determination of stripping time for different cement mortars. 17th international congress of the precast concrete industry (BIBM 2002), Turkish Precast Concrete Association, Istanbul, Turkey; 2002.
[24] Topçu İB, Karakurt C. Maturity concept on concretes produced with different cements. ECAS international symposium on structural and earthquake engineering, Bizim Büro, Ankara, Turkey; 2002.p. 476–83 [in Turkish].
[25] Kim KH, Jeon SE, Kim JK, Yang S. An experimental study on thermal conductivity of concrete. Cement and Concrete Research 2003;33:363–71.
[26] Uysal H, Demirboğa R, Şahin R, Gül R. The effects of different cement dosages, slumps, and pumice aggregate ratios on the thermal conductivity and density of concrete. Cement and Concrete Research 2004;34:845–8.
[27] ACI Committee 213R-03. Guide for structural lightweight-aggregate concrete. American Concrete Institute; 2003, September 26. p. 22–3.
[28] Lo TY, Cui HZ. Effect of porous lightweight aggregate on strength of concrete. Materials Letters 2004;58:916–9.
[29] Lo Y, Gao XF, Jeary AP. Microstructure of pre–wetted aggregate on lightweight concrete. Building and Environment 1999;34:759–64.
[30] Al-Khaiat H, Haque MN. Effect of initial curing on early strength and physical properties of a lightweight concrete. Cement and Concrete Research 1998;28:859–66.
[31] Sari D, Paşamehmetoğlu AG. The effects of gradation and admixture on the pumice lightweight aggregate concrete. Cement and Concrete Research 2005;35:936–42.
[32] Babu KG, Babu DS. Performance of fly ash concretes containing lightweight EPS aggregates. Cement and Concrete Composites 2004;26:605–11.
[33] Al-Jabri KS, Hago AW, Al-Nuaimi AS, Al-Saidy AH. Concrete blocks for thermal insulation in hot climate. Cement and Concrete Research 2005; 35: 1472–9.
[34] Hewlett PC, editor. Lea's chemistry of cement and concrete. New York: Wiley; 1998.
[35] Erdoğan TY. "Concrete", ODTÜ Geliştirme Vakfı Yayn. ve İletişim Şti, Ankara/Turkey; May 2003 [in Turkish].
[36] Park SB, Yoon ES, Lee BI. Effects of processing and materials variations on mechanical properties of lightweight cement composites. Cement and Concrete Research 1999;29:193–200.