COMPRESSIVE STRENGTH AND WATER SORPTIVITY OF STEAM CURED LIGHTWEIGHT AGGREGATE CONCRETE

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ABSTRACT

In this paper, the compressive strength and water sorptivity of concrete cubes prepared by replacing the aggregate mixture partially by lightweight fly ash aggregate in different ratio were studied. Different percentage of lightweight fine aggregate (LWFA) and a constant amount of lightweight coarse aggregate (LWCA) were used in preparing concrete cubes for yielding test. Various amounts of LWFA were achieved by volumetric substitution of fine aggregate in the concrete mixture. Six different replacement percentage (0%, 25%, 50%, 75%, and 100%) were utilized. Hence, in this experimental study, six various concrete mixtures were produced. Steam curing method was applied in the concrete production. Initially, concrete samples exposed to steam curing (SC) using the steam chamber, and then the samples were submerged by water until testing date. Water sorptivity test was conducted at 28 days and 56 days. While, compressive strength tests were conducted after 1, 3, 28, and 56 days.

Keywords: *Fly ash, Lightweight Aggregate, Strength development, Water Sorptivity***.**

1. INTRODUCTION

Fly ash is fabricated is massive volumes from coal-fired thermal power plants, but unfortunately, only a small quantity is utilized a cement replacement in concrete. The current disposal practice is to dump large amounts of fly ash in landfills and storage ponds. Fly ash has become one of the main causes of air and water pollution, which drives to problems of discarding as well as environmental damage. It is worth mentioning that in the recent past, fly ash and sintering aid powders were used in the advancement of new lightweight building materials. Physical features and strength of artificial lightweight sintered aggregates generated from different industrial byproducts were previously researched by Cheeseman and Virdi (2005), Cheeseman et al. (2005), Mangialardi (2001) and Wang et al. (2002).

The conformity of fly ash for the pelletization and sintering process, on the other hand, is hard to guess because many physicochemical factors are enclosed. The features of aggregates influenced by the types and amount of binder that did not change chemical composition but the microstructure of the aggregate, which is concluded by Ramamurthy and Harikrishnan (2006). Wasserman and Bentur (1997) reported that heat and polymer treatment change the structure and features of sintered fly ash lightweight aggregate (Lytag) to gain aggregates different in their strength, absorption, and pozzolanic activity. Verma et al. (1998) investigated that producing of lightweight aggregate becomes a kind of trade in some countries such as USA, Russia, UK, Germany, and Poland. The strength; stiffness and durability of concrete made with artificial lightweight aggregate studied by Al-Khaiat and Haque (1998), Al-Khaiat and Haque (1999), Kayali et al. (1999), Kayali et al. (2003), Yun et al. (2004) and, Chiaia et al. (2010). Kockal and Ozturan (2010) revealed that durability transports very significant for concrete structures, with respect to the strength/weight ratio. Long-term durability is defined by the permeability of concrete. Permeable concrete is defenseless and can be affected by water and harmful substances, which in turn cause disintegrate of the concrete and reinforcement. The interferential transition zone between aggregate and the cement matrix effects on the strength, stiffness, and durability of concrete.

Hanson (1963), Neville (1997), and Turkel and Alabas (2005) studied that when the steam is fabricated at atmospheric pressure, the temperature should be kept under 100^{o}C. Rajdy and Richards (1973), Taylor (1997) concluded that the pozzolanic reaction, thermo-activated by a high curing temperature, provided the development of C–S–H and confirmed the phases to the damage of calcium hydroxide. The negative influence of steam curing may be due to the coarser pore structure, improved micro-cracking, and delayed ettringite formation. The impact of curing temperature on the features of cement mortars and concretes has been the topic of several researchers. It is commonly clarified that a high curing temperature directly after casting supports the development of mechanical features at early ages but adversely influences the strength at later ages.

The findings of the study Mouret et al. (2003) showed that concrete cured at 35^{o}C had 10% less 28-day compressive strength when compared with the similar concrete cured at 20^{o}C. Verbeck and Helmuth (1968) pointed out that by increasing the curing temperature form 20^{o}C and 50^{o}C causes a 28% reduction in strength. Verbeck and Helmuth (1968) reported that the reduction at later age strength was referred to the rapid initial rate of hydration at a higher temperature which retarded the subsequent hydration and produced a nonuniform distribution of the hydration products.

According to the study of Topcu and Toprak (2005), the increase in the curing temperatures of 20^{o}C, 40^{o}C, and 60^{o}C improved the strength at the early ages, but affected negatively the 28-day compressive strength of concrete made with river sand or crushed stone sand. Baoju et al. (2005) exhibited the compressive strength of concrete containing ultrafine fly ash with or without slag effected by steam curing. They deduced that the concrete containing ultrafine fly ash (UFA) had much lower early strength after 13 h steam curing and the difference between the 28-day compressive strength of the 13 h cured steam concrete and that of the moist-cured concrete was significant. This finding indicated that the steam curing adaptability of UFA seemed to be rather poor. In another study Baoju et al. (2001), however, ultrafine fly ash composite was developed by adding some mineral powders into UFA. It was observed that concrete containing ultrafine fly ash composite and ground blast furnace slag gave the desired early compressive strength. Yazıcı et al. (2005) showed the usability of the fly ash in mixtures for the precast concrete industry. They revealed that steam curing enhanced the 1-day strength values of high volume fly ash concretes from about 10 to 20 MPa. However, the ultimate compressive strength of steam-cured fly ash concrete was much lower than that of the standard-cured concrete. They concluded that the number of bigger pores increased with increasing curing temperature associated with a rise in the mean pore radius, which was the reason for the difference in compressive strength at elevated temperatures compared to storage at 20^oC. Aside from the strength, the durability related features of the concrete were also negatively affected by curing at high temperatures. However, there is limited research on the durability performance of steam-cured concrete.

According to Ho and Lewis (1992) and Ho (1998), steam-cured ordinary Portland cement concrete cover was poor in quality and equivalent to that achieved with only 2–3 days standard curing as showed by the water sorptivity tests. Ho et al. (1992) discovered the potential benefits of steam-curing on concrete mixes incorporating various combinations of fly ash, slag, and silica fume. It was explored that the steam-cured concretes were more porous as showed by their higher sorptivity compared with the standard cured specimens. Mixes with silica fume appeared to have the best performance with high early strength and low sorptivity. Ho and Cao (1994) studied that the quality of steam-cured concrete containing 20% fly ash was better than that with 28-days standard curing. Similar results were attained for blended cement containing 35% blast furnace slag by Ho et al. (1997), Ho et al. (2003). According to the intensive research, trials spent to increase the durability of steam-cured concrete. In recent years, the interest in using fly ash in the generation of lightweight aggregate has been a growing. The performance features of the lightweight concrete and the normal weight concrete was studied through compressive strength, representing the mechanical behavior, and through water sorptivity, representing the transport features of concrete. In the light of the findings revealed in the literature, the main aim of this paper is to examine the influences of lightweight fly ash aggregate (including fine and coarse) on the compressive strength, water sorptivity of the steam-cured lightweight concrete which was kept for 17 h under high temperature about 70^oC.

2. EXPERIMENTAL METHODOLOGY

2.1Materials:

Portland cement, fine and coarse aggregates of crushed limestone for the control mixture; and artificial lightweight fine and coarse aggregate made with fly ash were used as materials in this study. To attain the required slump superplasticizer was used. CEM I-42.5R Portland cement (PC) complying with European Standards EN 197 (similar to ASTM C150 Type-1 cement) was used. Table 1 shows the physical properties and chemical composition of the PC.

The maximum particle size of coarse aggregate was considered as 12 mm, and local aggregates were used. Pelletization disc in the laboratory was used to produce the LWA including coarse and fine from fly ash. LWFA was substituted by fine normal weight crushed limestone. A commercially available sulfonated naphthalene formaldehyde-based superplasticizer with a specific gravity of 1.22 was used to provide a consistent workability.

2.2 PRODUCTION OF LWFA AND LWCA

In the first stage of the experimental program, lightweight fly ash aggregates (LWA) was produced through the cold bonding agglomeration process of fly ash and Portland cement in a tilted pan at ambient temperature. For this, 10% PC and 90% FA were mixed in powder form in the pelletizer shown in Fig. 1. After the dry powder mixture of about 10–13 kg was fed into the pan, the disc was rotated at a constant speed to assure the homogeneity of the mixture.

The amount of sprayed water used during pelletization process has been determined as the coagulant to form spherical pellets with the motion of rolling disc. The optimum water content required for each type of powder was determined according to ASTM D2216-10 [35]. Then, the water was sprayed on the mixture with a quantity of 22% by weight. The formation of pellets occurred between 10–12 min in trial productions.

TABLE 1.
Properties of plain Portland cement (CEM I 42.5R)

Composition	Percentage
SiO_2(%)	19.79
Al_2O_3(%)	3.85
Fe_2O_3(%)	4.15
CaO (%)	63.84
MgO (%)	3.22
SO_3(%)	2.75
Na_2O(%)	-
K_2O(%)	-
Cl^-(%)	0.0063
Insoluble residue(%)	0.34
Loss on ignition(%)	0.87
Free lime(%)	1.28
Vicat time strat	2:42
(h:min) stop	3:44
Le chatelier (mm)	1
Fineness	15.3
(%) 90 µm	1.47
Specific surface (cm^2/gr)	3349
Specific gravity (gr/cm^3)	3.12

The total pelletization time was determined as 20 min for the compaction of fresh pellets. Finally, they were kept in sealed plastic bags for 28 days in a curing room in which the temperature and relative humidity were 21 _C and 70%, respectively. The curing method adopted in this study is a practical and simple method to fit the laboratory conditions. At the end of the curing period, hardened aggregates were sieved into fractions from 4 to 16 mm sizes to be used as coarse aggregate in concrete production [36].

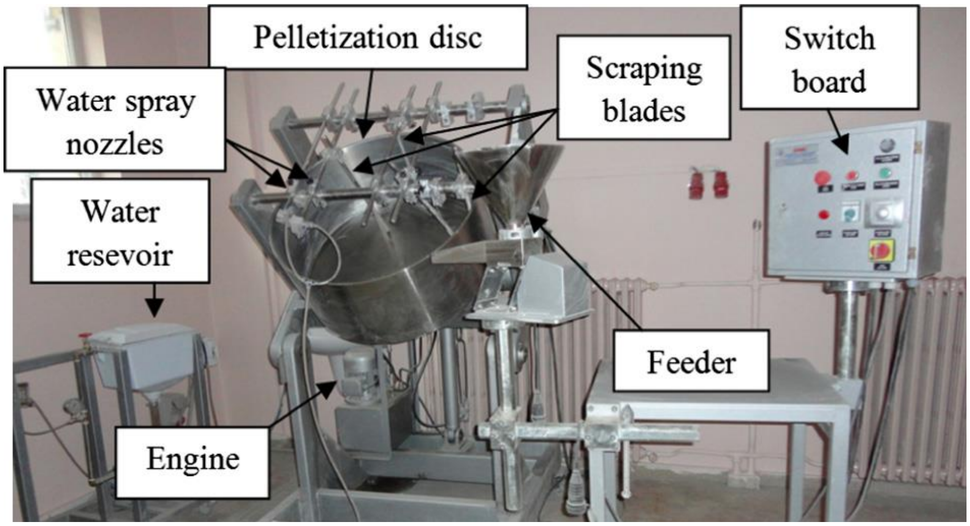

FIGURE 1. The general view of the pelletization disc.

2.3 CONCRETE MIXTURE DETAILS AND SPECIMENS

One set of control mixtures with the same w/cm ratios of 0.35 with 450 kg/m^3 were designed. Steam curing was applied. In order to examine the impact of lightweight fine aggregate, fly ash was used as a parameter which replaced with (0%, 25%, 50%, 75%, and 100%) fine normal weight crushed stone aggregate (by weight). Six different mixtures were set in this experiment, and the details are shown in Table 2. A constant of aggregate grading mixture was used for all concretes. The mixtures shown in Table 2 were designed to have slump values of 150 ± 20 mm for w/cm ratios of 0.35 for the ease of handling, placing, and consolidation. To attain the required slump the superplasticizer was added at the time of mixing.

All concretes were mixed in accordance with ASTM C192 standard in a power-driven revolving pan mixer. For each mixture, eight 150 mm x 150mm x 150mm cubes for compressive strength testing, three Φ100x200-mm cylinders for determining water sorptivity testing and compacted by a vibrating table.

The samples after finishing and casting process were put in a closed chamber for applying steam curing process and keeping for 17 h. After one day, all samples were taken out from the mold and then submerged in a water tank at 20 ±2 ^{0}C until the date of the test.

TABLE 2.
Mixture proportioning of the concrete Steam curing.

Description ID	w/c	Cement (kg/m3)	Coarse aggregate%		Fine aggregate %		SP*** (Gr/m3)
			NWA*	LWA**	NWA	LWA	
S0 (control)	0.35	450	100	0	100	0	12000
S-0	0.35	450	0	100	100	0	4086.96
S-25	0.35	450	0	100	75	25	3173.91
S-50	0.35	450	0	100	50	50	2000
S-75	0.35	450	0	100	25	75	900
S-100	0.35	450	0	100	0	100	500

* Normal weight aggregate
**Lightweight aggregate
*** Superplasticizer

2.4 CURING CONDITION

In steam-curing condition, fresh specimens within the molds were placed in the steam chamber and subjected to the heat treatment cycle, as shown in Fig. 2. In this study, the steam curing cycle had a total duration of 23 h inclusive of 2 h of preheating, 3 h of heating until the desired temperature of 70^{o}C was reached, which remained constant for 17 h, before the final cooling of the chamber which lasted 1 h. The steam curing chamber's humidity was above 90%. The samples were stripped and placed in water at 20 ± 2^{o}C in compliance with ASTM C192 until the date of testing.

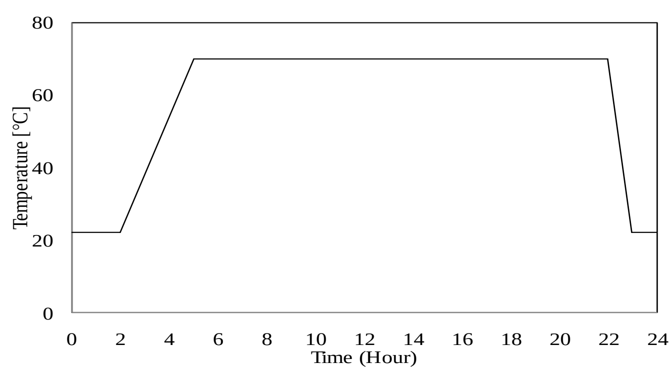

FIGURE 2. Schematic representation of steam curing procedure

2.4 TEST METHODS

2.4.1 COMPRESSIVE STRENGTH

The concrete cubes (150×150×150 mm) were tested under compression at one, three, 28, and 56 days after casting. The tests were performed by a 2000 kN capacity testing machine following ASTM C39 standards. For each mixture, two specimens were tested in all testing age and the average of the results was taken for the various amounts of LWFA replacements.

2.4.2 WATER SORPTIVITY

The term of water sorptivity is used to characterize water entry into pores of unsaturated concrete due to capillary suction. The rate of water absorption was measured according to ASTM C1585-04. For the test, two specimens with dimensions of (Ø100 x 85)mm cut from(Ø100 x 200) cylinders were utilized. At ages of 28days and 56days, the samples were dried first in an oven at about 105^0C for one day till steady mass and then allowed to cool to ambient temperature in a closed container. Then, the sides of the samples were painted with paraffin and the sorptivity test was performed by placing the samples on glass rods in a tray containing water such that their bottom surface was 5mm deep in water, thus allowing the water movement to be free through the bottom surface. The samples were weighed after they removed from the tray at different interval of times up to 1 h to evaluate the mass gain. The absorbed volume of water determined by dividing the gained mass by the nominal surface area of the sample and by the water density. These values were plotted against the square root of time. The sorptivity coefficient of the concrete was defined as the slope of the best fit line. For each feature of the concrete, two specimens were tested and the average of them was reported as the sorptivity coefficient.

3. RESULTS&DISCUSSION

3.1 COMPRESSIVE STRENGTH

Table 3 shows values of the compressive strength of the LWCs subjected to steam curing. As clarified in table 3, the decrease in compressive strength considerably occurs by increasing the amount of replacement of LWFA. Since the changing in coarse aggregate occurred from normal weight coarse aggregate of crushed limestone into lightweight coarse aggregate fly ash, a decrease in compressive strength can also be observed and this reduction continues with increasing amount of LWFA. A detailed comparison of the various LWFA replacements is shown in Figure 3. By replacing the amount of lightweight coarse aggregate fly ash fully instead of coarse aggregate crushed limestone the decrease of strength was observed more clearly. But when the fine aggregate became variable and the coarse lightweight fly ash aggregate kept constant for the remaining four mixes, the strength of each mixes decreases by a small value by increasing the amount of LWFA replacement, as shown in Fig. 4. The experimental results indicated that by increasing percentage of LWFA, the compressive strength of the concretes is reduced.

TABLE 3.
Values of compressive strength.

Amount of LWFA* (%)	Compressive-strength (steam-curing) (MPa)			
	1day	3days	28days	56days
Control	47.245	51.324	54.471	57.52
0	31.90	32.60	38.15	38.27
25	28.88	30.92	35.76	35.95
50	23.86	25.47	31.79	32.95
75	23.45	24.66	30.06	31.20
100	21.31	23.35	28.46	28.66

*Lightweight Fly Ash Fine Aggregate

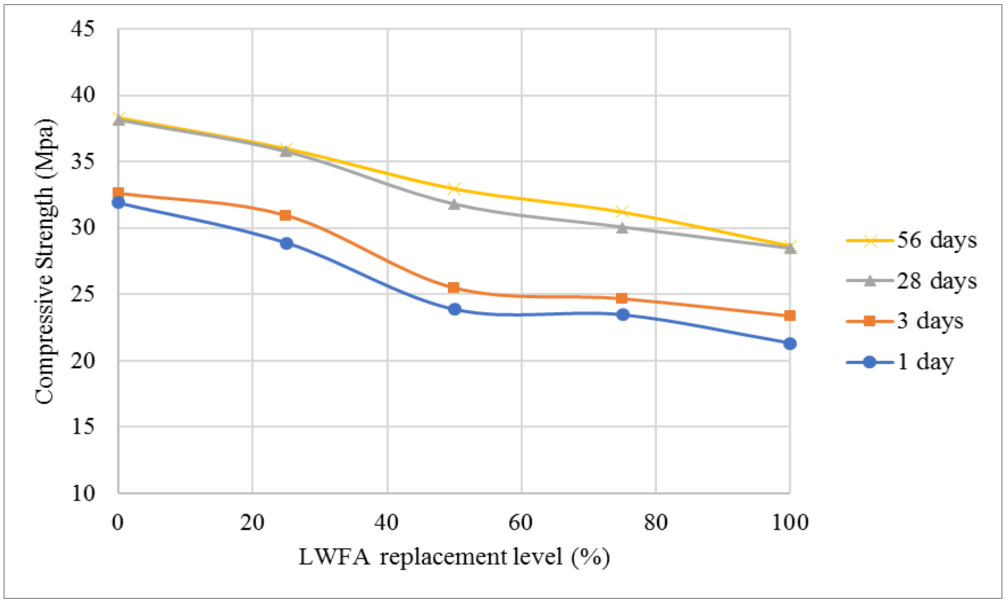

FIGURE 3. Compressive strength subjected to steam curing at different ages

3.2 WATER SORPTIVTY

The differences in the sorptivity values, based on the amount of LWFA, are given in Fig. 4. The increase of LWFA causes the increase in sorptivity of concretes. The sorptivity coefficients of the control concrete are very low. However, the comparison of the various LWFA replacements are shown in table 4, due to replacing normal weight coarse aggregate into lightweight coarse aggregate fly ash, the sorptivity values increase as the amount of replacement increase as shown in detail in Table 4. The replacement of LWFA at 0%, 25%, 50%, 75%, and 100% resulted in the increasing value of the sorptivity coefficients by almost 8.5%, 20.28%, 30.93%, and 31%, respectively, for 28-days, and by 11.63%, 12.13%, 26.74%, and 25.14%, respectively, for 56-days steam curing conditions. Moreover, increasing the amount of replacement of LWFA content increased the sorptivity associated with the strength reduction of the concrete for steam curing conditions as a result of the coarser pore-structure, this result also achieved by Gu¨neyisi and Mermerdas (2007), Bai et al. (2002), and Erdogdu and Kurbetci (1998). The increase in the sorptivity of steam-cured concretes may be attributed to the adverse effect of the pore size distribution. According to Erdogdu, and Kurbetci (1998), heat treatment affects the pore structure of cement paste by increasing the number of large pores in the cement paste. Similarly, Reinhardt and Stegmaier (2006) stated that increasing curing temperature consequence the number of bigger pores increased associated with the rising in the mean pore radius.

TABLE 4.
Values of water sorptivity (mm/min1/2).

Amount of LWFA (%)	28 days	56 days
	Steam Curing	Steam Curing
Control	0.0765	0.0795
0	0.168	0.159
25	0.1815	0.1775
50	0.2175	0.215
75	0.284	0.2725
100	0.3685	0.341

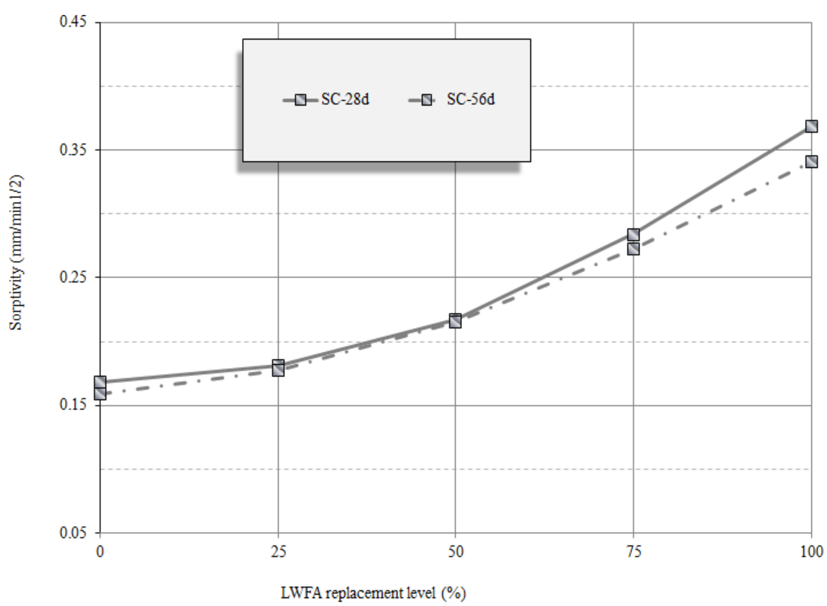

FIGURE 4. Water sorptivity coefficient of LWCs subjected steam curing at different ages

4. CONCLUSION

In this work, compressive strength and water sorptivity tests were conducted for steam-cured lightweight concrete. According to the results, the following outcomes can be obtained:

1- Most of the compressive strength is gained at an early age. In the mass production of precast units such as blocks, pipe, pre-stressed units, etc., it is often desirable to accelerate the process of hydration and hardening, so that the units may be installed within a few days after manufacture, and thus, avoiding storage problems.

2- Based on the test results achieved in this research, steam curing is preferable for lightweight concrete made with fly-ash aggregate since the difference between compressive-strength at 1-day and at 56-days was little.

3- The results also clearly show that increasing the amount LWFA replacement decreases compressive strength and increases in water sorptivity.

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