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Strength and transport properties of steam cured and water cured lightweight aggregate concretes

Mehmet Gesoğlu [a], Erhan Güneyisi [a], Barham Ali [a], Kasım Mermerdaş [b,*]

[a] Gaziantep University, Civil Engineering Department, 27310 Gaziantep, Turkey
[b] Hasan Kalyoncu University, Civil Engineering Department, 27410 Gaziantep, Turkey

HIGHLIGHTS

- Lightweight fine aggregate (LWFA) was produced through pelletization of fly ash.
- LWFA was replaced with natural fine aggregate at various levels up to 100%.
- Steam curing was applied to the concretes to obtain high early strength.
- Mechanical and transport properties of concretes were tested.
- Lightweight concrete production with proper performance was achieved.

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ABSTRACT

In this paper, effect of steam and water curing on the compressive strength development and transport properties such as water sorptivity, rapid chloride ion permeability, and gas permeability of concretes containing various volumes of lightweight fly ash aggregate (LWA) were investigated. In production of concrete, a fixed amount of lightweight coarse (LWCA) aggregate plus varying amounts of lightweight fine aggregate (LWFA) were used. Utilization of LWFA was achieved by volumetric substitution of fine aggregate with five different replacement levels namely, 0%, 25%, 50%, 75%, and 100%. Therefore, five different concrete mixtures were produced for this experimental study. The produced concretes were divided into two parts one of which was initially steam cured while the other was directly exposed to water curing. After initial steam curing regime, the steam cured (SC) concretes were also transferred to water until testing Mechanical properties of concretes were monitored through compressive strength development over 56 days, while transport properties were measured by means of water sorptivity, gas permeability and rapid chloride permeability tests conducted at 28 and 56 days.

1. Introduction

Coal-fired thermal power plants fabricate large quantities of fly ash, but only a small amount can be utilized in concrete industry. Disposal of huge amount of fly ash in landfills and storage ponds has been considered as one of the serious issues of air and water pollution.

In recent years, there has been a growing interest in the use of fly ash to produce lightweight aggregate [1–5]. Artificial aggregates may be produced by means of processing of various materials and production techniques such as cold bonding pelletization and sintering [5–12]. Cold bonding is a type of bonding method which accounts for the ability of pozzolanic powder material to react with calcium hydroxide at ordinary temperatures to form a water resistant bonding material. Pelletized aggregates are left to cure for several days to produce an aggregate with proper strength to be used in concrete production [12]. On the other hand, sintering method which is mainly based on atomic diffusion is a common application for mass production of lightweight aggregates. Because, aggregate particles, immediately after pelletization process are treated with high temperatures up to 1200 °C, and become ready for use without keeping for long term curing periods. Ramamurthy and Harikrishnan [5] reported that the properties of artificial aggregates depend on the type and amount of the binder which did not alter the chemical composition but the microstructure of the aggregate. The structure and features of sintered fly ash lightweight aggregate was changed by heat and polymer treatments to gain aggregates different in their strength, absorption and pozzolanic activity [13]. Many countries such as UK, USA, Germany, Poland and Russia are generating lightweight aggregates under different trade names [14]. Commercially generated lightweight aggregates were utilized in concrete by many investigators

* Corresponding author. Tel.: +90 342 2118080-1232; fax: +90 342 2118081.
E-mail address: kasim.mermerdas@hku.edu.tr (K. Mermerdaş).

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[15–20] to research the strength, stiffness and durability of concrete.

Curing in live steam at atmospheric pressure dramatically increases the rate of strength development of concrete for that is used primarily for precast concrete products like masonry block, pipe, pre-stressed beams, and wall panels, but can also be used for enclosed cast-in-place structures. In the precast concrete industry, steam curing allows increased production by a more rapid turnover of molds and formwork shorter curing periods before shipment or pre-stressing, and less damage to the product during handling. The pozzolanic reaction, thermo-activated by a high curing temperature, provided the development of C–S–H and assimilated the phases to the detriment of calcium hydroxide. The detrimental impacts of steam curing may be due to the coarser pore structure, improved micro-cracking and delayed ettringite formation [21–23].The effect of curing temperature on the features of cement mortars and concretes has been the topic of several researches. It is widely 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. In the study of Mouret et al. [24] it was reported that the concrete cured at 35 °C had 10% lower 28-day compressive strength when compared to the similar concrete cured at 20 °C. According to Verbeck and Helmuth's study [25], a 28% strength reduction was realized when curing temperature was increased from 20 °C and 50 °C. This reduction at later age strength was referred to the rapid initial rate of hydration at higher temperature which retarded the subsequent hydration and produced a nonuniform distribution of the hydration products [25]. Liu et al. [26] investigated the influence of steam curing on the compressive strength of concrete containing ultrafine fly ash with or without slag. 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 large. This finding indicated that the steam curing adaptability of UFA seemed to be rather poor. In another study of Liu et al. [27], 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.

Apart from the strength, later age durability related features of the concretes were also negatively affected by initial curing at high temperatures. However, there is limited research on the durability performance of the steam-cured concrete. According to Ho and Lewis [28], and Ho [29], steam-cured ordinary Portland cement concrete cover was poor in quality and equivalent to that achieved with only 2–3 days standard curing as indicated by the water sorptivity tests. Ho et al. [30] 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 indicated 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 [30,31] reported that the quality of steam-cured concrete containing 20% fly ash was better than that with 28 days standard curing. Similar results were obtained for blended cements containing 35% blast furnace slag [30,32].

Based on the facts pointed above, the main objective of this paper is to investigate the effects of steam and water curing regimes on the compressive strength development, gas permeability, water sorptivity, and rapid chloride ion permeability of the lightweight aggregate concretes. To this aim, in the first stage of the experimental study, lightweight coarse (LWCA) and fine (LWFA) aggregates were produced through cold bonding pelletization process. The concretes containing fixed amount of LWCA (50% of the total aggregate volume), and varying amounts of LWFA (0%, 25%, 50%, 75%, and 100% of the total fine aggregate volume) were produced. Two different curing regimes were applied to the concretes, namely steam curing (SC) and water curing.

2. Experimental

2.1. Materials

The materials used in this research were CEM I-42.5R Portland cement complying with European Standards EN 197 (PC), fine aggregate of crushed lime stone, and artificial fine and coarse light weight aggregate made of fly ash (FA). In order to provide similar workability for each mixture a sulphonated naphthalene formaldehyde based superplasticiser with a specific gravity of 1.22 was used at varying amounts. The chemical compositions and some physical properties of PC and FA are given in Table 1. Crushed limestone aggregate was obtained from local sources. The aggregate grading and some physical properties of crushed limestone sand is given in Table 2. The lightweight aggregates (LWA) including coarse and fine fractions were produced from fly ash through cold bonding pelletization process in laboratory conditions.

2.2. Details of producing LWA

In the first stage of the experimental program lightweight fly ash aggregates (LWA) were 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 [33]. 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. 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. Further details of cold bonding pelletization were presented elsewhere by the authors [12].

2.3. Concrete mixture details and specimens

All concretes were mixed in accordance with ASTM C192 standard in a power-driven revolving pan mixer. Two series of control mixtures with the same w/c ratios of 0.35 with 450 kg/m^2 were designed. The concretes in Series 1 was exposed to steam curing (Steam cured lightweight concrete: SC-LWC), while for those in Series 2, standard water curing method was adopted (Water cured lightweight concrete: WC-LWC). In order to investigate the effect of lightweight fine aggregate (LWFA), crushed limestone sand was replaced 0%, 25%, 50%, 75%, and 100% of LWFA by volume. Thus, totally 5 different mixtures to be tendered under two different curing regimes were prepared in this study. Details of the mixtures are given in Table 3. The mixtures shown in Table 3 were designed to have slump values of 150 ± 20 mm for the ease of handling, placing, and consolidation. Therefore, the superplasticizer was added at the time of mixing to achieve the specified slump.

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

Composition	Portland cement	Fly ash
SiO_2 (%)	19.79	56.20
CaO (%)	63.84	4.24
Al_2O_3 (%)	3.85	20.17
Fe_2O_3 (%)	4.15	6.69
MgO (%)	3.22	1.92
SO_3 (%)	2.75	0.49
Na_2O (%)	–	0.58
K_2O (%)	–	1.89
Loss on ignition (%)	0.87	1.78
Specific gravity	3.14	2.25
Specific surface (m^2/kg)	335	287