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Self-consolidating characteristics of concrete composites including rounded fine and coarse fly ash lightweight aggregates

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ABSTRACT

The objective of this paper is to characterize fresh properties of self compacting concretes produced with lightweight fine and coarse aggregates (LWFA and LWCA). Lightweight aggregates were produced by cold bonding pelletization of 90% fly ash and 10% Portland cement by weight in a tilted revolving pan at ambient temperature. Thereafter, a total of seventeen self compacting lightweight aggregate concretes (SCLCs) were designed with a water-to-binder (w/b) ratio of 0.32. The workability of SCLCs was quantitatively evaluated by slump flow time and diameter, V-funnel flow time, and L-box height ratio. Moreover, compressive strength of hardened SCLCs was measured at 28 and 90 days. It was found that all of the SCLCs have good deformability, passing ability, and resistance to segregation. Increasing replacement level for LWFA and/or LWCA simultaneously decreased density and increased the flowability. However, it was observed that LWCA was more useful than LWFA to obtain the same workability of SCLCs. The compressive strength of SCLC with full replacement by LWFA and LWCA was found to be 43 MPa at 28 days.

1. Introduction

Concrete is the world's most widely used construction material which has superior properties such as excellent versatility, availability and economy compared to other structural materials. Despite all advantages, the use of concrete is limited in some structures because of its high self weight and need of high skilled workers compared to other construction materials. Therefore, in recent years there has been a tremendous interest to develop new high performance materials such as self-compacting concrete (SCC) and lightweight concrete (LWC) used for some of the urgent needs of the construction sector [1–3].

LWC can easily be produced in the strength range of 30–80 MPa [4]. Increasing use of LWC brought the need for the production of artificial lightweight aggregates so the industrial waste materials such as fly ash and blast furnace slag are used for lightweight aggregate (LWA) production [5–10]. In Turkey approximately 15 million tones of fly ash are generated annually from thermal coal-fired power plants and only a very small proportion of it is used in the construction industry and other various purposes [11]. One way of producing LWA with an environmental impact and minimum energy consumption is the agglomeration of fly ash particles by cold-bonding process, where the water is the wetting agent acting as coagulant, so that the moist mixture would be pelletized in a tilted revolving pan [5,6,9,10]. Production of LWA with spherical shape by cold bonding process can be considered as an effective way to use such waste materials as aggregate in concrete.

Self-compacting lightweight aggregate concrete (SCLC) is a kind of high performance concrete developed by combining the favorable properties of SCC and LWC. It needs no external vibration and can spread into place, fill the formwork and encapsulate reinforcement without any bleeding or segregation [12]. The use of SCLC can be beneficial to obtain a significant reduction in the total mass of the structure which can result in size reductions of sections and simplify the construction [3]. Furthermore, the segregation of LWA in place of SCC can be prevented by skipping the process of vibration.

To achieve the desired workability, SCLC requires high fluidity, passing ability, and moderate resistance to segregation. Aggregates occupying 65–75% of the volume of concrete have a major influence on the characteristic properties of SCLC [13]. Since the wide diversity of the source and manufacturing process of LWA, the properties of concrete should be investigated independently for each type of LWA [14]. Many researchers studied the effects of the particle shape, specific gravity, unit weight, particle size, strength, moisture content, and absorption of the LWA on the properties of LWC [5–10]. However, so far, there are only a few studies on use of LWA in the production SCC. Müller and Haist designed three mix proportions for SCLC and evaluated the workability by slump flow, V-funnel, and J-ring tests. It was observed that

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compared with SCC there was no significant difference in the design of SCLC except for the aggregate used [15]. Wu et al. studied the mix design and workability of SCLC made with lightweight expanded shale aggregate by considering the water absorption of LWA [12]. Kim et al. reported that the smaller density of coarse LWA resulted in the higher flowability of SCC at the same LWA proportions [3]. However, Khaleel et al. found that by increasing the maximum size of coarse aggregate, flowability and passing ability of SCLC reduced [16]. Furthermore, the researchers showed that LWA with spherical form makes easier the mobility of fresh SCC. It can be concluded that the higher sphericity of LWAs is the reason of the lower flow resistance imposed by the particles [16–20]. On the other hand, despite its various favorable properties, there is a dearth of research related to the use of the cold-bonded fly ash lightweight aggregate in the production of SCC.

In this study, artificial LWAs manufactured through the cold-bonding agglomeration process of fly ash were used to produce SCLC. Natural coarse and fine aggregates of conventional SCC were partially substituted by LWAs at six volume fractions from 0% to 100% by 20% increments. Thus, a total of seventeen different SCLC mixtures were designed with constant water–binder ratio of 0.32 and the total binder content of 550 kg/m^3.

2. Experimental program

2.1. Cement, fly ash, superplasticizer

In this study, ordinary Portland cement (CEM I 42.5 R) conforming to the TS EN 197-1 (mainly based on the European EN 197-1) was utilized for producing both the artificial lightweight aggregates and the concrete mixes [21]. Class F type fly ash (FA) supplied from Çatalağzı Thermal Power Plant, Zonguldak, Turkey was utilized both as a secondary binder material at 20% replacement level by weight of cement and as for producing LWA. Physical and chemical properties of the cement and FA are given in Table 1. A polycarboxylic ether type superplasticizer (HRWRA) with a specific gravity of 1.07 g/cm^3 was used to achieve the desired workability in all mixtures.

2.2. Aggregates

Artificial LWAs were produced via cold bonding of Portland cement and FA in a tilted pan at ambient temperature. For this, a dry mixture of 10% Portland cement and 90% FA by weight was pelletized by moistening in an inclined rotating pan with a diameter of 80 cm and a depth of 35 cm (Fig. 1). Water spraying on the dry mixture at about 18–20% by weight of the total binder mixture took about 10 min [22]. For further stiffening the fresh pellets, the agglomeration process was prolonged for additional 10 min. Afterwards, the fresh pellets were put in plastic sealed bags for self curing and stored for hardening in a curing room at a temperature of 20 °C and a relative humidity of 70% for 28 days. Eventually, the hardened fly ash aggregates were sieved to obtain two group fractions of 0.25–4 mm sizes as lightweight fine aggregate (LWFA) and 4–16 mm sizes as lightweight coarse aggregate (LWCA) (Fig. 2). Furthermore, specific gravity and water absorption of lightweight fine and coarse aggregates were measured as per ASTM C127 [23]. After 24 h submersion, by weight water absorptions of LWCA and LWFA were about 17% and 21%, respectively.

Table 1
Chemical compositions and physical properties of Portland cement and fly ash.

Analysis report (%)	Cement	Fly ash
CaO	62.58	2.24
SiO_2	20.25	57.2
Al_2O_3	5.31	24.4
Fe_2O_3	4.04	7.1
MgO	2.82	2.4
SO_3	2.73	0.29
K_2O	0.92	3.37
Na_2O	0.22	0.38
Loss on ignition	2.99	1.52
Specific gravity	3.15	2.04
Blaine fineness (m^2/kg)	326	379

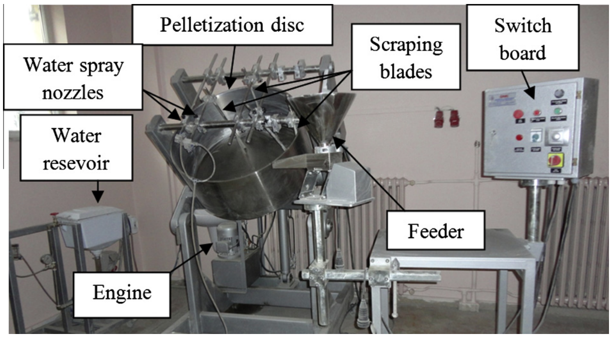

Fig. 1. The general view of the pelletization disc.

Natural fine and coarse aggregates were used together with fine and coarse LWA for producing SCLC. A mixture of crushed limestone and natural river sand as natural fine aggregate (NWFA) was used. Natural coarse aggregate (NWCA) was river gravel with a maximum particle size of 16 mm. Sieve analysis and specific gravities of natural and artificial aggregates are presented in Table 2.

2.3. Concrete mixture proportioning and casting

In the second stage of the experimental program, a total of seventeen Self Compacting Concrete (SCC) mixes were designed and produced at a constant water-to-binder ratio (w/b) of 0.32. A total binder content of 550 kg/m^3 was obtained by incorporating binary blends of 20% fly ash and 80% Portland cement by weight. The mixes were all the same except the natural aggregate being replaced by artificial LWA, for both fine and coarse fractions at different proportions as illustrated in Table 3. The process of replacement was carried out at 20% increments by volume of coarse, fine, and both (at equal proportions) natural aggregates in the control mix (CM) with 100% natural aggregates. Thus, concrete mixes were scheduled as three groups: first, MC group in which coarse lightweight aggregate replaced coarse normal weight aggre-

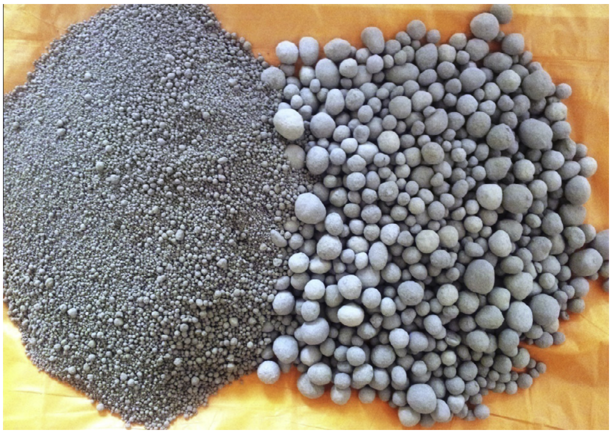

Fig. 2. Cold-bonded LWFA and LWCA.