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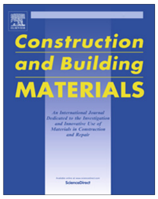

Effect of nano silica on the workability of self-compacting concretes having untreated and surface treated lightweight aggregates

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HIGHLIGHTS

- Fresh properties of self-compacting lightweight concrete (SCLC) is investigated.
- Lightweight aggregates (LWAs) made from 90% fly ash and 10% cement by pelletizing.
- Treated LWA and nano-silica (nS) contributed to a higher blocking ratio.
- Higher viscosity was accompanied the higher amount of nS addition.
- Treated LWAs improved SCLC workability and 28 days compressive strength.

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ABSTRACT

This paper presents the fresh properties of self-compacting lightweight aggregate concrete (SCLC) made with cold bonded fly ash (FA) lightweight aggregate (LWA) at a wide range of water-to-binder (w/b) ratios. For this, three concrete series including eighteen SCLCs were designed with w/b ratios of 0.25, 0.37 and 0.50, respectively. Each series have 6 different mixes in which two type of coarse LWAs (surface treated or not) and three nano silica (nS) replacement levels (0, 2.5% and 5.0%) are considered. The properties of SCLCs were observed in terms of slump flow diameter, T_{500} slump flow time, V-funnel flow time, and L-box height ratio. The compressive strength test was also conducted to obtain the strength level at 28 days. It is found that the fresh SCLCs have good fluidity, passing ability, uniform aggregate distribution and resistance to segregation. Incorporating treated coarse LWAs increased the workability characteristics of SCLCs. However, appreciable improvement in the consistency of SCLCs by nS addition was observed. The SCLCs made with treated LWAs and 5% nS were found to be the harder samples in this research.

1. Introduction

Considering the environmental pollution, the control and management of solid waste materials is one of the worldwide challenging matters. Large amount of fly ash (FA) generated by Thermal Coal-fired Power Plants has been remained unutilized in landfills and storage ponds. With the proper awareness and technology development, the utilization of industrial by-products and wastes powder materials such as FA in production of artificial lightweight aggregate (LWA) has attracted the attentions of investigators and practitioners in the recent years as an effective way for renewable resources [1–3]. Pelletization or cold bonding method is an alternative way to produce LWA from waste materials like FA. Moreover, it can be considered environment friendly and economic due to the minimum energy consumption. In cold bonding method, the reaction between FA and cementitious material during the production of LWA leads to form bonds in the spherical pellets produced by agglomeration of the moisturized fines with water acting as a coagulant in a rotating disc. The agglomerated particles left to cure for several days at ambient temperature to improve the LWAs strength [2]. The production of LWAs from FA is an important issue since the application of recycling waste is considered alternative sources to provide artificial LWAs and reducing the dependence of the concrete industry on natural aggregates.

Self-compacting lightweight aggregate concrete (SCLC) is a kind of high performance concrete developed by combining the favorable properties of self-compacting concrete (SCC) and lightweight

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concrete. Therefore, SCLC is a type of high performance concrete characterized by its ability to penetrate through congested reinforcement, fills complicated shapes without segregation and bleeding as well as places and compacts under self-light weight [4–6]. The reduction in self-weight of SCLCs can result in smaller areas of sectional members and easier for handling and transporting. Additionally, by skipping vibration process the segregation of LWAs in place of SCLCs can be prevented [7–9]. Due to the huge compensation of aggregates, the workability characteristics of SCLCs are very allergic to the aggregate shape, texture and size. The diversity of LWAs properties result in distinctive behavior among the SCLCs. Therefore, the characteristics of SCLCs should be examined independently for each type of LWAs. Choi et al. [10] showed that less than 50% coarse LWAs and fine 75% LWAs satisfied the fresh requirements of SCLCs. A comparison study demonstrated that less superplasticizer and viscosity modifying agent needed to obtain same workability of SCLCs to that of normal weight self-compacting concretes with a fresh density of 1640–2200 kg/m^3 respectively [11]. Lachemi et al. [12] noted that SCLCs mixes made with lightweight furnace slag sand exhibited lower flowability, passing ability and resistance to segregation with higher viscosity than mixes prepared with normal weight sand. Gamal [13] discussed the effects of water to cement ratio on fresh properties of SCLCs produced from locally expanded clay as coarse lightweight aggregates. Topçu and Uygunoğlu [14] founded that the lighter aggregates increased the slump flow diameters of self-consolidating concretes. However, Hwang et al. [15] indicated that the slump flow diameter of fresh SCLCs mixes ranged with 470 mm, 530 mm and 710 mm at water-to-binder (w/b) ratio of 0.24, 0.32 and 0.4, respectively. Gesoğlu et al. [16] demonstrated that SCLCs including 100% of LWAs was of nearly 25% less unit weight than control mix with 100% normal weight aggregates and also concluded that increased the replacement ratio of LWAs improved the flowability of fresh concrete and reduced the compressive strength of SCLCs. In the design of concrete, spherical shaped aggregates with smooth surface are preferred because they more readily flow past each other as well as the reduction in specific surface area requires less cement and water [10,16–19]. Furthermore, recent study stated that the incorporation of treated aggregates enhances the workability performance of SCCs [6].

Noticeable obstacles relevant with LWA application in concrete was reduction of compressive strength and phenomena of aggregates flooding. A number of studies have been reported in the literature concerning the use of mineral admixtures to overcome such obstacles and improve the self-compacting compatibility characteristics of the concretes [20–22]. Nano-Silica (nS) was quite efficient in enhancing strength, durability and microstructural behavior cement paste compared to the traditional pozzalanic materials [23]. It was reported that the FA has low initial activity, but the pozzolanic activity notably improved after using a little nS [24]. Yu et al. [25] observed that the retardation of cement hydration reaction resulted from the high amount of superplasticizer utilized to produce ultra-high performance concrete can be significantly compensate by incorporating nS. Incorporation of nS in ultra-high performance concrete significantly improves the resistance to aggressive environments as the value of capillary pores decreases [26]. Madani et al. [27] concluded that the larger particle size nanosilicas had better performance in improving later age microstructure of concretes compared to the finer particle size. Ghafari et al. [28] performed a review on ultra-high performance concrete enhanced with nano-materials. The authors concluded that the effect of nS on the workability properties and thixotropic behavior has not been well addressed. The experimental results of Jo et al. [29] showed that the compressive strength of mortars with nS particles were all higher than those of mortars with silica fume. On the other side, SCC incorporating nS enhances concrete quality, keeping into account the challenges for the side effects on the fresh properties as the water demand increases [30,31]. At the same line, there are several investigations on incorporation of nS in concrete proportioning but most of them have supposed high water to binder ratios (w/b), which cannot exactly exhibit the efficiency of them with low w/b ratios [32–35]. Moreover, in spite of various types of conventional pozzolanic materials are successfully applied to produce SCLC [36–38]; the use of nano technology in concrete production, so far, was restricted with production of conventional concrete [31,39–42]. In the present study, the incorporation of nS aims to lessen the adverse effects of artificial cold bonded LWA on concrete properties, reduce hazardous wastes effect, and access better performance of construction industries in civil engineering.

However different aspects of SCCs and SCLCs containing artificial cold bonded aggregates reported in recent literature. In the current literature, to the best of the authors' knowledge, there is no experimental work investigated fresh properties of SCLC incorporating treated fly ash cold bonded LWAs and nS. So this paper presents the hitherto unavailable results to fresh properties of the SCLCs produced over a wide range of w/b ratios with cold bonded LWA and three different replacement ratios of nS. Moreover, Low, moderate and high w/b ratios were selected to design eighteen SCLC mixtures as there is an expectation of change in the workability properties of SCLC by varying w/b ratio with the presence of nS and two types of LWAs (untreated and treated). To attain the purpose of our study, powder mixture of 90% FA and 10% Portland cement was used through the cold bonding process to produce artificial LWAs. Following the LWA production, aggregate were screened to have fractions between 2.0–4.0 mm and 4.0–16 mm. A potential treatment on a half of coarse LWA volume was implemented by using soluble solution of sodium silicates (water glass) in order to enhance the impermeability and strength of cold bonded aggregates. To attain the purposes of this study, a comparison between eighteen mixes was presented herein based on the results of slump flow, V-funnel, L-box height ratio and 28 days compressive strengths.

2. Experimental program

2.1. Cement, fly ash, nano silica and superplasticizer

In this study, a CEM I 42.5 R Portland cement was used for preparing the lightweight aggregates and the eighteen SCLCs mixes. Class F of FA confirming to the requirements specified in ASTM C 618 [43] was utilized as a mineral admixture in SCLC mixes at 25% replacement level by weight of cement and also for making LWAs. Additionally, the hydrophilic fumed silica with a specific surface area of 150 m^2/g was used. Table 1 shows the physical and chemical properties of cement, FA and nano silica (nS). High range water reducing admixture (HRWRA), based on polycarboxylic ether formulation with a specific gravity of 1.07 was utilized in all mixes to give the desired flowability.

Table 1
Chemical composition and physical properties cementitious materials used.

Item	Portland cement	Fly ash	Nano silica
CaO (%)	62.12	2.24	–
SiO_2 (%)	19.69	57.2	99.8
Al_2O_3 (%)	5.16	24.4	–
Fe_2O_3 (%)	2.88	7.1	–
MgO (%)	1.17	2.4	–
SO_3 (%)	2.63	0.29	–
K_2O (%)	0.88	3.37	–
Na_2O (%)	0.17	0.38	–
Loss of ignition (%)	2.99	1.52	$\leqslant$1.0
Specific gravity	3.15	2.04	2.2
Blaine fineness (m^2/kg)	394	379	–
Surface-volume ratio (m^2/g)	–	–	150 ± 15
Average primary particle size (nm)	–	–	14