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Research Article

Using of thermal power plant fly ash to produce semi-lightweight aggregate and concrete

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ABSTRACT

This article introduced a zero waste management of pulverized fuel ash in construction sectors via two different approaches. The first one was represented by production of spherical lightweight aggregates from fly ash (FA). The second approach was introduced by producing a non-conventional concrete type namely self-compacting concrete incorporated a high FA content. The production of aggregate and concrete was adopted through the use of lower consumptions of electrical energy. To this aim, fresh aggregate particles were self-cured at ambient temperature for 28 days, whilst no electrical or mechanical vibrators have been used in casting process. The quality of produced aggregate and concrete was examined by different experimental tests. The general conclusion of this study revealed that the use of FA in the production of lightweight aggregate and concrete can be tapped to protect the environment from the side effects of FA. In addition, the produced concrete can be utilized for structural purposes as the lower compressive strength was found to be higher than 55.1 MPa.

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INTRODUCTION

One of the most challenging matters throughout the world is the management of wastes; mainly the solid waste material. Nowadays, an increase in environmental pollution issues are resulted from industrial waste materials. Considering the solid waste material i.e. fly ash, it can be said that a large quantity is stilled dropped in landfills and produces a considerable amount of pollution. In the recent years, many investigators are pioneered serious efforts to utilize such solid waste materials in the construction technology. For example, they used powders from industrial by-products in the production of some types of artificial aggregate [1,2].

Artificial FA aggregates can be manufactured either by cold bonding pelletization or sintering processes. Cold

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bonding is environment friendly technic requires minimum energy consumption and a medium technical skill for making pellets. In this method, the reaction between pozzolanic powder material and calcium hydroxide caused to create bonds in the agglomerated particles. Typically, after the agglomeration process the spherical pellets are left to cure at ambient temperature inside selling bags so as to gain more strength [3–5]. The construction industry is depended on the natural resources (i.e. river aggregate and crushed stone aggregate). Therefore, the production of artificial aggregate from FA can be used to compensate the serious shortages of natural aggregate. Self-compacting semi lightweight aggregate concrete (SCSLC) is a kind of non-conventional concrete described by high fluidity under its own weight, easily spread through congested reinforcement bars without blocking, easily take formwork shapes in structural members without vibration, high resistance to bleeding, and long distance pumping ability. The low density of SCSLC can result in size reductions of structural members and overcome the inconveniences of handling and placing of fresh concrete while skipping compaction and vibration processes help to avoid floating of light weight aggregate (LWA) toward the concrete's surface during fresh concrete casting [6–8].

Due to the fact that aggregate occupies up to 75% by total concrete volume, aggregate can be considered as one of the most important constituent materials that affects fresh and other properties of concrete [9]. The presence of different types of lightweight aggregate source and several manufacturing methods result in distinguishing behavior among the concretes [8]. Many studies have been carried out to establish the factors affecting artificial lightweight aggregate properties produced from various industrial by products [10–12]. However, there is still a gap in the literature regarding the use of artificial lightweight aggregates manufactured from industrial by products to produce SCSLCs. Lachemi et al. [13] developed three mixtures of concrete with blast furnace slag aggregates and expanded shale aggregates. Besides, one mixture of self-compacting normal weight was produced by incorporating normal-weight gravel aggregates and considered as a control mixture. The feasibility of using such type of concrete in reinforced sections was also investigated by measuring bond strength of reinforcing bars and failure mode. Hwang et al. [14] evaluated the manufacture and performance of LWA from 10-50% fly ash and reservoir sediment for light weight concrete. They used pelletizing disk and sintering by a rotary kiln for producing artificial LWA. The study demonstrated that the increment of FA content increases the water absorption of LWA. The unite weight and 28-day compressive strength of SCSLC ranged from 1878 kg/m^3 to 2057 kg/m^3 and from 25.4 MPa to 54.9 MPa, respectively. Narattha and Chaipanich [15] introduced an experimental study about phase characterizations, physical properties and strength of cold-bonded fly ash LWAs. They found the optimum content of Portland cement is 10% by weight in order to manufacture cold bonded FA aggregate. Usanova [16] investigated the properties of concrete made with cold bonded fly ash aggregate. This study revealed that the water presoaking FA aggregate influenced the shrinkage of concrete. The utilization of nano technology in concrete production was restricted with production of normal and self-consolidation concrete [17–19]. To the knowledge of the authors, the reduction of hazardous wastes effect and better performance of construction industries can be accessed by incorporating nano technology in civil engineering.

In this study, cold bonding method was used to prepare artificial aggregate by mixing 90% FA and 10% Portland cement by weight. After the curing period, the manufactured aggregate was classified into fine and coarse aggregate. To attain the purposes of this study, several tests (fresh density, slump flow test, drying shrinkage and compressive strength) were conducted to compare between three different concrete mixtures.

MATERIALS AND METHOD

Materials

In this investigation CEM-I 42.5 ordinary Portland cement and FA class F were utilized in the production of concrete and LWAs. In this study, class F fly ash was utilized for manufacturing cold-bonded and sintered artificial fly ash aggregates. It was provided from thermal power plant, named Ceyhan Sugözü, located in Turkey. The chemical composition of FA is similar to that of Class F type fly ash as per ASTM C618 because the amount of CaO is > 10 % [20]. In all concrete mixtures FA content was set to be 25% by weight from the total binder content of 600 kg/m^3. The nano silica with a specific surface area of 150 m^2/g was utilized. In this research, two fraction of nano-silica was incorporated (2.5% and 5% by weight of total binder content). Table 1 presents the physical and chemical properties of the powders materials.

High range water reducing admixture (HRWRA) was used to achieve the required flowability for fresh concrete. The commercial name of HRWRA is Glenium 51 supplied in a plastic sealed container as a dark brown liquid and had a specific gravity of 1.07.

Aggregate and Concrete Production

In the agglomeration process, the palletization machine was calibrated to have a revaluation speed of 42 rpm and a tilted angle of 45-degree, see Figure 1. As aforementioned earlier, the fresh aggregate particles which manufactured from 90% FA and 10% cement were cured at 20 °C and 70% relative humidity for four weeks in sealed plastic bags [21].

Figure 2 shows the main production stages of artificial aggregate through cold-bonded process. Two main

Table 1. Properties of cement, FA and nano silica

Analysis Report	Portland Cement	FA	Nano Silica
Calcium oxide (%)	62.12	2.24	-
Silicon dioxide (%)	19.69	57.2	99.8
Aluminum oxide (%)	5.16	24.4	-
Ferric oxide (%)	2.88	7.1	-
Magnesium oxide (%)	1.17	2.4	-
Sulfur trioxide (%)	2.63	0.29	-
Potassium oxide (%)	0.88	3.37	-
Sodium oxide (%)	0.17	0.38	-
Loss of ignition (%)	2.99	1.52	≤ 1.0
Specific gravity	3.15	2.04	2.2
Blaine fineness (m^2/kg)	394	379	-

Figure 1. A 45-degree angle tilted pan.

Figure 2. Stages of aaggregate production.

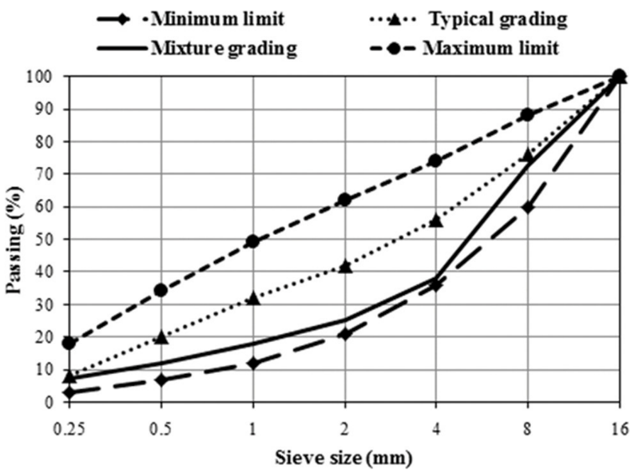

Figure 3. Aggregate grading according to standard limits [22].

fractions of 4-16 mm and 4-2 mm were used to category the prepared aggregate into coarse and fine aggregate, respectively. The specific gravity of artificial aggregate was 1.75, whereas it's about 1.74 for fine artificial aggregate. On the other hand, crushed sand having a specific gravity of 2.4 and size fractions of 0.25-2.0 mm was also used as a normal weight aggregate. The manufactured aggregate was used in all mixtures in a saturated surface dry condition to keep the effective water content at the same considered level.

Water to binder ratio of 0.25 was used to design three different SCSLC mixes having a 600 kg/m^3 binder ratio. The grading of aggregate was covered by 50%, 25%, and 25% artificial coarse aggregates, fine artificial aggregates, and crushed sand. The gradation curve of coarse and fine aggregate mixture is presented in Figure 3.

The details of mixing proportions are illustrated in Table 2, in which the mixes were designated according to nano silica fraction.

Table 2. Mix proportions of details in kg/m³

MIX ID	Cement	FA	Nano silica	Water	LWA		Sand
					Coarse	Fine	
SCSLC-0.0% NS	450	150	0	150	551.7	273.9	375.9
SCSLC-2.5% NS	435	150	15	150	549.9	273.0	374.7
SCSLC-5.0% NS	420	150	30	150	548.1	272.2	373.5

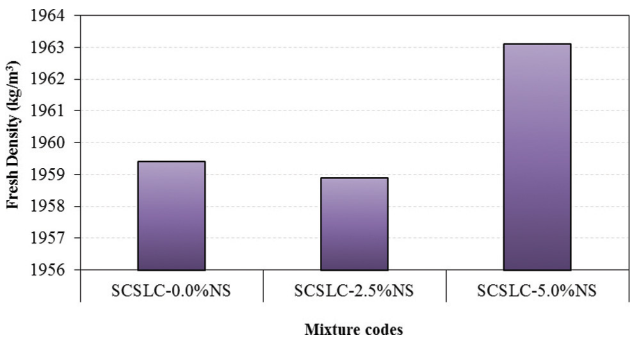

Figure 4. Comparison in the fresh density of SCSLC made with nano silica.

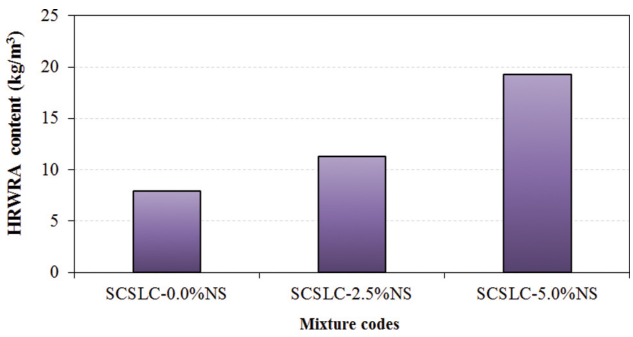

Figure 5. Variation of HRWRA contents.

FINDINGS AND DISCUSSION

Fresh density

The SCSLC characterized by its high deformability, fluidity, and amazing filling ability through congested sections as well as uniform aggregate distribution and maximum resistance to bleeding and segregation which can be assessed by special test procedure with respect to EFNARC (2005) [23].

The fresh densities of the three different concrete mixtures are presented in Figure 4. It can be seen the fresh density of concretes are found to be 1959.2, 1959.4 and to 1963.1 kg/m³ for SCSLC-0.0%NS, SCSLC-2.5%NS and SCSLC-5.0%NS, respectively. According to results of fresh density analysis, all concrete mixes can be considered as a semi-lightweight concretes. This behavior maybe resulted due to the use of crushed sand beside the lightweight aggregate, production concrete with high binder content of 600 kg/m³, and the utilization of low water to binder ratio [24]. Another observation must be stated that the use of nano silica (mix SCSLC-2.5%NS) decreases slightly the fresh density state of SCSLC compared to mixture namely SCSLC-0.0%NS. This is maybe attributed to the lower density of nano particles comparing to the cement particles as reported by Barfield and Ghafoori [25].

Slump flow test

All concrete mixtures in this study were modified by adjusting the amount of HRWRA to have a suitable slump flow which was specified by a diameters of 700±50 mm. The observation stated that all the consistency of fresh concretes having a homogeneity without any bleeding or segregation. The lower and higher flow diameters of SCSLC-5.0%NS and SCSLC-0.0%NS mixtures were measured as 680 mm and 700 mm, respectively.

Regarding the influence of nano silica on the flow diameter slump test results, Senff et al. [24] stated the utilization of nano particles increases the cohesion in the fresh concrete mixtures. Such influence can be clearly seen in mixtures incorporated 2.5 % and 5.0% nano silica. The flow diameter of SCSLC-0.0%NS, SCSLC-2.5%NS and SCSLC-5.0%NS were found to be 700, 690, and 680 mm, respectively. It was recommended T_{500} to be in the range of 2-5 s so as to obtain fresh concrete having good viscosity which can prevent or reduce segregation [25]. The test results indicate that the use of nano silica can be used to modify the slump flow time with the recommended range. The required doses of HRWRA to attain the required flow-ability for SCSLC made with artificial lightweight aggregate at different nano silica fractions are presented in Figure 5. The results indicate that the addition of 2.5% and 5.0% of nano particles to SCSLC mixtures had a significant effect to increase the amount of HRWRA gradually. To achieve the desired slump flow diameter, the control mixture SSLC-0.0%NS required a 7.9 kg/m³ of HRWRA while SSLC-2.5%NS and SSLC-5.0%NS required about 11.3 and 19.3 kg/m³ of HRWRA, respectively. Thus, it can be concluded that, the utilization of nano silica in the blending system results in a higher dosage of HRWRA to attain the workability reduction of fresh concrete. Hosseini et al. [26] stated that nano-particles reduces the amount of mixing water by the absorption ability. The

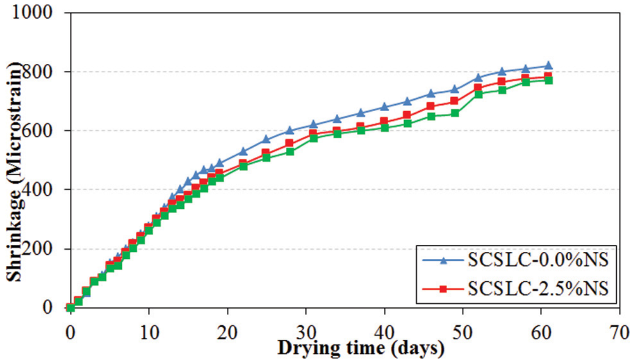

Figure 6. Variation of HRWRA contents.

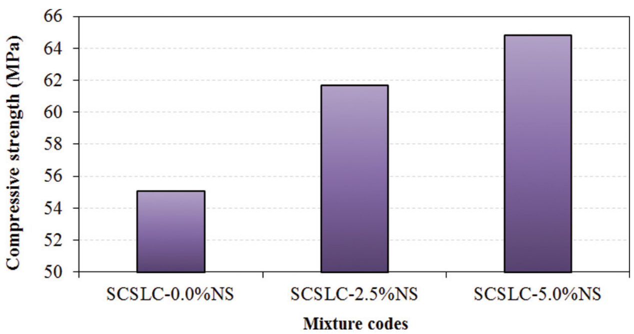

Figure 7. Variation of HRWRA contents.

physical properties of nano silica i.e. surface area and presence of unsaturated bonds attracting of water molecules to the surface of nano particles, however, this caused to create a chemical bond between them. As a result, the viscosity of fresh concrete will be increased due to the reduction of mixing water [24].

Drying shrinkage

The reinforcement bars in concrete structures can be exposed to corrosion and deterioration due to the presence of cracks. Drying shrinkage of concrete if happened may result in cracks and then the risk of corrosion is increased significantly.

The influence of nano silica on the strain behavior of the three different concrete mixtures produced in this study is shown in Figure 6. As can be seen from the figure, the alterations between shrinkage values of drying shrinkage exhibit an extremely steep development at the first 10 days. The results indicate that the use of nano silica in the ternary blends reduces the strain development. The drying shrinkages of SCSLC-2.5%NS and SCSLC-5.0%NS were lower than that of the concrete free of nano silica, namely SCSLC-0.0%NS. On the one hand, the positive effect seemed to be higher with the increase of nano silica replacement level. In addition, the results also showed that the 2.5% percent of nano silica seemed more dominant than 5.0% nano silica on shrinkage intensity. For example, an increase in nano silica did not directly correlate with the same percentage increase of the positive effect. Recent studies [27,28] also reported a beneficial effect due to the utilization of nano silica on drying shrinkage. Moreover, the shrinkage behavior detected in this study agrees with other investigations conducted to find the effect of ultrafine mineral admixtures on shrinkage [29–31].

28-days compressive strength

The results relevant to the compressive strength of SCSLC at 28 are graphically presented in Figure 7. The effect of nano silica on compressive strength of SCSLC is well observed in Figure 7. It can be indicated that there was a significant increase in compressive strength with the increase of nano silica content. According to the experimental values, the compressive strength of samples incorporating 2.5% and 5.0% nano silica are higher by about 12 % and 18 % than those free of nano silica. It was reported that nano silica more effective to improve compressive strength in higher w/b ratio (lower cement contents) [26]. However, the enhanced intensity of SCSLC compressive strengths decreases with the increasing content of nano silica up to 5.0%. The mixes that included binary blends and made with artificial aggregates exhibited lower values of compressive strength. The addition of nano silica remedies the compressive strength loss resulted from using inferior quality of artificial aggregate. For instance, the compressive strength at 28 days for SCSLC-0.0%NS was 55.06 MPa has increased to 61.68 and 64.83 MPa with the addition of 2.5% and 5.0% nano silica, respectively.

CONCLUSION

Based on the findings of the study, the following conclusions were drawn:

- The fresh densities of concretes in the range of 1959.4-1963.1 kg/m3 deduced that the produced concrete can be considered as a semi-lightweight self-compacted concretes. The replacement of denser particles (cement) with lighter particles (nano silica) decreases the fresh density state of concrete.
- It was inferred from the test results that all the mixes were executed to give a slump flow diameter of 700±50 mm which were achieved by adjusting the amount of HRWRA used. Moreover, HRWRA content increased with the increment of nano silica content. All of the mixtures manufactured in this study were classified as SF2.
- Employing nano silica in SCSLC up to 5% replacement level satisfied the requirements of self-compacted concrete as per by [23]. The addition of nano silica enhanced the consistency of the SCSLC. Hence, nano silica can be used to reduce bleeding and segregation.

- The use of 2.5% and 5.0% nano silica in the mixtures of SCSLC reduced drying shrinkage. Furthermore, the use of high amount of HRWRA caused to increase the efficiency of nano silica in reducing shrinkage.
- For all replacement levels, the nano silica modified SCSLC exhibited greater compressive strength in comparison to the SCSLC containing binary blend of Portland cement and FA.
- Finally, FA can be properly managed and recycled to beneficial reuse thought the production of valuable construction material, i.e. SCSLC. The production of artificial aggregate rather than concrete from FA can be used to avoid the hazards that result from storage of such type of solid waste.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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