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Effects of nano-silica on the gas permeability, durability and mechanical properties of high-strength lightweight concrete

Nihat Atmaca [a,*], Mohammed Layth Abbas [a], Adem Atmaca [b]

[a] Department of Civil Engineering, Engineering Faculty, Gaziantep University, Turkey
[b] Department of Energy Systems Engineering, Engineering Faculty, Gaziantep University, Turkey

HIGHLIGHTS

- Lightweight coarse aggregate (LWA) has been produced by pelletization technique.
- LWA has been replaced with coarse natural aggregate at different levels.
- The negative properties of LWAs can be remedied by the addition of nS particles.
- nS particles give better performance results in conventional concretes than LWCs.
- The durability of HSLWCs has been improved significantly by using nS particles.

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ABSTRACT

This study presents an experimental investigation on the effect of nano-silica (nS) on the gas permeability, durability and mechanical properties of high strength lightweight concrete (HSLWC). In order to expose the effects of nS on the performance of concrete, the lightweight coarse aggregate (LWA) has been fabricated through cold bonded method by the pelletization process by mixing 10% of cement with 90% of fly ash (FA). Then, the utilization of HSLWCs has been finished off by volumetric substitution of normal coarse aggregate with 5 different levels, namely (0%, 10%, 20%, 30% and 40%) with and without nS at a constant water/binder ratio of 0.35 and a constant ratio of 20% of FA. The concrete has been tested at the age of 28 and 90 days for splitting tensile strength, sorptivity index, gas permeability and compressive strength as well as 3 and 7 days for compressive strength. It has been observed that the increase in the replacement of lightweight coarse aggregate affecting the strength and permeability properties negatively. On the other hand, the results indicate that the addition of 3% nS to HSLWCs reduce the negative properties of lightweight coarse aggregate and leads to remarkable increase in mechanical properties while the sorptivity and gas permeability values have been decreased up to 25% and 40% respectively, when the values compared with the same replacement levels of LWAs. Moreover, it has been found that nS particles have better results on normal concrete compared to the LWCs.

1. Introduction

Waste management is of great importance in the prevention and reduction of environmental pollution. To cope with this problem and reduce contamination, it is important to employ and recycle the waste in the building sector. About 19 M tons of fly ash (FA) production which was 3% of the world total, was realized in Turkey in 2012. It is estimated that the amount of FA would increase by 30% by 2020 [1,2]. Therefore, the production of artificial aggregates solves two problems, decreases the environmental pollution and prevents the depletion of natural resources through the creation of a lack of natural aggregates in building industry [3,4]. Cold bonded and sintering are two practical methods to produce lightweight aggregate FA. Less energy is used during the cold bonded method to make the pellets by agglomeration of fine particles depending on its pozzolanic reactivity of FA resulting in lower strength aggregate [5,6].

The lightweight aggregate utilization in concrete has many advantages [7–9]. These are summarized as;

– Reduce the amount of dead load that's lead to reduce the footing sizes and gets lighter and smaller upper structure.

* Corresponding author.
E-mail address: atmaca@gantep.edu.tr (N. Atmaca).

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– Lighter weight and smaller precast elements, low cost of transportation.
– Reduction in sizes and dimensions of beams, columns, and slabs, larger flat area.
– High thermal efficiency.
– Enhanced resistance against fire [10].

The production and usage of LWA have many benefits;

– Effective recycling of FA.
– Conserve the natural materials (sand and coarse aggregate) which are found rarely in nature
– Protects the river bed, and beaches from scarring activities of aggregate mining.
– It is much lighter than the natural aggregate.
– Reduces the greenhouse gas emissions and specific energy consumption rates by reducing the need for the vast amount of cement which contributes majorly to carbon dioxide emissions [11,12].

High strength and high-performance concrete materials are used due to the aggressive environments that cause the premature deterioration of concrete structures. High-performance concrete (HPC) production is the best choice to produce a composite concrete characterized by its fine pore structure and low porosity that results in improvement in mechanical, transport and durability properties [13,14]. The mechanical properties and durability of HPC are mainly influenced by refining the hardened structure of the cement paste and enhancing paste-aggregate interface progressively by incorporating admixtures and additions [15,16]. There are many studies in the literature about the use of mineral admixtures to overcome and enhance the characteristics of concrete [17–19]. The addition of chemical and mineral admixtures to the conventional concrete leads to the emergence of new developments in the concrete related study to enhance the strength and durability [20].

Quing et al. [17] represented that nS is a quite effective in boosting strength, durability, and microstructure of cement paste when compared to the other traditional pozzolanic materials. There are many advantages of integrating nanotechnology into cement and concrete. It enhances the manufacture of cement, improves the properties of concrete, and revolutionizes the ability to monitor performance and has the ability to reduce permeability [21–23].

Li [24] reported that the FA has low initial activity but after using small amounts of nS, the pozzolanic activity notably increased and the reacts of nano-particles with calcium hydroxide crystals produce C-S-H gel resulting arrayed in the Interfacial transition zone (ITZ) between hardened cement paste and aggregate.

Beside strength appreciation, concrete deterioration is based on the difficulty to migrate the gas or liquid which migrate during the hardness process of concrete. As a result, the measurement of permeability provides an indication of the durability of concrete, for that reason the permeability is also called the key to durability [25,26]. The physical properties of concrete play a great role in a variety of processes of technological and environmental concern. Consequently, the permeability is very important for the structures under serious environmental and chemical effects [27,28]. In recent years, the gas permeability has been investigated by some researchers to estimate the pore structure and durability properties of concrete [29,30].

Du et al. [31] studied the effect of nS on mechanical and transport properties of LWA and they found the ITZ became denser and compact, the compressive strength increased and resistance to chloride ion and water has been improved with added 1% nS. Based on our search in the literature, this paper presents the first detailed experimental investigation about the effects of nS on the gas permeability, durability and mechanical properties of high strength lightweight concrete.

Within the scope of this study, the lightweight aggregate has been fabricated through cold bonded method by the pelletization process by mixing 10% of cement with 90% of FA. Then, the utilization of HSLWCs was finished off by volumetric substitution of normal coarse aggregate with 5 different levels, namely (0%, 10%, 20%, 30% and 40%) with and without nS at a constant water/binder ratio of 0.35 and a constant ratio of FA. The concrete was tested at the age of 28 and 90 days for splitting tensile strength, sorptivity index, gas permeability and compressive strength as well as 3 and 7 days for compressive strength only. This paper can contribute to a better understanding of the production of HSLWCs and parameters affecting its performance.

2. Experimental details and methodology

2.1. Materials

Through this study, a CEM I 42.5 R (TS EN 197-1:2012) ordinary Portland cement has been used to produce LWA with 10 different concrete mixtures. Class F of fly ash used in the production of LWA and concrete mix with respect to the requirements of Ref. [32]. nS with a specific area of 150 m2/g and high range water reducing admixtures (HRWRA) Glenium 51 with a specific gravity of 1.07 have been used in order to give all the mixes desired flowability. Table 1 shows the physical and chemical properties of materials used.

2.2. Aggregate

The LWA preparation consists of mixing, pelletizing and curing. The process begins by adding 90% of fly ash and 10% of cement to the total weight which is less than 10–13 kg as a dry powder. To ensure the homogeneity, the disk which has a pan diameter of 800 mm and depth of 350 mm was revived at a regular velocity and a slope angle. After that, water valve was operated to apply a water quantity at 18–20% of the total weight of powder materials. The total period for the pelletization process approach 20 min. It has been observed that the formation of the pellets occurred in the first 10 min at the moment of water spraying finished while the further time is necessary for sufficient stiffness.

The level of curing of LWAs must start at the end of pellets creation by conserving the fresh pellets for twenty-eight days in sealed bags at room temperature of 20 °C and relative humidity of 70%. The solidified LWA has been obtained at the end of the curing period. After that, the aggregate sieved to 4 to 16 mm to produce lightweight coarse aggregate which is used later to produce concrete. Fig 1 shows the production of LWAs.

Table 1
Chemical composition and physical properties of cementitious materials used.

Item	PC	FA	nS
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 on ignition (%)	2.99	1.52	≤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