Construction and Building Materials 150 (2017) 404–408

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Behavior of magnetic concrete incorporated with Egyptian nano alumina

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HIGHLIGHTS

- Using of MW instead of TW in OPC matrix enhances its slump, compressive strength.
- For Mc and NMC mixes, 3% NA mixtures gives the highest slump.
- The proper content of NA for in MC and NMC was 1% by weight of OPC.

ARTICLE INFO

Article history:
Received 20 March 2017
Received in revised form 14 May 2017
Accepted 2 June 2017

Keywords:
Nano alumina
Compressive strength
Magnetized water
Desorption

ABSTRACT

This research is the first attempt to determine the possibility of using magnetized water (MW) to improve fresh, mechanical, and microstructure characteristics of concrete incorporated with Egyptian nano alumina (NA). For this purpose, slump, compressive strength, desorption, and scanning electron microscopy (SEM) approaches were conducted. Eight concrete mixes and eight cement paste mixes were made with different NA contents (0, 1, 2, and 3% by weight of OPC). Two types of water, normal tap water (TW) and MW of 1.2 Tesla were used. Using MW instead of TW had led to a significant improvement in all considered characteristics of concrete. For non-magnetic concrete (NMC), the use of 1% replacement level of NA improved the properties of concrete. While, for magnetic concrete (MC), there was notable improvements in concrete characteristics of 1% NA and 2% NA specimens compared to control specimen. The proper content of NA to be used in both NMC and MC was 1% by weight of OPC. NMC made with 1% NA showed the highest increase in strength (17%) and decrease in capillary porosity (30%). MC made with 1% NA showed the highest increase in strength in (13%) and decrease in capillary porosity (27%) as compared to control specimen.

1. Introduction

A large number of the previous research has focused on improving the compressive strength and pore structure of concrete using various methods to do so, as the use of nano materials as cement replacement materials in concrete mixtures to increase strength [1,2]. However, the cost of incorporating of nano materials in concrete is not comparable with their advantages [3]. Most researchers concentrate their attention on producing economical concrete with higher strength using new philosophies in design methods, through modern technique, like using magnetic water [4].

1.1. Magnetic water

The application of magnetic-water technology in the concrete increased rapidly on the eighties and nineties decades as a result of the development of magnetic devices and its physical water effluents at concrete properties. Magnetized water is formed by passing the water through a magnetic field of certain strength under specific conditions. As a result of magnetization of water, there is a decrease in the surface tension of water which is measured using a device called Tensiometer [5].

Magnetic Field changes the structural elements of water, viscosity and electrical conductivity of water [6]. Low surface tension of water provides the breakage of large water clusters into new smaller ones. This leads to the change in the trajectory of water particles providing much better bonding between other additives to the water [7] and faster and complete hydration of cement takes place [8]. This leads to a significant enhancement in the different properties of concrete such as fresh and mechanical properties.

Some researchers studied the role of magnetized water in improving different characteristic of concrete [9,10]. The impact of magnetized water on concrete containing GBFS and Fly ash was investigated by [8]. He found that the early compressive strength of concrete was significantly increased when using magnetized water of 0.8 Tesla (T) and 1.2 Tesla. [11] found that slump

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http://dx.doi.org/10.1016/j.conbuildmat.2017.06.022
0950-0618/

and compressive strength of concrete were increased by 45% and 18% respectively when magnetic water was used for concrete preparation. He also determined that, with the same slump and compressive strength, cement content could be reduced by 28% in the case of magnetic concrete.

This research aims at maximizing the benefit of using nano materials such as Egyptian nano alumina (NA) as a cement replacement material in concrete due to the high cost of incorporating such materials in concrete mixtures. So, a comparison was made during this study between the behavior of both magnetic concrete (MC) and non-magnetic concrete (NMC) incorporated with Egyptian NA, where, two types of water, TW and MW were adopted in concrete preparation. The specific objectives were as follows:

1. To investigate the impact of MW on workability of concrete in terms of slump.
2. To clarify the effect of using MW on the mechanical behavior of OPC/NA concrete using compressive strength test.
3. To determine the proper content of NA to be adopted in both magnetic concrete and non-magnetic concrete.
4. To determine the possibility of using MW to improve the microstructure of OPC/NA concrete using desorption test and SEM analysis.

2. Experimental

2.1. Materials and mix proportions

Ordinary Portland Cement (OPC) of chemical composition given in Table 1 was utilized throughout this research. Egyptian Nano-Al_2O_3 with average particle size of 15 nm, 100 m^2/g Blaine fineness, and impurity of 99.3% was used throughout this investigation.

Siliceous natural sand complying with ASTM C33 was used. Coarse aggregates are crushed stone (maximum size 19 mm). A Polycarboxylate superplasticizer (SP) with a relative density of 1.1 was incorporated into all mixes. Two types of waters (Normal Tap Water (TW) and Magnetized water (MW)) were used. Magnetized water of strength (1.2 Tesla) and surface tension (0.081 N/m) was prepared in the electrical engineering department, faculty of engineering, Beni-Suef University.

The experimental program includes two main phases. In the first (non-magnetic mixtures), eight OPC concrete mixes and eight OPC paste mixes made with different contents of NA (0, 1, 2, and 3% by weight of OPC) were mixed using tap water (TW) to investigate the effect of adding different percentages of NA on fresh, mechanical, microstructure characteristics of concrete. In the second phase (magnetic concrete mixtures), the same mixes performed in phase 1 were mixed again but using MW to study the effect MW on fresh, mechanical, microstructure characteristics of concrete incorporated with NA. The proportions of both concrete and paste mixtures are shown in Tables 2 and 3, respectively.

To fabricate the concrete mixtures in phase 1 and 2, SP is firstly mixed into MW or TW in a mixer, and then NA is added and stirred using the magnetic stirrer. Coarse aggregate, sand and cement are mixed at a low speed for 2 min in a concrete centrifugal blender, then the mixture of MW, SP and NA stirred for another 2 min.

Cubes of size 150 × 150 × 150 mm were used for the compressive strength testing. After being demoulded at the age of one day, all specimens were cured in water at 25 °C for 28 days.

All cement paste mixes were manually mixed for about 5 min. Circular cement paste discs of thickness 5 mm and 50 mm diameter were then prepared for microstructure analysis (using desorption and SEM approaches). After casting, all molded samples were covered with plastic sheets for 24 h and then immersed in water curing tank (20 ± 2 °C) till the age of testing. For all tests, triplicate specimens were used for each case of study and the average of results was then considered.

2.2. Test technique and procedures

2.2.1. Slump cone test

The conventional slump test on fresh concrete mixes was carried out as outlined by ASTM C-143 to determine workability in terms of slump.

2.2.2. Mechanical properties

Compressive strength test was performed using crushing machine of the type ELE with maximum load 500 kN. The reported values for concrete represent the average results of three specimens.

2.2.3. Desorption test

This test was used to estimate the amount of interconnected pores (capillary porosity), as described in [12,13]. The saturated specimens specified for this study were dried in a desiccator at 90.7% relative humidity for the determination of capillary porosity. Procedures of this test are described in details in [12–14].

2.2.4. Scanning electron microscopy

Scanning electron microscopy (SEM) analysis was performed to investigate the impact of MW on the microstructure of OPC/NA concrete using SEM Model Quanta 250 Field Emission Gun.

3. Results and discussion

3.1. Slump

Slump test were conducted on all concrete mixes prepared with either TW or MW, the results are shown in Fig. 1. It is apparent from the results that slump values of all magnetic concrete mixes are higher than those of non-magnetic concrete mixes. The amount of increase in slump reaches about 38, 37, 39, and 38% when 0, 1, 2, and 3% NA replacement levels were adopted. These results agree with those of previous research [4,15].

Moreover, these improvements in workability may be attributed to the fact that magnetic field has a considerable effect on clusters of water molecules and causes the decrease of the number of water molecules, which causes more participation of water molecules in the cement hydration reaction [16]. Also, when water is mixed with cement, cement particles are surrounded by water molecule clusters. In the case of magnetized water, in which the clusters have a smaller size and lower density, the thickness of the water layer around the cement particle is thinner than in the case of tap water [16].

It was also observed that the addition of NA slightly increased the slump of both MC and NMC mixes. For magnetic and non-magnetic concrete mixes, 3% NA mixtures gives the highest slump (4.2 and 5.8 cm), respectively, compared with 0% NA mixtures.

3.2. Compressive strength

The effect of both NA content and MW on the compressive strength of OPC/NA concrete mixes is illustrated in Fig. 2. It can be seen from the results that, for non-magnetic concrete mixes, the increase of the substitution of OPC with NA up to 1%, increases the compressive strength. The amount of increase in the 28-day compressive strength reaches about 13% when 1% NA replacement level was adopted compared to 0% NA mixture. The enhancement of the compressive strength of concrete can be attributed to that nano particles can act as nuclei for cement phases, further promoting cement hydration due to their high reactivity, as nano reinforcement, densifying the microstructure and the interfacial transition zone, thereby, leading to a reduced porosity. Also, nano particles would fill pores to increase the compressive strength [17].

Further, it is obvious that increase in the NA content beyond 1% decrease the compressive strength of the composites instead of improving it. The amount of decrease in the 28-day compressive strength reaches about 8% and 25% when 2% and 3% NA replace-

Table 1
Chemical analysis and surface area of OPC.

Element	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	LOI	Fineness, m^2/g
OPC	21.2	4.53	3.61	61.6	2.38	0.36	0.22	2.8	1.98	0.3