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Mechanical properties and durability of concrete specimens containing nano silica in sulfuric acid rain condition

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HIGHLIGHTS

- Acid RAin Simulator (ARAS) was made to simulate acidic condition.
- Sorptivity coefficient and weight loss percentage have inverse relation with nano silica content.
- Electrical resistance, sorptivity coefficient and weight loss percentage increase by raising the acidity of solution.
- Compressive strength of concrete declines by increasing the acidity of solution.

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ABSTRACT

During acid rain concrete begins to lose its mechanical strength that lead to cracking, weight losing and finally, destruction of structures. Since the control of acid rain and its effects on the environment is inevitable, many researchers have carried out different studies on this issue and have offered solutions to eliminate or control acid rain's effects. One of these new methods is to use nanoparticles as cementitious or additive materials. In recent years, several studies have been focused on the nano silica, with the goal of increasing strength and durability of concrete.

In this paper, the influence of nano silica on performance of cementitious materials in acid rain condition has been studied. Four concrete mixtures were prepared containing 0–6% of nano silica. Mechanical properties and durability of concrete, such as weight losing, compressive strength, electrical resistance and water absorption in acid rain condition with various pH values will be discussed.

The results show that nano silica has positive effects on mechanical properties and durability of concrete specimens. In addition, by increasing the pH value of acid rain, mechanical properties and durability of concrete specimens are improved.

1. Introduction

Concrete has been widely used nearly two centuries in different countries. Cost effectiveness, abundant resources of concrete components, compatibility with the environment and suitable strength are concrete characteristics that desirable for applications [1,2]; however, because of sulfuric attack, many of deteriorations has been widely observed over time [3,4]. Studies have showed that when concrete is exposed to acidic solution, degradation of concrete occurs, because acid leaches into concrete and reacts with concrete components [5]. It realized that chemical composition of acid rain was affected by some factors such as wind direction, rainfall intensity and distribution, combination of water and fuel [6]. Xie et al. simulated the deterioration of cement concrete in acid rain condition. Neutralized depth, strength and chemical composition were measured. The results showed that $Ca(OH)_2$ in hardened cement paste was dissolved by H^+ in acid rain and that SO_4^{2-} also corroded it [7]. Fan et al. determined damage depth of concrete with ultrasonic nondestructive technique and computed tomography (CT) scanning technique. They investigated the effects of acid rain on concrete performance by testing on 354 concrete prism specimens that were submerged in pure water and acid solutions with pH values of 1.5, 2.5 and 3.5 for accelerated conditions. The results showed that at the initial stage, the strength of deteriorated specimens improved slightly, and then decreased gradually [8]. Shengyuan et al. showed that when pH value of immersion solution was 2.50, the erosion depth was maximum. In addition,

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with the reduction of pH value from 4 to 2, sides of concrete specimens will turn gray, yellow and then white. [9]. Torgal and jalali investigated sulfuric acid resistance of plain, polymer modified, and fly ash cement concretes. They showed that using of polymer impregnation increases the chemical resistance of concrete extremely and it is economically more reasonable in comparison of polymer addition. They also showed that using sulfate resistant cements improves the chemical resistance more economically [10].

Nanotechnology is a new approach that has been entered in various fields of knowledge and technology [11]. By development of nanotechnology, new perspectives have been created in concrete technology in recent years [12,13]. Nano silica is a nano materials that has been used as an alternative of silica fume in concrete [14]. By development of nano silica, many nano based particles has been developed to be used in concrete. Nano alumina [15], nano titanium oxide [16], carbon nano tube [17] and nano clay [18] are examples of nano materials used in concrete.

Many studies have been carried out about effects of nano silica on properties of concrete and hardened cement paste. Qing et al. investigated the influence of nano silica addition on properties of hardened cement paste as compared with silica fume [19]. Said et al. investigated the effects of colloidal nano silica on concrete incorporating single (ordinary cement) and binary (ordinary cement + Class F fly ash) binders [20]. Li investigated properties of high-volume fly ash high-strength concrete incorporating nano silica [21]. Jo et al. investigated properties of cement mortars containing nano silica [22]. The results of these studies indicated that addition of nano silica can improve mechanical characteristics of hardened cement paste and concrete.

Jalal et al. investigated effects of nano silica, silica fume and Class F fly ash on different properties of high performance self-compacting concrete (HPSCC). They prepared 14 concrete mixtures with the constant water/binder ratio of 0.38 and total binder content of 400 and 500 kg/m^3 and 10%, 2% and 10% +2% replacement of Portland cement by silica fume, nano silica and composition of silica fume and nano silica, respectively. They showed that mechanical properties of concrete were improved in mixtures containing admixtures especially composition of nano silica and silica fume [14]. Janković et al. investigated the influence of nano silica and barite aggregate on properties of ultra-high performance concrete. Results showed that by increasing the nano silica content up to 2%, compressive and flexural strength of concrete containing quartz and combination of quartz and barite aggregate were increased and by increasing the nano silica content between 2% and 5%, compressive and flexural strength were decreased [23].

In this paper, the influence of nano silica on performance of cementitious materials in acid rain condition has been studied. Four concrete mixtures were prepared containing 0% to 6% of nano silica. Mechanical properties and durability of concrete, such as weight losing, compressive strength, electrical resistance and water absorption in acid rain condition with various pH values will be discussed.

2. Experimental program

2.1. Materials

For all mixtures, rounded washed sand and crushed stone were used for fine and coarse aggregates, respectively. Specific gravity of fine aggregates according to ASTM C128-01 [24] and coarse aggregates according to ASTM C127-01 [25] in the case of SSD (Saturated Surface Dry) were 2.551 and 2.584, respectively. According to ASTM C128-01 and ASTM C127-01, water absorption of fine and coarse aggregates was measured 1.83% and 2.56% in the case of SSD, respectively. The grading of fine and coarse aggregates is showed in Fig. 1 according to the ASTM C136-01 [26]. ASTM C150-07 [27] type II Portland cement was used in concrete mixtures. Chemical and physical properties are showed in Table 1. Potable water was used in all mixtures. Nano silica colloidal solution with density of 30% and purity of 99.9% was used. The poly-carboxylate-based super plasticizer with specific weight of 1.20 kg/lit was employed to reach the favorite workability in specimens having W/C = 0.5.

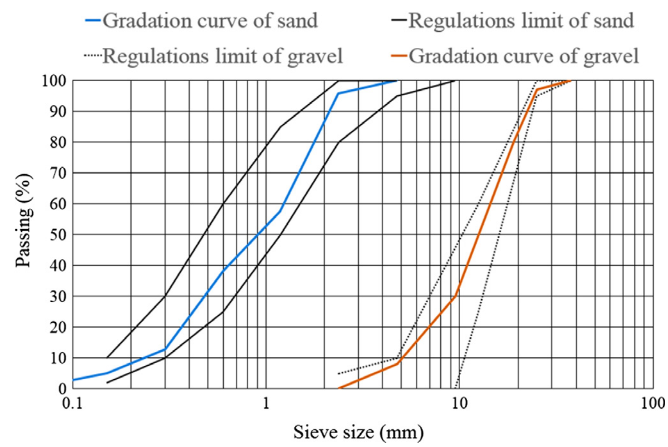

Fig. 1. The grading curve of fine and coarse aggregates.

Table 1
Physical and chemical properties of type II Portland cement.

Chemical components	
Calcium oxide (CaO) (%)	62.94
Silicon dioxide (SiO_2) (%)	21.15
Magnesium oxide (MgO) (%)	2.75
Aluminium oxide (Al_2O_3) (%)	4.52
Ferric oxide (Fe_2O_3) (%)	3.83
Sulphate oxide (SO_3) (%)	1.92
Potassium oxide (K_2O) (%)	0.68
Sodium oxide (Na_2O) (%)	0.30
LOI (%)	1.35
Mineralogical composition	
C_3S (%)	54.13
C_2S (%)	19.83
C_3A (%)	5.51
C_4AF (%)	11.65
Physical characteristics	
Blaine (m^2/kg)	320
Specific gravity	3.21
Initial setting time (min)	186
Final setting time (min)	276

2.2. Mixture design

Four concrete mixtures were prepared containing 0%, 2%, 4% and 6% of nano silica. All replacements were made by mass. The W/C ratio was kept constant at 0.5 in all mixtures. Slumps were kept constant at 9 ± 1 cm according to ASTM C 143/C 143M – 03 standard [28]. Table 2 shows the mixture designs for concrete specimens.

2.3. Preparation of Acid Rain Simulator (ARAS)

The Acid Rain Simulator (ARAS) consisted of various parts including water supply system, rainfall screen and specimens' storage, was constructed. The rainfall screen had 6 nozzles and its height could be changed from 70 to 100 cm from the storage bottom. The angle of rainfall was changeable from 0 to 25 degrees. The pressure gauge was installed to control water pressure. There was also an automatic control system for switching the pump off at the desired time. In this study, the ARAS was turned on for one hour a day and then was turned off, automatically. In addition, to produce acidic rain water, the commercial and traditional sulfuric acid salt is used. The amount of acid salt added to the water was enough to produce the desired pH. During the addition of acid salt, the pH value was controlled by the pH meter. The construction of acid rain simulator is shown in Fig. 2.