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Simultaneous effects of microsilica and nanosilica on self-consolidating concrete in a sulfuric acid medium

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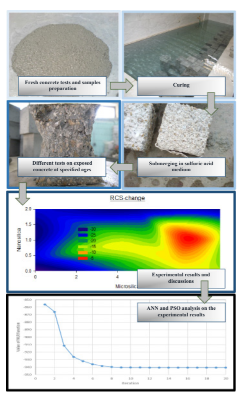
HIGHLIGHTS

- Seven percent substitution of micro-silica has the same effect as 2 percent of nano-silica.
- For the first time RS is used in the field of concrete technology.
- In contrast to micro-silica, nano-silica has no effect on residual compressive strength.
- Concrete performance and durability are considerably improved by using micro- and nano-silica simultaneously.

GRAPHICAL ABSTRACT



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ABSTRACT

Combination of microsilica and nanosilica (colloidal silica) are considered to design a high strength self-consolidating concrete to resist in the sulfuric acid medium. Artificial intelligence was used to predict and compare the behavior of these two pozzolans in a sulfuric acid medium. Contour plots were used to investigate the products combination better. Thermogravimetric analysis (TGA) was also used to find the calcium hydroxide range while using these two pozzolans. TGA revealed that colloidal silica did not contribute to cement hydration within seven days of curing while a combination of them boosted calcium hydroxide consumption. The results show that more substitution of the pozzolans could lead to lower mass loss while nanosilica has marginal effect on the residual compressive strength. The results also revealed that 7 percent substitution of microsilica showed the same effect as 2 percent nanosilica replacement.

1. Introduction

Vibration is a substantial need to compact a normal concrete (NC) and labors skill can significantly impact the final compaction. Self-compacting concrete (SCC) has been introduced to take out the labors hand from the compacting and the consequent effects on

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concrete durability. The SCC necessity was first proposed by Okamura in 1986 and a prototype of this kind of concrete was made by Ozawa in 1988 [1]. The fresh mortar properties, volume of coarse aggregates as well as the plasticizer are three important characteristics in the SCC production [2]. Therefore, investigations on SCC mix designs started on packing density field for aggregates [3–5], based on continuous packing models [6] and/or discrete ones [7,8] to produce powder type of SCC [9]. As SCC microstructures are different from NC, they define their distinct durability criteria and thus their durability should be investigated separately.

Three main sources of sulfuric acid are depots containing sulfur (usually FeS_2) [10] in stockpiles, crown of sewage pipes and acidic rains which could have deleterious effects on infrastructures. Investigations on the microbiological sulfuric acid attack started in 1945 when Parker introduced corrosion process with Thiobacillus bacteria [11]. After Parker's discovery, many efforts were carried out to understand corrosion process and the results revealed the metabolic effects of thiobacilli [12].

Generally, three techniques of visual inspection, mass-loss and compressive strength-loss are used to assess the corrosion process [13–16]. Microsilica is a widely used pozzolan whose effects on concretes exposed to a sulfuric acid medium does not follow a general pattern. For instance, some studies [10,16–22] have shown either enhancing or neutral effects while some other studies [23–25] have revealed contradictory results. Such behaviors have been shown in changing parameters, such as the water to cement ratio [26–28] and the use of different types of Portland cement [10,20,21,29]. Nanoparticles are widely used in studies [30,31] to enhance the concrete properties where nanoparticles act as a center of crystallization and also consuming $Ca(OH)_2$ [32]. Nanosilica can reduce the corrosion of concretes under sulfuric acid medium (pH = 2) [33,34]. The main concern in using nanosilica is its uniform dispersion. The agglomeration of nanoparticles causes a lot of defects especially in high pressure [35]. Nanosilica as a low-cost nanoparticle results in the higher pozzolanic activity and the compressive strength and the lower concrete permeability even by low contents of substitution [36]. Colloidal nanosilica has been reported more effective than microsilica [37–40], except that some researchers ([41,37]) believe that nanosilica particles result in a lower compressive strength and a higher capillary pores.

The behavior of concrete in an acidic solution is related to multiple factors and drawing a conclusion based on one parameter is fallible. Interpreting all of the factors together with usual statistical analyses is not possible. In this study, four methods for interpreting results were used. First, an analysis of variance (ANOVA) and Spearsman's correlation were used to identify the effective parameters. Second, the related plots were drawn to show the correlations. These two analyses cover the relationship between separated input parameters and cannot clarify the combining effects. Third, the non-linear regression (NLR) as a multi-dimensional analysis was implemented to distinguish every parameter effect with preliminary assumptions. Therefore, analytical data were predicted using recommender systems (RS) for a certain amount of substitution. Finally, to reduce the amount of preliminary assumptions, an artificial neural network (ANN) was used to predict the mass-loss values and the root-mean-square-error (RMSE) was calculated to determine the accuracy of the model. The ANN and NLR are widely used in different aspects of concrete properties [16,42,43] and the accuracy of these two prediction methods was compared to find the more reliable one.

2. Materials

The following materials were used in this study:

2.1. Cement

Ordinary Portland cement Type I in accordance with ASTM C 150 [44] was used to make the samples. The chemical composition of the cement and its physical properties are illustrated in Table 1.

2.2. Aggregates

Two types of calcic sand (Sand 0–4 and sand 0–8) and one type of calcic coarse aggregate (CA) were chosen to have a wide variety of particle size distribution (PSD) in the aggregates (Sand 0–8 was out of ASTM C33 [45] limitations). Physical properties of the aggregates are provided in Table 2. ASTM C 136-01 [46] was implemented for aggregate grading. Sample preparation was consistent with ASTM C 702 [47] using B and C methods. Specific gravity of the coarse and fine aggregates was obtained in accordance with ASTM C 127 [48] and ASTM C 128 [49], respectively.

2.3. Additives

Two types of additives were used as a partial cement replacement. The first one was Microsilica (MS) with the average particle size of 0.25 μm and the relative

Table 2
Physical properties of the aggregates (passing percentage).

Sieve number (size)	Sand 0–4	Coarse aggregate	Sand 0–8
3/4 (19.06)	100	100	100
1/2 (12.7)	100	98.32	100
3/8 (9.53)	100	58.65	99.44
1/4 (6.35)	99.97	6.18	92.11
3/16 (4.76)	99.96	3.44	80.18
8 (2.36)	87.65	2.38	59.45
16 (1.18)	54.97	1.97	39.48
30 (0.6)	32.75	1.94	25.53
50 (0.3)	22.89	1.83	18.35
100 (0.15)	8.58	0.8	7.08
150 (0.11)	0.47	0.26	2.22
200 (0.08)	0.37	0.11	1.26
Specific gravity	2690	2710	2680
*SSD (%)	3	1	3

* Saturated surface dry.

Table 1
Chemical compositions of the cement and microsilica and physical properties of the cement.

Chemical Composition	SiO2	Al2O3	Fe2O3	CaO	MgO	Na2O	K2O	All of alkali content	SO3	Insoluble residue
Cement (%)	26.5	5.70	2.90	61.3	2.60	–	–	0.75	2.20	0.40
Microsilica (%)	95.4	1.32	0.87	0.49	0.97	0.31	1.01	–	0.1	–

Physical Characteristics of cement	Results	
Autoclave expansion (%)		0.05
Compressive strength (MPa)	3 Days	15.0
	7 Days	30.0
	28 Days	46.0
Specific gravity		3.10
Blaine fineness (m^2/kg)		320
Time of setting	Initial, minutes	160
	Final, minutes	215