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The effects of nano particles on freeze and thaw resistance of alkali-activated slag concrete

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HIGHLIGHTS

- Adding nanoparticles could decrease the slump of AAS concrete.
- Nano-silica and nano-alumina induced more slump reduction than nano-clay.
- Adding NS, NA, and NC could increase the AAS concrete compressive strength.
- Adding NS, NA, and NC could reduce the compressive strength loss due to F-T cycles.

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ABSTRACT

Alkali-activated slag (AAS) concrete could be considered as an environmentally friendly and economical concrete. The aim of this study was to investigate the effect of nanoparticles including nano-silica, nano-alumina, and nano-clay on the resistance of AAS concrete against freeze and thaw cycles. Sodium hydroxide and sodium silicate were used for the activation of slag in AAS concrete. In this investigation, a control mix without nano materials and 3 mixes containing 1, 2 and 3 wt% of nanoparticles were prepared. Samples were tested by the freezing-thawing test, according to the ASTM C666-B standard. The compressive strength and mass loss of AAS concrete specimens were measured. The results showed that nano-silica and nano-clay, respectively, performed better than the nano-alumina in improving the strength and durability of alkali-activated slag concrete subjected to freeze and thaw cycles. Adding 2% and 3% of nano-silica had a marginally smaller effect on AASC properties compared with 1% nano-silica.

1. Introduction

As one of the components of normal concrete, Portland cement acts as a binder for concrete aggregates [1]. Cement production consumes a high level of energy in addition to other environmental consequences [2,3]. Therefore, the use of alternative binders with lower energy consumption and environmental risks (lower CO_2 emission and the possibility of reusing industrial by-products) with a comparable performance instead of Ordinary Portland Cement (OPC) seems crucial. One of these alternatives, if designed properly, is alkali-activated binders [4,5]. Various natural resources, industrial by-products, and recycled alumina silicates can be employed as the components of alkali-activated binders. Alkali-activated slag (AAS) cement is a mixture of silica and alumina components. To produce one type of this cement, which is called the two-part alkali-activated cement, the alkaline solution of sodium hydroxide or potassium hydroxide is prepared separately and then added to liquid sodium silicate; the resulting solution is mixed with ground granulated blast furnace slag (GGBFS). Slag is a by-product of metallurgical industries [6]. In comparison with OPC concrete, alkali-activated slag concrete (AASC) has advantages such as rapid early strength development, high compressive strength, remarkable resistance against chemical attacks and chloride ion penetration, and resistance against freeze and thaw cycles [7,8]. However, it suffers from drawbacks such as high drying shrinkage and a high rate of carbonation [9].

On the other hand, numerous concrete structures need to be repaired due to exposure to harsh low-temperature conditions. Durability against freeze and thaw cycles is an important factor influencing the durability of concrete structures in cold regions. Concrete is a naturally porous material. Its freezing and thawing strength depends mainly on the structure of its paste; for example, its porosity, pore size, capillaries, distribution, and type of pores (open or close). Proper pore distribution can cause pressure

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diffusion and improvement in resistance against freezing-thawing cycles. Obviously, utilizing a cementitious material with lower permeability in producing concrete could increase the lifetime of the concrete structures; this, in fact, has been one of the main objectives of this study.

Foo et al., investigated the durability of alkali-activated slag concrete against freeze and thaw cycles. Their results indicated that the product of the final reactions in AASC included C-S-H gel with a low Ca/Si ratio. This gel resulted in the symmetric and compact structure of the paste. High compactness of the paste hindered water permeation, freezing, and saturation, thereby enhancing the concrete durability against freezing-thawing cycles [11]. Recently, numerous studies have shown that application of nano scale materials in the paste or concrete can result in a more compact structure and improve the paste properties [12,13]. Addition of nanomaterials can also reduce the water permeability and effluents of concrete [10].

Fan et al., investigated the effect of nano-kaolinite clay (NKC) on the normal concrete freezing-thawing cycle resistance. Their results showed that the dispersion and activation effect of NKC could enhance the resistance of concrete against freezing-thawing cycles [14].

Gao et al., also studied the properties of alkali-activated slag and the fly ash concrete containing nano-silica. Their results indicated that incorporation of nano-silica significantly reduced slump-flow due to an increase in the aspect ratio. Initial and final setting times could be slightly increased by the rise of nano-silica content. Addition of 2% nano-silica also decreased porosity and increased the compressive strength. However, higher contents of nano-silica could have a negative impact on concrete properties [15].

Asaedi et al., investigated the impact of nano-clay on the mechanical and thermal properties of geopolymers. They found out that addition of 2% nano-clay to geopolymer compound could enhance bending and compressive strength; however, further addition of nano-clay did not have any positive impact on these properties due to agglomeration and non-uniform dispersion; also, it could increase porosity [16].

Young et al., studied the effect of nano TiO_2 on the strength and the fine structure loss of alkali-activated slag pastes; their results showed that addition of TiO_2 to the alkali-activated slag paste would accelerate the hydration process and increase hydration products, resulting in a compacted structure; moreover, addition of nano TiO_2 could increase compressive and bending strength [17].

Behfarnia and Rostami, on the other hand, studied the effect of microsilica and nano-SiO_2 particles on the permeability of AAS concrete. They reported that both microsilica and nano-SiO_2 could reduce the permeability of AAS concrete samples effectively. They also reported that the synergic application of microsilica and nano-SiO_2, if mixed properly, could more effectively reduce the permeability of the AAS concrete samples [18].

T. Phoo-ngernkham et al., studied the effect of adding nano-SiO_2 and nano-Al_2O_3 on properties of high calcium fly ash geopolymer cured at ambient temperature; their results showed that the use of nano SiO_2 as additive to fly ash results in the decrease of the setting time, while the addition of nano Al_2O_3 results in only a slight reduction in setting time. Adding 1–2% nano particles could improve compressive strength, flexural strength, and elastic modulus of pastes due to the formation of additional calcium silicate hydrate (CSH) or calcium aluminosilicate hydrate (CASH) and sodium aluminosilicate hydrate (NASH) or geopolymer gel in geopolymer matrix. In addition, the additions of both nano-SiO_2 and nano-Al_2O_3 enhances the shear bond strength between concrete substrate and geopolymer [19].

Behfarnia and Salemi studied frost resistance and mechanical properties of concrete containing nano-silica and nano-alumina. Nano-particles were employed as a partial substitute of cement. The specimens were subjected to cycles of freezing and thawing in water according to ASTM C666A. The reduction in compressive strength, loss of mass, change in length and water absorption of specimens was measured after specified number of freeze and thaw cycles. Experimental results showed that the frost resistance of concrete containing nano-particles were considerably improved, as result of a more compacted microstructure. It was also concluded that the frost resistance of concrete containing nano Al_2O_3 was better than that containing the same amount of nano SiO_2. Compressive strength of normal concrete containing nano SiO_2 was higher than that containing the same amount of nano Al_2O_3 [20].

The aim of this research was the production of AAS concrete with less permeability and more freeze and thaw resistance. Researches showed that adding nano particles improve the permeability and freeze and thaw resistance of regular concretes. Therefore, in this research in order to improve freeze and thaw resistance of alkali activated slag concrete, nano particles have been used. Other novelty of this study was the application of nano-clay in AAS concrete. In addition to nano-clay, the effects of nano-silica and nano-alumina have also been investigated on the durability of AAS concrete. Based on the authors experience and also the suggestions of the other researchers such as Gao et al. [15], Asaedi et al. [16], Young et al. [17], T. Phoo-ngernkham et al. [19] alkali-activated slag mixes containing 1, 2 and 3 wt% of nanoparticles were provided. A sample without nanoparticles was also provided as the control. AAS concrete specimens were subjected to 100, 200 and 300 freezing-thawing cycles and their compressive strength and mass loss were measured.

2. Materials

In this research, slag was supplied from Isfahan steel plant (in granule form); it had been ground in Madaen cement factory in Isfahan. Nano-silica and nano-clay were purchased from the Iranian Nanomaterial Innovation Company. Nano-alumina was provided by Mehregan Shimi Company. Chemical and physical features of these materials are listed in Tables 1 and 2.

The density of the slag was 2.75 g/cm^3 and its Blaine was about 4500 cm^2/g. The slag was activated by sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). The used sodium hydroxide had the purity of 98%; it had been dissolved in appropriate amounts of water and used in a solution form. The ratio of SiO_2 to Na_2O was 2.31 in the sodium silicate solution. (SiO_2 = 33.5, Na_2O =

Table 1
Chemical composition of nano materials (%).

GGBFS	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO			
(%)	33.5	9.5	0.05	36	9.5			
Nano	SiO_2	Ti	Ca	Na	Fe			
Silica	>99%	<120 ppm	<70 ppm	<50 ppm	<20 ppm			
Nano	Co	Mn	Na	Cr	Fe	Ca	Al_2O_3		
Al_2O_3	<2 ppm	<3 ppm	<70 ppm	<4 ppm	<80 ppm	<25 ppm	>99.7%		
Nano-clay(%)	LoI	Fe_2O_3	TiO_2	CaO	K_2O	SiO_2	Al_2O_3	MgO	Na_2O
	15.45	5.62	0.62	1.97	0.86	50.95	19.6	3.29	0.98