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Review

Micro and macro level properties of natural zeolite contained concretes

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HIGHLIGHTS

- Effect of natural zeolite, as a supplementary cementitious material (SCM), on properties of concretes having different w/cm.
- SEM/XRD study on pastes containing natural zeolite.
- Influence of natural zeolite, as an SCM, on quality of paste and transition zone.

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ABSTRACT

This study assesses effects of natural zeolite, as a supplementary cementitious material, on micro and macro properties of pastes and concretes having different water-to-cementitious materials ratios. The experimental program included evaluation of strength, transport properties, and microscopic images. Strengths of natural zeolite contained concretes were almost similar to or slightly lower than that of reference concretes. Transport properties improved considerably through replacing a portion of Portland cement with natural zeolite, whereas contrary was found for carbonation depth. The microstructure analysis showed modifications in transition zone and quality of pastes by use of natural zeolite through production of secondary C–S–H.

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1. Introduction

Nowadays, Portland cement (PC) concrete is the most applicable construction material worldwide for its outstanding properties like high strength, appropriate durability, formability and economical aspects. Despite the above-mentioned advantages, there are some concerns regarding its applications. Environmental pollution arising from the manufacture of Portland cement, as a main component of concrete, has been a main problem for several years [1]. The statistical evaluations show that the total CO_2 emission due to production of PC will increase to 3.5 billion tons per year by 2025 [2]. In recent decades, durability of PC concrete has become another major issue reducing the longevity of concrete structures. Therefore, reducing PC consumption and prolonging service life of cement and concrete composites through enhancing their mechanical and durability properties have gained great importance [3–7].

Supplementary cementitious materials (SCMs), such as natural Pozzolans or industrial by-products (artificial Pozzolans) like fly ash, slag and silica fume, have been recently utilized toward solving these issues [8–11]. While partial replacements of PC with SCMs lead to decreases in CO_2 emission, their inclusions in concrete mixtures have been proven to be effective in enhancement of concrete properties in terms of late-age strength and durability [6,7].

Natural zeolite is an especial type of natural Pozzolan which has been recently applied in different cement and concrete manufacturing plants in Russia, Germany, Slovenia, Cuba, Serbia, and Spain [12]. The most utilization of natural zeolite in cement and concrete industry has been reported in China, with an estimation of 30 million tons per year [13]. In recent years, there has been a growing trend in use of natural zeolite as a Pozzolanic material in Iran as well [4,14,15].

A large number of studies have been devoted to investigate effects of natural zeolite incorporation on the mechanical and durability properties of PC composites [16]. In these studies, Ding et al. [17], Feng and Zang [18], and Ahmadi and Shekarchi [19] stated that use of natural zeolite enhanced the concrete strength. Poon et al. [20] concluded that natural zeolite was more effective than fly ash and less effective than silica fume on concrete strength. They also concluded that the influence of natural zeolite on strength was higher in pastes with lower water-to-cement ratio. Studies conducted by other researchers also showed that the natural zeolite could improve the compressive strength and mechanical properties of cement and concrete composites [18,21,22]. Chan and Ji [23] reported improvement in concrete strength by use of natural zeolite, but they stated that addition of zeolite decreased the strength for high water-to-cement ratios, emphasizing role of w/c on performance of natural zeolite contained composites. Natural zeolite also prevented the chloride penetration, sulfate attack and undesirable expansion due to alkali silica reaction (ASR) [19,24–27]. Ahmadi and Shekarchi showed that at 10–20% natural zeolite, there was a marked decrease in diffusion coefficient [19]. They also found that when an increasing amount of PC was replaced by natural zeolite, expansion of mortar bars due to ASR decreased significantly [19]. The results of ASR expansion carried out by Feng, revealed a considerable benefit of natural zeolite inclusion in preventing expansion of mortar due to ASR expansion [27]. These improvements were mainly related to drop in calcium hydroxide of the hydrated cement paste due to Pozzolanic reaction, as well as filler effect of natural zeolite resulting in enhanced microstructure and transition zone [6]. The only research on carbonation showed reduction in carbonation by use of natural zeolite as an SCM; however, due to the condition of the used experiment, it is necessary to carry out more experimental tests to confirm the results [28]. Use of natural zeolite can prevent bleeding and segregation in the fresh state, as its application increases the viscosity of fresh concrete [18]. Its usage, however, may result in increases in water demand, which in turn, increases the demand for high range water reducing admixtures [29,30].

Despite the fact that several research studies have been conducted recently on the effects of natural zeolite on concrete properties, there is a need for comprehensive research studies encompassing effective factors on the strength, transport and durability properties of natural zeolite contained concrete. This study considered effects of natural zeolite contents, water-to-cementitious materials ratio (w/cm) and age on properties of natural zeolite contained concretes. Several tests were designed including compressive strength, indirect tensile strength, water permeability, capillary absorption, rapid chloride penetration test, electrical resistivity, and carbonation. For the first time, the accelerated carbonation test was conducted for concretes containing natural zeolite. Characteristics of the transition zone were evaluated using electron microscope images and energy-dispersive X-ray spectrometry (EDX) analysis to find a relation between microstructure of pastes and properties of concretes containing natural zeolite.

2. Experimental program

The current study was conducted in two phases. First phase included a comprehensive experimental program to assess strength, transport and durability properties of natural zeolite contained concretes. This phase was conducted on concrete mixtures having various water-to-cementitious materials ratios and different replacement levels of natural zeolite. The second phase of this study dealt with characterization and microscopic evaluation of natural zeolite contained pastes.

2.1. Materials

The materials used in this study included Type I Portland cement meeting the requirements of ASTM C150 as a primary binder, a clinoptilolite type of natural zeolite as a supplementary cementitious material (secondary binder), fine and coarse aggregates meeting the requirements of ASTM C33, tap water and high range water reducer (HRWR). The chemical composition and physical properties of binders are

Table 1
Chemical composition of cement and natural zeolite.

Compound/property (%)	Cement	Natural zeolite
Calcium oxide (CaO)	63.00	1.68
Silica (SiO_2)	21.95	67.79
Alumina (Al_2O_3)	4.35	13.66
Iron oxide (Fe_2O_3)	3.80	1.44
Magnesium oxide (MgO)	2.00	1.2
Sodium oxide (Na_2O)	0.30	2.04
Potassium oxide (K_2O)	0.77	1.42
Sulfur trioxide (SO_3)	2.43	0.52
Mineral compounds (%)		
Clinoptilolite	–	70.6
Opal CT ($SiO_2{\cdot}nH_2O$)	–	18.8
Quartz (SiO_2)	–	1.6
Plagioclase ($Na_{0.5}Ca_{0.5}Si_3AlO_8$)	–	2.4
K-feldspar ($KAlSi_3O_8$)	–	1.5
Smectite/illite (clay minerals)	–	5.2

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