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Effect of chloride treatment curing condition on the mechanical properties and durability of concrete containing zeolite and micro-nano-bubble water

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HIGHLIGHTS

- The chloride and standard curing method compared from view point of the effects on the mixture properties.
- The micro-nano bubble water effect, as a new material, on the both curing method is evaluated.

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ABSTRACT

Chloride ion has the highest proportion of chemical compounds present in seawater. This research utilized the chloride curing conditions in order to study the effect of chloride ion on properties of concrete containing zeolite as a mineral admixture and micro-nano-bubble water. The objective was to improve the durability and the mechanical properties of concrete. It was observed that the addition of zeolite-pozzolan and micro-nano-bubble water to the concrete under chloride curing conditions improved the mechanical properties and durability of concrete of 28 days old by forming Friedel's salt. With increasing age of concrete and decomposition of Friedel's salt in concrete samples, the process of improvement was reduced. The greatest effect on improving the mechanical properties and durability of 28 days old concrete was related to the mixture containing 15% zeolite and 100% micro-nano-bubble water under chloride curing conditions. Results also showed that in the mixture containing 15% zeolite and 100% micro-nano-bubble water, under chloride treatment condition, there was 45% increase in the compressive strength. Also, tensile strength and electrical resistance were improved 78 and 254%, respectively, and the chloride penetration and water absorption were reduced by 83 and 49%, respectively, compared to the control mixture.

1. Introduction

Concrete is one of the most durable materials. Its history in marine environments verified that this material is seriously threatened in terms of durability in sea water, which is one of the most corrosive natural environments in the world [1]. The initial chemical composition of sea water varies in different locations, but in general, it can be said that chloride, sodium, magnesium, calcium and potassium are the major ions in the seawater. In seawater, sodium chloride (NaCl) is a dominant salt (about 88% of total mentioned salt weight) [2]. The diffusion of chloride ion into the reinforced concrete elements is one of the major problems being faced by concrete construction industry. Therefore this subject has been the focus of many researchers in order to solve the problem or decrease vulnerability of structures.

When chloride ions enter into concrete, the chemical processes leading to corrosion commences. The chloride process mainly involves two mechanisms: the Friedel's salt formation with the general formula $3CaO{\cdot}Al_2O_3{\cdot}CaCl_2{\cdot}10H_2O$ and the stabilizing of the ions that come in contact with C-S-H gel [3,4]. Zibara [5] proved that the ability of a system to binding chlorides is related to the calcium aluminates and calcium alumina-ferrites content, which causes the formation of Friedel's salt.

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It was discovered found from studies that pozzolanic materials reduce the ingress of chloride by improving the microstructure condition and chloride binding behaviour [6–8]. Wild et al. [9] tested the effect of metakaolin (MK), pulverised fuel ash (PFA) and the binary of MK and PFA on the durability of concrete in marine environments. The results of these experiments proved that by substituting MK and PFA in place of PC, a significant decrease in chloride penetration depth was observed. This decrease increased with increasing replacement and treatment time. This is attributed to relative changes in intrinsic penetration and adhesion capacity of chlorine with age related to different paste compounds [9]. Qiu et al. [10] examined the effects of chloride condition on concrete containing MK. In their research, it was pointed out that treating of concrete in chloride conditions increased the compressive strength and reduced chloride penetration in specimens containing pozzolan. Also from their study, it was demonstrated that the compressive strength of the control sample at 90 days old was reduced compared to the similar sample under standard conditions [10].

Recently, the use of natural zeolite as a mineral admixture in concrete industry is on the increase. Natural zeolite contains large amount of reactive SiO_2 and Al_2O_3 [11]. It has been established that the addition of natural zeolite causes the production of an extra content of fine crystalline ettringite and C-S-H (B) type in the mineral non-clinker part of Portland cement [12–17]. The structure of the utilized natural zeolite is rough and porous, and therefore its high surface area caused a decrease in concrete fluidity and paste setting time [18–23]. The use of natural zeolite delayed growth of the strength during the early stage, but concretes having 10% natural zeolite showed almost similar compressive strength to that of the reference concretes at the long term stage [24–28]. The inclusion of zeolite resulted in an increase in compressive strength at the early ages [28].

Recently, the introduction of nanotechnology industry to construction presents numerous opportunities and challenges. The use of micro nano materials (MNMs) in the construction of concrete structures should be encouraged not only for improving material properties and functions but also for energy conservation [29]. Micro-nano bubbles (MNBs) are very small sized bubbles with diameters on the order of micrometers and nanometers, showing major potential in environmental remediation [30]. In recent years, microbubble and nanobubble technologies have gained considerable attention [31]. The relevant diameter of microbubbles and nanobubbles are estimated as 10–50 nm and <200 nm [32]. the sizes of nano-bubble increase with increasing concentration of dissolved carbon dioxide gas and oxygen gas [33]. Results showed that micro-nano bubbles could effectively enhance the mechanical properties of the concrete but reduced its workability. It was established that the compressive and tensile strengths increased by 16 and 19%, respectively, while the temperature during the setting period reduced remarkably [34].

Desired results for pozzolans led to the study of the effect of zeolite, as a commonly used pozzolan in the world, along with micro-nano-bubble, which is one of the new nanomaterials being used in the concrete industry, in chloride environment. Therefore for the first time, the simultaneous effects (binary) of using zeolite and micro-nano bubble water on the mechanical properties including compressive strength, tensile strength and durability of concrete including water adsorption, electrical resistance, rapid chloride permeability test chloride (RCPT) and ultrasonic pulse velocity in the mentioned environment condition, was evaluated. Also, X-ray diffraction (XRD) and Scanning Electron Microscopy (SEM) images were used to explain in details the microscopic properties in concrete.

2. Experimental program

2.1. Materials

A locally made ordinary Portland cement type I was used in this study in accordance with ASTM C150 [35]. The zeolite as a cement replacement material used in this study was Clinoptilolite extracted from mines in Semnan province, Iran. The chemical analyses of cement and zeolite were carried out in accordance with the ASTM C618 [36], with results presented in Table 1. The XRD diagram of the zeolite and the results of cement and zeolite SEM images are presented in Fig. 1. From the figure, the grains of zeolite were crystalline, with a high surface area and fine particle size distribution. In this study, micro-nano bubble water was used as a substitute for mixing concrete water. For the production of micro-nano bubbles water, using the method of cutting and Venturi tubes together with the process of hydraulic cavitation, semi-stable bubbles in micro and nano sizes entered into the water. One of the important properties of micro-nano bubble water is its Zeta potential, which ranges between −10 and −30 Mv. Fig. 2 presents the distribution graphs of the micro-nano sized water bubble dimension over time in terms of volume and number. River sand with a specific gravity of 2620 kg/m^3 was also applied as fine aggregate. Crushed limestone as the coarse aggregate with a maximum size of 19 mm and specific gravity of 2680 kg/m^3 was also used. The particle size distribution of materials used in this research is presented in Fig. 3. A polycarboxylic super-plasticizer (SP) with a density of 1.08 g/cm^3 and a pH of 7 was used in order to improve the workability of the mixture.

2.2. Mixture proportions

For evaluation of the mechanical and durability properties of concrete, mixture proportions were made in two phases. The first phase contained 5 mixtures including ratios of 10 and 15% zeolite instead of cement and 50 and 100% of the micro-nano bubble water instead of the concrete water. The second phase contained 4 mixture ratios in combinations of 50 and 100% micro-nano bubble water with 10 and 15% zeolite. In all mixtures, the water to cement ratio was 0.45. Mixtures proportions used in this study are listed in Table 2.

2.3. Preparing chloride treatment condition

In this study, to study the mechanical properties and durability of mixtures containing zeolite and micro-nano bubble water in chloride conditions and its comparison with standard conditions, two treatment conditions were used. In the first system, the samples were treated under chloride conditions. After one day, samples were removed from the mold and treated under standard conditions for two days, ie, in saturated limewater, which was followed by treatment in a condition containing 5% NaCl. A container with the dimension of 0.65 × 0.65 × 0.90 m was used with a volume of 380 L. The final concentration of the solution after adding 5% NaCl was 0.456 M. To prevent concentration changes, the solution was reconstituted weekly. To determine the concentration of chloride ion in water during the week, an argentometric method was used. In this method we use silver nitrate measurement and find the amount of chloride in water based on the amount of silver nitrate. In the second method, the samples were treated according to the standard method. After a day, samples were removed from the mold and then placed in saturated limewater.

2.4. Test procedure

2.4.1. Compressive strength test

The compressive strength of the mixtures was measured according to the ASTM C39 [37] and the results were reported after 28 and 90 days of wet curing in standard conditions.

2.4.2. Indirect tensile strength test

The indirect tensile strength test of concrete mixtures was conducted according to the ASTM C496 [38].

Table 1
Chemical composition of cement and zeolite.

Composition	Cement (%)	Zeolite (%)
Silica (SiO_2)	22.3	69.28
Calcium oxide (CaO)	62.40	3.56
Iron oxide (Fe_2O_3)	3.70	0.49
Alumina (Al_2O_3)	4.50	10.43
Magnesium oxide (MgO)	2.30	0.5
Sodium oxide (Na_2O)	0.27	0.73
Potassium oxide (K_2O)	0.76	1.27
Sulfur trioxide (SO_3)	2.25	0.005