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Effects of micro-nano bubble water and binary mineral admixtures on the mechanical and durability properties of concrete

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HIGHLIGHTS

- We presented a comprehensive study on the mechanical and durability of mixtures containing natural pozzolans.
- A locally natural pozzolan called Chekneh extracted from mines in Iran is used in this study.
- The micro-nano bubble water effect as a new material and as a substitute for the ordinary water in the concrete is evaluated.

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ABSTRACT

This paper presents an experimental research on effects of micro-nano bubble water and mineral admixtures (zeolite and Chekneh pozzolans) on the mechanical and durability properties of concrete. In this study, 18 types of mixtures including 3 categories of conventional concrete were prepared. The first category was a mixture containing just one type of mineral admixture (zeolite or Chekneh) at different percentages; the second category contained a binary combination of zeolite and Chekneh; and the third category including a combination of zeolite, Chekneh, and micro-nano water bubble. The results emphasized that zeolite and Chekneh pozzolan notably improve the durability properties of concrete, such as water absorption, electrical resistance, and chloride permeability, leading to the increased pozzolanic replacement. In addition, using micro-nano bubble water improved mechanical properties of concrete such as compressive and tensile strength at different ages and reduced the rate of water absorption and chloride permeability. In this regard, the greatest improvement in the compressive, tensile strength, and electrical resistance tests were for the mixture including a combination of 10% zeolite, 10% Chekneh pozzolan, and 100% micro-nano bubble.

1. Introduction

Concrete is among the main materials used in numerous man-made infrastructures. From the natural resources point of view, it is virtually infeasible to imagine replacing concrete by any other material [1]. Cement is an important part of concrete preparation. Energy consumption in cement industry is high and emissions of CO_2 produced during the generation of Portland cement create serious environmental issues [2]. About two-thirds of global CO_2 emissions are generated by cement plants as producing 1 ton of cement emits about 900 kg CO_2 into the atmosphere [3,4]. In this regard, reducing cement consumption and replacing a part of cement with slags or pozzolans is considered a solution for a sustainable development [5].

As their main role, Pozzolans are added to Portland cement because they usually enhance the durability and mechanical properties of concrete structures. The most important effects of pozzolans in the microstructure of cementitious paste are changing the interfacial transition zone (ITZ) and pore structure produced by the reduction in the particle size caused by the pozzolanic reactions. Thus, today applying newly developed pozzolans has become a necessity for building concrete structures, especially in aggressive environmental conditions [6–10].

Recently, using zeolite as a natural pozzolan material has been increasing. Pozzolan contains a high content of reactive SiO_2 and Al_2O_3 [8]. Addition of zeolite provides growth of an extra fine crystalline ettringite amount and tobermorite-like calcium hydrosilicates of CSH (B) type in the mineral non-clinker part of Portland

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cement [9–14]. Natural zeolite has a rough and porous structure and a very large surface area, leading to a significant decrease in concrete workability and setting time [7,15–19]. Addition of zeolite decreases the early age strength development. Accordingly, concretes containing 10% natural zeolite provide compressive strength similar to that of control mixture [16,20–22]. However, some researchers have found that the addition of zeolite results in an increase in compressive strength at early curing ages [23]. Using natural zeolite leads to significant reductions in permeability and capillary water absorption for all selected water-to-cementitious materials. Because the addition of zeolite to concrete decreases chloride diffusion coefficient and increases electrical resistance, the capacity for corrosion resistance of reinforced concretes is expected to increase [16,23–26].

Table 1
Chemical properties of cement and pozzolanic mineral admixtures.

Constituents/property	Cement (%)	Chekneh (%)	Zeolite (%)
Silica (SiO_2)	22.3	65.21	69.28
Calcium oxide (CaO)	62.40	3.22	3.56
Iron oxide (Fe_2O_3)	3.70	0.63	0.49
Alumina (Al_2O_3)	4.50	8.96	10.43
Magnesium oxide (MgO)	2.30	1.5	0.5
Sodium oxide (Na_2O)	0.27	0.94	0.73
Potassium oxide (K_2O)	0.76	1.63	1.27
Sulfur trioxide (SO_3)	2.25	0.004	0.005
Limiting oxygen index (LOI)	–	2.72	2.98

Today, the application of nanotechnology in construction structures offers many opportunities and challenges and determines a way to enhance the concrete properties [27]. Micro-nano bubble (MNBs) are very small bubbles with diameters on the order of micro- and nanometers with great potential in environmental rebuilding [28]. In recent years, micro-nano bubble technologies have received great attention because of their wide applications in many fields such as nanomaterials, water treatment, and biomedical engineering. [29] The diameter of microbubbles (MBs) and nanobubbles (NBs) are within the ranges of 10–50 mm and <200 nm, respectively [30,31]. In addition, it has been evidenced that micro-nano bubbles cab effectively improve mechanical properties of the concrete but reduce its workability. In this regard, the addition of these micro-nano bubble leads to 16 and 19% increases in compressive and tensile strength values of the mixture, respectively [32].

The present study was conducted to determine the micro-nano bubble, local pozzolan (called Chekneh), and zeolite effects on the concrete properties separately. Then, for the first time, the simultaneous effects (binary) of the using local natural pozzolan and zeolite and micro-nano bubble water on the mechanical properties and durability of concrete are evaluated. To investigate the mechanical properties, tests including compressive and tensile strength and for the durability properties, tests including volumetric water adsorption, electrical resistance, rapid chloride permeability test chloride (RCPT), and ultrasonic pulse velocity

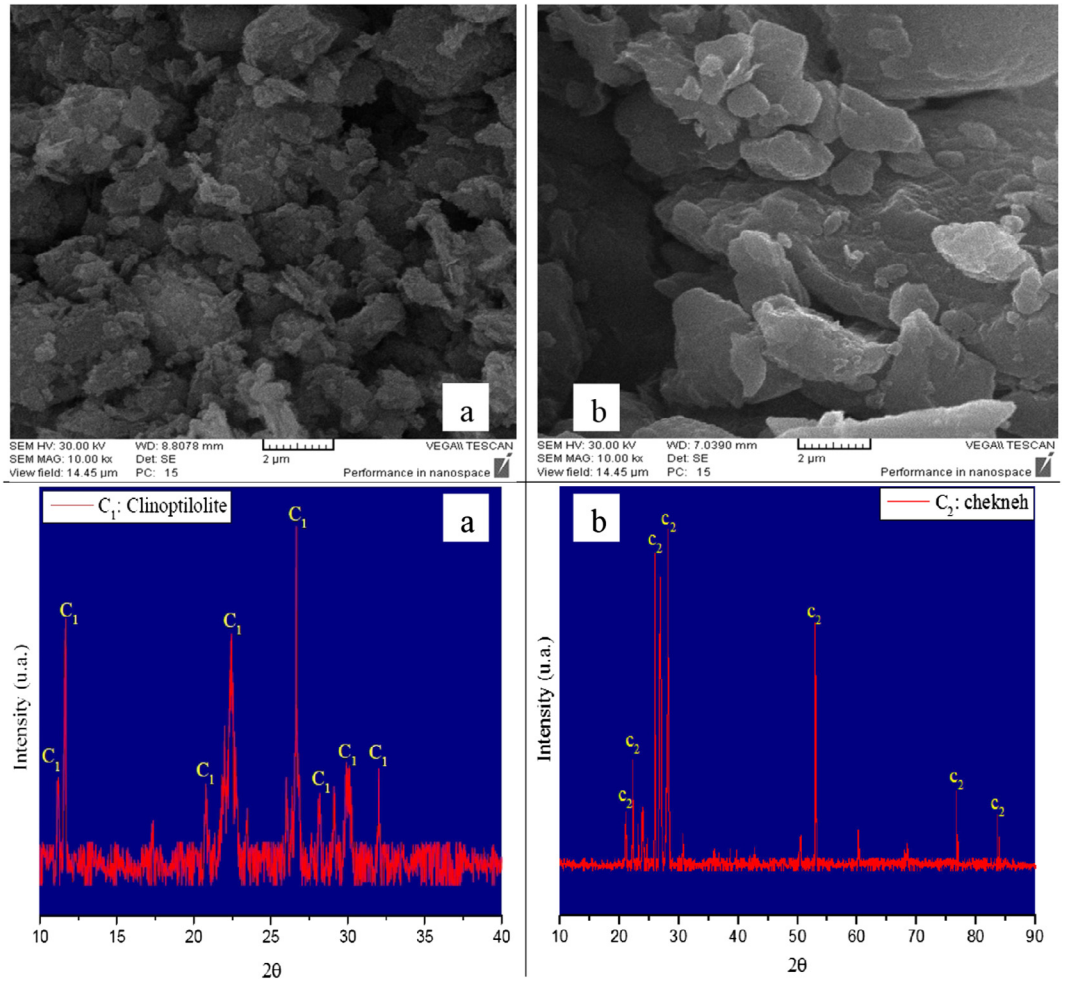

Fig. 1. The XRD diagram of the Chekneh and zeolite and their SEM images: a) Zeolite and b) Chekneh.