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Influence of pumice and zeolite on compressive strength, transport properties and resistance to chloride penetration of high strength self-compacting concretes

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HIGHLIGHTS

- Pumice and zeolite pozzolanic activity is related to f_c and transport properties.
- The substitution of 10% of OPC by pumice increases f_c at both early and long terms.
- Chloride penetration in HSSCCs with zeolite is lower than mixture with pumice.
- HSSCCs with pumice and zeolite exhibit higher resistance to immersion and tidal conditions.

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ABSTRACT

This paper investigates the effect of two different natural pozzolan (pumice and zeolite) on compressive strength (fc), transport properties and resistance to chloride penetration both in immersion and tidal conditions when used in high strength self-compacting concrete (HSSCC). First, the chemical and mineralogical composition as well as the microstructure and the pozzolanic activity of the natural pozzolan are studied. Then, two percentages, 10% and 15%, of pumice and zeolite instead of Portland cement in HSSCC are investigated. Five concrete mixtures with a control mixture without any pozzolan are prepared and tested in both fresh and hardened states. The results show that the studied zeolite is a clinoptilolite that presents higher pozzolan activity compared to pumice. However, the compressive strength of mixtures containing zeolite remains low compared to control mixture. On the contrary, mixtures with pumice present compressive strength values close or higher than the ones of the control mix at both early and long term ages with a remarkable increase at long term. For durability purposes, the transport properties of the different mixtures are studied through capillary absorption, water absorption, water penetration, electrical resistivity, chloride migration and diffusion tests. The results show that, both pumice and zeolite pozzolan are found to have a significant effect on the increase of the resistance to chloride penetration in both immersion and tidal conditions. However, zeolite mixtures exhibit better resistance. This research shows that, the substitution of Portland cement by 15% of pumice or 10% of zeolite in HSSCC is affordable in all aspects.

1. INTRODUCTION

The concept of self-compacting concrete (SCC) was conceived by Okamura in the late 1980 s. According to his research [1], some health risks and environmental problems could be avoided (white finger syndrome, noise, vibrations ...). If it offers multiple benefits to their users, SCC is also an area of research that has a high growth potential. One disadvantage of SCC is its cost. The alternative to reduce the cost of the SCC is the use of mineral additives which replace a part of cement. Two features are important, the use of chemical additives and cement in large quantity which is necessary in the production of SCC to improve the passing ability, the filling ability and stability.

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Ordinary Portland cement (OPC), with a total production of around 3000 Mt/year, is the dominant binder used in the construction industries [2,3]. Estimates for global demand for the OPC show that cement consumption will reach nearly 6000 Mt/year in the next 40 years [3]. Environmental problems caused by 5–7% of CO_2 emissions from the cement industry are constantly increasing. Consequently, the use of pozzolan to replace a portion of the cement in concrete production can be as a convenient choice to reduce pollution and is more economical.

The durability of structures situated in aggressive environments as marine environments (e.g. Persian Gulf side) and industrial area is important because they are constantly exposed to aggressive agent. Therefore, economic additions as well as durability issues are considered as vital issues and addressed by researchers around the world including Iran. Consequently, the purpose of this article is to study the influence of two natural pozzolan, widely available in Iran, and particularly pumice from Khash (south east of Iran), and zeolite from Semnan (center of Iran) on different properties of HSSCC.

Pumice is one of the natural volcanic pozzolanic materials. Due to frequent volcanic eruption, it is found plentifully in the world and has been used with Portland cement or blended cement either individually or in combinations [4]. In 122 BCE, the Romans used the lightweight material made of pumice aggregate to build part of their temples with concrete. Recently pumice, due to its appropriate rheological behavior, mechanical and durability properties as well as its low cost has become of interest for researchers to further investigate their impact on the concrete. However, only few studies related to pumice exist in the literature. According to Ramezanianpour, pumice as a pozzolanic material increases the later age compressive strengths of SCC [4]. Application of natural zeolite in manufacture of pozzolanic cements started in the first decades of the 20th century and has been shown to be a growing trend in recent decades. Recently, the use of a large amount of natural zeolite in cement and concrete industry has been reported in China. It is reported that, volcanic material containing 45% of zeolite deposited in the Black Forest in Germany is used in the concrete industry in Germany, Switzerland and France [5]. Currently, very little information is available on the durability properties of HSSCC containing pumice and zeolite. Consequently, the investigation of SCC containing pumice and zeolite is beneficial and requires further investigation in fresh and hardened phases and durability properties. According to literature, the different studies focused on the mechanical properties and transport properties [6-11]. The studied transport properties are mainly obtained using chloride migration, water penetration, capillary absorption and electrical resistivity tests. However, one can observe a lack in the literature on the characterization of the microstructure and the pozzolanicity of these pozzolan, as well as on their performance in non-saturated conditions like in tidal zone in marine environment.

This paper investigates and compares the effect of two different natural pozzolan (pumice and zeolite) on rheological behavior, compressive strength and transport properties of HSSCC at early ages and up to 365 days. The impact on the resistance to chloride penetration both in immersion and tidal conditions is also investigated. For this purpose, first, the chemical and mineralogical composition as well as the microstructure and the pozzolanic activity of the two natural pozzolan were studied. Then different tests such as slump flow, V-funnel, L-box, U-tube, J-Ring and sieve, were performed to study the fresh phase of HSSCC, and then mechanical testing was done on hardened states to evaluate the compressive strength of the different prepared mixtures. The tests concerning the transport phenomena were also performed at different ages in order to evaluate the durability properties with time including permeable pores, water absorption, absorption after immersion and boiling, capillary absorption, water penetration, chloride ion diffusion in non-steady state, chloride ion migration in non-steady state by electric field (RCMT), chloride diffusion ions in marine area and electrical resistivity. Finally, the resistance to chloride penetration of the different mixtures was evaluated in immersion and tidal conditions.

2. Materials

Five concrete mixtures were prepared with the same Portland cement type II content (450 kg/m^3), constant W/C_m ratio of 0.4 and constant gravel to sand ratio of G/S = 1. A concrete mixture based on Portland cement was used as the control concrete (HSL). In the other four formulations, HSP10, HSP15, HSZ10 and HSZ15 pumice and zeolite were used respectively as an addition with two different replacement percentages of 10% and 15% by Portland cement. A Portland cement with a specific gravity of 3.15 g/cm^3 and a Blaine fineness of 2900 cm^2/g, in compliance with ASTM C150 was used.

The pumice used in this study has a specific surface area of 4220 cm^2/g and a specific gravity of 2.58 g/cm^3. The used zeolite as shown in Table 1 is a siliceous zeolite since it contains a high amount of Silica. It has a specific surface area of 4060 cm^2/g and a specific gravity of 2.25 g/cm^3. The chemical analysis and particle size distribution (PSD) of cementitious materials are shown in Table 1 and Fig. 1 respectively.

For all mix designs, crushed angular material of 6–12 mm nominal size was used as a coarse aggregate (gravel), and natural sand with a maximum size of 4 mm was used as a fine aggregate. The physical characteristics of gravel and sand according to ASTM C 27–88 and ASTM C128-97 respectively are shown in Table 2. Also, their particle size distributions are shown in Fig. 2. A high range water-reducing admixture (HRWRA), with a specific gravity of 1.11 g/cm^3 based on chains of modified poly-carboxylate ether (PCE 180), was used in all mixtures to produce HSSCC. Potable water was also used to prepare concrete mixes. The balance between high flow and high segregation resistance is made possible by the dispersing effect of HRWRA combined with cohesiveness of high concentration of fine particles in additional filler material. The dosage of superplasticizer is experimentally determined from tests on fresh concrete to obtain a slump flow diameter of 700 ± 30 mm for all HSSCCs. Table 3 shows the mix proportions of the mixtures. To enhance the stability of SCC mixes, 150 kg/m^3 limestone powder was used as filler in the five mixtures. By increasing the replacement level of additives from 10% to 15%, the viscosity of fresh concrete and the amount of superplasticizer required to achieve the desired slump flow is also increased. This last is very significant in the HSZ15 mixture and therefore, this mixture is considered to be uneconomical (Table 3). From this aspect, although natural zeolite is cheaper than Portland cement, the high demand of superplasticizer in concretes containing high levels of natural zeolite may result in more production costs. Some researchers concluded that a large amount of superplasticizer is required to produce concrete containing high percentage of zeolite replacement [8,12-18]. It can be justified by the following reasons: i) the fine microstructure of zeolite, ii) increase of volume paste and iii) high surface area of natural pozzolan.

3. Microstructure investigation

3.1. SEM analysis

Observations by scanning electron microscopy (SEM) combined with the elemental microanalysis were performed on the studied pozzolans using a JSM 7100F SEM equipped with an Oxford EDS