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The effect of mineral admixtures on permeability, porosity and electrical resistivity of concrete

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ABSTRACT: Evaluation of concrete durability is commonly performed by measuring its permeability, porosity and electrical resistivity. Moreover, using mineral admixtures in concrete mix design is one of the methods to enhance concrete durability. For this reason, in this paper, the effect of pozzolanic admixtures (silica fume, fly ash and zeolite) and limestone powder on permeability, porosity and electrical resistivity of 28-day and 120-day cubic concrete specimens with 15cm dimension was investigated. For concrete preparation, 5%, 10%, 15% and 20% of cement mass were replaced by the same amount of these admixtures. In this paper, the innovative method of the "Cylindrical chamber" was used for measuring concrete permeability. The results obtained revealed that except for the 28-day concrete specimen that 20% of its cement mass was replaced with limestone powder; other concrete specimens had lower permeability and porosity and higher electrical resistivity than the concrete specimen without admixtures. X-ray diffraction (XRD) test results also showed that pozzolanic materials produce more calcium silicate hydrates by consuming calcium hydroxide which results in the reduction of permeability and porosity and increase of electrical resistivity, compared with the concrete specimen without admixtures. In addition, a slight reduction in calcium hydroxide and calcium silicate hydrate peak intensities was observed for the concrete specimen containing limestone powder. This behavior showed that limestone powder enhances concrete durability, mainly due to filler and dilution effects.

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1- Introduction

Concrete is the most common man-made material which is used extensively in the building and construction industries. For this reason, concrete should have satisfactory durability properties, meaning that it should be capable of withstanding the conditions for which it has been designed throughout its serviceability life. Replacing a part of cement mass with mineral admixtures is one of the methods to achieve this goal. For this purpose, the aim of this study is to investigate the effects of different mineral admixtures, including silica fume, fly ash, zeolite and limestone powder, on the durability properties of concrete, such as water permeability, permeable porosity and electrical resistivity. During this investigation, water permeability and electrical resistivity were measured using "Cylindrical chamber" [1, 2] and bulk methods, respectively. Permeable porosity was also measured according to ASTM C642-06 [3].

2- Concrete specimens

In this paper, a series of laboratory tests were performed to measure water permeability, permeable porosity and specific electrical resistivity of 28-day and 120-day concrete specimens with 150mm dimensions. To prepare concrete specimens, 5%, 10%, 15% and 20% of type II Portland cement mass were replaced with the same amount of silica fume, fly ash, zeolite and limestone powder. Water to binder ratio was also 0.5 in all concrete mixtures. It should be noted that a polymer-based superplasticizer was used in the mix designs of the concrete specimens containing silica fume and zeolite to achieve proper workability. Figure 1 shows the prepared concrete specimens for water permeability and electrical resistivity measurements, using the "Cylindrical chamber" and bulk methods, respectively.

3- Results and Discussions

The results obtained for the durability properties of the prepared concrete specimens are plotted in Figure 2. As it is seen from this figure, the incorporation of silica fume and fly ash in the concrete mixture enhances the durability of the 28-day and 120-day concrete specimens. Moreover, Figure 2 shows that water permeability and porosity decrease with increasing silica fume and fly ash content. On the contrary, there is a direct correlation between silica fume and fly ash content with specific electrical resistivity. These behaviors are mainly attributed to the pozzolanic reaction of silica fume and fly ash particles. During the pozzolanic reaction, calcium

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(a) Measuring water permeability of concrete using "Cylindrical chamber" method

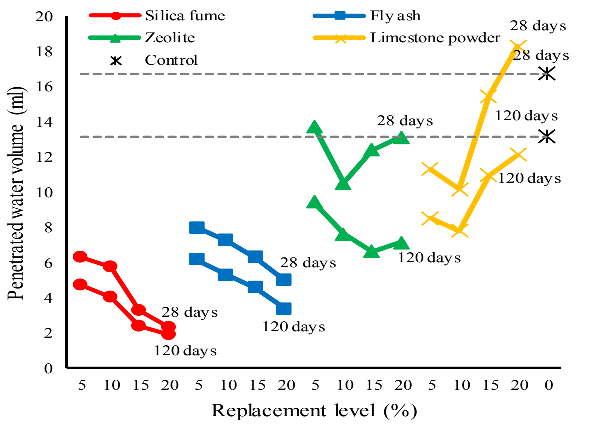
(b) Measuring electrical resistivity of concrete using bulk method

Fig. 1. Concrete specimens prepared for water permeability and electrical resistivity measurements

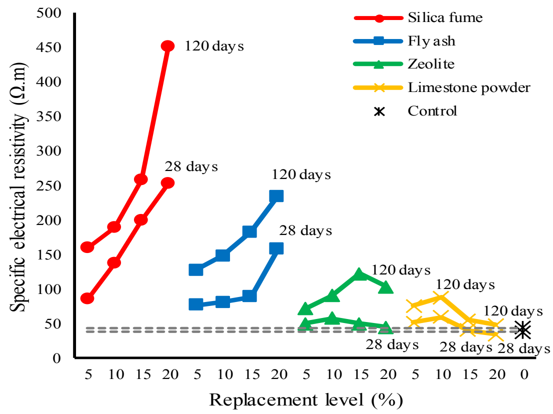
hydroxide produced by cement hydration reacts with the active or glass phase of pozzolan (mainly SiO_2). The result is the production of the secondary calcium silicate hydrate gel which fills the existing pores [4]. In addition, the filler effect of mineral admixture particles enhances the density of the cement matrix.

According to Figure 2, an optimum replacement level appears to exit for the 28-day and 120-day concrete specimens containing zeolite and limestone powder. This behavior is due to the dilution effect and the possibility of the formation of agglomerations. By the addition of zeolite and limestone powder in excess of the optimum replacement level, permeability and porosity increase while specific electrical resistivity decreases. It is also seen from Figure 2 that at the age of 28 days, due to the dilution effect, replacing 20 percent of cement mass with the same amount of limestone powder has resulted in the reduction of the durability of the concrete without admixtures. Limestone powder mainly improves concrete durability due to physical influence on the hydration process (filler and dilution effects) [5], but for longer curing periods, limestone powder improves concrete durability by altering the hydration process by both physical and chemical means. This is why the concrete specimen containing limestone powder with a replacement level of 20% showed enhanced durability properties, compared with the specimens without admixtures. In addition, Figure 2 shows that zeolite optimum replacement level has changed from 10% to 15% by increasing the specimen age. With increasing the specimen age, due to the hydration progress, that part of zeolite particles that have not contributed to the hydration process will contribute to this reaction, which results in the increase of optimum replacement level. It should be noted that zeolite is a pozzolanic mineral admixture.

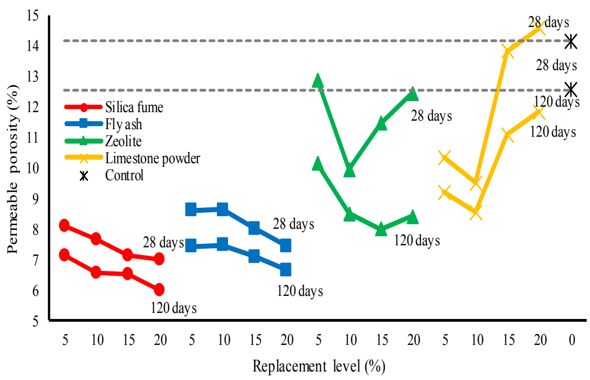
In order to investigate the effect of the studied mineral admixtures on concrete microstructure, X-ray diffraction technique was performed on the 28-day concrete specimens with a replacement level of 5% and the corresponding results



(a) Penetrated water volume measured for the prepared concrete specimens



(b) Specific electrical resistivity measured for the prepared concrete specimens



(c) Permeable porosity measured for the prepared concrete specimens

Fig. 2. Penetrated water volume, specific electrical resistivity and permeable porosity measured for the prepared concrete specimens

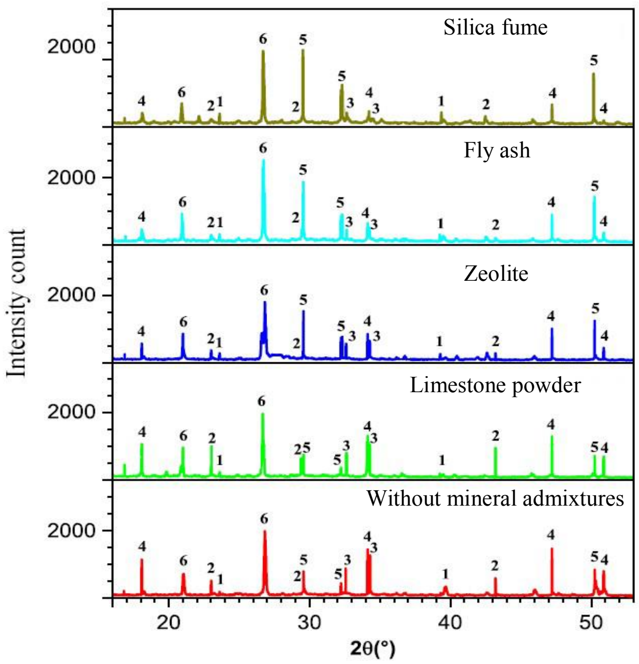


Fig. 3. XRD spectrums for the prepared 28-day concrete specimens with and without mineral admixtures (replacement level is 5%, 1:C3AH6, 2:CaCO3, 3:C2S/C3S, 4: Ca(OH)2, 5: C-S-H, 6=SiO2)

are plotted in Figure 3. According to this figure, concrete specimens containing silica fume, fly ash and zeolite have shown lower peak intensities for calcium hydroxide, compared with the concrete specimen without admixtures. In addition, higher peak intensities are observed for calcium silicate hydrates. This behavior is attributed to the pozzolanic reaction and extreme fineness of mineral admixture particles. In the case of limestone powder, physical effects (filler and dilution effects) mainly govern hydration reaction at young ages. For this reason, a slight reduction was observed for peak intensities of calcium hydroxide and calcium silicate hydrate for the concrete specimens containing limestone powder.

4- Conclusions

In this paper, the effects of different types of mineral admixtures, including silica fume, fly ash, zeolite and limestone powder on the durability properties of concrete were evaluated. For this purpose, 28-day and 120-day concrete specimens with different replacement levels (5%, 10%, 15% and 20% of cement mass) were prepared and their water permeability, permeable porosity and specific electrical resistivity were measured. The results showed that silica fume, fly ash and zeolite enhance concrete durability by consuming calcium hydroxide and producing secondary calcium silicate hydrate which densifies concrete microstructure. In addition, limestone powder mainly influences the hydration process through dilution and filler effects. XRD results were also consistent with the laboratory measurements since peak intensities for calcium hydroxide were decreased when silica fume, fly ash and zeolite were incorporated in concrete mixtures. In addition, these concrete specimens showed higher peak intensities for calcium silicate hydrate. In the case of limestone powder, a slight reduction for calcium hydroxide and calcium silicate hydrate peak intensities was seen.

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