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Effective solution for low shrinkage and low permeability of normal strength concrete using calcined zeolite particles

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HIGHLIGHTS

- The use of pre-wetted zeolite particles in normal strength concrete for shrinkage reduction, especially the drying shrinkage.
- The long-term permeability of concrete with the porous zeolite (such as 90 days) is better than that of the control concrete.
- The designed mixtures with addition of pre-wetted zeolite particles have a comparable cement amount used in normal strength concrete.

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ABSTRACT

The purpose of this paper is to explore the mixture design of normal strength concrete towards low shrinkage and low permeability using calcined zeolite as internal curing agent. Shrinkage, strength and permeability tests were conducted on the concretes. Through above tests, efficiency of shrinkage reduction using pre-wetted calcined zeolite particles in normal concrete, and impacts of porous zeolite particles in concrete on the movement of ions in concrete, are evaluated. Based on the present study, the following conclusions can be drawn: 1) the use of pre-wetted zeolite particles in normal strength concrete can reduce shrinkage of the concrete, especially the drying shrinkage; 2) the addition of the porous zeolite may negatively influence the permeability of concrete at early-ages. However, the long-term permeability of concrete (such as 90 days) is better than that of the control concrete; 3) designed four mixtures with addition of pre-wetted zeolite particles have a comparable cement amount normally used in practice for normal strength concrete based on the present study.

1. Introduction

Shrinkage induced cracking in concrete has become a serious concern for application of high performance concrete. In general, environmental drying and cement hydration are the two principal processes causing moisture loss of concrete [1–4]. The resulting shrinkage from above two processes of moisture loss is called drying shrinkage and autogenous shrinkage, respectively. Generally, the higher the water to cement ratio of concrete is, the lower the autogenous shrinkage of the concrete. Correspondingly, the lower the water to cement ratio of concrete is, the higher the drying shrinkage of the concrete. Therefore, autogenous shrinkage and drying shrinkage are the main constituent of the total shrinkage of high strength and normal strength concrete respectively. Decreasing drying shrinkage of normal strength concrete, which may still be mostly used in practice, becomes another critical work apart from autogenous shrinkage reducing. Use of pre-wetted lightweight aggregate as an internal reservoir to provide water as the concrete dries is an effective method to reduce autogenous shrinkage of high strength concrete [5–7]. However, there are certain restrictions to using lightweight aggregates in concrete due to the resource of such man-made material. Meanwhile, some disadvantages of using pre-wetted lightweight aggregate in high strength concrete were also observed, for example, the negative effect on bending and tensile strength, as well as the deleterious effect on permeability of concrete [8].

Recently, Zhang et al. [9,10] introduce the calcined zeolite particle as internal curing agent of cementitious composites, which are not difficult to be manufactured than the artificial lightweight aggregate. Meanwhile, the small porous particle can effectively overcome the depressing impact of normal lightweight aggregate on permeability of concrete [10]. Research on the use of the calcined zeolite particle in high strength concrete for shrinkage reduction was conducted by Zhang et al. [10]. Their results have shown that autogenous and drying shrinkage of high strength concrete are

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considerably reduced after using pre-wetted calcined zeolite particle. Meanwhile, rapid durability tests on the concrete show the addition of the porous zeolite increases the permeability of high strength concrete at early-age. Nevertheless, this negative effect is decreased with increase of age. At 90 days after casting, permeability of concrete with pre-wetted zeolite addition is already lower than that of control concrete. In addition, apart from high strength concrete, normal strength concrete, such as the compressive strength lower than 80 MPa, is still the mostly used type in practice. Therefore, decrease on the drying shrinkage of normal strength concrete may need to be given attention as well to prevent shrinkage cracking in these structures.

The purpose of this article is to explore the mixture proportion of normal strength concrete with adding the calcined zeolite particles for both shrinkage reduction and permeability improvement. In this study, calcined zeolite particles with size of 0.18 mm in average are used as internal curing agent of concrete. In the experiments, three group tests were carried out. In the first test group, eight normally cured concrete mixtures, with three binder contents and five water to binder ratios were used. Shrinkage, strength and rapid permeability tests were conducted on these concretes. In the second test group, five mixtures with pre-wetted zeolite addition for internal curing were designed according to the test results of the first test group. Shrinkage, strength and rapid permeability tests were conducted on these internally cured concretes. In the third test group, cracking sensitivity of the internally cured concretes under shrinkage load was evaluated with steel-concrete composite ring tests. Through above tests, efficiency on shrinkage reduction using pre-wetted calcined zeolite particles in normal concrete, and the possible impacts of porous zeolite particles in concrete on the movement of ions in concrete, are evaluated. In summary, there are three contributions of present paper to the knowledge of design of normal strength concrete 1) Quantitative evaluation of shrinkage performance of normal strength concrete with pre-wetted calcined zeolite particles addition; 2) Quantitative evaluation of the impacts of porous zeolite particles on permeability of normal strength concrete; 3) Mixture proportion of normal strength concrete with calcined zeolite particles for both low shrinkage and low permeability.

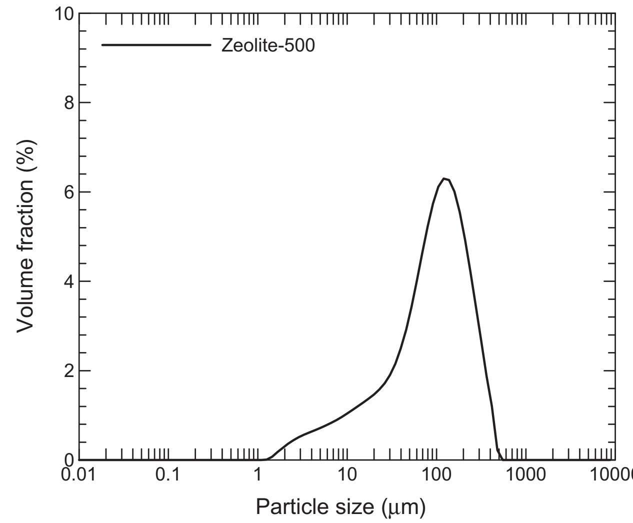

Fig. 1. Particle sizes distribution of zeolite-500.

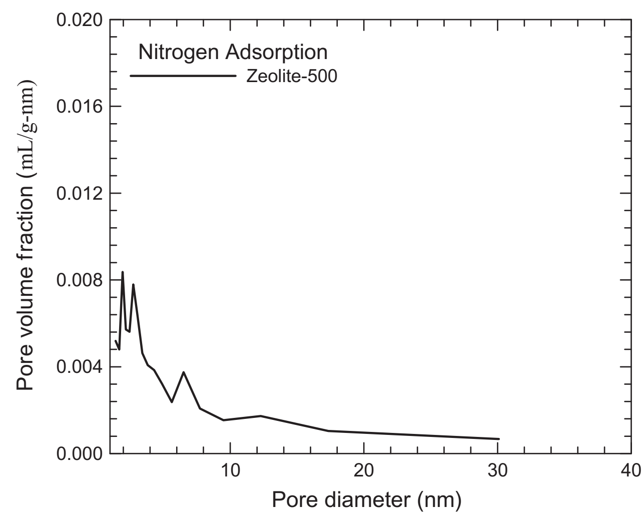

Fig. 2. Pore distribution of zeolite-500 based on nitrogen adsorption.

2. Experimental program

In this study, a kind of grinding zeolite with an average particle size of 0.18 mm, produced in China was used as internal curing agent. Zeolite is aluminosilicate mineral containing large amount of micropores and physically bonded water in it. In the present study, the zeolite particles were calcined in a muffle furnace under 500 °C for 30 min (named zeolite-500) before using in concrete in order to increase the water releasing ability as concrete is dried [9]. Fig. 1 shows the particle sizes distribution of the calcined zeolite. Fig. 2 shows the pore distribution of the calcined zeolite based on nitrogen adsorption. The specific surface area and porosity of the zeolite-500 are 49 m^2/g and 0.26 ml/g according the nitrogen adsorption test. To examine the effect of calcination on water reservation and releasing ability, water sorption and desorption tests on zeolite-500 and natural zeolite were carried out. The test results of water adsorption and desorption behavior of the zeolite-500 and the common zeolite without calcining is present in Fig. 3. From Fig. 3, it can be seen that the calcination process can obviously increase the water adsorption of the porous particles, which in turn increases the releasing ability of water under drying, as displayed on the desorption curves. The calcinations can make more physically bonded water to evaporate, which normally cannot escaped from the pores under atmospheric environment. In such, increasing the water adsorption that can make more water should be used as internal curing water in concrete.

To achieve the target of the present study, two groups of tests were conducted. In the first test group, eight normally cured concrete mixtures, with three binder contents, 300, 400 and 450 kg/m^3, and five water to binder ratio of 0.62, 0.52, 0.42, 0.35 and 0.30, were used. The same Portland cement and fly ash were used for all mixtures as binder. Natural sand and crushed limestone with a maximum particle size of 5 mm and 20 mm, respectively, were used as normal fine and coarse aggregates. A polycarboxylate superplasticizer with 30% solid content was used in these mixtures to guarantee the fresh concrete has a similar slump in 90–120 mm. The concrete mixture proportions used in the first test group are listed in Table 1. The purpose of the first group tests is to obtain a general variation trade of autogenous and drying shrinkage with water to binder ratio and binder amount. Then further to know how to reduce the difference of autogenous and drying shrinkage of concrete, which may provide the direction of mixture design with low shrinkage. The shrinkage reduction should include not only on autogenous shrinkage, but also on drying shrinkage.

In the second test group, five mixtures with pre-wetted zeolite addition for internal curing were designed according to the test