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Self-healing test of concrete mixed with permeable crystalline materials

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Abstract

Concrete is a core component of infrastructure. Owing to its low tensile strength and exposure to complex service environments, it is prone to cracking, which seriously impairs the durability and safety of structures. Traditional repair techniques suffer from drawbacks such as high cost and low efficiency, while the self-healing technology of concrete slabs provides a new approach by simulating biological self-healing mechanisms to achieve autonomous crack repair.

Keywords

Concrete; Crack repair; Self-healing; Durability

1. Introduction

Concrete has maintained its position as one of the most widely used construction materials globally, thanks to its core advantages such as excellent compressive strength, abundant raw material reserves and low production cost, and is extensively applied in the construction of concrete slab components including road surfaces, bridge decks and building floor slabs. However, concrete has an inherent drawback of low tensile strength Under the combined influence of multiple factors like temperature fluctuations, wet-dry cycles, external loads and uneven foundation settlement, microcracks are prone to initiate and gradually develop into macrocracks. Such cracks not only damage the structural integrity of concrete slabs, but also serve as penetration channels for aggressive media such as water, chloride ions and sulfates, thereby accelerating the corrosion of internal steel bars and the degradation of matrix materials, and ultimately forming a vicious cycle of “crack propagation→intensified erosion → loss of structural bearing capacity”.

Permeable crystalline self-healing technology: The implementation approach of this technology is the internal incorporation or surface coating of cement-based permeable crystalline materials, which are mainly composed of active chemical substances. Its self-healing mechanism takes water as the transmission carrier. The active components penetrate and diffuse through the internal pores of concrete, and then chemically react with calcium hydroxide, a hydration product of cement, to generate water-insoluble calcium silicate hydrate (C-S-H) gel and ettringite crystals, thus filling the pores and microcracks inside the matrix. When new cracks occur in the structure subsequently, the infiltrated water can reactivate the unreacted active components, promoting the continuous generation of crystals and achieving crack sealing. Eventually, a long-term cyclic mechanism of "water and air triggered repair" for concrete cracks is established.

2. Research Status of Self-healing Technology for Concrete Slabs at Home and Abroad

As a key component in the field of concrete modification, reactive mineral admixtures have become a research hotspot in the field of civil engineering materials in recent years, due to their resource utilization value and excellent modification effects. Centering on the core issues such as the action mechanism, dosage optimization and performance regulation of fly ash concrete mixed with reactive mineral admixtures, scholars at home and abroad have carried out systematic research and achieved fruitful results.

Hou Jingwen and Qin Yamei studied and analyzed the effect of fly ash dosage on the compressive strength of fiber-reinforced concrete. The purpose of their research was to clarify the variation law of compressive strength of fiber-reinforced concrete under different fly ash dosages, reveal the correlation characteristics between fly ash dosage and compressive strength of fiber-reinforced concrete through experimental methods, and deeply explain the core mechanism of the improvement of early compressive strength and the attenuation of later strength of fiber-reinforced concrete.

Su Jun and Wang Jie carried out flexural tests on fly ash steel fiber ultra-high-strength concrete with a steel fiber volume fraction of 1.5%, systematically obtained its flexural mechanical property parameters, and preliminarily discussed the crack propagation law and failure evolution process during the flexural tests.

Khaloo et al. found that the increase in steel fiber dosage could significantly improve the splitting tensile strength and flexural tensile strength of concrete. However, there exists a reasonable threshold for steel fiber dosage. When the dosage is too high, it will not only seriously deteriorate the workability of concrete, but also easily cause problems such as uneven fiber distribution and local agglomeration, which in turn leads to an increase in the internal porosity of concrete and ultimately results in a significant attenuation of its compressive strength and splitting tensile strength.

Zhang HM discussed the improvement effect of fly ash and silica fume on concrete performance and workability, and conducted a comprehensive analysis from both macroscopic and microscopic perspectives. By preparing and testing two sets of high-flow steel fiber-reinforced concrete (HF-SFRC) mixed with fly ash and silica fume, the mechanical properties such as compressive strength, compressive toughness and flexural toughness, as well as the microstructure were systematically evaluated. The microstructure analysis showed that fly ash and silica fume could reduce the matrix voids to varying degrees, and the dense structure formed by complete hydration could enhance the interfacial bonding between steel fibers and cement matrix. The synergistic effect of fly ash, steel fibers and cement effectively improved the fluidity and comprehensive mechanical properties of concrete.

3. Effect of Permeable Crystalline Materials on Mechanical Properties of Concrete

Permeable crystalline materials possess special chemical properties. When in use, they can be directly mixed with water to uniformly disperse the active components inside concrete or mortar. Their active components can react with calcium hydroxide, a hydration product of cement-based materials, to generate calcium silicate hydrate, which can efficiently block capillary pores and cracks, thus exhibiting excellent water-based permeation-sealing performance.The raw materials include the following components: P·O 42.5 cement, Grade II silica fume, Class F fly ash, manufactured sand (fineness modulus of 2.7), medium sand (river sand, fineness modulus of 2.6), crushed stone (particle size of 5–16 mm), and high-efficiency water reducer.

3.1. Compressive strength test

The concrete mix ratio was determined through strict design, calculation, and trial-mixing procedures in accordance with Code for Design of Ordinary Concrete Mix Proportions (JGJ 55-2011).

Figure 1. Failure Modes of Concrete

Table 1. Primary Compressive Strength of Concrete Under Different Curing Conditions

Dosage of Permeable Crystalline Materials/%.	3d	7d	14d	28d
0	13.78	21.12	26.15	34.69
0.15	14.38	23.18	27.59	35.64
0.25	15.67	21.23	26.87	34.58

4. Microscopic Analysis of Concrete Self-healing Mechanism

4.1. SEM analysis

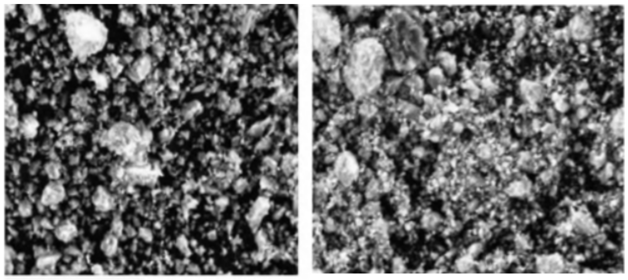

Figure 2. SEM Images of Concrete Specimens with Different Dosages of Permeable Crystalline Materials under Standard Curing Conditions for 28 d

It can be seen from Figure 4-1 that after the incorporation of permeable crystalline materials, the main hydration product of the cement-based system is calcium magnesium carbonate. This product can not only significantly improve the early mechanical properties of the material, but also exert a certain promoting effect on the self-healing performance of cement-based materials.

Combined with the test data, it can be inferred that the action mechanism of this permeable crystalline material is similar to the precipitation reaction mechanism. According to the theory of precipitation reaction mechanism, permeable crystalline active materials take water as the transmission medium and chemically react with free calcium oxide in the cement matrix, eventually generating insoluble calcium carbonate crystals.

5. Conclusion

(1) Permeable crystalline admixtures can significantly improve the comprehensive performance of concrete. Verified by a series of comparative tests under different curing conditions and ages, the optimal dosage of this admixture is stably determined as 0.2% of the mass of cementitious materials.

(2) Permeable crystalline materials exhibit a particularly prominent enhancement effect on the initial compressive strength of concrete at an early age. In a high-humidity curing environment, such materials can effectively improve the compressive strength of concrete at the curing ages of 3 d and 7 d. In contrast, under low-humidity conditions such as natural curing, their enhancement effect on the compressive strength at 3 d and 7 d ages is relatively limited, but they still exert a certain strengthening effect on the compressive strength at 14 d and 28 d ages.

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