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Effect of Microbial Self-Repairing Agent on Anti Permeability of Concrete

Haoming Sun

School of of Naval Architecture and Maritime, Zhejiang Ocean University, Zhoushan, 316022, China

Abstract

In this study, the effect of microbial remediation on the impermeability of concrete was studied by using Sporosarcina pasteurii as self-repairing agent and coral reef calcareous sand with open pores as the carrier. Concrete impermeability was characterized by water absorption test, chloride ion permeation test and SEM observation of microbial mineralization. The experimental results show that the anti-permeability of concrete can be improved by adding self-repairing agent to the concrete and curing the specimens in an appropriate environment. After 28 days of curing, compared with the control, the water absorption of self-repairing concrete decreased by 38%, and the permeability of chlorine-resistant ions increased, and the electric flux and RCM decreased by 20% and 35%, respectively. Furthermore, scanning electron microscopy (SEM) analysis showed that a large number of microbial mineralized crystals were formed inside the self-repairing concrete with higher density and lower porosity.

Keywords

Concrete, Self-Repairing, Impermeability, SEM.

1. Introduction

As the concrete forms certain pores and micro-cracks, it will cause moisture and harmful substances (Cl-, etc.) to infiltrate into the concrete, induce corrosion of steel bar or accelerate the aging of concrete, thus significantly reducing the integrity and durability of concrete structure, and cause many problems to the safety of engineering structure[1]. Therefore, it is very important to study the impermeability of concrete. The self-repair technology based on microbial mineralized deposition can diagnose and repair the small cracks which are difficult to find in the concrete matrix, which is helpful to improve the durability of concrete structure, thus reducing the consumption of manpower and material resources in the later stage, reducing the maintenance cost, and conforming to the concept of green environmental protection[2].

The research report on the influence of microorganism on the impermeability of concrete is abundant. In 1995, some scholars used microorganisms (urease bacteria), nutrients, sand and so on as filling materials to repair concrete cracks by filling method. After curing, it was found that the impermeability of concrete was improved[3]. A series of Muynck’s[4]studies have shown that the capillary water absorption and chloride ion permeability of concrete matrix decrease after the repair of concrete with Bacillus spherulis as a repair agent. Dick’s[5] studies have found that the strain with high urea decomposition efficiency can produce calcite precipitation on the surface of degraded limestone, thus reducing the capillary water absorption coefficient of limestone surface. Wang W H[6]made use of the mineralized deposition of aerobic alkalophilic microorganisms, and through the study of impermeable water performance test, it is shown that this new self-repairing concrete has good water seepage resistance. Chen H C [7] were immobilized on microbial Bacillus glialis and beer yeast with ceramsite particles, and used glucose as nutrient to prepare fracture self-repairing cement.

After adding microorganism and nutrient, the seepage rate of the specimen decreased, and the repair area of the crack reached 87.5. Qian C X and other scholars[8] used the method of bacterial film mulching to reduce the water absorption coefficient of concrete samples by one order of magnitude, and the impermeability was significantly enhanced. Jia Q [9] used the method of microbial grouting to test the sealing of cracks, which showed that the filling medium in cracks accelerated the sealing of cracks, and the ability of impermeability and pressure bearing was also improved. Lian J J[10] used injection and diffuse irrigation self-repair fluid to repair concrete with cracks of different apparent shapes. The best repair effect can reduce the permeability of concrete by four orders of magnitude (from 10-4 m/s to 10-8 m/s). According to the results reported in the literature, microbial self-repairing agents can promote calcium carbonate sediment deposition and enhance concrete permeability and self-repairing. The design and implementation of this study was carried out by using Sporosarcina pasteurii as fracture repair agent and coral sand with surface as hole as repair agent. Compared with other carriers, coral reef calcareous sand has large porosity, high water absorption and high calcium content, which is more conducive to microbial mineralization and deposition, and the impermeability of concrete is obviously improved. The results showed that the self-repairing agent could improve the self-repairing ability and crack of concrete the pores are effectively blocked, and the ability of water permeability and chloride ion permeability is significantly enhanced, which greatly reduces the possibility of erosion medium entering the concrete body through the crack pores, thus improving the impermeability of concrete.

2. Experimental Program

2.1 Preparation of Coral Reef Calcareous Sand Loading System with Modifier

The laceration repair agent was made of Sporosarcina pasteurii with aerobic alkalophilic properties. According to the routine inoculation and culture method of aerobic microorganism, the purchased bacteria were prepared by liquid medium, and the solution was diluted to OD600 value 0.40. Then sieve coral reef calcareous sand(1.18-2.36mm), use vacuum impregnation method to mix the diluted bacteria solution with coral reef calcareous sand, after 15 min of coral reef calcareous sand adsorption bacteria solution, filter the coral reef calcareous sand to remove excess non-adsorbed bacteria solution, put into oven 40℃ to dry, dry to constant weight. The treated repaired particles are shown in Figure 1 and Figure 2.

Figure 1. and Figure 2. Microbial Self-repairing granules.

2.2 Preparation of Test Raw Materials and Specimens

HC, MC represent ordinary concrete and self-repairing concrete, respectively, and the mix ratio design is shown in Table 1(coral sand content is 5% of sand). The number of specimens for the seepage resistance test is shown in Table 2, and the number of specimens for the chloride ion permeability test is shown in Table 3.

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Table 1. Concrete mix proportions

Number	Cement /kg	Sand/kg	Coarse aggregate /kg	Water /kg	Coral sand/kg	Mixed bacteria or not
HC	408	562	1250	180	28	NO
MC	408	562	1250	180	28	YES

Table 2. Design List of Water Absorption Specimens

Type of specimen	Sample size/mm	Total number of specimens
HC1	70×70×70	3
MC1	70×70×70	3

Table 3. Design list of anti-chlorine penetration specimens

Type of specimen	Sample size/mm	Total number of specimens
HC2	100×50	6
MC2	100×50	6

The materials used are as follows:

Sand: ordinary medium sand, fineness modulus of 2.9, packing density of 1450 kg/m3.

Stone: well-graded gravel, packing density of 1600 kg/m3, mud content less than 0.5.

Coral reef calcareous sand: nansha, hainan, producing area, size of 1.18-2.36 mm, packing density of 1244 kg/m3.

Cement: Conch brand P.O42.5 grade ordinary Portland cement, its chemical composition and performance index are shown in Table 4 and Table 5.

Water: tap water is used unless otherwise stated.

Table 4. Chemical properties of ordinary Portland cement, w/%

CaO	SiO2	Al2O3	Fe2O3	MgO	SO3	K2O	R2O
62.19	22.41	6.12	3.67	2.32	2.05	0.81	0.43

Table 5. Physical properties of ordinary Portland cement

Initial setting time/min	Final setting time/min	Compressive strength/MPa		Bending strength/MPa	
		3d	28d	3d	28d
148	248	26.9	49.5	5.2	8.5

According to the Standard of Test Methods for Mechanical Properties of Ordinary Concrete GB/T50081-2016[11], the specimens are made, maintained and obtained. The stereoscopic specimen with a side length of 70 mm are shown in Figure 3 and the pie-like test with a diameter of 100 mm and a height of 50 mm are shown in Figure 4.

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Figure 3. 70mm Cube test block

Figure 4. φ100mm×50mm Cylinder block

2.3 Test Methods

2.3.1 Water Absorption Test

According to the ASTMC642-13[12], the water absorption test was carried out to determine the improvement of the water permeability resistance of concrete. Prepared the cube concrete test block of 70 mm. And after 28 days of curing the concrete test piece, the sample was dried in 110℃ oven and measured twice at 24 h intervals. The measured quality was recorded as A, and establish a mass balance of less than 0.5% between quality differences. The test blocks were then immersed in water at about 21℃ for 48 h, to calculate the saturated mass after immersion (recorded as C). and then the test block was placed in a suitable receptacle, covered with water and boiled for 5 h, to further calculate the saturated mass after boiling. A test block is suspended by wire and the apparent mass in water is calculated according to the formula (recorded as D):

Volume of permeable voids % : (C-A)/(C-D)×100.

2.3.2 Anti-Chlorine Ion Permeation Test

This paper evaluates the impermeability of concrete according to the national standard and the method of flux and RCM from the test method standard of long-term performance and durability of ordinary concrete GB/T50082-2009[13].

(1) Electric flux test

The design principle of the electric flux method is that the ions in the solution can penetrate quickly under the acceleration of the electric field, and under the same conditions, if the electric flux is more, the permeability of the concrete specimen is worse. a NJ-DTL type concrete chloride ion flux tester is used in this test. the test device is shown in Figure 5.

(2) Chloride Rapid Migration Test (RCM)

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A rapid chloride ion transport coefficient method (RCM method) was used to measure and calculate the non-steady-state chloride ion transport coefficient. As shown in Figure 6, the RCM test device calculates the chloride ion migration coefficient according to formula (1):

$$D_{RCM} = \frac{0.0239\times(273+T)L}{(U-2)t}\left(X_d\text{-}0.0238\sqrt{\frac{(273+T)LX_d}{U-2}}\right)(1)$$

Figure 5. Electric flux test device

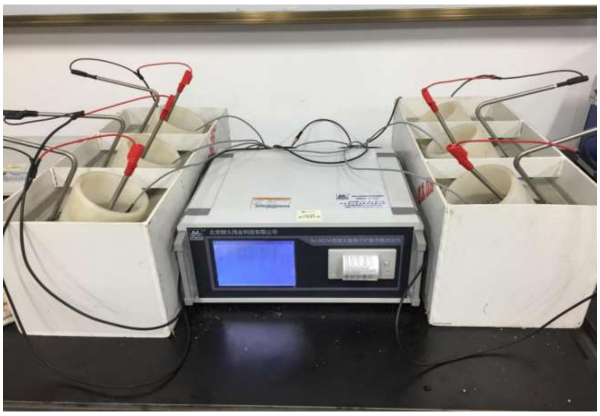

Figure 6. Test device for RCM method

2.3.3 Scanning Electron Microscope (SEM)

The deposition effect of self-repairing particles on calcite in concrete was analyzed by SEM. the specimens were collected and dried at100 C in oven for 3 days and then examined at accelerating voltages ranging from30 to 35 kV by a SEM. In the microscopic scanning experiment, the surface of the sample was cleaned with a washing ear ball, and then the sample was fixed on the loading table with conductive tape. For the powder sample, the conductive tape is pasted on the carrier table then the powder sample is placed on the conductive tape, and the fixed unstable sample particles are blown off by ear washing ball. After the sample is fixed ,60 s of gold spray treatment is carried out on the sample, and then the electron microscope scanning test is carried out under the arrangement of the laboratory staff, and the test process is carried out according to the operating specifications of the scanning electron microscope. By using the SEM image of concrete specimen, the shape and distribution of calcium carbonate crystal inside concrete are studied.

3. Result and Discussion

3.1 Water Absorption

The effect of microbial remediation agent on water absorption of concrete is shown in Figure 7. According to ASTMC642-13, the water absorption test was carried out 28 days later. The results

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showed that the presence of microbial remediation agent resulted in a significant decrease in water absorption of concrete, which was nearly 38% less than that of the control specimen. Due to the deposition of a layer of calcium carbonate on the surface and pores of concrete specimens, the water absorption and permeability are reduced. Once the pores are sealed, a decrease in water entry is observed. This microbial mineralization deposition can seal pores and microcracks, making the liquid inaccessible. Wang L et.al[14] carried out impermeability test through surface coating repair agent method, which showed that coating repair agent can obviously improve the repair ability of cracks and holes in concrete, thus effectively improving the impermeability of concrete. Therefore, it can be clearly shown from this experiment that the microbial remediation agent makes the concrete exist calcium carbonate improve the resistance of concrete to water.

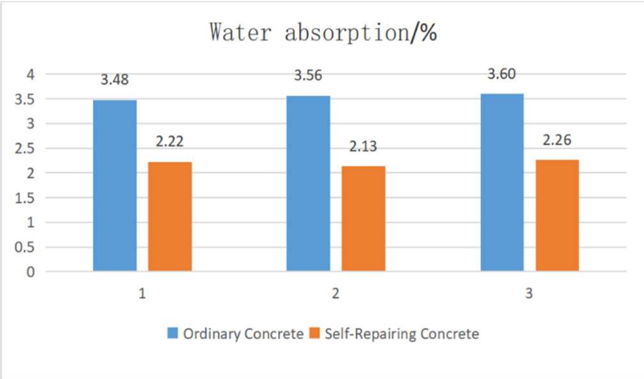

Figure 7. Water absorption

3.2 Analysis on the Permeability of Concrete with Chloride Ion

Figure 8 and Figure 9 are the electric flux values and chloride ion migration coefficient values of the two groups of concrete after 28 days and 6 hours under standard curing conditions. It can be seen from the diagram that the electric flux of ordinary concrete group is obviously higher than that of self-repairing concrete, the cementitious material in ordinary concrete is only cement, and the pores between mortar are only cement particles, so this causes the concrete to have poor compactness and many internal pores, which leads to the very poor permeability of concrete to chlorine ions. Concrete with microbial remediation agent can fill smaller pores in concrete because of calcium carbonate deposition due to mineralization, which improves the compactness of concrete and further improves the impermeability. It can also be seen from figures 1 and 2 that the electric flux of self-repairing concrete is nearly 20% lower than that of ordinary concrete, and the chloride ion migration coefficient is reduced by 35%. the reason is that the mineralized deposition of calcium carbonate improves the microstructure inside the concrete and increases the blocking force of concrete to chloride ion transmission. In this paper, with cement as cementitious material, the porosity of concrete is reduced, the pore structure is improved, and the impermeability of concrete is improved.

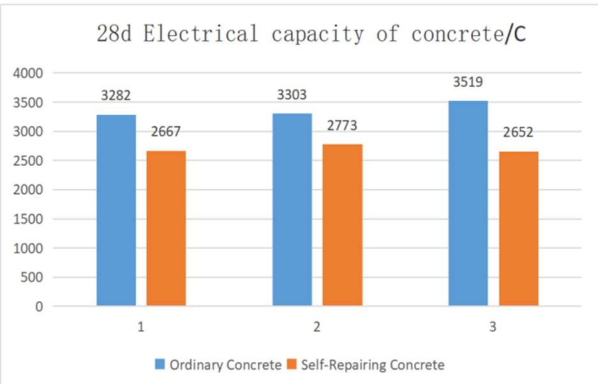

Figure 8. 28d Electrical capacity of Concrete

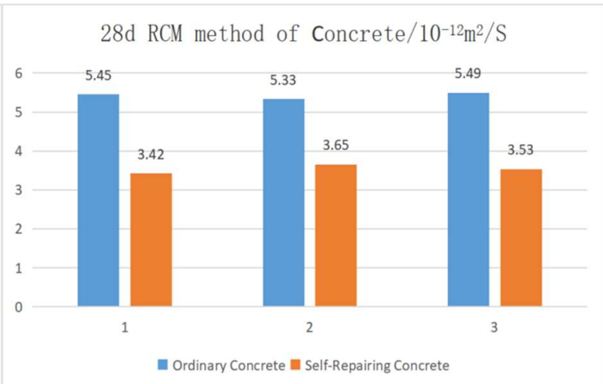

Figure 9. 28d RCM method of Concrete

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3.3 Concrete SEM Microscopic Analysis

The concrete specimens were scanned by electron microscope. Figure10 shows clearly the pores inside the concrete and the crystalline calcium carbonate embedded in the concrete. Figure11 shows that the concrete produces a large amount of calcium carbonate, which proves that calcite exists in the form of calcium carbonate due to the mineralization of bacteria. It indicates that the crystalline calcium carbonate present in concrete is due to the mineralization of bacteria. The deposition of calcite as a barrier of harmful substances, thus improving the impermeability of concrete.

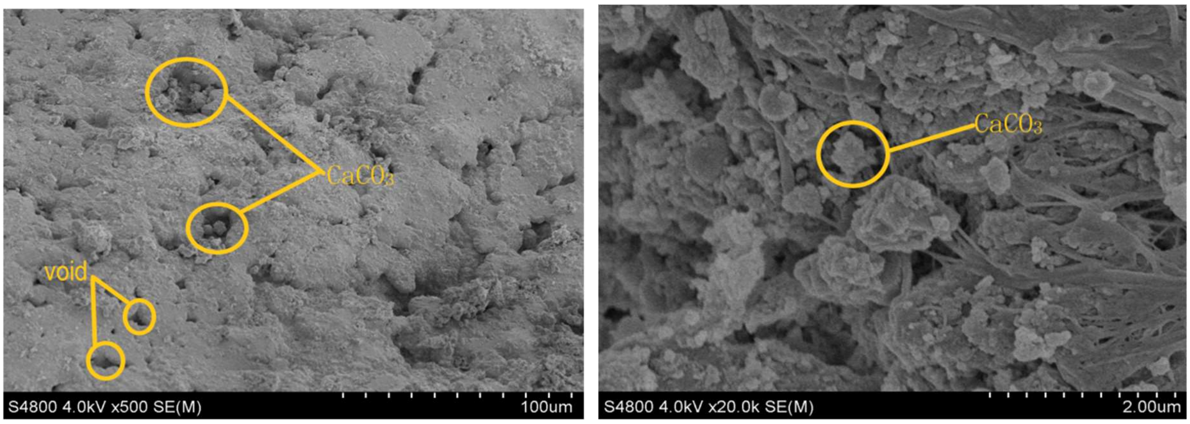

Figure10. and **Figure11.** Scanning electron micrograph (SEM)

4. Conclusion

Through the experimental study on the impermeability of self-repairing concrete at 28 days of age, the following conclusions are obtained: microbial mineralized deposition technology can reduce the water absorption of concrete and improve the chloride ion permeability of concrete. The improvement of concrete impermeability is due to the mineralized deposition of calcium carbonate produced by microbial self-repairing agent, filling the pores inside the concrete, reducing the porosity of concrete and improving the pore structure, thus effectively improving the impermeability of concrete.

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