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Research on Crack Repair Based on Reclaimed Aggregate Supported Microbial Concrete

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Abstract: Based on the characteristics of sparse and porous surface of recycled aggregate, this paper used recycled aggregate as a carrier to prepare microbial concrete by solid loading of Bacillus subtilis, and treated with kaolinite geopolymer for external wrapping to indirectly evaluate the difference of crack repair effect by capillary water absorption. The results showed that the water absorption of the untreated recycled aggregate was 6.17%, and the water absorption of the recycledaggregate was 8.94% after the treatment with metakaolin; after 28 d repair, the cumulative water absorption of the two groups of solid-loaded microbial concrete treated with recycled aggregate and external wrapping was significantly reduced compared with that of the direct bacteria-doped group; with the extension of the repair time, the initial water absorption of the three groups S1 gradually decreased, and the later water absorption S2 still showed a general trend of gradual decrease. The ratio of S1 / S2 water absorption of the three groups basically showed a decreasing pattern; due to the volcanic ash effect of the metakaolin, the ratio of S1 / S2 between the initial and late water absorption of the recycled aggregates treated with metakaolin increased.

1. Introduction

Concrete is widely used in the construction industry because of its high compressive strength, durability and low cost [1]. As a multi-phase non-homogeneous material, it also has disadvantages such as low tensile strength, high brittleness and easy cracking, and is highly susceptible to many tiny cracks due to internal and external factors. If the traditional late manual repair method is used [2,3]. This will not only bring high economic costs, but also with the increase of service age repair effect will become significantly worse [4-6]. This is not only costly, but will also become less effective as the service life increases. Microbial self-healing concrete has both "cracking stimulation" and "automatic repair" characteristics, which effectively improves the long-term service life of concrete structures, and at the same time, due to the low cost of repair, it has become the solution to cracking concrete [7,8]. It has become an effective way to solve the problem of concrete repair after cracking, and once became one of the current hot spots in the field of construction research.

The pH of the solution in the cracked concrete area is usually higher than 12, and the growth and reproduction of microorganisms are inhibited in the highly alkaline environment. In addition, as the concrete hydrates its internal environment becomes more dense, it will inevitably squeeze the microorganisms, which will have a negative impact on their activity. Therefore, in order to mitigate the adverse effects of high alkaline environment and extrusion, microorganisms need to be anchored in a carrier to provide "protection". Some commonly used carriers, such as ceramic pellets, diatomaceous earth, polyurethane and expanded perlite, are limited by their own material properties and can improve restoration at the expense of reducing a component's performance. Therefore, for microbial cement-based self-healing materials engineering to be widely used, it is necessary to find the ideal carrier that has both economic, microbial carrier and mechanical properties. Recycled aggregate [9], it is a product of crushing, screening and processing of construction waste concrete. A large number of studies at home and abroad have found that the mechanical properties of recycled aggregate concrete designed with optimized proportions are close to those of natural aggregate concrete[10] Therefore, based on the surface sparseness of recycled aggregates, the concrete can be made from natural aggregates. Therefore, based on the sparse and porous characteristics of recycled aggregate surface, this paper adopts recycled aggregate as microbial carrier and treats it with outer wrapping of metakaolin ground polymer to investigate the difference of crack repair effect by capillary absorption test.

2. Test Preparation

2.1. Materials

The lyophilized powder of Bacillus subtilis was purchased from Shanghai Conservation Biological Center, and the microorganisms were inoculated and cultured by conventional methods.Conventional P.O.42.5 ordinary silicate cement was used, and the recycled aggregate was selected from the on-campus laboratory of Shenyang University of Architecture. The recycled coarse aggregate was screened and crushed manually, and the recycled aggregate with particle size of 3~10 mm was selected as the microbial carrier.

2.2. Outer Wrapping Treatment

Metakaolin geopolymer. Kaolin-like geopolymer is an inorganic gelling material prepared by the polymerization reaction of kaolinite under the action of alkaline activator, which has the advantages of high compressive strength, corrosion resistance, low energy consumption, fast curing, high temperatureresistance and durability. The fineness of the metakaolin used in this test is 1250 mesh, the activityindex is ≥110, and the chemical composition is shown in Table 1.

Table 1: Chemical composition of metakaolin

Chemical composition	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	Burning loss
Content (%)	55.06	43.02	0.76	0.24	0.17	0.06	0.55	0.06	0.62

The water glass used in this test was purchased from Tianjin Zhiyuan Chemical Reagent Co, and the chemical composition is shown in Table 2.

The metakaolin geopolymer was prepared in the ratio of metakaolin: water: water glass = 30:33:25 and applied evenly to the surface of the recycled aggregate with a spray gun.

Table 2: Chemical composition of water glass

Chemical composition	Na_2O	SiO_2	Chloride	Sulfate	Heavy Metals	Ammonia precipitate
Content (%)	29.1	28.25	0.01	0.01	0.001	0.05

2.3. Specimen Fitting Ratio and Crack Production

Three groups of self-remediated replicate specimens (all with 1% calcium lactate admixture) were designed, including BRC group, which was untreated concrete with recycled aggregate as carrier; BRD group, which was uncarrier concrete directly admixed with bacteria; and BRC-M group, which was concrete with recycled aggregate as carrier treated with metakaolin. The solid-loaded microorganisms were: vacuum impregnated and adsorbed for 30 min under 0.6 MPa negative pressure, and dried in a sterile constant temperature oven at 40 ℃ for 24 h. Cracks with an average width of 0.4 mm were created by the "steel insertion and removal method", and the steel pieces were pulled out on the fifth day of specimen maintenance (recorded as 0 d, the same below), and the specimen sizes were 100 mm × 100 mm × 100 mm. 100 mm × 100 mm, the carrier is 30% of the volume of concrete (volume ratio). The specimen fits are shown in Table 3.

Table 3: Specimen fitting ratio

	Cement (kg)	Sand (kg)	Gravel (kg)	Water (kg)	Water reducing agent (g)	Carrier
BRD	5.16	7.85	10.2	760 ml of water + 1000 ml of bacterial solution	103.2	None
BRC	5.16	7.85	10.2	1.76	103.2	Recycled aggregates
BRC-M	5.16	7.85	10.2	1.76	103.2	Recycled aggregates after kaolin treatment

2.4. Carrier Water Absorption

As an important reference index of carrier absorption of bacterial solution, it is necessary to further study its water absorption rate. Three 200 g specimens were taken, placed in water and soaked for 5 days, then taken out, wiped to saturated surface dry state and weighed; then placed in 105℃ drying oven and dried to constant weight, then weighed.

Water absorption rate according to the formula (1) Calculation, the results are accurate to 0.01%.

$$S = (m1 - m0)/m0 \tag{1}$$

S is the water absorption of carrier (%), m1 is the drying constant weight state mass (g), m0 is the saturated surface dry state mass (g). And the arithmetic mean of the three measurements was taken as the average water absorption rate.

2.5. Capillary Water Absorption Test

Capillary water absorption test is an indirect evaluation method to characterize concrete defects and crack repair, based on ASTM C1585-13, this test in the 60 ℃ drying oven to dry the specimen to constant weight, remove the cooling to room temperature, surrounded by a uniform application of waterproof glue, after the waterproof glue dries, placed in the lower part of the test chamber on the support bar, and the treated specimen is placed smoothly on the support bar, and then slowly add distilled water, and ensure that the water level does not exceed the bottom 5 mm. And ensure that the water level does not exceed the bottom of the specimen 5 mm. respectively in the water absorption 0, 1, 3, 5, 10, 15, 25, 40, 60, 90, 120, 150, 170 min when weighed to determine the quality of the specimen. Cumulative water absorption and water absorption rate can be calculated by the formula (2) and (3) obtained.

$$I=\Delta m/(A\times\rho) \quad (2)$$

$$I=S\sqrt{t}+b \quad (3)$$

I is the cumulative water absorption of the test piece (mm); Δm is the mass change (g); A is the contact water surface area (mm2); ρ is the water density (g/cm3); S is the water absorption rate (mm/s-0.5); t is the water absorption time (s); b is the cut-off distance (mm).

3. Results and Discussion

3.1. Carrier Water Absorption

The water absorption rate of the carrier as an important index of its ability to measure the strength of the adsorption of bacterial solution, but also affects its own fragmentation index. Although too high water absorption rate can substantially adsorb bacterial solution, it may lead to premature fragmentation of the carrier in mixing microbial con crete, resulting in extensive microbial death and affecting the restoration effect. Figure 1 shows the magnitude of water absorption of untreated recycled aggregates and recycled aggregates treated with metakaolin. It can be seen from the figure that the water absorption rate of the untreated recycled aggregate is 6.17%, while the water absorption rate of the recycled aggregate treated with metakaolin is 8.94%, which is analyzed to be due to the strong adsorption property of metakaolin itself, thus the water absorption rate is greatly increased.

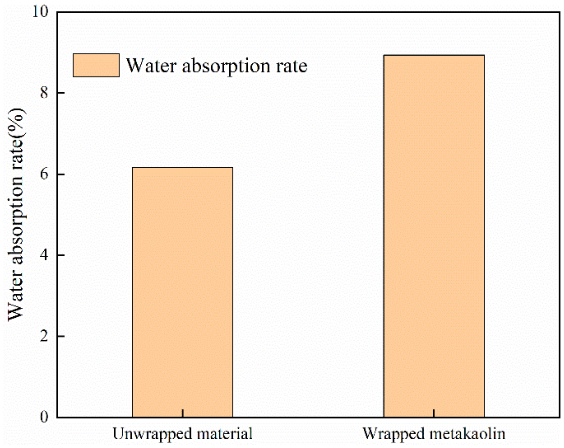
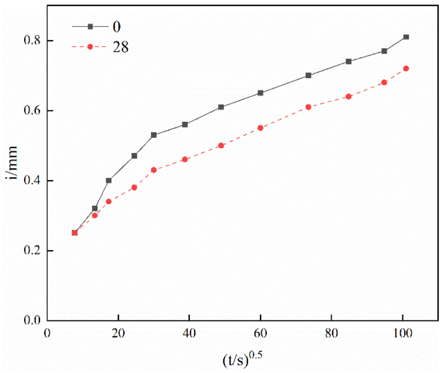


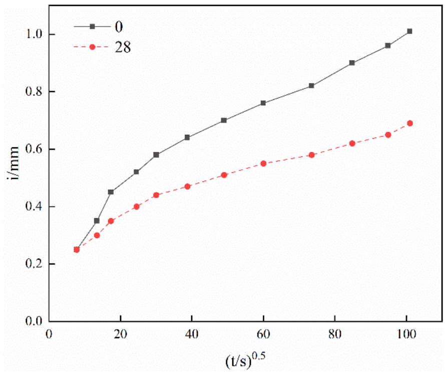
Figure 1: Water absorption of treated carriers

3.2. Cumulative Capillary Water Absorption Gradient

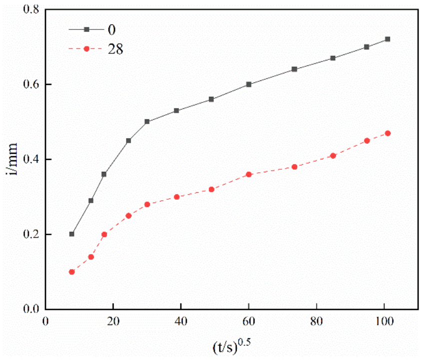
The water absorption performance is also another important parameter to characterize the durability of concrete, and its performance reflects the strength of concrete against the ability of external water to enter the concrete interior, which can indirectly measure the effectiveness of repair. Figure 2 (a) (b) (c) shows the cumulative water absorption gradients of the three groups of specimens at 0 and 28 d, respectively. From the analysis of Figure 2, it can be seen that the cumulative water uptake decreased to a certain extent with the extension of the remediation time, and the cumulative water uptake of BRD, BRC and BRC-M groups decreased by 11.11%, 36.14% and 31.68% after 28 d. The cumulative water uptake of BRC and BRC-M groups decreased significantly compared with that of BRD group, which indicates that if the microorganisms were added directly without the help of carrier protection, the water uptake of BRC and BRC-M groups was significantly reduced compared with that of BRD group. The direct addition of microorganisms and placing them in a highly alkaline environment will lead to direct contact with the cementitious material, reducing the survival activity and causing budding death, which will affect the restoration effect. It also shows that the concrete of BRC group and BRC-M group effectively sealed the cracks inside the specimen in the initial stage under the protection of the carrier, and the concrete became more and more dense inside, which effectively hindered the circulation rate of water molecules and finally realized the trend of decreasing water absorption rate; however, the restoration effect of BRC-M group decreased compared with that of BRC group, probably because the water absorption rate of the carrier increased and the fragmentation index decreased, which led to This may be due to the increase in water absorption of the carrier and the decrease in fragmentation index, which led to the premature fragmentation of the carrier and weakened the bacterial survival rate, thus affecting the restoration effect.



(a) BRD



(b) BRC-M



(c) BRC

Figure 2: Cumulative water absorption gradient

3.3. Capillary Water Absorption Rate

The capillary water absorption process of concrete can be roughly divided into two stages: The first stage is the initial stage when water just starts to contact with the concrete surface and the surface area rapidly absorbs water, which is defined as the initial water absorption rate of concrete S1. The second stage is when water penetrates into the internal pores of concrete, and a film is formed to prevent water adsorption inside the concrete due to the pulling force, and this stage is defined as the later water absorption rate of concrete S2. Therefore, the curve of cumulative water absorption rate of concrete versus water absorption time is bilinear. The best-fit equation was obtained by regression analysis of the three cumulative water absorption curves, and the initial water absorption rate S1, and the late water absorption rate S2 for each group can be determined by the slope of the fitted equation, which can be calculated as S1 / S2, and the resulting fitted parameters are shown in Table 4.

Table 4: Water absorption of concrete and parameters of hyperbolic curve fitting

	Number of days (d)	S1/ (10-3 mm/s1/2)	S2/ (10-3 mm/s1/2)	S1/ S2
BRD	0	12.66	3.83	3.31
BRD	28	7.86	4.01	1.96
BRC	0	13.59	3.07	4.43
BRC	28	8.37	2.63	3.18
BRC-M	0	14.7	5.84	2.52
BRC-M	28	8.57	3.33	2.57

From Table 4, it can be seen that the initial water absorption rate S1 gradually decreases with the increase of repair time in BRD, BRC and BRC-M groups; the later water absorption rate S2 still shows a trend of gradual decrease in general; from the ratio of initial and later water absorption rate S1 / S2, the ratio of water absorption rate in BRD, BRC and BRC-M groups basically shows a change law of decrease with the increase of repair time, and the analysis of BRC-M group shows that the bias kaolinite has volcanic ash effect, which slowly affects the hydration process of concrete itself, thus causing the increase of S1 / S2 ratio; combined with Figure 2, it can be found that the initial water absorption gradually increases with the increase of repair time, indicating that the adsorption effect dominated by pores and microfractures gradually decreases, and it can be considered that microbial self-healing technology effectively improves the microdamage inside concrete.

4. Conclusion

(1) The water absorption rate of untreated recycled aggregate is 6.17%, and the waterabsorption rate of recycled aggregate after treatment with metakaolin is 8.94%.

(2) After 28 d of repair, the cumulative water uptake in the BRC and BRC-M groups was substantially reduced compared to the BRD group.

(3) With the extension of the restoration time, the initial water absorption S1 of the three groups gradually decreased, and the later water absorption S2 still showed a gradually decreasing trend; the ratio of water absorption S1 / S2 of the three groups basically showed a decreasing change pattern, and the volcanic ash effect of the partial kaolinite caused the increase of the ratio S1 / S2 of the BRC-M group.

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