Experimental Study on Impermeability of Waste Fiber Recycled Concrete

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Abstract: The natural diffusion method was used to test the impermeability of waste fiber concrete. The influence of fiber volume rate and fiber length on the impermeability of waste fiber recycled concrete was studied. The results show that the influence of fiber length on the impermeability of recycled concrete is greater than that of fiber volume ratio. When the length of the fiber is 19mm and the volume ratio of the fiber is 0.16%, the impermeability of the specimen is the best.

1. Introduction and background
The research and application of recycled aggregate concrete (RAC) are of great significance to the economic and social development. Many scholars at home and abroad studied impermeability and erosion resistance of waste fiber concrete. In the 1960s, the performance of fiber reinforced concrete has been studied by researchers in some developed countries [1]. Combined fiber and recycled concrete is applied to structural components, can take full advantage of the characteristics of both. The incorporation of staple fiber yarns improves the ductility of recycled concrete and plays a connecting role when cracks appear in the concrete matrix. The durability and working performance of concrete can be improved by adding staple fiber yarns with corrosion resistance and high temperature resistance [2]. According to the experimental study of XIAO [3], the volume replacement rate of recycled coarse aggregate is less than 50%, and its performance is not different from that of ordinary concrete. The permeability test results of polypropylene fiber concrete show that, the permeability coefficient of concrete decreases correspondingly with the increase of fiber content and fiber length and the polypropylene fiber can improve the permeability of concrete [4-5]. ZHANG Peng et al[6] studied the effects of nano-SiO$_2$ and steel fiber on the frost resistance and crack resistance of concrete. The results indicate that the addition of nano-SiO$_2$ can improve the freezing resistance and cracking resistance of the concrete when the content of nano-SiO$_2$ is limited in a certain range. However, too large amount of nano-SiO$_2$ particles may be adverse for the freezing resistance and cracking resistance of concrete.

In this experiment, the influence of different fiber volume and fiber length on the impermeability of recycled concrete was studied by adding waste polypropylene fiber into recycled concrete.

2. Experiment method
2.1. Raw materials and mix proportion design
Recycled coarse aggregate consists of two parts, half of which are concrete with original strength of C40. After artificial crushing and other treatment, recycled coarse aggregate with particle size of 5 ~
25mm and continuous gradation is obtained. Its physical properties are shown in Table 1. The other half is made of natural coarse aggregate with particle size of 5 ~ 25mm and continuous gradation of crushed stone. The sand is medium sand and natural river sand with fineness modulus of 2.8.

Table 1. Physical properties of recycled coarse aggregate

| Physical property          | Value       |
|---------------------------|-------------|
| Apparent density (kg/m³)  | 2340        |
| Packing density (kg/m³)   | 1435        |
| Particle size              | 5~25        |
| Crush indicators           | 16%         |
| Porosity                   | 39%         |
| Water content              | 3.3%        |
| Water absorption           | 4.1%        |

P·O 42.5R ordinary Portland cement is used for cement, and waste carpet is used for waste fiber. The chemical composition of waste carpet is polypropylene. The design strength of waste fiber recycled concrete is C40. It is proposed in DG/TJ 08-2018-2007 technical specifications for the application of recycled concrete to divide the water consumption of recycled concrete into net water consumption and additional water consumption. Where, when the volume fraction of regenerated coarse bone is 50%, the water consumption for adsorption is 10kg/m³, and the water-cement mass ratio is 0.5. A mix design method was put forward that recycled concrete water consumption is divided into net water consumption and additional water consumption in DG/TJ 08-2018-2007 technical specifications for the application of recycled concrete. When the volume fraction of regenerated coarse bone was 50%, the water consumption for adsorption was 10kg/m³, and the water-cement mass ratio was 0.5.

Table 2. Mixing amount of waste fiber recycled concrete

| The length of fiber/mm | µ(fiber) | Cement | Sand | Gravel | Recycled aggregate | Water |
|------------------------|---------|--------|------|--------|--------------------|-------|
| 0                      | 0       | 390    | 709  | 578    | 578                | 205   |
| 12                     | 0.08%   | 390    | 709  | 578    | 578                | 205   |
| 19                     | 0.08%   | 390    | 709  | 578    | 578                | 205   |
| 30                     | 0.08%   | 390    | 709  | 578    | 578                | 205   |
| 12                     | 0.12%   | 390    | 709  | 578    | 578                | 205   |
| 19                     | 0.12%   | 390    | 709  | 578    | 578                | 205   |
| 30                     | 0.12%   | 390    | 709  | 578    | 578                | 205   |
| 12                     | 0.16%   | 390    | 709  | 578    | 578                | 205   |
| 19                     | 0.16%   | 390    | 709  | 578    | 578                | 205   |
| 30                     | 0.16%   | 390    | 709  | 578    | 578                | 205   |

The volume ratio of fiber was 0.08%, 0.12%, 0.16%, and the fiber length was 12, 19, and 30 mm, respectively. The method of dry mixing was adopted in the test to make the fiber mixed evenly in the concrete. This means first mixing sand, stone, cement and fibre together, and then adding water to make concrete. The size of the test pieces are all standard cube test blocks of 150 mm × 150 mm × 150 mm. The proportion of waste fiber recycled concrete was determined by premixing. Test block group and mixing amount of fiber recycled concrete were shown in Table 2.

The wet etchant used in the test was made up of anhydrous sodium chloride and the water used in the test was tap water. 14 blocks were made in this test, with 3 test pieces per group, and the test results were averaged.

2.2. Experimental method

All the test blocks were cured for 28 days by standard. Then, the 5 sides of each test block were coated with solventless epoxy resin coating for sealing, leaving only one exposed surface. Then, the test blocks were immersed in NaCl solutions with mass fractions of 10% and 20% respectively. After 60 days, the test blocks were taken out and dried. The distribution of chlorine ions in the direction of the depth of waste fiber regenerated concrete was measured, Fick second law and Matlab were used to calculate the chloride ion diffusion coefficient of waste fiber recycled concrete. The groups of test Numbers are shown in Table 3. After soaking for 60 days, the waste fiber recycled concrete samples
were sampled in layers parallel to the exposed surface with a grinder along the direction of the vertical exposed surface. In this experiment, every 3 mm layer was used, with a total of 6 layers. Before titration, the sample powder was filtered through a 0.63mm sieve for later use.

The determination of chloride ion content in waste fiber recycled concrete refers to GB/T 50344-2004 "technical standards for building structure detection". The treated powder was taken and titrated to determine the chloride ion content. The results of chlorine ion content in different layers were fitted.

| number | The length of fiber/mm | ω(fiber) | ω (NaCl) |
|--------|------------------------|----------|----------|
| 1      | 12                     | 0.12%    | 10%      |
| 2      | 19                     | 0.12%    | 10%      |
| 3      | 30                     | 0.12%    | 10%      |
| 4      | 12                     | 0.08%    | 20%      |
| 5      | 12                     | 0.12%    | 20%      |
| 6      | 12                     | 0.16%    | 20%      |
| 7      | 19                     | 0.08%    | 20%      |
| 8      | 19                     | 0.12%    | 20%      |
| 9      | 19                     | 0.16%    | 20%      |
| 10     | 30                     | 0.08%    | 20%      |
| 11     | 30                     | 0.12%    | 20%      |
| 12     | 30                     | 0.16%    | 20%      |
| 13     | 0                      | 0        | 10%      |
| 14     | 0                      | 0        | 20%      |

3. Results analysis

Water-soluble chloride ion content in waste fiber concrete is calculated according to the following formula:

$$\omega = \frac{c(V_1 - V_2) \times 0.03545 \times 100}{m_1 \times 50/250}$$

Where, \(\omega\) is the mass fraction of chloride ion in concrete; \(c\) is the concentration of silver nitrate standard solution and the unit is mol/L; \(V_1\) is the volume of the standard solution of silver nitrate and the unit is mL. \(V_2\) is the volume of the standard solution of silver nitrate in blank test and the unit is mL. \(M_1\) is the mass of waste fiber recycled concrete sample and the unit is g.

3.1 Influence of waste fiber on impermeability of recycled concrete

3.1.1. Effect of fiber length on impermeability

According to the different lengths of fibers mixed into recycled concrete, 9 different types of impermeability tests of recycled concrete with waste fibers were conducted, and the test results are shown in figure 1.

As can be seen from figure 1, no matter which type of ratio is used, the content of chloride ion in the specimen without fiber is greater than that with fiber, but the difference is not the same. When the volume ratio of fiber is 0.08%, the content of chloride ion in recycled concrete of abandoned fiber decreases with the increase of fiber length, which indicates that the toughness is better when the fiber length is longer with a small content. Therefore, the effect of crack resistance is stronger, and the impermeability is improved. When the volume ratio of fiber is 0.12% and 0.16%, the content of chloride ion in recycled concrete increases with the increase of fiber length, which indicates that when the fiber content is larger, the short fiber is more densely distributed in concrete, and the short fiber
will introduce more interfaces than the long fiber. However, when the volume ratio of the fiber is 0.12%, there is no significant difference in the content of chloride ions in the recycled concrete when the fiber length is 12mm and 19mm, especially when the content is basically equal with the increase of depth. The content of chloride ion in recycled concrete decreased with the increase of depth of all kinds of samples.

The content of chloride ion in recycled concrete decreased with the increase of depth of all kinds of samples.

![Fig.1 Fitting parameters of w(Cl\textsuperscript{-}) variation in recycled concrete with different fiber lengths](image)

3.1.2. The influence of fiber content on impermeability

Fig.2 shows the fitting parameters of w(Cl\textsuperscript{-}) variation of the regenerated concrete specimen under different fiber content when the fiber length is 12mm, 19mm and 30mm and the mass fraction is 20% in sodium chloride solution. As can be seen from figure 2, no matter what the fiber content is, the content of chlorine ion in the waste fiber recycled concrete is lower than that without fiber. When the fiber length is 12mm and 19mm, the content of chloride ion in recycled concrete decreases with the increase of the content.

![Fig.2 Fitting parameters of w(Cl\textsuperscript{-}) variation in waste fiber concrete with different fiber content](image)

According to the fiber spacing theory [7], when the fiber length and content are within a certain range, the smaller the fiber spacing, the better the impermeability. When the length of the fiber is 30mm, the content of chloride ion in the recycled concrete increases with the increase of the fiber content, which indicates that when the length reaches 30mm. At this time, the interface area between the cement-based material and the fiber increases, which not only reduces the internal cracks of the concrete but also increases the pores. However, when the fiber volume fraction was 0.12% and 0.16%, there was no significant difference in the content of chloride ions in recycled concrete.

3.2 The influence of the proportion of soaking solution on the performance of waste fiber recycled concrete

Fig.3 shows the fitting curve of w(Cl\textsuperscript{-}) change in waste fiber recycled concrete after immersion in NaCl solution with different mass fractions when the fiber volume fraction is 0.12%. As can be seen from Fig.3, w(NaCl) does not affect the overall trend of fiber length on the content of chloride ions in recycled concrete. However, it is obvious from Fig 3 that the higher the NaCl solution concentration is, the higher the chloride content in the recycled concrete will be, especially the closer to the surface. This is completely consistent with the research of Mangat [8].
3.3 Influence of waste fiber on chloride permeation coefficient of recycled concrete

Table 4 shows the infiltration test results of chloride ions in the waste fiber regenerated concrete samples soaked in NaCl solution with a mass fraction of 20%. For 12 mm or 19 mm the waste fiber, chloride ion permeability of recycled concrete are increased, when the increase of fiber content is reduced. The reason is that bigger dosage better fills the porosity of the recycled concrete to effectively prevent the chloride ion penetration of recycled concrete. For the 30 mm waste fiber, the chloride ion permeability coefficient in recycled concrete increases when the increase of fiber content. The permeation coefficient of chloride ion in recycled concrete decreases first and then increases with the increase of fiber length. As can be seen from table 4, the fiber length and volume fraction of test block 9 were 19 mm and 0.16% respectively. This combination ratio has the smallest chloride ion permeability coefficient, which indicates that the fiber has the best impermeability at a certain length, not the shorter or the longer the better.

| number | 4     | 5     | 6     | 7     | 8     | 9     | 10    | 11    | 12    |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Apparent diffusion coefficient/10^{-11}m^2s^{-1} | 5.29  | 2.93  | 2.39  | 2.97  | 2.73  | 2.34  | 3.88  | 3.94  | 4.27  |

3.4 Mechanism analysis

The erosion of concrete by chloride ion is the result of the combined action of the above mentioned ways, and is also affected by the physical bond, chemical bond and adsorption between concrete materials. Generally speaking, the concentration of chloride ion can be regarded as a linear diffusion process. Mixing waste fiber (polypropylene) can effectively improve the apparent diffusion coefficient of chloride ion. This is because the incorporation of polypropylene fiber can effectively improve the pore size distribution of recycled concrete. Because the polypropylene fiber in the recycled concrete shows three-dimensional random distribution, effectively inhibits the formation of harmful holes, the structure of the coarse hole refinement, improve the concrete internal hole structure.

3.4 Mechanism analysis

The addition of waste fibers is mainly due to the fact that tens of millions of fibers are evenly distributed in the cement matrix, which plays a role in preventing cracks in the concrete matrix. The number of cracks, the length and the width of cracks can also be significantly reduced due to the effect of fiber cracking resistance, thus reducing the possibility of forming penetrating cracks. The interface between the concrete aggregate and the cement mortar is made tight, so that the permeation resistance of chloride ion is strengthened.

4. Conclusion

Waste fiber can effectively improve the impermeability of recycled concrete, but it is not true that the longer the waste fiber is or the greater the proportion of waste fiber is, the better the impermeability of recycled concrete will be. The influence of waste fiber length on the impermeability of recycled concrete is greater than that of the proportion of waste fiber. When the fiber length is 19mm and the volume fraction of waste fiber is 0.16%, the specimens have the best impermeability. The content of chloride ions in the waste fiber recycled concrete increases gradually as the mass fraction of NaCl in the erosion solution increases.
Acknowledgments
The authors gratefully acknowledge funding and support provided by Science and Technology Project of Henan Province (19A560025 ) and NSFC(U140454).

References
[1] Dong J, ZHANG G, ZHANG H. (2001) Study and application of modified polypropylene fiber concrete in water project [J]. Jilin Water Resources. 9:1-7.
[2] Chen R, ZHANG G, GU G. (2001) State of Study and Application of Synthetic Fibers Reinforced Concrete in China [J]. Journal of building materials. 6:167-173.
[3] Xiao K. (2004) Study on the properties and the modification of recycled concrete[D]. Wuhan university of technology, Wuhan.
[4] Li G. (2002) Effect of polypropylene fibre on concrete cracking resistance[J]. Design of Hydroelectric Power Station, 6: 98-101.
[5] Zhu Y. (2003) Research on the fiber reinforced concrete in guarding against cracking and seepage[J]. Concrete. 168 (11) : 31- 32.
[6] Zhang P, ZHAO S, CHANG H et al. (2018) Freezing resistance and cracking resistance of nano-SiO2 and steel fiber reinforced concrete[J]. Journal of Civil Engineering and Management. 35(3):73-78.
[7] Romualdi J P, MANDEL J A. (1964) Tensile strength of concrete affected by uniformly distributed and closely spread short lengths of wire reinforcement [J]. ACI Journal, 61(6):657-670.
[8] Mangat P S, MOLLOY B T. (1994) Prediction of long-term chloride concentration in concrete [J]. Materials and Structures, 27:338-346.