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To cite this article: Qian Xu and Hong-Mei Liu 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **233** 052051

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Research on Chloride Resisting Properties of Recycled Concrete

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Abstract. Chloride ion erosion is one of the main factors leading to the decline in durability of concrete structures. When a building is in a chloride environment, the permeability of the chloride ion is often used to reflect the ability to resist chloride penetration in concrete. Due to the particularity of its raw materials, recycled aggregate concrete determines that its own structure is weaker than natural aggregate concrete, and its resistance to chloride ion penetration is lower. Based on the analysis and summary of relevant research methods at home and abroad, this paper draws some factors worthy of research on the ability of recycled concrete to improve chloride ion resistance and some strengthening methods. And the conclusion will provide direction and recommendations for our further research.

1. Introduction

As China's urbanization process continues to accelerate, the amount of construction waste generated and discharged in cities is also growing rapidly. While enjoying urban civilization, people are also suffering from urban garbage. Of total waste, urban garbage accounts for 30%-40%. According to rough statistics, the construction waste generated per 10,000 square meters of construction is about 500 tons to 600 tons. At present, the newly completed area of China is 18 billion square meters per year, which is close to half of the total annual construction of the world. Based on this estimation, only the construction process will cause construction waste of one billion tons per year. Together with the construction waste caused by building decoration, demolition and building materials industry, the total amount will exceed 2 billion tons. If the construction waste can be fully reused, it can not only solve about one-third of the landfill and pollution problems, but also reduce the secondary pollution generated by the surrounding city together with the domestic garbage.^[1,2]

The aggregate formed by crushing, classifying and mixing a certain amount of waste concrete is called recycled aggregate. Concrete that uses part or all of recycled aggregate to replace natural aggregate is called recycled concrete.^[3] As early as the 1980s, China had proposed the principle of solid waste pollution control that was "Reduction, Resource, Harmless". The generation of recycled concrete is the embodiment of this principle applied to the architectural field. From the perspectives of environmental protection and resource conservation, it is predicted that recycled concrete is a technical solution to the problem of waste concrete. It will have a promising application prospect. However, the recycled concrete prepared at present has not caught up with ordinary concrete in terms of performance and economic indicators, and thus it is difficult to promote. If not widely used, recycled concrete will lose its "sustainable development" advantage.



2. Chloride ion erosion

Concrete is a typical porous medium, and solid-gas liquids coexist. Due to the addition of recycled aggregates, the microstructure and interface characteristics become more complicated. Compared with ordinary concrete, the durability of recycled concrete is more prominent. Especially in some coastal areas, where the environment is pleasant and suitable for human habitation, however it imposes higher requirements on the durability of building materials.

Chloride ion erosion is one of the main factors leading to the decline in durability of concrete structures. When a building is in a chloride environment, Chloride ions' permeability is often used to reflect the ability of concrete to resist chloride attack. In reinforced concrete, after the chloride ion content reaches a certain limit value, the passivation film on surface of steel bar is destroyed and an etch pit is generated^[5]. Thus, under the action of water and air, micro-batteries are formed, causing corrosion of the steel bars. Volume-expanded steel bars cause damage to the concrete cover. At the same time, they will reduce the bearing capacity of the concrete structure. The recycled aggregate that has been crushed will produce a large number of micro-cracks that will increase the passage of chloride ions. Therefore, the resistance to chloride ion permeation of recycled concrete is lowered.^[6] Due to the prevalence of chloride ions (coastal environment, deicing salt environment, saline-alkali land, industrial plants, etc.) and the severity of damage, in recent years, domestic and foreign scholars have started from a number of factors, and have carried out a large number of anti-chloride ion permeation performance of recycled concrete. The research, through the analogy of ordinary concrete against chloride ion penetration, summarized the factors including admixture, cement dosage, water-cement ratio, aggregate gradation, surface state, temperature and humidity.

3. Research status at home and abroad

Since the recycled aggregates generate a large number of micro-cracks during the crushing process, the porosity is increased. Therefore, the interface transition zone, aggregate quality, and recycled aggregate replacement rate are the research focus on the resistance of recycled concrete to chloride ion penetration.

3.1. Mechanism of chloride ion penetration

Hardened cement paste and concrete are porous materials. The number and size of capillary pores determine the transport and penetration of chloride ions. From the microscopic point of view, when the concrete mixture is stirred, the water will form a water film on the surface of the aggregate. The cement slurry water ash at 20~100μm from the surface of the aggregate is relatively large, so an interface transition zone is formed between the aggregate and the cement slurry, which is the most porous and weakest zone in the concrete.^[8] The structural characteristics of recycled concrete interface are more complicated. In addition to the interfacial transition zone (ITZ) between natural aggregate and new mortar, there is also the old interfacial transition zone (OITZ) between old and old cement mortar and new and old cement mortar. The new interface zone (NITZ), and the latter two are two interfacial transition zones unique to recycled concrete^[5]. Nanoindentation testing shows that OITZ and NITZ are the weakest areas in recycled concrete. Electron microscopy showed that the transition zone between the new and old interfaces was loose, and there were a large number of pores, fissures and unhydrated cement particles, which increased the permeability of chloride ions^[6-7]. Qin He-Ying et al.^[9] measured the chloride ion permeability coefficient of recycled concrete by RCM method, and then calculated the chloride ion permeability coefficient of the interface transition zone according to the thickness of the interface transition zone. The results show that the transition zone of the recycled concrete interface, the chloride ion permeability coefficient is about 6 times that of the ordinary concrete interface transition zone, which is about 290 times that of the mortar.

3.2. Effect of recycled aggregate replacement rate

For the replacement rate of recycled aggregate in recycled concrete, many scholars have shown that the chloride ion permeability of recycled aggregate concrete decreases with the increase of the

replacement rate of recycled aggregate ^[10-14]. Xiao Jianzhuang et al. ^[15] also reached the same conclusion with mesoscopic numerical simulation. Luo Guang et al. ^[10] measured the chloride ion permeability coefficient of recycled concrete with 100% replacement of coarse aggregate by NEL method, which increased by 104% compared with ordinary concrete. This indicates that as the replacement ratio of recycled coarse aggregate increases, the number of interfacial transition zones increases, which increases chloride ion infiltration channels and reduces the chloride ion resistance of recycled concrete ^[6]. Wei Qingdong et al. ^[11] found that when the coarse aggregate replacement rate is less than 15% and the fine aggregate replacement rate is less than 30%, the electric flux increment will be smaller, respectively less than 6% and 12%; Moreover, the electric flux of 15% substitution rate of recycled coarse and fine aggregate is greater than the electric flux of 30% substitution rate of the coarse or fine aggregate alone. Evangelista et al. ^[12] found that the unsteady diffusion coefficient and water absorption of chloride ion increased linearly with the replacement rate of fine aggregate of recycled concrete, and pointed out that recycled concrete with a replacement ratio of recycled fine aggregate of less than 30% can be applied to the structure. Wil et al. ^[13] found that with the increase of the replacement rate of recycled coarse aggregate, the corrosion cracking time of steel bars caused by chloride ion erosion in recycled concrete accelerated. It can be seen that the key to solving the application technology of recycled concrete is how to solve the contradiction between the recovery rate of recycled aggregate and the resistance to chloride ion penetration efficiently and economically.

3.3. *Improvement of recycled aggregate quality*

The old mortar and micro-cracks on the surface of the recycled aggregate make the chloride ion permeability of the recycled concrete larger than that of ordinary concrete. The existing research has found that the recycled aggregate can be significantly improved by physical strengthening, chemical strengthening and composite strengthening treatment, and the chloride ion permeability is also improved.

3.3.1. *Physical strengthening*

After the regenerated coarse aggregate is shaped and sieved, the old mortar on the surface of the aggregate is removed, the edge of the surface is eliminated, the particles are smooth, the shape optimization is optimized, the gradation is more reasonable, and the compactness of the recycled concrete is improved; significantly reduced, improved porosity and porosity of the recycled concrete interface area, reduced porosity of recycled concrete, and significantly improved its ability to resist chloride ions. Nagataki et al. ^[16-17] used mechanical grinding to remove the bonded mortar on the surface of the regenerated coarse aggregate to obtain high quality recycled aggregate, and its water absorption rate decreased significantly. Zhu Chongji et al. ^[18] found that, after particle shaping, the chloride aggregate resistance of the recycled aggregate was about doubled, but slightly lower than that of natural aggregate concrete. Han Shuai et al. ^[19] found that the particle resistance of recycled coarse aggregate concrete after particle shaping was improved, and the secondary particle shaping effect was the best and superior to ordinary concrete. Ordinary concrete fell by 9.7% to 25.5%. Polyvinyl alcohol (PVA) and silane-based polymers are water-repellent, and the inclusion of aggregate pores due to macromolecular effects can reduce the water absorption of porous materials. Kou et al. ^[20] modified the recycled aggregate by PVA and found that its resistance to chloride ion penetration was enhanced, and pointed out that 10% is the optimum concentration of PVA. Zhu et al. ^[21] used silane-based polymer to completely agitate and surface-coat the recycled concrete, and found that the surface treatment can improve the chloride ion permeability of recycled concrete more effectively than the overall treatment.

3.3.2. *Chemical strengthening*

With the promotion of “Energy conservation” in China, the improvement of building material performance through nanotechnology has been highly valued. Taylor et al. ^[22] found that the cement hydration product, the C-S-H gel, has a nano-meter size. The nano-powder is incorporated into the

cement as a highly active admixture to promote cement hydration, which will form a hydrated calcium silicate gel to improve the pore structure of regenerated aggregate. Zhang Jinjian et al. [23-24] found that the admixture of highly active nano-SiO₂, nano-CaCO₃ and nano-modified minerals in pairs could significantly improve the chloride ion penetration resistance of recycled concrete, and the amount of electricity would be reduced by more than 30% compared with recycled concrete without nano-material. Through microstructural analysis, it was found that after nano-reinforcement of recycled aggregate, the original pores in the interfacial transition zone were filled with nanoparticles, forming dense hydration products, which strengthened the interface transition zone. In addition, acidic solution could dissolve cement hydration product, effectively removed bonding mortar, thereby improved the quality of recycled aggregate. Tam et al. [25] used 0.1mol HCl, H₂SO₄ and H₃PO₄ solutions to soak the recycled aggregate for 24h to remove the mortar adhering to the surface of the recycled aggregate. It was found that all three solutions reduced the water absorption of recycled concrete and immersed in HCl solution. The chloride ion content of recycled concrete is higher than that before treatment, while the chloride ion content of recycled concrete after H₂SO₄ and H₃PO₄ solution immersion treatment is reduced, indicating that pre-soaking with H₂SO₄ and H₃PO₄ solution can improve the chloride ion resistance of recycled concrete; The production cost is high and the practical application is difficult. Kou et al. [26] found that the use of CO₂ to regenerate recycled mortar aggregates can improve the resistance of recycled concrete to chloride ion penetration by nearly 40%. Grabiec et al. [27] used a medium consisting of concentrated beef juice, peptone, and urea to carry out microbial culture. Using biotechnology to treat recycled aggregates, due to the existence of sufficient potential, bacteria precipitated calcium carbonate on the surface of the cell wall. It was found that after the bioprecipitation of calcium carbonate was strengthened, the water absorption of the recycled aggregate concrete decreased and the resistance to chloride ion penetration was enhanced.

3.3.3. Composite strengthening

Guo Yuanxin et al. [28-29] used physico-chemical composite strengthening method (particle shaping + silicone waterproofing agent) to strengthen simple broken reclaimed coarse aggregate and fine aggregate. Studies have shown that physical reinforcement of recycled aggregate can reduce chloride ion. Penetration; chemical strengthening does not work. This is because after chemical strengthening treatment, a layer of hydrophobic layer is wrapped on the surface of the recycled aggregate, so that the interface with the cement slurry is not strong, thus reducing the recycled concrete. Resistance to chloride ion permeability; secondary ion strengthening and chemical impregnation composite strengthening has the best resistance to chloride ion penetration. The chloride ion permeability coefficient of recycled coarse aggregate concrete is reduced by 13.6%, and recycled fine aggregate concrete is reduced by 15 %. This is because the surface roughness of the aggregate is reduced after the composite strengthening, the gradation of the aggregate is optimized, the compactness of the recycled concrete is increased, and the chloride ion permeability of the recycled concrete is improved. Sun Jun et al. [30] found that, through electric flux test, both the adjusting mix proportion method and the adding expansive agent method can improve the chloride ion penetration resistance of recycled concrete. It is also proposed that, under the high replacement rate, these two methods can be used at the same time.

4. Conclusions and prospect

From the research situation, the research on the resistance of chloride ion penetration is still in its infancy. For one thing, due to the different test methods used, the differences in design content, etc., coupled with the significant differences in raw materials, mix ratios and construction techniques between recycled concrete and ordinary concrete. Therefore, the conclusions obtained by the researchers vary widely. For another thing, most researches on recycled concrete stay in the understanding of macroscopic laws, however, from the micro level, the discussion on the mechanism is not deep enough. From the research results, it basically stays in the qualitative research stage, mainly the research on the influencing factors affecting the chloride ion penetration resistance of

recycled concrete, and there is little research on the physical model for predicting the performance applied to practical engineering. At the same time, the environment in which the actual project is located is complex and variable, and the recycled concrete structure is also affected by various conditions, especially in coastal areas, which are affected by various aspects of erosion. Therefore, in the future research, quantitative comparison can be combined with multi-factor simulation to comprehensively consider the effect of recycled concrete on chloride ion penetration resistance.

Acknowledgments

The work described in this paper was fully supported by Nantong Science and Technology Plan Project “Processing Technology Improvement Research on Recycled aggregate concrete”(YYZ16010), and Nantong University Xinglin College Research Fund Project (2014K119).

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