Journal of Engineering Research and Reports

Volume 26, Issue 7, Page 17-25, 2024; Article no.JERR.118287
ISSN: 2582-2926

Research Progress on Frost Durability of Rubber Recycled Concrete

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

Article Information

DOI: https://doi.org/10.9734/jerr/2024/v26i71190

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/118287

Review Article

Received: 02/04/2024
Accepted: 06/06/2024
Published: 10/06/2024

ABSTRACT

Rubber recycled concrete is a new type of green concrete material that partially replaces natural coarse aggregate with recycled aggregate and partially replaces fine aggregate with rubber. Recycled rubber concrete not only improves the problem of poor frost durability of recycled concrete, but also solves the problem of large amounts of waste concrete and rubber difficult to deal with, as well as a series of ecological and environmental problems caused by this. Therefore, it is of great significance to carry out the research on the frost resistance of rubber recycled concrete to promote its application in cold regions. In this paper, based on the current status of domestic and international research on the freeze-thaw damage of rubber recycled concrete, the freeze-thaw damage mechanism of rubber recycled concrete is introduced, and its influencing factors and improvement measures are discussed, so as to provide a favorable basis for the research on the freeze-thaw damage of rubber recycled concrete.

Keywords: Concrete; rubber; recycled aggregate; freeze-thaw.

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Cite as: *Ding, Nan. 2024. "Research Progress on Frost Durability of Rubber Recycled Concrete". Journal of Engineering Research and Reports 26 (7):17-25. https://doi.org/10.9734/jerr/2024/v26i71190.*

1. INTRODUCTION

Concrete is one of the most widely used materials in construction projects, in which the volume of aggregate accounts for about 70% of concrete [1]. It is estimated that the demand for construction aggregates in China will reach 66 billion tons in 2025 [2]. With the development of the construction industry, the demand for natural aggregates, such as sand and gravel, increases and the market supply is tight. The application of recycled products can not only reduce the harm of construction waste to the environment, but also alleviate the problem of the contradiction between the supply and demand of natural aggregate re-sources. The quantity of waste concrete occupies a large proportion in construction waste [3], through the crushing, screening and other treatments of waste concrete can be used for foundation backfill, road base layer, preparation of recycled aggregates and so on.

In the rapid development of the world automobile industry today, the tire manufacturing industry is also soaring, China has also become a large country of tire production and consumption, a large number of waste tires and rubber products continue to increase. Relevant data show that China produces a large number of discarded tires every year, and the growth rate is getting faster and faster, only in 2010, the number of discarded tires reached more than 200 million [4]. In 2018, the total number of discarded tires in China reached 380 million [5]. Hundreds of millions of discarded rubber, if left unused or even discarded, not only wastes land resources, but also its insolubility in water and difficult to degrade in the ground, which will pollute the soil and water, produce germs and diseases, and ultimately jeopardize the living environment of human beings. Therefore, how to deal with these wastes, how to efficiently and energy-saving use of waste tires has become an urgent matter, for the protection of the ecological environment and promote the improvement of economic development is of great significance.

At present, environmental degradation has gradually become a major challenge affecting the ecological balance of nature and the sustainable development of human society. There-fore, for the sustainable development of the construction industry, it is especially crucial to make more efforts to solve the waste problem. Especially for the rational reuse of waste concrete and waste tires, the feasibility and implementation strategies need to be thoroughly explored. In summary, freeze-thaw damage is the main source of damage to concrete structures under cold conditions, which not only affects the service life of the building structure, but also lays a hidden danger for the safety of the building structure. Every year, government departments around the world spend more than the cost of reinforcing and repairing buildings, how to rationally use rubber and recycled aggregates in concrete, so that all aspects of its performance to meet the standards required by the specification, is a major problem facing the current research. This paper combines the domestic and international research status of rubber recycled concrete, introduces the freeze-thaw damage mechanism of rubber recycled concrete, and discusses its influencing factors and improvement measures, in order to provide a favorable basis for the research of freeze-thaw damage of rubber recycled concrete.

2. FREEZE-THAW DAMAGE MECHANISM OF RUBBERIZED RECYCLED CONCRETE

Due to the water-cement ratio, pore structure, degree of water saturation and aggregate quality and other factors, different types of concrete frost resistance performance varies greatly, which leads to the freeze-thaw cycle after the internal damage of concrete is extremely complex, and has a certain degree of randomness [6]. Therefore, it is difficult to get a consistent conclusion for the freeze-thaw damage mechanism of concrete, at present, there are mainly the following three representative theories: hydrostatic pressure theory, osmotic pressure theory and micro-ice lens theory. 1945, Powers [7] put forward the hydrostatic pressure theory, and think that during the freezing process, some of the water in the pores of the concrete freezes and expands, forcing excess water to migrate outward, resulting in the formation of hydrostatic pressure on the pore wall of the unfrozen water, thus making the concrete expand. hydrostatic pressure on the pore wall, thus causing the concrete to expand. After Powers et al [8] put forward the osmotic pressure theory, and that the freezing point of water in the pore and pore size, the smaller the pore size, the higher the freezing point, so the large holes (pore size greater than 10 μm) in the part of the pore liquid first icing, resulting in pore liquid in the remaining solution in the concentration of Na +, K + and Ca_2 + plasma rise, and the surrounding unfrozen small holes (pore size less than 10 μm) in the solution The concentration difference was formed with the solution in the surrounding small unfrozen pores (pore size less than 10 μm), and thus the water in the small pores migrated to the large pores. Although the hydrostatic pressure theory and osmotic pressure theory are well recognized, they cannot explain the phenomenon of concrete shrinkage by freezing and the increase in the rate of water absorption in concrete during the freeze-thaw process. In 2001, Setzer [9] proposed the micro-ice lens model, which suggests that during the freezing process, unfrozen water in the capillary pores is squeezed out of the gel matrix and transported into the ice crystals in the pores, i.e., "microcrystals" are formed. "microcrystal" growth, a process equivalent to drying contraction. During the melting process, the pressure difference between unfrozen pore water and ice decreases, and water is transported from the ice want unfrozen pore water and transported, at this time, if there is water in the outside world, the outside water will be absorbed by the gel matrix. The micro-ice lens model can better explain the phenomenon of concrete shrinkage by freezing and the increasing water saturation of concrete during freeze-thaw.

Due to the large difference in physical properties between recycled coarse aggregate and natural aggregate, at the same time, the incorporation of rubber changes the pore structure of concrete, resulting in the freeze-thaw damage mechanism of ordinary concrete can not reasonably explain the freeze-thaw damage process of rubber recycled concrete.

Concrete can produce freeze-thaw damage is essentially because the water content inside the concrete reaches the critical water saturation degree of freeze-thaw damage [10], so the difference between ordinary concrete and recycled concrete freeze-thaw damage process and its mechanism is caused by the different degree of sensitivity of the two for water. Zhang Leishun et al [11] that, the recycled coarse aggregate surface attached to the old mortar in the pore space and broken in the process of micro-cracks so that the recycled concrete water absorption is high, and compared with ordinary concrete, recycled concrete interface structure is more complex, including the old mortar - new mortar, old aggregate - new mortar and old aggregate - old mortar interface transition zone. Among them, the old interface (i.e., old aggregate - old mortar interface) transition zone ITZ3 width is larger, strength is small [12]; with the increase of recycled aggregate mixing, recycled concrete in the structure of the more loose weak interface is also increased, thus increasing the transmission of water in the concrete channel. Under the combined effect of these two aspects, the recycled concrete is more likely to reach the critical water saturation degree of freeze-thaw damage, resulting in freeze-thaw damage, so the recycled coarse aggregate is the key to determine the frost resistance of recycled concrete. However, some scholars [13-14] believe that the following characteristics of recycled aggregate can enhance the freezing performance of concrete: 1) compared with natural aggregate, recycled aggregate more pore space at the interface of the cement mortar to play a conservation role, so that the interface transition zone structure is more dense, so that the freezing performance of recycled concrete is comparable with that of ordinary concrete, and even in the freezing and thawing cycle of the recycled concrete advantage over ordinary concrete; 2) recycled coarse aggregate is the key to determine the freezing performance of recycled concrete. Concrete is more obvious; 2) There are a certain number of closed holes in the old mortar attached to the recycled aggregate, which can buffer the expansion stress produced in the freezing process, so the appropriate mixing of recycled aggregate in concrete can enhance the freezing performance of concrete.

Rubber particles are a kind of polymer material, it is difficult to make a better combination with cement mortar, which leads to bad bonding between rubber particles and aggregate, forming a relatively weak bonding surface. In the process of freezing and thawing, the internal moisture freezing and expansion makes the stress increase, and the internal cracks are constantly generated and gradually expand into cracks, because it is an elastomer, so it can buffer the expansion pressure, prevent the internal cracks from continuing to expand, so that the concrete obtains a better anti-freezing performance. At the same time, the addition of gum particles can improve the internal pore structure, introduce a large number of bubbles, and form a lot of closed holes, which can inhibit the development of capillary pores formed by cement hydration inside the specimen, and can effectively improve the frost resistance of concrete.

3. FACTORS AFFECTING FROST RESISTANCE OF RUBBERIZED RECYCLED CONCRETE

3.1 Effect of Recycled Coarse Aggregate

3.1.1 Recycled coarse aggregate quality

Recycled coarse aggregate can be classified into three categories through its quality parameters such as water absorption, apparent density, void ratio, crushing index, needle and flake particle content, and particle gradation [15]. Different sources of recycled coarse aggregates show different qualities, Li Fei et al [16] used recycled coarse aggregates from waste bricks to replace natural aggregates proportionally (50%, 100%) to make reclaimed concrete, and found that the effect of waste brick aggregates on the freezing resistance was not obvious, Shu et al [17] used 40% of recycled aggregates from FULLING's waste bricks to replace the natural aggregates, and found that the prepared recycled concrete achieved a D100 frost resistance class, which can meet the requirements of conventional use. Wang Jiahua et al [18] showed that the frost resistance of recycled concrete made from waste tiles was better than that of ordinary concrete when the optimal mix ratio was used, which was attributed to the stronger bonding ability of the aggregate to the cement stone interface. The study of Wang Lei et al [19] also proved this point and suggested its use in building structures that are subject to severe freeze-thaw hazards. The results of Liu [20] showed that if the source of recycled aggregate is high-strength concrete, the frost resistance performance of the prepared recycled concrete will be even better.

3.1.2 Coarse aggregate admixture

Some scholars believe [21-23] that the unhydrated cement particles on the surface of recycled coarse aggregate can undergo secondary hydration reaction with water to increase its strength, and the denser the concrete is, the more obvious the optimization of its frost resistance is with the increase of the substitution rate of recycled coarse aggregate.

However, most scholars believe that, due to the unique properties of recycled coarse aggregate, if the substitution rate continues to increase, the degree of deterioration of frost resistance of recycled concrete will continue to decline. Niu Haicheng et al [24] found that the frost resistance of recycled concrete decreases with the increase of the substitution rate of recycled coarse aggregate, and the relative dynamic elastic modulus of fully recycled concrete has been more than 10% lower than that of ordinary concrete after 100 freeze-thaw cycles. Wei Chengjuan et al [25] prepared high-strength recycled concrete mixed with 0%, 40%, 60%, 80% and 100% recycled coarse aggregate, and the replacement rate of recycled coarse aggregate did not show a significant effect when the freeze-thaw cycle was lower than 200 times, but the relative dynamic elastic modulus decreased more and more significantly with the increase of the replacement rate when it was higher than 200 times. Miao Zhuang [26] concluded that the freezing resistance of recycled concrete did not decrease significantly in the case of half substitution, but in the case of full substitution, the freezing resistance was lower due to the internal loss was too serious. Zhou yu et al [27] designed five kinds of recycled concrete with different substitution rates for 200 freeze-thaw cycles, and after 150 freeze-thaw cycles, the recycled concrete showed the phenomenon of aggregate detachment which did not occur in ordinary concrete, and the phenomenon was more obvious with the increase of substitution rate, which was attributed to the high water absorption of the recycled coarse aggregate that made the recycled concrete more susceptible to damage by freezing.

It can be seen that the uncertainty of quality and the difference of substitution rate can greatly affect the frost resistance of the recycled concrete, but how to standardize the quality of recycled coarse aggregate and the specific mechanism of the effect of substitution rate of recycled coarse aggregate on the frost resistance need to be further studied.

3.2 Effects of Rubber

3.2.1 Rubber admixture

Lu Shasha, Ma Fenghai [28] et al. investigated the effect of rubber aggregate on the frost resistance of concrete by means of experimental analysis, and the results showed that when the rate of mass loss of concrete specimens doped with rubber aggregate is less than 5% and the rate of strength loss is less than 20%, the frost resistance of concrete specimens doped with rubber aggregate can be improved by increasing the mixing amount of rubber particles in a certain range after 100 freeze-thaw cycles, and its optimum mixing amount is 30 kg/m^3.

performance, and its optimum admixture is 30 kg/m^3.Wen Yang and Cui Hao [29] et al. investigated the frost durability of rubber concrete under salt freezing conditions and analyzed the change of the flexural strength of rubber concrete after freezing and thawing, and the results showed that the admixture of rubber powder improves the freezing resistance of the concrete, but reduces the flexural strength of the concrete, and the optimum substitution rate of the rubber concrete for the resistance to sulphate freezing and thawing and the flexural strength of the rubber concrete is 10%.Zhang et al [30] found that the moderate addition of rubber powder can improve the frost resistance of geopolymer concrete under the premise of guaranteeing the strength, and the optimum mixing rate is 10%. Wang [31] et al. found that the incorporation of rubberized aggregate reduced the volume expansion of the specimens and improved the frost resistance of the specimens. After 600 freeze-thaw cycles, the volumetric expansion of rubberized concrete specimens (R-10) with 10% admixture was reduced from 0.033% to 0.015% compared to normal concrete (CO). In steel fiber rubber concrete (SR), the volumetric expansion of the specimens was further reduced with the increase in rubber ad-mixture.

3.2.2 Rubber particle size

Xu Jinhua and Feng Xiating [32] took two different particle sizes and four different dosages of rubber instead of equal volume of fine aggregate sand, and made rubberized concrete specimens for fast-freezing test, to study the effect of rubber particle size and dosage on the frost resistance of concrete. The results show that the rubber powder mixed with 5%-10% and particle size ≤0.27mm has a significant improvement on the frost resistance of concrete.Alan Richardson et al [33] sought the rubber particle gradation that can improve the frost resistance of concrete with as little loss of concrete compressive strength as possible through the freezing and thawing test, and the results show that the rubber particle size of ≤0.5mm is the optimal size. Guo [34] and others found that the incorporation of crumb rubber particles significantly im-proved the frost resistance of concrete. Crumb rubber concrete (CRC-110) was made by using 40-60 mesh rubber crumbs to replace 35.2% of fine aggregate by equal volume. After 200 freeze-thaw cycles, the relative modulus of elasticity of ordinary concrete (OC) de-creased to less than 60%, whereas the relative modulus of elasticity of crumb rubber concrete (CRC-110) remained around 65% even after 500 freeze-thaw cycles. The mass loss of OC was more pronounced than that of CRC-110, and the mass loss of OC and CRC-110 was about 0.49% each after the 175th freeze-thaw cycle. loss was about 0.49% and 0.17%, respectively. Xue [35] et al. found that the incorporation of rubber particles reduced the strength reduction induced by freeze-thaw cycles. Crumb rubber concrete was made using 30-mesh rubber crumb with 15% fine aggregate replaced by equal volume. After 60 freeze-thaw cycles, the strength of normal concrete was reduced by 38%, while the strength of crumb rubber concrete was reduced by 24.8%.

3.3 Influence of Freezing and Thawing Media

The frost resistance of rubber recycled concrete in different freezing and thawing media will be somewhat different. Xiao Qianhui [36] and other 30% replacement rate of recycled concrete immersed in different concentrations (0%, 3%, 5%, 10%) of Na_2S0_4 solution for freezing and thawing test, the test results show that the recycled concrete in the 10% Na_2S0_4, after the test in the solution, its compressive strength and the maximum loss of mass, and 3% of the specimens in the Na_2S0_4 solution with the specimen in the water performance is closer to the specimen performance. close. This is due to sulfate can reduce the freezing point of water, slowing down the freeze-thaw damage, and when the sulfate concentration is too high will increase the permeability of water and erosion to the concrete internal production of expansion products leading to more susceptible to frost damage of concrete Yuan Lidong et al [37] compared the regenerated concrete in the Na_2S0_4 solution and the $MgS0_4$ dissolution wave in the damage to the thickness of the difference between the results show that in the $MgS0_4$ solution, magnesium salts and the double corrosion of sulfate leads to freeze-thaw damage of the concrete in the Na_2S0_4 solution and the $MgS0_4$ dissolution wave in the $MgS0_4$ solution, the magnesium salts and the $MgS0_4$ solution. sulfate double corrosion led to more serious freeze-thaw damage. Zou Jun examined the frost resistance of regenerated concrete in sulfate and chloride salts, and found that the erosion of chloride salts was mainly reflected in the surface erosion, and its damage was not as severe as that of sulfate salts.

It can be seen that the freezing and thawing medium on the frost resistance of recycled concrete is multifaceted, in the real environment of recycled concrete is not just a single water erosion, but the study on the effect of different freezing and thawing medium on its freezing performance is still less, and most of them stay in the macro level, the micro level of investigation is rarely reported, and is expected to be further explored.

4. IMPROVEMENT OF FROST RESISTANCE OF RUBBER RECYCLED CONCRETE

4.1 Rubber Modification

Some scholars have found that the performance of rubber concrete can be further optimized by modifying rubber. Liu Songan, Liu Yafei et al [38] used different reagents to modify rubber particles, the results show that the use of synthetic resin modification can effectively improve the freezing resistance of rubber concrete, epoxy resin, unsaturated resin modification although it can improve the mechanical properties of the concrete, but make the concrete freezing resistance and resistance to sulfate erosion performance decreased significantly. Su Youwen and Yang Qinsong [39] used different kinds of polymer emulsions to modify rubber concrete, and found that styrene-butadiene emulsion and synthetic resin had a better effect on the improvement of frost resistance of rubber concrete, and the optimal mixing amount was 3%.

4.2 Recycled Aggregate Modification

By pretreating recycled coarse aggregate, the various properties of recycled concrete can be effectively improved. Wang Lingling [40] and others found that the use of recycled coarse aggregate intensive treatment and recycled concrete secondary mixing process can improve the compressive strength and frost resistance of recycled concrete, and the combination of the two has the best effect. Liu Quansheng [41] investigated the pretreatment of recycled aggregate by three treatments: encrustation, shaping, and water saturation, and the results showed that all the three methods can improve the mechanical properties of recycled concrete after freeze-thaw cycle, in which encrustation treatment is the best, shaping treatment is the second best, and water saturation treatment is the worst.

4.3 Incorporation of Fibers or Concrete Admixtures

Some scholars improve the frost resistance of rubber recycled concrete by adding appropriate amount of fiber or concrete admixture, mainly because one is to increase the denseness of recycled concrete, the second is to be able to alleviate the freezing and expansion stresses and inhibit the development of micro-cracks, and the third is to improve the adhesion between the rubber aggregate and the cement matrix.

Liu Duo [42] investigated the effect of rubber powder admixture and nano Si02, admixture on frost resistance of recycled concrete and assessed the frost resistance of rubberized recycled concrete in terms of mass loss rate and strength loss rate The results showed that rubber powder admixture and nano $Si0_2$, admixture of 5 % and 3%, respectively, resulted in the lowest loss rate of strength of the recycled concrete compared to the dry other admixtures. They concluded that rubber aggregate has elastic deformation capacity, which can buffer the internal stress caused by freeze-thaw cycles and limit the extension and expansion of micro cracks to some extent. Nano-$Si0_2$, which has filling effect and volcanic ash effect, can increase the density of recycled concrete and improve the frost resistance of concrete. Wang Hanyu [43] mixed pretreated modified rubber particles, and 1% polypropylene fibers in recycled concrete to study the mechanical properties and frost resistance of concrete. The study showed that the modified method can improve the frost resistance of concrete because the hydrophobicity of the rubber aggregate is modified, the hydrophilicity of the rubber aggregate surface is improved, and the adhesion of the rubber aggregate to the cement matrix is also improved, which improves the frost resistance of concrete. Polypropylene fibers can also improve the frost resistance of recycled concrete, polypropylene fibers in the concrete will form a three-dimensional network structure, sharing multi-directional stress, reducing the development of cracks, but also improve the densification of recycled concrete, thus improving the frost resistance of concrete [44].

5. CONCLUSION

The study of frost resistance of rubber recycled concrete is of positive significance to promote the resource utilization of waste tires and construction waste, and to promote the application and development of rubber recycled concrete in cold regions. Rubber aggregate admixture than recycled aggregate admixture has a significant effect on the air content of recycled concrete, and the air content of concrete increases with the increase of rubber admixture and the decrease of rubber particle size. Incorporation of appropriate rubber admixture and rubber particle size has improved frost resistance of recycled concrete, and recycled aggregate characteristics and admixture also affect the frost resistance of concrete. Adding appropriate amount of fiber or concrete admixture can improve the frost resistance of recycled concrete, assessing the frost resistance of rubber recycled concrete by mass loss rate, relative dynamic modulus or strength loss rate, etc., which can then predict the damage model of rubber recycled concrete, calculate the life of rubber recycled concrete, study the law of frost resistance of concrete more deeply, and improve the frost resistance theory of recycled concrete.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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Peer-review history:
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