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Review on the Role of Rubber on the Performance of Concrete

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Author's contribution

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

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Review Article

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ABSTRACT

Due to the rapid development of the vehicle manufacturing industry, the hazards caused by scrap tire rubber have become one of the serious problems faced by people today. Rubber concrete is made of waste rubber into different particle sizes to replace the fine aggregate in ordinary concrete formed by a new type of composite material, for the disposal of waste tires and rubber opened up a new way, so that waste rubber can be reused. Rubber concrete compared to ordinary concrete has Light weight, good elasticity, high toughness, ductility, impact resistance, good damping, good frost resistance, but its strength is reduced. From the perspective of mechanical properties, durability and modification treatment, the article introduces the research progress of its compressive strength, frost resistance, carbonation resistance, modification treatment, etc., which provides a method for rubber concrete to be used in a wider range of practical projects.

Keywords: Concrete; rubber; performance; resource recycling.

1. INTRODUCTION

With the accelerated development of the automobile manufacturing industry, more and more worn-out tires are produced, and the decomposition of rubber itself is difficult to complete under natural conditions, which not only occupies a large amount of land, but also

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brings great pollution to the environment. If the waste rubber can be ground instead of fine aggregate in concrete, not only can save the construction cost, but also help to alleviate the problem of environmental pollution, is a kind of green sustainable development way of utilization [1, 2].

Rubber concrete is a cementitious composite material made from concrete as a matrix, utilizing rubber powder or rubber particles instead of fine aggregates. Ordinary concrete ductility, fatigue, impact resistance and other properties are poor, while the rubber has good ductility and toughness, rubber as an aggregate mixed into the concrete can better improve the ductility of concrete, fatigue, impact resistance and other properties. Therefore, in recent years, many scholars in the field of civil engineering materials at home and abroad have carried out extensive and in-depth research on rubberized concrete, and achieved a large number of research results. This paper combines the current status of rubber concrete research at home and abroad, mainly introduces the mechanical properties and durability of rubber concrete, points out the shortcomings of the current rubber concrete research, and puts forward the future research direction of rubber concrete, in order to provide reference for the application of rubber concrete in the field of civil engineering.

2. ADVANCES IN MECHANICAL PROPERTIES OF RUBBERIZED CONCRETE

Domestic and foreign scholars agree that rubber in concrete will reduce its compressive strength, flexural strength, tensile strength and modulus of elasticity, and reduce the magnitude of rubber mixing increases with the increase in the magnitude of the increase, which is mainly attributed to the hydrophobicity of the rubber surface leads to the adhesion between the rubber and the cement mortar is poor elasticity modulus of rubber is also much smaller than that of natural aggregates.

2.1 Effect of Rubber Admixture on Mechanical Properties of Concrete

Tao Ran et al. [3] investigated the mechanical properties and durability of rubberized concrete (PBRC) with added polypropylene and basalt fibers under sulfate attack and freeze-thaw coupling environments. The results showed that:with the increase of the number of freeze-thaw cycles, the mass loss rate of RC and PBRC gradually increased, and more pits and cement paste spalling appeared on the surface of specimens;moreover, the compressive strength and split tensile strength of the RC and PBRC groups had obvious trends, and the residual strength of the former was lower than that of the latter. After 160 freeze-thaw cycles in 5% $MgSO_4$ solution, the residual compressive strength of RC group was only 69.4%.

Miaoyan Liu et al. [4] conducted fatigue tests on plain concrete beams and precast cracked rubberized concrete beams in order to study the crack extension process and damage mechanism of rubberized concrete under fatigue loading. The results show that:after rubber doping, the maximum deformation of rubberized concrete under fatigue loading is about twice that of plain concrete, and the fatigue life and fracture energy are improved;the acoustic emission signal confirms that there is a hysteresis between cracks and loads under fatigue loading due to the hysteresis of energy transfer. The incorporation of rubber particles also reduced the range of variation of stress intensity factor.

Haifeng Yang et al. [5] investigated the compressive shear properties of steel fiber rubber concrete. The parameters were analyzed for compressive shear strength. The results showed that:The equivalent initial energy density increased with the increase of rubber powder content, the equivalent shear residual toughness increased after the peak value, but the shear strength and peak displacement decreased. With the addition of steel fibers, the initial shear strength, peak displacement and equivalent residual strength increased. A calculation criterion for the compressive shear strength is proposed, and the theoretical values are in good agreement with the experimental values.

Xiangyi Zhu et al. [6] investigated the effects of rubber dosage and particle size on the mechanical properties of pervious concrete through experiments and discrete element method (DEM) simulations. It is found that the compressive damage mode of pervious concrete gradually transitions from tensile damage to shear damage with the increase of rubber admixture, and the compressive strength shows a wdecreasing trend, and the larger the particle size is, the stronger the attenuation effect on strength is.

F.M. Zahid Hossain et al. [7] investigated the effect of adding polypropylene fibers to concrete mixes by partially replacing coarse and fine aggregates with recycled components such as (Recycled Coarse Aggregate) RCA and (Granular Rubber) CR respectively. Fifteen different mixes were considered with RCA content of 10% and 30%, CR content of 5% and 10%, and fiber content of 1% and 2%, respectively. The compressive strength, splitting tensile strength and flexural strength decreased with increasing CR content and increased with increasing fiber content. In terms of toughness and ductility, the role of fibers was greater than that of RCA and CR and increased with the increase in fiber addition. It was also observed that the destruction process of fiber-containing beams was slower.

2.2 Effect of Rubber Particle Size on Mechanical Properties of Concrete

Rubber particle size also plays an important role in affecting the mechanical properties of concrete. Some foreign scholars think that the strength and stiffness of concrete under the same rubber dosage decreases with the increase of rubber particle size, while some scholars in China think that the smaller the particle size is under the same dosage, the lower the strength and stiffness, the cause of the disagreement may be due to the differences in the mixing sequence, slump, curing conditions, gradation or chemical composition of the rubber used by these scholars during the test. From the theoretical point of view, the smaller the particle size of the rubber, the larger the specific surface area, the more weak interfaces are formed with the cement matrix, so the smaller the particle size under the same dosage, the more the strength and stiffness decrease is caused.

Yan Zhizhuo [8] on different particle sizes of different volume fractions to replace the fine aggregate rubber concrete compressive flexural test, analyze and compare the rubber particle size and volume fraction of the impact on the compressive and flexural properties of the concrete material, for rubber particles of different particle sizes, the same admixture of the concrete, the cubic compressive strength of the concrete with the particle size of the larger become smaller; 40 purposes of the compressive strength of the concrete in several admixtures are consistently greater than the other two rubber particle sizes of the concrete, presumably due to the reason for the size of the particles is too small, close to the powder, so that the internal structure of the concrete by the rubber to fill the position of the very small gaps, so that the strength of the strength of the decline in the lesser.

Feng Lingyun et al [9] configured concrete with rubber particle sizes of 3mm to 6mm, 1mm to 3mm and 60 mesh, respectively, and its flexural strength decreased by 19.6%, 16.7% and 22.2%, and concluded that the correlation between flexural properties of rubberized concrete and rubber particle size is not very large, and that the flexural properties of rubberized concrete are inversely proportional to the amount of rubber admixture. Effect of rubber modification on mechanical properties of concrete.

Cao Hongliang, Shi Changcheng, etc. [10] after different curing time, measure the strength of different particle size rubber formulated concrete compression, concluded that for different curing time are: the addition of rubber for the concrete compressive properties are unfavorable, the rubber concrete compressive strength is directly proportional to the size of rubber concrete compressive strength with the fastest increase in the curing time of the rubber rubber concrete compressive strength of rubber concrete with the configuration of the rubber of the large particle size.

3. PROGRESS IN RESEARCH ON THE DURABILITY OF RUBBERIZED CONCRETE

The durability performance of concrete refers to the ability of concrete to resist the action of environmental media and maintain its good serviceability and appearance integrity for a long period of time, so as to maintain the normal and safe use of concrete structures [11]. Rubber concrete, as an emerging civil engineering material, with the increasing maturity of the research on its mechanical properties, scholars have extended the research direction to the durability performance. This paper focuses on the frost resistance and carbonation resistance of rubber concrete.

3.1 Anti-Freezing Properties

Wen Yang [12] conducted rapid freeze-thaw cycle tests on rubberized concrete and ordinary concrete. With the increase of rubber powder dosage, the concrete quality and dynamic elastic modulus showed a decreasing trend, and the dosage of rubber powder improved the freezing resistance of concrete, and the proportion of harmful and multi-hazardous holes in rubber concrete after 300 freeze-thaw cycles was 37.97%, compared with the ordinary concrete after 300 freeze-thaw cycles of harmful and multi-hazardous holes less than 14.27%, and the internal structure of rubber concrete was more dense. The relative dynamic modulus of elasticity of rubberized concrete with 0.18 mm decreases more slowly than that of concrete with 0.425 mm and 0.125 mm, and the frost resistance is better.

Chunfeng Yang [13] explored the effect of changing the strength class of concrete and volume fraction of sand replaced by rubber particles on the frost resistance and resistance to chloride ion penetration of rubberized concrete.For high strength concrete with strength class C60 and C70, the rubber particles admixture led to a decrease in the frost resistance of the concrete, which was attributed to the fact that the weak surface between the rubber particles and the cement stone increased the possibility of frost heave, and the rubber The reason is that the weak surface between rubber particles and cement stone increases the possibility of frost expansion, and the pressure relief effect of rubber particles is not as obvious as that of normal strength concrete. The incorporation of rubber particles improved the resistance of rubberized concrete to chloride penetration, and the best results were obtained at a volume fraction of rubber particles of about 8%.

Yao Weijing[14] studied the deterioration process of apparent phenomena, spalling amount, compressive strength loss and other performance indexes within 60 cycles of salt freezing by preparing ordinary concrete and rubber/concrete matrix, the results showed that with the increase of the number of cycles of salt freezing, the more significant surface corrosion of concrete specimens, the increase in the amount of spalling, the internal damage, strength loss is gradually aggravated, but the mixing of elastic rubber fine aggregates effectively alleviate the internal cracking and pore enlargement caused by the freezing pressure, the degradation degree of rubber/concrete matrix is better than ordinary concrete at all stages, with 10% rubber dosing of each performance index is optimal, after 60 cycles of salt freezing. Cracking and pore enlargement caused by icing pressure, the degradation of rubber/concrete matrix is better than that of ordinary concrete at all stages, and the rubber dosage of 10% is optimal for all the performance indexes, and the loss of compressive strength of ordinary concrete is 58.5% after 60 cycles of salt freezing and the loss of compressive strength of rubber concrete is 48.0%.

Wang Tao [15] studied the freeze-thaw durability of concrete with 80 mesh rubber powder at four dosages (0, 30, 60, 90 kg/m3). Rubber powder improved the freeze-thaw resistance of concrete significantly, and the higher the dosage, the better the freeze-thaw resistance of concrete. Rubber powder improves the frost resistance of concrete for two reasons: increasing the air content of concrete and 80 mesh rubber powder itself can improve the frost resistance of concrete.

3.2 Carbonation Resistance

Carbonation damage of concrete refers to the reaction of hydration products in cement stone with CO_2 in the air to generate carbonates and other substances, which changes the internal structure of concrete, lowers the pH value of cement concrete, and makes steel reinforcement more susceptible to corrosion, thus affecting the durability performance of concrete structures.

Yuan Qun [16] investigated the effects of carbonation time, different particle sizes of rubber particles and mixing amount on the carbonation resistance of rubber concrete. The results show that: after 3 d of carbonation, the carbonation depth of concrete mixed with 1~3mm rubber particles and 60 mesh rubber powder is reduced by 40% compared with that of the reference concrete, and the concrete mixed with 3~6mm rubber particles is closer to that of the reference concrete; after 7 d and 14 d of carbonation, the carbonation depth of concrete mixed with small particles of rubber and powdered concrete is close to that of the reference concrete, and that of concrete mixed with large particles of rubber increases, but there is no significant difference; after 28 d of carbonation, the depth of carbonation of concrete mixed with small particles of rubber and powdered concrete is close to that of the reference concrete, and the concrete mixed with large particles of rubber increases, but there is no significant difference. After 28 d of carbonation, the carbonation effect of concrete mixed with small rubber particles is better in the range of 15% to 20%, the carbonation depth of concrete mixed with large rubber particles is larger than that of the reference concrete, but there is a tendency to decrease with the increase in the amount of rubber particles, and the carbonation effect of concrete mixed with rubber powder is poorer.

Yu Qun [17] investigated the effects of rubber particles with volume fractions of 5%, 10% and 15% and rubber particle sizes of 2~4mm, 30~40 mesh and 60~80 mesh on the carbonation resistance of concrete. The test results show that: the rubber particles have adverse effect on the carbonation resistance of concrete in the early stage, but improve the carbonation resistance of concrete in the later stage; different rubber particles particle size and dosage have different effects on the carbonation resistance, the optimal dosage of rubber particles is 10% by volume, and the smaller the size of the particles, the better the effect.

Li Kecheng [18] studied the effect of rubber powder mixing amount and carbonation time on the carbonation depth, and strength index of concrete after carbonation through experiments. The test results show that the rubber powder on the depth of carbonation, carbonation compressive strength and flexural strength of the influence of the law is not obvious, when the dosage is less than 10%, the concrete carbonation mainly occurs after 14 d, and when the dosage is greater than 20% of the carbonation accelerated from the beginning of the 7 d. The more the rubber powder dosage, the greater the folding compression ratio of the carbonated concrete, and the better the bending toughness of the concrete.

4. EFFECT OF RUBBER MODIFICATION ON MECHANICAL PROPERTIES OF CONCRETE

The combined effect of recycled coarse aggregate (RCA), rubber crumb (CR) and polypropylene fibers (PP) on the physico-mechanical properties of fiber-reinforced rubber recycled concrete (FR3C) was investigated by Md. Shahjalal et al[19]. Several combinations were designed using CR content (5% and 10%) and steel ratio (0.59% and 1.60%) as variables, with RCA and fiber content fixed at 30% and 0.5%, respectively. The results of the experimental study showed that the short-term and long-term mechanical properties of concrete were improved by the incorporation of CR and PP fibers. Concrete beams containing 30% RCA, 5% CR and 0.5% PP fibers showed better flexural capacity, ductility and toughness.

Zeng Lei [20] conducted a comparative analysis of the damage morphology, compressive strength and flexural strength of rubber concrete with different fiber admixture through axial compressive test and flexural test, and the admixture of PVA fibers can effectively alleviate the attenuation tendency of the strength of rubber concrete, and the optimal admixture is controlled at about 1%, which effectively improves the internal interfacial defects of rubber concrete.

Zheng Lijuan [21] et al. experimentally investigated the effect of different modified treatments of waste rubber by NaOH solution and maleic anhydride on the mechanical properties of concrete. The results showed that the 28 d flexural strength of rubber concrete modified by NaOH solution and maleic anhydride increased by 11.4% and 5% respectively, the flexural compression ratio increased by 14.3% and 9.5% respectively, and the bond strength increased by 3% and 16v respectively, which indicated that the modification effect of NaOH solution was better than that of maleic anhydride.

Celal Cakiroglu et al. [22] compiled a comprehensive experimental database of compressive, tensile, and flexural strength values of fiber-reinforced rubberized recycled aggregate concrete (FRRAC). Based on these experimental results, seven data-driven machine learning models were developed. A total of 16 input variables were considered in developing these machine learning models. The results showed that the CatBoost model performed best in predicting compressive and tensile strengths, while the Random Forest model performed better in predicting flexural strength. Age of concrete, fineness modulus of natural fine aggregate and substitution rate of RCA were the most influential input characteristics for predicting compressive, tensile and flexural strengths, respectively, based on SHapley's additive interpretation (SHAP) values.

5. CONCLUSION AND FUTURE ASPECTS

The environmental hazards of waste rubber have become one of the serious problems facing people today. The birth of rubber concrete has added to environmental protection, not only making large use of waste tire rubber, which is known as black waste, but also improving the performance of concrete. Through the unremitting efforts of researchers at home and abroad, many advantages of rubberized concrete have been discovered, enabling it to be used as a building material in daily life. This paper focuses on the current status of research on the basic mechanical properties of rubber concrete, frost resistance, carbonation resistance, and rubber modification methods. Although the incorporation of rubber particles will reduce the strength of concrete, it can effectively improve the anti-freezing property of concrete, which makes rubber concrete have a better application prospect in road traffic engineering.

However, there are still many aspects of this new building material that need to be studied in depth, such as the effect of dynamic and cyclic loading on the performance of concrete components; the cost-effectiveness of rubber surface modification; the compressive strength of rubberized concrete, flexural strength and split tensile strength and other mechanical indicators of the relationship between the determination of the aspects of the study.Rubber concrete in mechanical properties, carbonation resistance and other aspects of the shortcomings in a certain degree to limit the scope of its application, and due to the specificity of rubber such as easy aging, affected by the temperature, etc. makes the rubber concrete microcosmic situation and unadulterated rubber concrete is very different, how to achieve efficient resource utilization of waste rubber is also a problem to be considered. In this regard, it is necessary to take certain measures to improve the mechanical properties and carbonation resistance of rubber concrete, and to increase the utilization rate of waste rubber, such as modification of rubber particles, the addition of mineral admixtures, etc., which requires a large number of socially responsible researchers to further explore and observe, and to contribute to the sustainable development of resources and the environment.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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