Mechanical Properties of Rubberized Concrete and Its Application in Green Buildings

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Abstract. Global warming has become an increasingly pressing issue today due to excessive carbon emissions. The application of rubberized concrete material provides a new method for the disposal of waste rubberized tires. In terms of mechanical properties, rubberized concrete has poorer compressive strength, weaker splitting and tensile strength, but higher toughness and deformation capacity than ordinary concrete. In this paper, some of the properties of rubberized concrete are verified through finite element analysis. In terms of thermal performance, by synthesizing relevant literature, it is concluded that rubberized concrete has lower thermal conductivity and less thermal expansion than the traditional one. In terms of applications in green buildings, rubberized concrete materials are superior in thermal and acoustic insulation and have vibration damping effects, yet the peak performance is low. The research on the mechanical properties, thermal conductivity, thermal expansion, and acoustic and thermal insulation properties of rubberized concrete will provide a broader vision for rubber concrete to become a new sustainable construction material.

Keywords: Rubberized concrete, sustainable construction, finite element analysis, thermal engineering properties.

1. Introduction

Due to a rise in carbon emissions, global warming has become an increasingly urgent concern. Demands for infrastructure construction has increased as a result of developing nations' ambition to industrialize. The production of building materials like cement and steel results in significant carbon dioxide emissions, making the civil engineering sector one of the major contributors to carbon emissions across all industries. Finding sustainable and clean solutions is crucial for civil engineers in this situation. Recent studies have examined rubberized concrete (RC), a challenging material to work with, and discovered it to be a viable replacement for fine aggregates.

RC may be used to reduce the cost of the initial concrete building project. The collection of used rubber tires has become a "black pollution" that the world cannot readily solve. In order to lessen or even eliminate "black pollution," people should try to start recycling old rubber tires by integrating them into the concrete's basic ingredients. The feasibility of this method has already been shown by a large body of current literature, tests, and experiments on the impact of rubber as a fine aggregate. These studies can serve as the foundation for further investigation. Analyzing and researching the mechanical and thermal performance of RC in conjunction with green construction is original, nevertheless.

The data gathered on the mechanical properties of rubber concrete are compiled and summarized to derive the RC constitutive model and flexural properties data, and finite element modeling is conducted based on the data. The material modeling is then applied to regular three-dimensional specimens like squares, rectangles, and cylinders; load and impact resistance experiments are conducted based on the experimental findings and derived impact resistance, bending resistance, and durability. Subsequently, the benefits and drawbacks of RC compared to conventional concrete are

then determined, allowing this paper to examine the applications for which RC is the most appropriate construction material. Secondly, in the field of green buildings, a comprehensive review of the literature on the sustainability and adaptability of RC is presented in the context of a model built with the material. At the same time, this paper studies the properties of RC in terms of carbon content, abrasion resistance, impermeability, material savings in fabrication, frost resistance, sound insulation, etc., and summarizes and analyzes the contribution of the material to environmental protection.

2. Mechanical Performances of the Rubberized Concrete

2.1. Compressive strength

The data show that the addition of rubber particles to concrete leads to a reduction in the compressive strength of RC, and the compressive strength of concrete decreases more rapidly with the grow of the adding rubber particles. In the experiments of Zhao et al., rubber granules were used in place of concrete fine aggregates and recycled stones were used to replace concrete coarse aggregates to produce rubberized recycled concrete testing blocks, and the following results were obtained in the compressive experiments with the replacement rate of 10%, 20% and 30% of rubber granules by an equal volume of sand [1].

As shown in Fig. 1, the addition of rubber grains decreases the cubic compressive strength; specifically, the cubic compressive strength decreases gradually with an increase of its admixture. As Fig. 2 and Table 1 shown, Chen et al. also conducted experiments on the mechanical properties changes of rubber concrete, in which the production of RC using the rubber powder up to 7.5% of the cement mass substitutes the sand and the 3mm ~ 4mm rubber particles to 7.5%, 10%, 15% of the cement mass equal amount of substitution sand production of concrete and add water reducing agent and air-entraining agent. Then the concrete pressure molding Conclusion is drawn that with the augment of rubber particles, the compressive properties of concrete decreased [2].

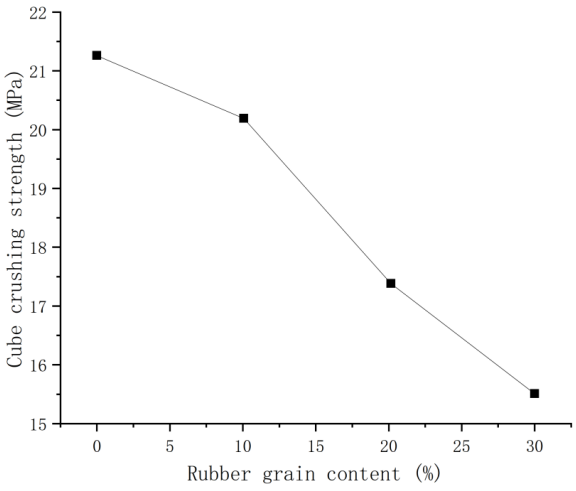

Figure 1. Cube strength under crushing [1]

Table 1. Proportions of materials in the mixed concrete (kg/m³) [2]

Number	Cement	Sand	Pebble	Rubber	Water
C50	457	586	1246	0	160
C50P7.5C	423	586	1246	34	160
C50P7.5S	457	552	1246	34	160
C50G7.5S	457	552	1246	34	160
C50G10S	457	540	1246	46	160
C50G15S	457	517	1246	69	160
C50JS*	457	586	1246	0	160

Note: P- rubber powder, G- granulated rubber, C- cement, S- sand

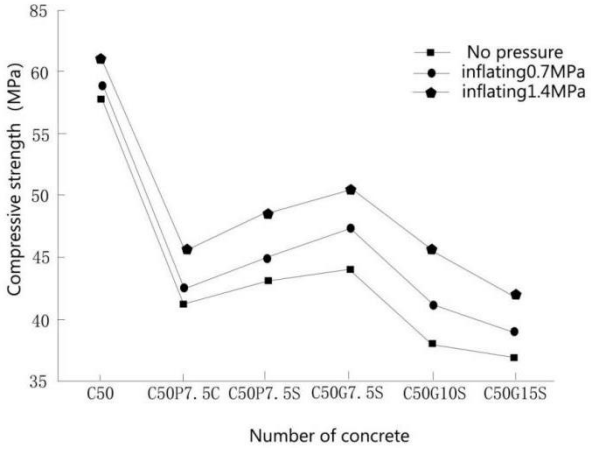

Figure 2. Concrete strength under crushing [2]

There are several factors contributing to the phenomenon. Firstly, rubber particles do not have good adhesion to the surrounding concrete, forming a hollow part inside the concrete, thus leading to a decrease in the compressive strength of the concrete. Therefore, the rubber particles can be considered to be modified so that their adhesion to the concrete increases without being altered in other properties. Secondly, the compressive properties of rubber concrete can be enhanced by controlling the amount of rubber participation with compression molding as the porosity is reduced and therefore become more compressive.

Generally, compressed concrete with 30% rubber substitution rate can be used for structural design because it does not reduce Young's modulus and compressive strength due to the addition of rubber particles [3]. Additionally, the mechanical performance of precast concrete is enhanced by compressing it because the spacing between the microscopic rubber particles and the molecules of the mixture in cement is reduced, which increases the density, strength and Young's modulus of the rubber, and this method is also applicable to normal concrete [3]. More notably, even though the compressive resistance and Young's modulus of rubber concrete decreased, properties related to post-peak, such as ductility, freeze-thaw resistance, crack resistance, and dynamic properties, increased [3]. In addition to the comparison with conventional concrete, it was shown that even though compressing the preforms of rubber concrete can improve Young's modulus and compressive properties when compared cross-sectionally. Wu et al. proposed that the performance of rubber concrete is enhanced after compression. The limit strain, specific toughness, and peak strain of rubber concrete specimens are higher than those of uncompressed specimens with the same material ratio [3].

2.2. Splitting tensile strength

As shown in Fig. 3, the addition of rubber also decreases the splitting tensile strength of concrete, and the splitting tensile strength of rubber concrete gradually decreases as the replacement rate of rubber particles increases. Zhao et al. also listed relevant data in their experiments [1].

The experiments of Yang and Xiao used the equal volume substitution fine aggregate method to make RC specimens and tested the splitting tensile properties in this way as in Fig. 4 [4]. It is obvious from Fig. 4 and Table 2. that the splitting tensile strength of rubber concrete is reduced to different degrees compared with the benchmark group, regardless of the amount of admixture. This is because rubber deformation is larger and concrete deformation is smaller, and the two due to the inconsistency of the deformation, resulting in its interface is prone to cracks, splitting tensile strength is not high.

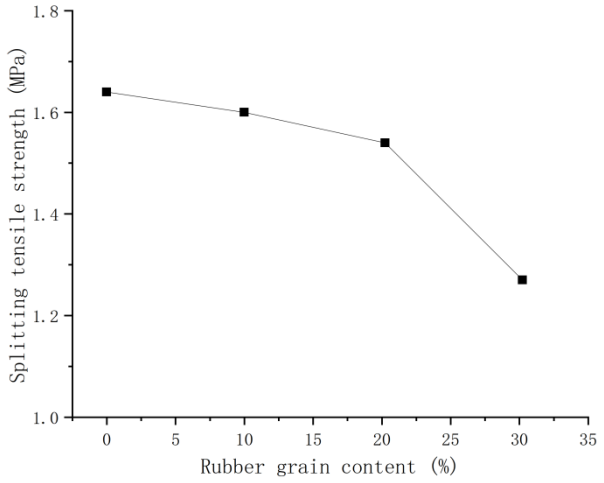

Figure 3. Concrete splitting tensile strength [2]

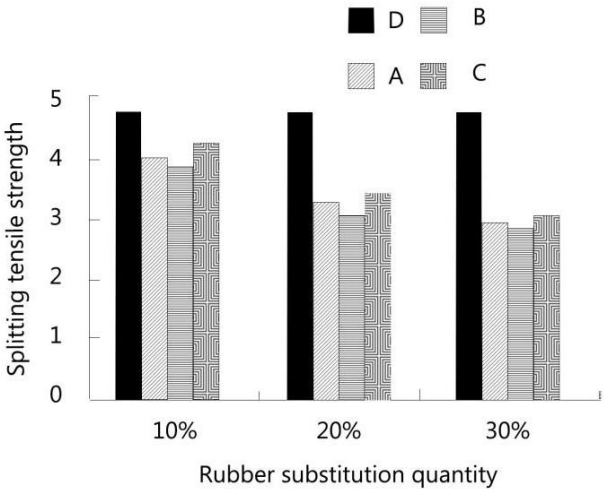

Figure 4. Splitting tensile strength after 28 days [4]

Table 2. Experimental results of cubic splitting tensile strength [4]

Number	Compressive strength/MPa	Splitting tensile strength/MPa	Tension and compression ratio
D0	52.2	4.81	0.092
A1	42.9	3.97	0.093
A2	35.5	3.33	0.094
A3	22.4	2.91	0.130
B1	32.4	3.88	0.120
B2	28.5	3.08	0.108
B3	24.7	2.82	0.144
C1	34.4	4.2	0.122
C2	25.1	3.43	0.126
C3	21.9	3.01	0.137

2.3. Small deformation damping and modulus of elasticity

Concrete mixed with rubber has lower strength and modulus of elasticity compared to normal concrete. After referring to the literature, it was found that there is a linear relationship between rubber powder admixture a% and static modulus of elasticity *E*. The linear regression equation of the paper is E = 4.188-0.397 Gpa with a correlation coefficient of 0.990 for the results of different mix ratios,

which indicated that the modulus of elasticity of concrete decreases with the increase of rubber admixture, and the correlation is nearly linear.

During the experiments, the ratio of the intrinsic frequencies of any concrete specimen is close to the theoretical value in the first three orders, which shows that the method of testing the concrete damping in the paper has a considerable degree of confidence.

The damping ratio ζ of concrete increases with the rise of rubber powder admixture. Similarly, in the linear regression using the results of different fit ratios, the equation is $\zeta = 1.029 + 0.27a$ correlation coefficient is 0.972. It is concluded that the rubber powder involved in the concrete can significantly increase the damping ratio of concrete. The damping ratio increases rapidly with the increase of the rubber powder after it is mixed with more than 2.5%, and the concrete with a higher damping ratio, elastic modulus, and compressive strength can be obtained at about 4.5%.

2.4. Flexural strength

After replacing the sand with rubber particles, it can be seen that the flexural strength (FS) of the specimen decreased with the increase of the replacement amount of rubber particles. When the volume content of rubber particles exceeded 20%, the FS of the specimens was reduced to a greater extent. This is consistent with the findings of other researchers.

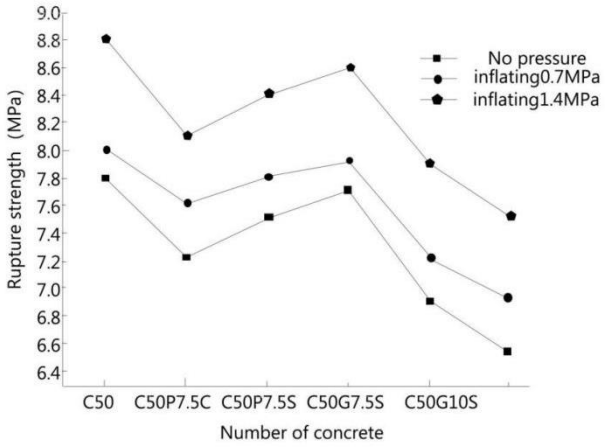

Figure 5. Flexural strength of concrete [2]

The compressive and flexural strengths of the pressurized concrete were obviously higher than those of the unpressurized rubber concrete, and the addition of 1.4 MPa pressure dramatically improved the FS of the RC compared to 0.7 MPa pressure. Fig. 5 shows a peak at C50G7.5S, indicating that there is an optimal amount of rubber admixture.

2.5. ABAQUS Modelling analysis

In order to gain more insight into the compressive properties of concrete and the changes after incorporation of rubber particles, this paper decided to analyze the stress-strain conditions of concrete using ABAQUS simulations to determine its basic mechanical properties. However, due to the lack of practical conditions, this paper uses concrete data from existing literature to perform ABAQUS analysis using elastic modulus and CDP plastic damage model.

Firstly, a cube of size 150mm×150mm is used as the basic member, and Young's modulus, Poisson's ratio and CDP model data are input. In order to simplify the analysis steps and reduce the difficulty of the analysis, in which the tensile damage is used GFI and the compression damage is zeroed to simulate the approximate curve.

Fully fixed constraints are created at its bottom, and to avoid data non-convergence, a force of displacement 1 in the vertical direction is applied at the top only, and the global size of the mesh is selected as 25 to create the model in Fig. 6, which is submitted and analyzed.

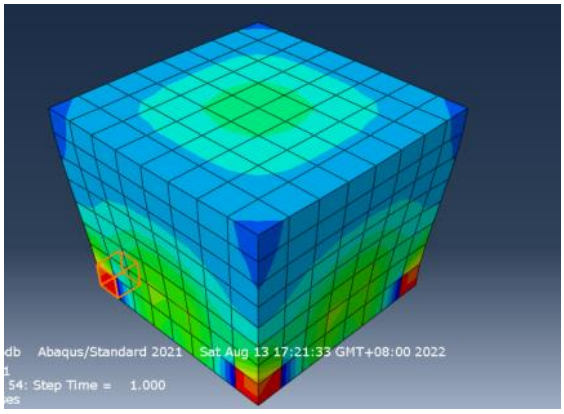

Figure 6. Cubic specimen

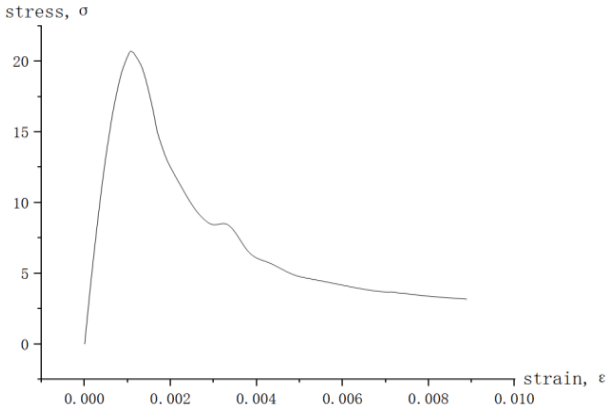

Figure 7. Stress-strain curve of traditional concrete (S-S)

It can be seen from Fig. 7 that the obtained simulation curve conforms to the standard S-S of concrete, which proves that the preliminary simplification method adopted has no effect on the experimental results. Based on the study of the paper by Xiong et al. [5], it was found that the incorporation of rubber causes a significant decline in the density of concrete, but in ABAQUS the density parameter only influences the dynamic analysis, so the effect of the density parameter can also be ignored in the simplified simulation analysis, and the only variables to be considered are Poisson's ratio and Young's modulus.

In the study of Xue et al., it is known that the Poisson's ratio of rubber does not change significantly compared to that of aggregate [6]. For rubber concrete, its Poisson's Ratio does not change much, so that Young's Modulus will be only modified in this paper. Through the study of Zhao, the elastic modulus of RC decreases with the grow of rubber admixture, and referring to the data of this paper in Fig. 8, the elastic modulus of simulated concrete is adjusted in the same proportion in this paper [7].

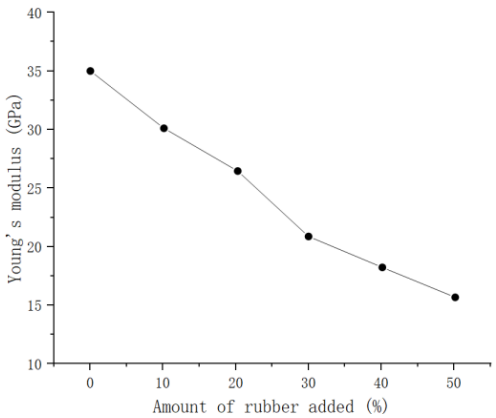

Figure 8. Young's modulus [7]

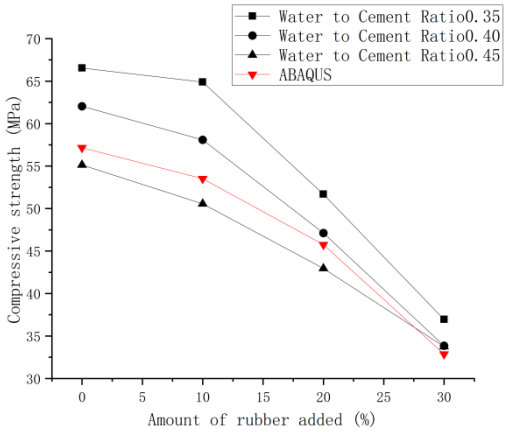

Figure 9. Compressive strength

In Fig. 9, the compressive strength curves have a similar downward trend that compressive strength of concrete decreases while increasing rubber admixture, where the ABAQUS curves are derived from software analysis and the other three curves are borrowed from the data of Xue et al. [6]. The variation of the curves is consistent with the results of other studies, so this paper concludes that this simplified ABAQUS analysis method is able to simulate the basic mechanical properties of RC. Therefore, this analysis method is tried to perform displacement analysis of members in buildings to determine the feasibility of replacing ordinary concrete with RC.

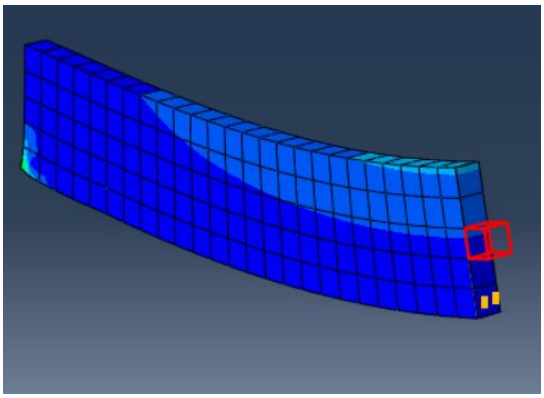

Figure 10. Stress cloud image of the beam

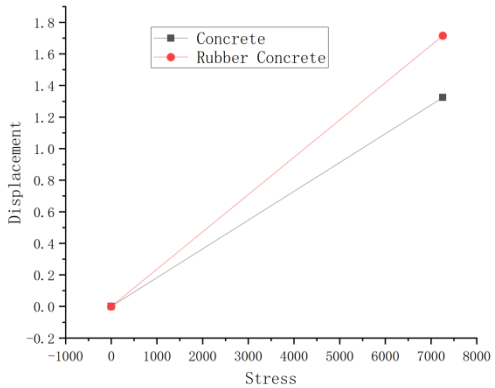

Figure 11. Selected points' variation of status

By using the above simple simulation method, a simple beam member is designed to simulate the force in the building, as shown in Fig. 10, which is a high section beam with a usual reinforcement, and the selected unit is the center point of the beam. According to the existing building code, a pressure of 10000 Pa is applied to the upper part of the beam within the conventional range to simulate the displacement changes of the beam member. The displacements and forces at the selected point are shown in Fig. 11 for two types of concrete, plain concrete and rubber concrete with 20% rubber content. It can be seen that the degree of deformation of the RC does increase compared to the normal

concrete under the conventional load, but it is still within the tolerable range. Considering that the safety load itself has exceeded the actual load, this paper concludes that it is feasible and more environmentally friendly to use RC instead of ordinary concrete in civil building construction.

3. Engineering Thermal Properties

The thermal properties of RC have a critical impact on what applications it is suitable for. For example, RC used for pouring pavements can be affected by environmental factors such as sunlight and high temperatures, so it is necessary to study the thermal properties of RC.

3.1. Thermal conductivity

Xu et al. revealed that the thermal conductivity of RC is poor [8]. The study on the thermal conductivity of rubber concrete shows that, since rubber is a material with poor thermal conductivity, the thermal conductivity of reinforced concrete is slow and small, and decreases with the increase of rubber powder.

Rubber is a poor conductor of heat, and adding rubber to concrete reduces its thermal conductivity. In addition, rubber granules are hydrophobic materials, making it low in combination with mortar when making, leading to an increase in the air content of concrete, which reduces the thermal conductivity.

3.2. Thermal expansion

The thermal expansion of rubber concrete is not identical to that of concrete. Xu et al. conducted a linear expansion coefficient test on RC by means of the thermal expansion coefficient formula and concluded that the linear expansion coefficient of rubber powder does not change much on concrete under different admixtures [8]. This is because rubber particles do not show a significant expansion phenomenon when heated, so adding to concrete also does not have a significant effect on the expansion of concrete.

In conclusion, by conducting thermal tests on RC at different parameters, it was concluded that the thermal conductivity of RC decreases with the increase of rubber granule parameters. By comparing the thermal expansion phenomenon of RC with that of ordinary concrete, it is concluded that the thermal expansion coefficient of RC is not much different from that of ordinary concrete.

4. Applications in Green Buildings

Rubber replacement particles make the concrete mix more porous, which increases the amount of air in the mix. Furthermore, rubber and air components also have poor heat conductivity, making them excellent insular materials.

A considerable decrease in the amplitude of transmitted acoustic waves occurs as a result of increased acoustic wave scattering caused by increasing porosity. As a result, the noise reduction coefficient rises as rubber content increases, and the sound absorption effect is more pronounced in the higher frequency range above 500Hz. In line with the results of previous studies, RC exhibits stronger vibration damping than ordinary concrete mixes because of the viscous nature of the rubber particles (supra, small damping deformation). As a result, it can absorb more energy under vibrational stress. This research draws the conclusion that RC is lightweight, suitably robust, and highly recommended for nonstructural uses to lessen noise and vibration in office, residential, and medical structures. For instance, a structure with rubber concrete floor, brick, and wall panels will guarantee minimum energy loss and preserve the building's insulating qualities throughout changes in outside temperature. The objective of creating sustainable and energy-efficient green buildings will thus be aided by the use of waste tire rubber materials [9, 10].

In conclusion, RC is lightweight, low-strength, and highly recommended for non-structural uses to lessen noise and vibration in office, residential, and medical structures. Low energy loss and

preservation of the building's insulating qualities during changes in outside temperature are guaranteed in a structure made up entirely of RC components, such as the floor, bricks, wall panels. Rubber from used tires can help achieve the objective of creating green, sustainable structures that are also energy efficient.

5. Conclusion

In this paper studied the RC material to search some mechanical properties, thermal properties and its application value in green building, and obtained the following conclusions.

(1) While increasing the rubber admixture, the compressive strength of RC gradually drops, and with the raise of water-cement ratio, the decreasing trend of compressive strength becomes relatively moderate. With the increase of water-cement ratio, the strength of rubber particles and mortar interface and mortar strength ratio increases, the decreasing trend of RC cubic compressive strength is relatively moderate. For the small deformation damping of RC, the damping ratio, elastic modulus and compressive strength can be obtained when the rubber powder admixture is about 4.5%. For the crack resistance and bending deformation performance of RC, the conclusion is drawn that, in the net cement paste, the mixing of rubber particles of waste tires can delay the cracking time of the circular specimens of cement net paste, which helps to improve the cracking resistance of cement-based cementitious materials. The delay time is related to the amount of rubber particles, the larger the content of rubber particles, the more significant the delay effect.

(2) Replacing part of sand with used tire rubber granules in cement mortar and concrete will reduce the mechanical properties such as compressive strength, splitting tensile strength, bending strength and elastic modulus. However, the toughness and adaptability to deformation of mortar and concrete can be significantly improved. The damage form changes from brittle fracture to ductile damage, and the final deformation value increases greatly.

(3) Through the thermal test of RC under different parameters, it is turn out that the thermal conductivity of RC declines while increasing the rubber grain parameters. By comparing the thermal expansion phenomenon of RC with that of ordinary concrete, it is concluded that there is not much differences between RC and ordinary concrete in the thermal expansion coefficient. By knowing these properties, RC can enter its more applicable field as a material with good thermal insulation and low thermal expansion.

As far as the value of RC in civil construction is concerned, it is a good building material for sound insulation, thermal insulation, and reduction of energy dissipation and even vibration damping. Therefore, future research can be extended to a material or casting method that is environmentally friendly and can achieve additional properties while maintaining or enhancing the original mechanical properties of concrete. The research in this paper is only a preliminary discussion of the cracking and deformation resistance of RC, and there are still many issues to be further investigated, such as the cracking and toughening mechanism, frost and seepage resistance and durability of RC.

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