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Study on Influence of Waste Tire Rubber Particles on Concrete Crack Resistance at Early Age

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Abstract: Two groups of variables, the amount of rubber particles and the size of rubber particles, were set up to evaluate the early crack resistance of rubber concrete after 24 hours of forming. Combined with the test results, the influence of the amount and particle size of rubber particles on the early crack resistance of concrete is analyzed. The experimental results show that the early crack resistance of concrete increases with the decrease of the size of rubber particles when the content of rubber particles is small, but decreases first and then increases when the content of rubber particles is large. When the size of rubber particles is large, the early crack resistance of concrete increases with the increase of the content of rubber particles, on the contrary, decreases first and then increases.

1. Introduction

It is an indisputable fact that the waste tire has become a new environmental pollution problem. At present, China has become the second largest country generating waste tires only next to the United States. Meanwhile, the quantity of waste tires increases continuously which has been over 3 million tons. The truth that the quantity of waste tires increases with a high speed has become a new source of solid waste pollution, which increases the pressure on resources and the environment.

In general, there are 5 main ways to recycle the waste tires^[1] including renovation of waste tires, production of rubber powder, production of reclaimed rubber, pyrolysis and refining method. However, all sorts of methods cannot be expanded on a large scale due to technical and economic constraints or serious environment pollution. Rubber concrete is one kind of novel concrete whose admixture is partially replaced by waste tire powders in order to extend recycling ways of waste tires and improve concrete performance at the same time. At present, the development and utilization of rubber concrete is still in its infancy, and most researchers only focus on its mechanical performance or working performance^{[2]-[4]} although tests associated with crack resistance of rubber concrete have been conducted by some researchers and the conclusion^[5] that rubber particles is in favor of the improvement of crack resistance of concrete has been obtained. In addition, gradient of adding amount of rubber particles has been set under the premise of a certain size of rubber particles with the obtainment of the variation tendency of crack resistance of concrete affected by the adding amount of



rubber particles. In fact, crack resistance of rubber concrete, especially crack resistance of rubber concrete at early age, is affected not only by the adding amount of rubber particles but the size of rubber particles as well. As a result, considering gradient of the adding amount of rubber particles and the size of rubber particles and exploring the change regularity by analyzing the results of tests are positive to the development of rubber concrete.

2. Materials and method

The test and assessment methods of crack resistance of rubber concrete are not unified at present. Comparative tests are adopted in general cases with the utilization of two forms of concrete specimens including plate specimen and cylinder specimen.

Plate specimens are anchored on the die frame with bolts around the specimen, and the bottom of the specimen is separated from the bottom of the die by plastic film. After casting, the dry exposure test is carried out at the prescribed time. Plate specimen does not need to remove the surrounding template before data measurement. It is easy to operate. It is easy to control the specimen which starts drying. The exposed surface is uniform when it is blown by air. It is also convenient to measure the length and width of cracks. Therefore, flat specimen is used in this experiment ^[6].

2.1 Material

Chinese PO.42.5 type ordinary Portland cement conforming to GB175 was used. River sands used as fine aggregates in the test were provided by local supplier whose fineness modulus was 2.6. The coarse aggregates used in this project were gravel whose maximum particle size was 30 millimeters. Rubber particles were fine particles made of steel wire tires.

2.2 Mixing proportion

Mixing proportion in the test was: c: w: s: g= 0.49: 1: 2.38: 1.58. Rubber replaced concrete and the method of equal-volume replacement was adopted in the test. Density of rubber was 1g/cm³. Test grouping was shown in Table 1.

Table.1 Table of test grouping

Group number	1	2	3	4	5	6	7	8	9	10	11	12	13
Adding amount (%)	0	5	5	5	5	10	10	10	10	15	15	15	15
Size (mesh)	-	10	20	30	40	10	20	30	40	10	20	30	40
Volume (L/ m ³)	0	50	50	50	50	100	100	100	100	150	150	150	150

2.3 Test method

2.3.1 Production of specimens for testing

The concrete specimens are 600 mm×600 mm×63 mm thin plates. The edge frame of the die is made of 63mm×40mm×6.3mm channel steel. The inner frame is equipped with 6 double-row bolts with a distance of 40mm. The bolts are arranged at 50mm and 100mm short and long intervals respectively. The 100mm bolts are in the upper layer and the 50mm bolts are in the lower layer. The bottom plates are made of a density plate of 20 mm thick, and a polyethylene film isolation layer is laid on the bottom plate. Figure 1 is physical diagram of the template.

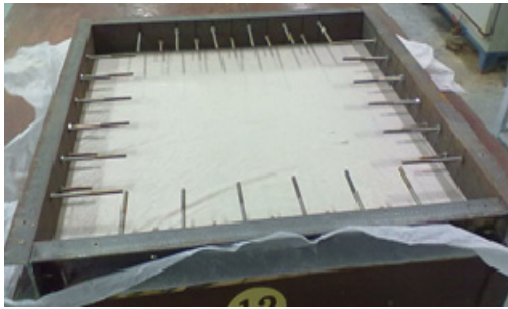


Figure.1 Physical diagram of the template

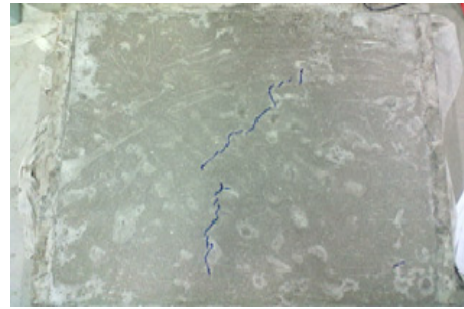


Figure.2 Factual picture of the flat sheet specimen

Forced action mixer was used to stir rubber concrete, with the mixing method of wetting after drying. Cement, sand, macadam and rubber particles of waste tires were dry-mixed for 1 to 2 minutes before being mixed with water for 2 to 3 minutes.

Specimens were covered with polyethylene film after molding. Polyethylene film was removed 2 hours later and the test started. Wind supply system offered parallel wind to the surface of specimen with the wind speed of 5 meters per hour. Surface wind speed was monitored by KIMO-VT100-type anemometer. Ambient temperature remained $30^{\circ}\text{C} \pm 2^{\circ}\text{C}$. 24 hours after forming, the quantity, width and length of cracks in all specimens were observed, and the evaluation parameters were calculated. Figure 2 is the physical diagram of the plate specimen.

2.3.2 Quantity of cracks

Visible cracks were regarded as main research objects whose length was measured with ruler. The straight distance between two ends of the crack was treated as the length of the crack approximately. When cracks appeared obvious bent, the sum of the length of polylines represented the length of cracks. Width of cracks was measured by DJCK-2-type crack width measuring instrument.

2.4 Evaluation of crack resistance at early age

Four parameters were used to finish the quantitative analysis of cracks of concrete^[7] including average cracking area a , total cracking area c , total cracking length, total quantity of cracks. The first 2 parameters were calculated according to the following methods.

$$a = \frac{1}{2N} \sum_{i=1}^N W_i L_i \quad (\text{mm}^2)$$

In the formula, W_i was the maximum width of the crack in section i . L_i was the maximum length of the crack in section i . N is the total quantity of cracks in the test area.

$$c = aN \quad (\text{mm}^2)$$

In the formula, a was the average cracking area and N was the total quantity.

3. Test results

According to the established test grouping and test method, the early crack resistance of rubber concrete is tested. The results are shown in Table 2.

Table.2 Table of test results of crack resistance

Group number	1	2	3	4	5	6	7	8	9	10	11	12	13
Total quantity of cracks	10	11	5	2	4	1	12	5	3	1	10	6	6
Total cracking length (mm)	521	510	170	120	100	15	680	225	255	60	440	120	185

Average cracking area (mm ²)	7.5	10.6	7.0	10.8	3.3	0.15	26.0	11.6	26.3	6.0	8.0	2.0	7.5
Total cracking area (mm ²)	75.0	116.8	69.5	21.5	13.3	0.15	312.0	58.0	79.0	6.0	80.3	12.2	45.3

3.1 Total quantity of cracks

The changes of the total quantity of cracks at early age of rubber concrete varying with the adding amount and size of rubber particles are showed in the figure 3.

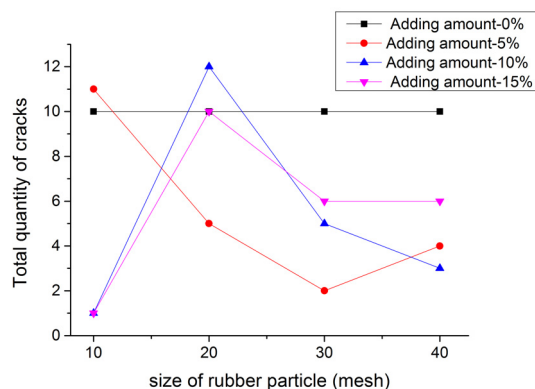


Figure.3 The total quantity of cracks

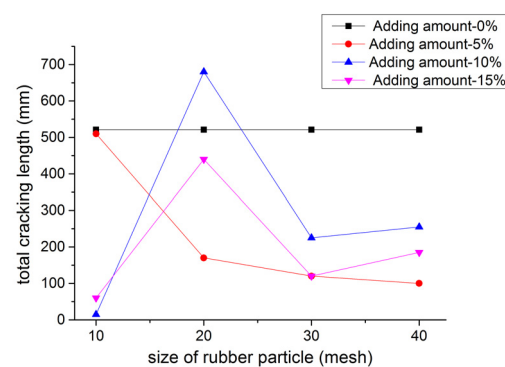


Figure.4 The total length of cracks

What can be obtained is followed.

- (1) When the adding amount of rubber particles is 5%, the quantity of cracks of concrete at early age decreases with the diminution of the size of rubber particles.
- (2) When the adding amount of rubber particles is 10% or 15%, the quantity of cracks of concrete at early age first increase and then decrease with the diminution of the size of rubber particles.
- (3) When the size of rubber particles is relatively large, the quantity of cracks of concrete at early age decreases with the increase of adding amount of rubber particles. On the contrary, when the size of rubber particles is relatively small, the quantity of cracks of concrete at early age increases with the increase of adding amount of rubber particles.

3.2 Total cracking length

The changes of the total cracking length at early age of rubber concrete varying with the adding amount and size of rubber particles are showed in the figure 4.

What can be obtained is followed.

- (1) When the adding amount of rubber particles is 5%, the total length of cracks of concrete at early age decreases with the diminution of the size of rubber particles.
- (2) When the adding amount of rubber particles is 10% or 15%, the total length of cracks of concrete at early age first increase and then decrease with the diminution of the size of rubber particles.
- (3) When the size of rubber particles is relatively large, the total length of cracks of concrete at early age decreases with the increase of adding amount of rubber particles. On the contrary, when the size of rubber particles is relatively small, the total length of cracks of concrete at early age first increase and then decrease with the increase of adding amount of rubber particles.

3.3 Average cracking area

The changes of the average cracking area at early age of rubber concrete varying with the adding

amount and size of rubber particles are showed in the figure 5.

What can be obtained is followed.

(1) When the size of rubber particles is relatively large, the average cracking area of concrete at early age decreases with the increase of adding amount of rubber particles.

(2) when the size of rubber particles is relatively small, the average cracking area of concrete at early age first increase and then decrease with the increase of adding amount of rubber particles.

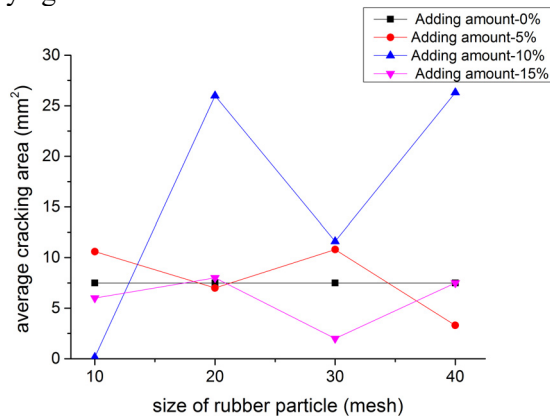


Figure.5 The average cracking area

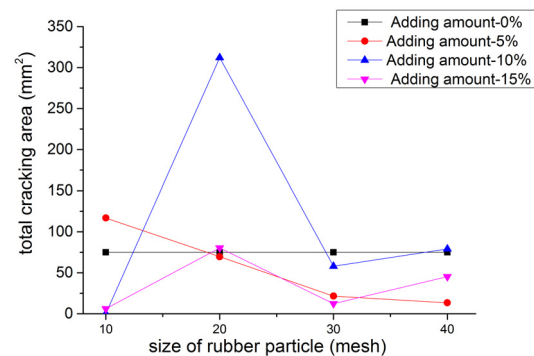


Figure.6 The total cracking area

3.4 Total cracking area

The changes of the total cracking area at early age of rubber concrete varying with the adding amount and size of rubber particles are showed in the figure 6.

What can be obtained is followed.

(1) When the adding amount of rubber particles is 5%, the total cracking area of concrete at early age decreases with the diminution of the size of rubber particles.

(2) When the adding amount of rubber particles is 10% or 15%, the average cracking area of concrete at early age first increase and then decrease with the diminution of the size of rubber particles.

(3) When the size of rubber particles is relatively large, the total cracking area of concrete at early age decreases with the increase of adding amount of rubber particles. On the contrary, when the size of rubber particles is relatively small, the total cracking area of concrete at early age first increase and then decreases with the increases of adding amount of rubber particles.

4. Causal analysis of crack resistance of rubber concrete

On the basis of experimental demonstration, there is no doubt that rubber particles can improve crack resistance especially crack resistance at early age of concrete. And the reason why rubber particles of waste tires can affect crack resistance of concrete is followed.

(1) As one kind of material with low elastic modulus, rubber particles of waste tires are able to offer sufficient deformation space to concrete shrinkage including plastic shrinkage, drying shrinkage, concrete creep, carbonized shrinkage, autogenous shrinkage and so on, and buffer the internal stress generated by the aforementioned deformation behavior, eliminating the stress concentration in the gap. The verification of the above conclusion is connected with the truth^[8] that stress relaxation occurs in the process of shrinkage of elastic rubber particles of waste tires and rubber concrete has significant energy dissipation function^[9].

(2) As micro flexible particle swarm distributed in concrete, rubber particles can intercept micro cracks in concrete. As a result, the growth of cracks from microcosm to macrocosm can be retarded or prevented^[10].

(3) The surface of rubber particles is rough, impermeable and flexible, as a result of which, bonding morphology located in the interfacial transition zone between rubber particles and cement

paste is better than that between rubber particles and polypropylene fiber and other concrete crack resistance and toughening material^[11], forming more uniform distribution of scalable particle swarm, significantly reducing the elastic modulus of concrete and improving its toughness.

(4) Thermal effect of rubber deformation caused by entropy change (tensile exothermic and retraction endothermic) helps to reduce the adiabatic temperature rise caused by cement hydration heat during concrete setting and hardening process, thereby reducing the temperature deformation of concrete.

(5) Rubber particles themselves do not absorb water but they have excellent water retention. Added into concrete, rubber particles contribute to the decrease of evaporation of free water in concrete, diminishing the shrinkage of concrete related to the loss of water and the stress connected with above shrinkage.

(6) The incorporation of rubber particles changes the pore structure of concrete, reduces the connecting holes in concrete, blockades the seepage passage, and reduces the evaporation and drying shrinkage of water in concrete.^{[12]-[13]}.

Previous studies have shown that when the content of rubber particles is less than 10%, the impermeability of concrete can be improved. When the content of rubber particles exceeds 10%, the impermeability of concrete will decrease^[14]. When the content of rubber particles is less than 50 kg/cm³, the impermeability of concrete will increase with the increase of the content of rubber particles. When the content of rubber particles is more than 50 kg/cm³, the impermeability of concrete will increase with the increase of the content of rubber particles^[15]. Adding rubber particles improves the frost resistance of concrete and with the increase of rubber particles content, the quality loss of concrete is smaller^[16]. Adding waste rubber particles into concrete can improve the sulfate resistance of concrete, and the optimal content of waste rubber particles is 2% - 5%^[17]. One of the main reasons for deterioration of concrete is the rapid infiltration of corrosive factors such as water, sulfate, chloride, carbon dioxide in the form of carbonate and cathode oxygen caused by early cracks in concrete. Therefore, the improvement of early crack resistance of concrete by adding waste tire rubber particles should be closely related to the improvement of durability and have similar influence trend, which also provides evidence for the correctness of the relevant conclusions of this experiment.

5. Conclusions

The following conclusions can be drawn by measuring and evaluating the relevant parameters of early crack resistance of concrete using flat plate specimens.

(1) When the adding content of rubber particles is 5%, the early crack resistance of concrete increases with the decrease of the size of rubber particles. When the adding content of rubber particles increases to 10%, the crack resistance of concrete decreases first and then increases.

(2) When the size of rubber particles is relatively large, the crack resistance of concrete at early age increases with the increase of adding amount of rubber particles. When the size of rubber particles is relatively small, the crack resistance of concrete at early age decreases first and then increases with the increase of adding amount of rubber particles.

(3) According to the trend of early crack resistance of rubber concrete varying with particle size gradient and content gradient, large particle size (10 mesh) is more suitable for mixing large amount of rubber into concrete to improve its early crack resistance.

(4) It is necessary to further study the micro-analysis of the interface between treated rubber particles and matrix and the early crack resistance and deformation mechanism of waste tire rubber concrete based on micro-mechanics.

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