Mechanical Enhancement Mechanism of Recycled Concrete Pavement

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Abstract. In pavement engineering, concrete is the most widely used building material, but it has its own shortcomings such as low tensile and flexural strength, brittleness and poor durability, which easily lead to pavement damage. Common cement concrete repair materials have a long construction period, which affects traffic. Therefore, it is necessary to adopt fast repair materials to meet the requirements of traffic in a short time. The addition of fibers in pavement cement concrete can significantly improve the tensile and flexural strength and durability of concrete, and play a role in strengthening toughness. Compared with the single fiber concrete, which is relatively mature at present, this paper aims at strengthening and repairing the defects of waste concrete subgrade and base cracks, void at the bottom of pavement slab, etc. The fluidity and mechanical properties of recycled aggregate grouting material are studied through experiments, and on this basis, the mechanical properties of recycled concrete grouting are further analyzed. The results reveal the relationship between the amount of recycled fine aggregate, ambient temperature and the fluidity of recycled aggregate grouting, and the influence of the amount of recycled fine aggregate and the water-cement ratio on the mechanical properties of recycled aggregate grouting and grouting recycled concrete.

Keywords: Building Waste, Waste Concrete, Fluidity, Flexural Strength, Compressive Strength

1. Introduction
With the rapid development of national economy and the increasing traffic volume, transportation vehicles tend to be large-scale and heavy-duty, and the service life of high-grade asphalt concrete highway is generally not up to the design level [1-4]. Especially for asphalt pavement under heavy traffic conditions in hot and humid areas of southern China, cracking, water loss and rutting are very common. How to improve the usability and durability of road asphalt pavement under the conditions of large traffic volume and complex environment, while taking into account the requirements of green environment protection [5-9], has become an urgent issue to be solved in the construction of high-grade highway. At present, the method of adding modifier or fiber in asphalt is widely used at home and abroad to improve the performance of asphalt, so as to improve the performance of asphalt concrete pavement [10, 11].

Aiming at a large number of reinforcement and repair projects in road engineering, such as void reinforcement of old cement concrete pavement slab, grouting reinforcement of pavement base,
grouting reinforcement of roadbed, grouting reinforcement around bridge piers and abutments, soil reinforcement of roadbed behind bridge abutments, grouting reinforcement of surrounding soil around box culverts and so on [12-17]. Grouting or grouting concrete can be used to repair it. In recent years, many scientific research institutions and experts at home and abroad have studied the raw materials of grouting material and repairing construction technology, etc. [18-20]. In this paper, the preparation of grouting material with recycled fine aggregate and its application in road repair have been deeply explored. In this paper, reclaimed fine aggregate is used to prepare grout with high fluidity. The effects of the amount of reclaimed fine aggregate and environmental temperature on the fluidity and strength of grout are studied.

2. Summary of recycled concrete
Recycled Aggregate Concrete (RAC) is short for Recycled Concrete. Recycled concrete Aggregate (RCA) is a kind of concrete which is made up of waste building refuse by crushing, cleaning and grading, and mixing according to a certain proportion and gradation to form Recycled Concrete Aggregate (RCA) for short, and partly or totally replacing natural aggregate. Waste concrete can not only save resources but also protect the environment by recycling, crushing and screening natural aggregates as concrete preparation. Since the birth of recycled concrete, a lot of research has been done on the mix ratio and performance of recycled concrete at home and abroad.

At present, there is no independent classification method to classify recycled concrete. Most scholars classify recycled concrete according to the classification method of natural aggregate. The regenerated particles with particle size of 0.16 mm to 5.00 mm are fine regenerated aggregates, while the coarse regenerated aggregates are regenerated particles with particle size greater than 5 mm. There are many fine cement slurry particles doped in recycled fine aggregate, so the particle size range of recycled fine aggregate can be 0.08 mm to 5.00 mm.

In recent years, fiber reinforced concrete has been initially applied in bridge deck, highway pavement and special structures in China. Among the fibers mixed with concrete, polyacrylonitrile fibers and steel fibers show good application prospects in strengthening concrete performance. They have their own advantages in improving concrete performance. Polyacrylonitrile fibers can effectively improve the early crack resistance of concrete and mortar, and with the increase of fiber content, the better the crack resistance effect, the more significant the crack resistance effect of long fibers. Polyacrylonitrile fibers can also significantly improve the wear resistance and impact resistance of pavement concrete, improve the carbonation resistance and sulfate resistance of concrete, which shows that polyacrylonitrile fibers can effectively improve the durability of concrete. The steel fiber has remarkable effect on improving the flexural strength, wear resistance and impact resistance of pavement concrete: the flexural strength increases by 13.1%-39.6%, the wear resistance increases by 6.8%-42.6%, and the impact resistance reaches 1.62-3.46 times of plain concrete. Gu Jichun and others [44] suggested that steel fiber content should be 1% from the point of view of engineering characteristics and economy. Mixing single fiber into concrete cannot achieve the ideal goal of comprehensive improvement of concrete performance, so the concept of hybrid fiber reinforced concrete is introduced. The properties of different fibers complement each other, and the properties of hybrid fibers are optimized. From its comprehensive effect, not only the cost of concrete is reduced, but also its performance meets the requirements of the project. The flexural toughness and fracture toughness of concrete are obviously improved. The two kinds of fibers make the reinforcing effect of concrete superimposed and the material properties complement each other. When steel fibers and polyacrylonitrile fibers are mixed into concrete, the formation and expansion of cracks on the coagulation are restricted. The number of plastic cracks on the coagulation of mixed fibers is less, the width is obviously smaller, and the internal voids on the coagulation are less. In addition, polyacrylonitrile fiber also has a certain effect on the frost resistance of coagulation.

3. Influence of recycled brick aggregate permeable concrete on mechanical properties
The particle size of recycled aggregate determines the mechanical strength and permeability of
pervious concrete to a large extent. It is difficult to obtain recycled brick aggregates with better granularity and smaller aggregate size by mechanical or manual crushing. Most of them are needle-like or sheet-like, and sintered clay bricks have more internal cracks and lower strength after repeated crushing. The recycled brick aggregate has larger particle size and less cementation point, and the integrity of the permeable concrete specimen is poor. Considering the comprehensive consideration, the design of recycled brick aggregate with diameter of 4.75mm to 31.5mm is selected.

The relationship between the particle size of recycled brick and the mechanical strength of specimens can be seen: The 28-day compressive strength and flexural strength of the pervious concrete first increase with the increase of recycled brick aggregate size, then stabilize or even decrease slightly. This is because the pervious concrete aggregate in this test is recycled brick aggregate with a single particle size. When the particle size of recycled brick aggregate is smaller, the contact points between aggregate particles are more and the total contact area is larger, and the contact surface and contact point are cemented by cement paste, so the strength of concrete will not be too low at this time. At the same time, the smaller the aggregate size of recycled brick, that is, the more times the clay brick is broken, the more irregular granular shapes such as needle flakes, the more developed the micro-cracks in the aggregate, the larger the crushing value of aggregate itself, resulting in the strength of concrete specimens will not be too large. When the aggregate size is too large, the contact points between aggregates are less, the voids are larger, and the integrity of the specimen is poor. Under the action of vertical pressure, the reinforcement effect of steel-like fibers is not obvious, mainly the compressive effect of recycled brick aggregate itself. In the flexural test, the bonding force of cementitious materials between bricks and aggregates first withdraws from work. The flexural strength of the specimens is mainly provided by imitation steel fibers which connect and anchor recycled brick aggregates. Under continuous pressure, some imitation steel fibers are pulled out or deformed significantly, and the specimens are damaged. Although the flexural strength of the specimens increased by imitation steel fibers compared with the same period, the compressive strength and flexural strength of the specimens were not ideal when the aggregate size was large. The test results show that the compressive strength of the test block is the greatest when the aggregate size of recycled brick is 13.2 mm to 16 mm, and the flexural strength of the test block is the greatest when the aggregate size of recycled brick is 9.5 mm to 16 mm.

Waste concrete is superior to ordinary concrete in terms of physical and mechanical properties. There are two main theories about the reinforcement mechanism of waste concrete: one is the theory of composite material mechanics, the other is the theory of fiber spacing based on fracture mechanics. These two theories explain the reinforcement effect of steel fibers on concrete from different angles, but the results are the same. The theory of composite mechanics regards waste concrete as a kind of fiber reinforced system. The direction coefficient of fiber (c) and the length coefficient of fiber (l) are introduced. The stress, elastic modulus and strength of waste concrete are deduced by the principle of mixing. According to the theory of composite mechanics, the formula for calculating tensile strength of waste concrete is as follows:

\[ f_{\beta} = f_{i}(1 - \rho_{f}) + \eta_{p} d_{f} \rho_{f} / d_{f} \]  

(1)

In the formula, \( f \) is the volume ratio of steel fibers, \( f_{i} \) is the length of steel fibers, \( d_{f} \) is the diameter of steel fibers, and the average bond stress between steel fibers and concrete. The theory of fiber spacing is based on the principle of linear elastic fracture mechanics to explain the restraint effect of steel fibers on the occurrence and development of cracks, and the final results are the same as the previous formula. The main factors affecting the performance of waste concrete are the type of steel fiber, the content of steel fiber and the ratio of length to diameter of steel fiber. In addition, sand ratio, maximum particle size ratio of coarse aggregate, water reducing agent, admixture and other factors can also affect the performance of waste concrete. When waste concrete is applied to pavement materials, it is also affected by underground drainage conditions.
4. Strengthening mechanism of concrete

At present, there are two different theoretical explanations for the reinforcing mechanism of short fibers uniformly and arbitrarily distributed in concrete. One is the "fiber spacing mechanism" proposed by Romualdi, the other is the "composite material mechanism" proposed by Swamy, Mangat and others in Britain.

The mechanism is that according to the linear elastic fracture mechanics, the restraint effect of fibers on the occurrence and development of cracks is explained. In order to improve the strength of this material, it is necessary to reduce the degree of defects, improve the toughness and reduce the stress concentration factor at the end of internal cracks. Assuming that the fibers are in checkerboard distribution (spacing S) in the direction of tension and that cracks (radius a) exist in the center surrounded by four fibers, the bond stress distribution (t) caused by tensile stress occurs near the end of the crack adjacent to the fibers and plays a role in restraining the development of cracks. If the stress concentration factor Kδ at the end of an internal crack is not caused by tensile stress, but the stress concentration factor, which is contrary to the bond stress distribution near the end of the crack and plays a restraining role, is Kf, the total stress coefficient Kt will decrease, that is:

$$K_t = K_δ - K_f$$

Therefore, the initial crack strength can be improved. It can be seen that the greater the number of fibers per unit area (n), that is, the smaller the fiber spacing, the better the effect of strength improvement.

In order to confirm that the initial crack strength of concrete is dominated by the fiber spacing, Romuldi et al. have also made corresponding experiments. The experimental results are close to the theoretical deduction. Both theoretical calculation and experimental results show that the tensile strength is approximately proportional to the fiber spacing at a certain volume fraction.

The starting point of this mechanism is the mixing principle of composite materials. Fiber reinforced concrete (FRC) is regarded as a fiber reinforced system, and the tensile and flexural strength of FRC is deduced by the mixing principle. The strength of the composite is determined by the volume ratio and stress of the fiber and the matrix when the matrix and the fiber are fully bonded and the tensile force is applied on the composite composed of the matrix and the continuous fiber. The formula is expressed as follows:

$$R_{X1} = R_{j1} \quad V_j / v + \delta_{vy} = R_j \quad V_j + \delta_{vxx}$$

In the formula, the tensile strength of RX1, Rj1 inflammatory fiber reinforced concrete and matrix, δx is the tensile stress of fiber when the tensile strength of fiber reinforced concrete is reached, and the volume of matrix in unit volume is vj=v-vx=1-vx. The above formula is based on the principle that the fibers are pulled out from the matrix, that is, the bond failure between the matrix and the fibers. The relationship between the strength of waste concrete and the amount of fibers, slenderness ratio and bond force is proposed. The above two mechanisms are all used to estimate the initial crack strength or proportional limit of fiber reinforced concrete. As for the ultimate strength of fiber reinforced concrete, it mainly depends on the volume percentage, radius of fiber and the interface bond between fiber and concrete matrix.

5. Waste concrete construction technology requirements

(1) It is advisable to use mechanical mixing. When the volume ratio of steel fibers is high and the consistency of mixtures is high, the mixer's primary mixing quantity is not more than 80% of its rated mixing quantity.

(2) The feeding sequence and method of mixing should be based on the principle that the steel fibers are not agglomerated, bending or breaking occurs during mixing, that the mixer is not stopped running because of overload, and that the outlet is not blocked. Generally, according to the sequence of cement, steel fiber, fine aggregate, coarse aggregate and water, dry mixing is first followed by wet
mixing. Steel fibers should be put in two to three times to ensure that steel fibers are not agglomerated, bent or broken in the mixer.

(3) The mixing time of waste concrete should be determined by field mixing test, and the mixing time should be prolonged by 1-2 minutes compared with that of ordinary concrete. When the mixing test of dry mixing before wet mixing is adopted, the dry mixing time should not be less than 1.5 minutes.

(4) Tunnel steel fiber cement concrete pavement is preferred to adopt the slip form paver. Sliding form paver can ensure the quality uniformity, smoothness, flexural strength and wear resistance of tunnel pavement, and eliminate the influence of poor quality of manual paving of plain concrete on traditional tunnel pavement. Sliding form paving technology is used to pave the waste concrete pavement and the preparation work before the general cement concrete pavement paving is the same, which generally includes the cleaning of the base, measuring and laying out, and the preparation of various materials and so on.

(5) According to the meteorological and hydrological conditions in the tunnel area, the waterproof and drainage work of the tunnel entrance, lining and roadbed should be done well. The comprehensive treatment measures of "prevention, drainage, blockage and interception" should be adopted, with "prevention and drainage" as the main method.

6. Summary
The main diseases of overlay asphalt layer are reflective cracks and rutting. The mechanism is that stress concentration exists in overlay layer due to the influence of original pavement diseases. After the implementation of this project, the road condition has been fully restored, and all the indexes meet the standards. Good application results have been achieved by adding steel fibers into the cement concrete for quick repairing the pavement, and the cubic compressive strength has been significantly improved, while the addition of polyacrylonitrile fibers has slightly improved. The cubic compressive strength of concrete with mixed fibers is higher than that of concrete without mixed fibers. The degree of improvement depends on the mixing ratio of mixed fibers. In fact, it is too early to make a qualified technical and economic evaluation of steel fiber reinforced concrete. It is also necessary to take into account the long-term and short-term benefits, one-time investment, maintenance costs and material costs.

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