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Research Progress on Mechanical Property and Durability of Recycled Aggregate Road Base

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Abstract: With the rapid development and modernization of the construction industry in China, large-scale infrastructure projects and the demolition of aging buildings have led to a shortage of natural aggregates and a significant increase in construction waste. This paper provides a comprehensive review of recent research on the application of recycled aggregates in highway engineering, focusing on the mechanical properties, durability, and reinforcement techniques of recycled cement stabilized macadam pavement base. The findings offer valuable insights for the practical use of recycled aggregates in engineering projects.

Keywords: recycled aggregate; mechanical properties; durability; aggregate reinforcement

I. Introduction

The cement stabilized macadam (CSM) base has good stiffness and flexural tensile strength, can provide strong load distribution ability and fatigue resistance, and is widely used in highway construction in China. With the rapid development of highway construction in China, the demand for stone is increasing, but natural aggregates are becoming increasingly scarce. On the other hand, the amount of construction waste generated in China is increasing year by year, and this kind of waste not only occupies land, but also seriously affects the environment. Scholars at home and abroad will crush and grade construction waste to produce recycled aggregates, and study the performance and application of recycled aggregates, which can not only alleviate the contradiction between supply and demand of natural building materials, but also realize the recycling of construction waste[1].

The application of recycled aggregate rebase shows good road performance[2], but there are many microcracks inside the recycled aggregate, and the surface is attached to the old mortar[3], which has a great impact on the performance of CSM base. In this paper, the performance of recycled aggregates in recent years and their intensification research are summarized, so as to provide a reference for the application of recycled aggregates in the substrates.

II. Study on the Performance of Recycled CSM

Zhang[4] studied the CSM of waste concrete recycled coarse aggregate instead of part of natural aggregate, and analyzed the 7-day strength of the mixture under different substitution rates and cement contents. When the cement content of recycled concrete is constant, with the increase of substitution rate, the compressive strength and splitting strength of recycled concrete are relatively reduced. When the substitution rate is constant, increasing the cement content can effectively increase its compressive strength and splitting strength. Xiao[5] carried out 7-day unconfined compressive strength tests and splitting tests on CSM with different recycled aggregate substitution rates. Its unconfined compressive strength and splitting strength first increased and then decreased with the increase of recycled aggregate content, and the strength was the highest when the substitution rate was 30%. Li[6] conducted strength tests on recycled CSM, with the increase of the substitution rate of recycled aggregate, the compressive strength and splitting strength of CSM showed an upward trend, and the strength was the highest at 100% substitution rate. Li[7] conducted experiments on recycled CSM. The experimental results showed that the 7-day unconfined compressive strength of the material first decreased and then increased with the increase in the proportion of recycled aggregate. The 7-day unconfined compressive strength and splitting tensile strength from the aforementioned literature are illustrated in Figure1 and Figure2:

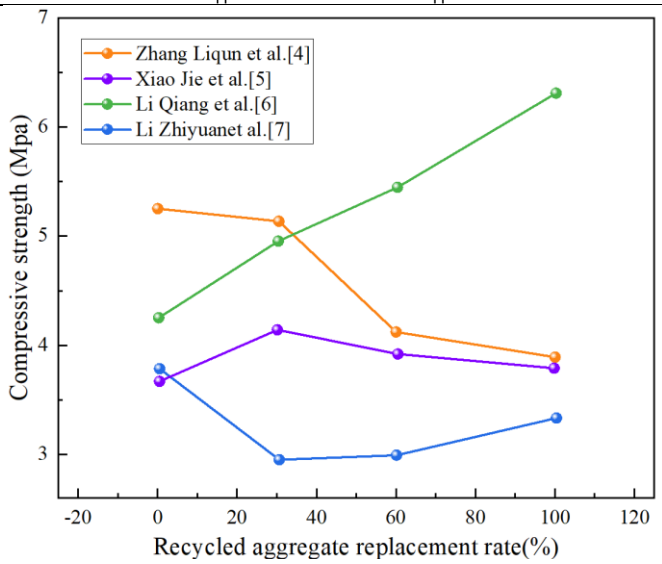

Figure1: 7-day Unconfined Compressive Strength

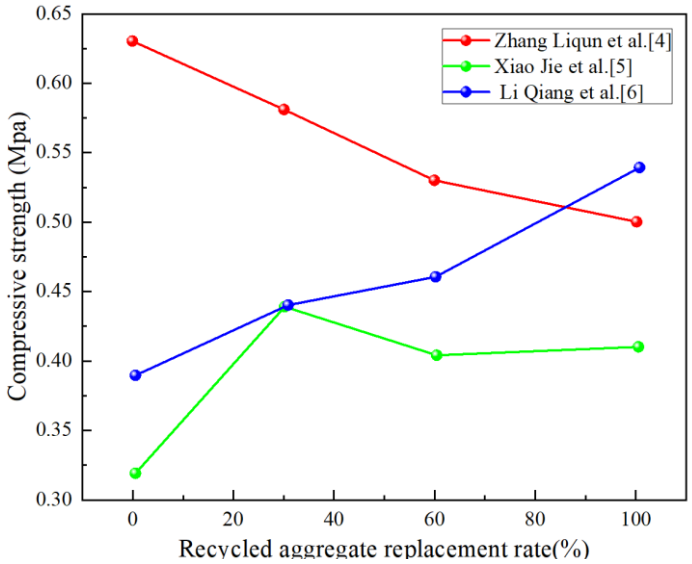

Figure 2: Cleavage Strength

In summary, in the study of recycled CSM, the influence of recycled aggregate on the mechanical properties of CSM is very different. Due to the complex impact of recycled aggregate on concrete, on the one hand, aggregate has high porosity and high water absorption, which has an adverse effect on the compressive performance of concrete. On the other hand, there will be hydrated cementitious materials inside the old mortar to which the aggregate is attached, which has a favorable effect on the compressive performance of concrete. In the test of recycled concrete, the effect of recycled aggregate from different sources on the concrete is different.

Concrete durability is the ability to maintain the safety and normal use of a structure. Recycled aggregate is crushed and produced, which has problems such as large porosity and high water absorption, which has a great impact on the durability of concrete. Mo[8] conducted freeze-thaw tests on recycled CSM. The test results show that with the increase of the number of freeze-thaw cycles, the mass loss rate and strength loss rate of crushed stone material gradually increase. With the increase of recycled aggregate content, the mass loss and strength loss of crushed stone material are greater.

Yang[9] conducted freeze-thaw tests on recycled CSM, and the experimental results showed that the more recycled aggregate, the greater the aggregate strength loss. Yang[10] found that the greater the substitution rate of recycled aggregate, the greater the mass of the mixture erosion loss. Chen[11] evaluated the erosion resistance of CSM cold recycling mixture through the erosion test. The test results show that the scouring amount of the recycled mixture decreases with the increase of cement dose, and increases with the extension of cumulative scouring time.

Recycled aggregate, characterized by its higher water absorption and porosity, significantly increases the water content in CSM. After undergoing freeze-thaw cycles, the material experiences increased ice formation and frost heaving, which subsequently leads to structural damage and a reduction in strength. In terms of erosion resistance, the semi-rigid base layer is insufficient to withstand erosion, resulting in material loosening. Due to its elevated water content, recycled aggregate suffers greater erosion loss. However, an increase in cement content can mitigate the erosion volume.

As a semi-rigid base material, like CSM, cement-stabilized construction waste recycled material will shrink in the process of water dispersion and loss. Yue Hongping[12] used the dry shrinkage index and dry shrinkage strain as indicators to study the variation law of the dry shrinkage performance of the mixture. The results show that the dry shrinkage strain of recycled cement stabilized crushed stone increases with the increase of water loss rate, and the dry shrinkage strain increases the fastest from 4 to 7 days. Gu Wan[13] studied the applicability of recycled CSM to crushed asphalt concrete and cement concrete. The results show that with the addition of cement recycled aggregate, the dry shrinkage strain and temperature shrinkage coefficient of CSM will be significantly increased, and the corresponding water loss rate will also be increased. The addition of asphalt recycled aggregate will reduce the sensitivity of CSM to water and temperature, and improve its dry shrinkage and temperature shrinkage performance.

Zou[14] showed that the water demand and water loss rate of recycled aggregate CSM were high, resulting in a significant increase in the shrinkage strain of the recycled aggregate mixture compared with natural aggregates, but the shrinkage strain was occurred mostly in the early stage, and the shrinkage of all mixtures tended to be stable after 28 days. Zhang[15] found that the dry shrinkage law of recycled aggregate CSM with different substitution rates was similar, and the dry shrinkage strain increased the most from 0d to 7d, the largest at 28d, and then tended to be stable. The temperature shrinkage coefficient of cement stabilized recycled mixture decreases first and then increases with the decrease of temperature. In terms of the overall trend, it increases with the increase of recycled aggregate content. The presence of old mortar on the outside of the recycled aggregate increases the water requirement for the preparation of CSM, and the water loss and shrinkage strain also increase. In order to improve the crack resistance of recycled CSM, the maintenance should be strengthened in the early stage of road construction to prevent the rapid dispersion of water and the occurrence of shrinkage cracks.

III. Reinforcement of Recycled CSM

There have been a lot of studies on the application of recycled aggregates in cement stabilized bases, and the conclusion of more research is that most of the recycled aggregates, because of their use of deterioration and destruction methods and other reasons, their mechanical properties are often lower than natural aggregates. How to strengthen the cement recycled base layer and ensure the mechanical properties of the base layer while increasing the utilization rate of recycled aggregate has become a research direction that has attracted great attention.

For the recycled CSM, the recycled aggregate is used as the aggregate for secondary processing, and the crushing value is high, and poor surface mortar adhesion, and it is difficult to achieve a large improvement breakthrough in the utilization rate of aggregate waste. A series of studies have been carried out on the improvement of the mechanical properties of CSM by domestic and foreign researchers, and it is believed that the relevant external modified materials can improve the performance of CSM to a certain extent[16].

Xue[17] studied the effect of basalt fiber on the performance of cement to stabilize gravel road. As shown in Figure 3, when the fiber is not mixed, the strength and dry shrinkage performance of CSM with 100% recycled aggregate content are lower than those of ordinary CSM. After adding 100% fiber, the strength and dry shrinkage performance of CSM increased compared with that of CSM without fiber, though it was still lower than that of ordinary CSM.

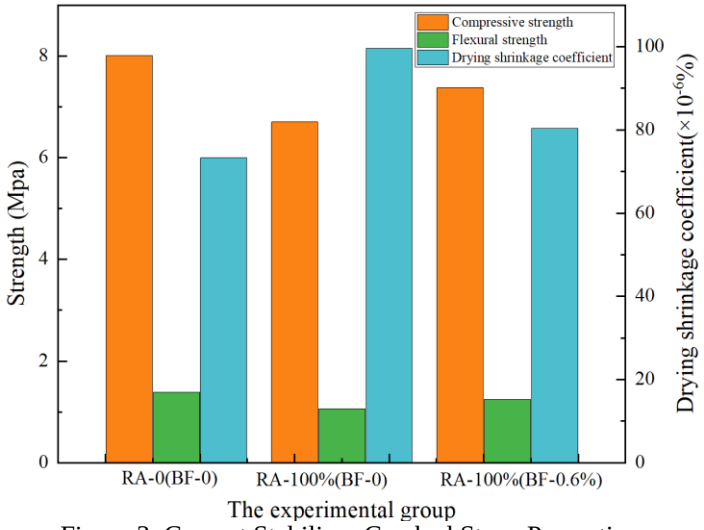

Figure 3: Cement Stabilizes Crushed Stone Properties

Yang[18] studied the properties of polypropylene fiber-reinforced recycled CSM base materials. It was found that the use of 0.3% polypropylene fiber significantly improved the performance of recycled CSM. Compared with ordinary recycled CSM materials, the compressive strength of CSM mixed with 0.3% polypropylene fiber is generally increased by about 6.0%. The overall splitting strength increased by about 21%.

Song[19] selected polypropylene fiber and imitation steel fiber as the external fibers of CSM and recycled CSM, and compared the properties of polypropylene fiber and imitation steel fiber materials, natural gravel and recycled aggregate. The compressive strength, splitting strength and dry shrinkage properties of the two fibers on CSM and recycled CSM were strengthened, and the effect of imitation steel fiber is better than that of polypropylene fiber.

Lei[20] used fly ash and polypropylene fiber mono and compound blending to study their improvement effect on the stable gravel performance of recycled cement. In the experiment, the fly ash monodoping, polypropylene fiber monodoping, and fly ash polypropylene fiber doping were compared and analyzed. The mechanical strength and durability of the recycled CSM material improved by the addition of fly ash and polypropylene fiber were improved, and the compressive strength and fatigue life of the recycled CSM material improved by fly ash were better than those of polypropylene fiber, while the splitting strength and drying shrinkage resistance of polypropylene fiber were more significant in improving the crushed stone material, and the results of compound doping were significantly better than those of single doping.

From the perspective of the mechanism of action, fly ash is an alkaline cementitious material, which will produce a chemical reaction similar to the hydration and decomposition of cement when fused with water, which can further enhance the overall strength of CSM material. The addition of fibers is mainly through the disordered distribution in the process of material mixing, to realize the overlapping and reinforcement between fibers, cement and aggregates, and to optimize and enhance the internal structure of materials from the physical and mechanical stress level. Therefore, the compound blending of fly ash and polypropylene fiber can make up for the lack of improvement of a single material, realize the composite improvement and enhancement of the physical and chemical layers of recycled CSM, and is more conducive to promoting the long-term safe service and improving the durability of recycled CSM material.

Katz[21] used ultrasonic intensification to remove the mortar on the surface of the recycled aggregate, and added a certain amount of silica powder to reduce the water absorption rate of the aggregate, and at the same time, the alkalizing reaction between the silica powder and the surface of the aggregate was carried out to increase the crushing value of the aggregate. Li[22] used three methods to strengthen the aggregates: physical abrasion, hydrochloric acid immersion, and silicone resin spraying. In the mechanical experiments, the mechanical strength of CSM was improved after physical abrasion and hydrochloric acid immersion strengthening, and the physical abrasion method was more effective, but the dry shrinkage performance was still worse than that of natural aggregate CSM. The mechanical strength of recycled CSM was not improved by the strengthening treatment by silicone resin spraying, but its dry shrinkage performance was similar to that of CSM made of natural aggregates.

Yang[9] used an abrasion tester and three chemical reagents, sodium silicate, nano-SiO2 and permeable crystalline materials, to physically and chemically strengthen the recycled aggregates, respectively. Compared

with physical strengthening, chemical strengthening has a more meditative effect on improving the water absorption of recycled aggregates.

Li[23] used PVA solution to strengthen the recycled mixed aggregate and brick slag, and the crushing value of the reinforced recycled aggregate decreased to varying degrees, and the strength increased, but the durability of the cement stabilized recycled mixture after aggregate reinforcement was not significantly improved.

The intensification treatment of recycled aggregate is mainly divided into removal of old mortar and aggregate strengthening, and the treatment methods mainly include physical strengthening (mechanical grinding, ultrasonic cleaning, etc.) and chemical strengthening (PVA solution, acid solution, sodium silicate, etc.). Remove part of the old cement mortar on the surface of the recycled aggregate, so as to improve the mechanical strength and shrinkage performance of CSM to a certain extent, but its shrinkage performance is still worse than that of all natural aggregates. Strengthened treatment, such as organic silicone resin spraying, will make the surface of the recycled aggregate smooth, which is not conducive to the formation of effective intercalation and gripping between the aggregates, so the mechanical strength of CSM cannot be improved; However, the silicone resin film formed on the surface of the recycled aggregate can fill its pores, thus improving its shrinkage properties and making it nearly entirely natural aggregate.

IV. Conclusion and Outlook

(1) The influence of recycled aggregate on the mechanical properties of CSM is complex, with a multitude of factors involved. Experimental results from different scholars regarding the properties of recycled aggregates exhibit considerable variability. Therefore, specific experimental analysis is required to accurately determine the mechanical properties of particular types of recycled aggregates.

(2) Strengthening recycled CSM is also a primary research focus for many scholars. Existing strengthening methods primarily involve the addition of external admixtures and the treatment of recycled aggregates. External admixtures mainly include materials such as fibers and fly ash, while the treatment of recycled aggregates aims to enhance the aggregate itself, thereby bringing its mechanical properties closer to those of natural aggregates.

(3) The application of recycled building materials aligns with national green development plans and offers significant economic benefits. For a long time, research into the application of recycled aggregates has been and will continue to be the mainstream, showing an increasing trend in future applications.

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