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Research Article

Study on Strength Enhancement Factors of Cement-Stabilized Recycled Aggregate

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With the rapid development and urbanization, huge amounts of construction and demolition (C & D) waste are produced. In order to protect the environment and conserve natural resources, promoting renewable materials, with C & D waste as raw materials, is imperative. However, the poor mechanical properties of recycled aggregate hinder its applicability in projects. In this study, two kinds of recycled aggregates, that is, concrete and brick slag, were strengthened with polyvinyl alcohol (PVA) solution, and the optimal strengthening time and soaking concentration were determined. Recycled mixed aggregate and brick slag were designed with two kinds of graded recycled aggregate. Recycled cement-stabilized crushed stone specimens were prepared for a 7-day unconfined compression and freeze-thaw cycle test. The results showed that the recycled aggregate strength was improved to a certain extent, while the improvement of brick slag aggregate was more pronounced. The recycled mixture with less cement-stabilized brick slag can be used for the base course of heavy traffic secondary highways before strengthening. Cement-stabilized unreinforced brick slag has shown low strength, so it is not suitable to be used as a base on heavy traffic roads. The strengthened cement-stabilized recycled mixture and cement-stabilized brick slag could meet the requirements of heavy traffic class I and class II highways, respectively. When the cement grade, dosage, and grading type were kept the same, the strength of cement-stabilized crushed stone prepared with larger aggregates was slightly lower. After the freeze-thaw cyclic test, the strength loss of the recycled stable gravel was low, and its durability did not significantly improve after the reinforcement of recycled aggregate.

1. Introduction

The exploitation of natural sand causes great damage to the local environment. Sand mining can change the landform of the riverbed, reduce the visibility of water bodies, destroy the living environment of aquatic organisms and the ecosystem of the whole river, and change the overall local environment [1, 2]. Stone mining also causes great damage to the surrounding environment. A series of byproducts such as dust, wastewater, noise, and waste residue are produced during stone mining and processing, damaging the construction and the surrounding living environment [3–5]. It requires new sand and stone resources. In order to ensure the project's quality, new sand and stone will be used to partially or completely replace natural aggregates to alleviate the contradiction between the supply and demand of natural sand and stone. Construction of urban infrastructure, demolishing rural houses, urban waste buildings, and abandoned overpasses produce a lot of construction and demolition (C & D) waste, accounting for 30%–40% of the total urban waste [6–9].

Construction waste treatment has always been a problem faced by the world [10]. Recyclable green building materials are produced through different processing techniques, such as the crushing and sieving of solid waste, which can achieve the sustainable development of building materials. Such techniques have been recognized and supported by the global construction industry [11, 12]. The types of C & D waste are mainly affected by urban construction, demolition, and new construction, including concrete, glass, ceramics, bricks, wood, coal gangue, rubber, and roof tiles [13]. In addition, the composition of construction waste in demolishing old buildings is closely related to the type and structural form of buildings. For example, in the old brick-concrete structure, bricks, tiles, and concrete account for 80% of the total, and the rest are lime, wood, broken glass, and slag. Kadir and Mohajerani [14] reviewed the current research progress in the production of sintered clay bricks using various wastes. It was shown that adding different materials to bricks had different effects on the mechanical and physical properties of bricks. It has now been found that most of the various wastes added to the production of sintered clay bricks positively affect the performance of bricks.

Cement concrete is the most commonly used material in infrastructure, such as roads, buildings, and bridges [15]. Structures reaching the end of their service life, housing demolition, and highway reconstruction result in a great amount of waste concrete being generated [16]. Recycling concrete waste is of great help to society, and it has considerable economic benefits in reducing the accumulation of building materials, vehicle transportation costs, and soil resources [17]. Cement concrete is a mixture of cement, stone, and water in certain proportions [18]. Using waste concrete to produce recycled concrete can reduce the use of quarried stones and carbon dioxide emissions while ensuring the balance of the ecological environment. Doušová and Ritterman [19] performed ion adsorption experiments in batches by adding concrete mud waste (CSW) at a laboratory temperature of 20°C and observed the experimental data. It was found that the modified concrete mud waste (CSW) enhanced the adsorption selectivity of anions in polluted water bodies, and the percentage of improvement was about 20%.

Governed by the increasing shortage of mineral resources and the concept of green and sustainable road construction, recycling technology has been used in different road structural layers. Many waste concrete blocks are produced in the reconstruction and expansion projects of traditional cement concrete roads, and the recycled aggregates can be obtained by crushing and processing them. Some of its properties can meet the requirements of road aggregate. Using recycled aggregate in the cement-stabilized crushed stone base can ensure the adequate mechanical properties of the base and can promote the recycling of waste mineral resources. However, due to the high crushing value of recycled aggregate and the significant amount of adhered mortar, it is difficult to achieve a breakthrough in improving the aggregate recycling rate.

Many researchers have conducted experimental studies on improving the mechanical properties of cement-stabilized macadam materials. It is believed that the relevant admixture of modifier materials can improve the properties of cement-stabilized macadam to a certain extent. Saccani et al. [20] developed composites using the wastes derived from recycling carbon fiber/epoxy composites. The short fibers were added to the Portland cement, and its processability, porosity, microstructure, and physical and mechanical properties were studied. It was found that the resulting flexural strength and toughness were improved. Thus, the waste from epoxy resin-carbon fiber composites can be used as reinforcement in building materials.

Recycled aggregate is loose, porous, rough, and light in texture. Part of the aggregate surface has adhered mortar. However, the natural aggregate surface is smooth, and the particle size distribution is uniform [21]. At present, the recycling of waste concrete is the focus of researchers all over the world. Recycled concrete is the most valuable, cost-effective recycling, and the most widely used concrete in research studies [22]. Many researchers have used different proportions of recycled aggregates in concrete, and the resulting physical, mechanical, and durability properties have been studied [23]. Due to the high porosity, low strength, and other inferior properties of recycled concrete, different improvement measures such as mixing ratio, mixing process, and recycled aggregate transformation on the aggregate surface have been suggested, leading to a greater replacement level of natural aggregates with recycled aggregates. The corresponding results have shown satisfactory performance [24]. Recycled cement refers to using limestone in waste concrete as calcium hydride in cement to produce cement clinker or cement mixture, which is added to it [25]. Through the statistics and analysis of Shenzhen's 2010–2015 information data on demolition waste from generation to disposal, Wu et al. [26] found that Shenzhen produces tens of millions of tonnes of construction waste every year and shows a continuous upward trend in the future. Thus, by maximizing the recycling of construction waste, the benefits will be substantial.

A cement-stabilized macadam base is widely used in highway engineering because of its high mechanical strength, durability, frost resistance, and good water stability. Since the strength of brick slag is lower than that of natural stone, the research and applications of construction waste with brick slag as the main component in the cement-stabilized crushed stone base are less. Previous research studies have primarily focused on waste concrete aggregates. However, due to the demolition of a large number of brick-concrete structures, a large amount of brick slag is produced. Therefore, the mixed recycled aggregate containing bricks and pure recycled brick aggregate are taken as the research objects in this study. The reinforcement effect of recycled cement-stabilized aggregate and its influencing factors are analyzed through the mix proportion design and corresponding strength and durability tests. The study serves as the technical support for expanding the applicability of recycled cement-stabilized aggregate.

2. Materials and Methods

2.1. Materials

2.1.1. Recycled Aggregate. The recycled aggregate used in the tests and research was provided by Xuchang Jinke Resources Recycling Co., Ltd. Recycled aggregate used in the study is the waste generated from demolishing old buildings, obtained through crushing, impurity removal, screening, grading, and other treatments. It is mainly composed of concrete, mortar, and brick aggregate. The proportion of each component is related to the source. If the source is a demolished brick concrete structure, brick aggregate is the main component of recycled aggregate; if the source is another structural type, the brick aggregate composition is relatively small. Brick aggregate mainly comes from sintered clay brick, and its strength is lower than that of concrete aggregate. Since the brick aggregate proportion in recycled aggregate significantly impacts the strength of recycled aggregate, two kinds of recycled aggregate were selected in this study to make the research more meaningful and applicable. One is the mixed recycled aggregate (RC), which is composed of concrete and contains about 20% brick aggregate and mortar, as shown in Figure 1. The other kind of recycled aggregate is the recycled brick aggregate (RB) separated from mixed recycled aggregate, as shown in Figure 2. RB and RC represent recycled aggregate from demolished brick and concrete buildings and other buildings.

Aggregate crushing value is the performance index of aggregate resistance to crushing. It is used to measure the mechanical properties of aggregate. The crushing value test is shown in Figure 3. The test procedure for determining the aggregate crushing value is as follows. Recycled aggregate was sieved, and an aggregate of particle size ranging from 9.5 mm–13.2 mm was oven dried. A 9 kg sample of aggregate was evenly put into the metal cylinder, placed in the press, and was pressurized. It reached 400 kN within 10 minutes. After stabilizing for 5 seconds, the sample was removed and passed through the 2.36 mm sieve. The mass passing through the sieve divided by the total mass multiplied by 100% was obtained, representing the aggregate crushing value. The crushing value reflects the mechanical properties of the aggregate under pressure; that is, the greater the aggregate strength, the lower the crushing value. The crushing value test results are shown in Table1. The crushing values of RC and RB were found to be 31.8% and 41.9%, respectively, which are lower than the strength of natural gravel and do not meet the strength requirements of aggregate crushing value ≯ 30% of class II highways specified in the Technical Guidelines for Construction of Highway Roadbases (JTJ F20-2015). Therefore, without strengthening treatment, these aggregates cannot be used in class II and above highway cement-stabilized macadam bases.

The recycled aggregate from the construction waste recycling company was divided into coarse, medium, and fine aggregates, which were sieved ,respectively, to obtain the aggregate gradation, as shown in Table 2.

2.1.2. The Stabilizing Material. PO 42.5 cement was used as the stabilizing material for cement-stabilized recycled aggregate. The physical and mechanical properties of cement were tested, and the setting time, stability, strength, and other technical indexes were determined. It can be used for cement-stabilized recycled aggregate mix proportion and strength tests.

2.1.3. Reinforcing Material. At present, the strengthening methods of recycled aggregate mainly include chemical and physical strengthening methods. The chemical strengthening method mainly improves the internal defects of the

Figure 1: Mixed recycled aggregate.

Figure 2: Recycled brick aggregate.

aggregate by soaking it in a suitable concentration of chemical solution to improve the strength of recycled aggregate. In this investigation, through the analysis of the effect of the strengthening test, the immersion strengthening method of polyvinyl alcohol (PVA) solution was tested (Figure 4). PVA is a high molecular polymer with good water solubility. It is soluble in water at high temperatures. Its aqueous solution has good adhesion. Studies have shown that soaking recycled aggregate in PVA solution with a certain concentration and consistency can improve its strength [27]. It is proposed to use the solution prepared from PVA type bp-05 to strengthen the recycled aggregate. The solution prepared from BP-05 PVA is used to strengthen the recycled aggregate.

2.2. Experimental Procedures

2.2.1. Recycled Aggregate Strengthening. Recycled aggregate is crushed, graded, and sieved during its production process. Some pore cracks might be produced during these processes, resulting in low strength and poor working performance. In order to obtain the best strengthening effect, the recycled aggregate was soaked in different concentrations of PVA and at different soaking times. The aggregate was then dried. The solution infiltrated the cracks and pores of the recycled aggregate and was solidified and hardened to provide a strengthening effect. The best concentration and strengthening time are determined according to the crushing value improvement effect. Then, the physical indexes are measured. SRC and SRB represent reinforced RC and RB.

The strengthening process of recycled aggregate is as follows. First, a PVA solution with a concentration of 6%–12% was prepared. Then, the weighed PVA particles and

(a) (b)

Figure 3: Crushing value test. (a) Aggregate crushing and (b)crushed aggregate screening.

Table 1: Physical and mechanical indexes of two recycled aggregates before and after strengthening.

Recycled aggregate type	Apparent density		Water absorption		Crushing value	
	Apparent density/kg/m^3	Compared with before enhancement	Water absorption/%	Compared with before enhancement	Crushing value/%	Compared with before enhancement
SRC	2507	Reduce 1.1%	7.06	Reduce 2.8%	24.59	Reduce 23.0%
SRB	2514	Reduce 5.2%	11.91	Reduce 6.51%	29.40	Reduce 30.1%

Table 2: Gradation of three aggregates.

	Mass percentage passing through square sieve/%							
Mesh size/mm	37.5	31.5	19.0	9.50	4.75	2.36	0.6	0.075
Coarse aggregate	100	90.3	42.1	5.2	1.3	1.1	1.0	0
Medium aggregate			100	71.8	32.1	18.2	13.7	0
Fine aggregate				100	98.2	63.5	27.1	11.8

water were poured into a clean iron container, which was subsequently put into an electric blast drying oven for heating. The oven temperature was set to 110°C, and the mixture was heated until PVA was completely dissolved in water. The container containing PVA was taken out, and a mixer was used to stir it to accelerate the dissolution. The prepared recycled aggregate mixture of size more than 5 mm was poured into the PVA solution container, as can be seen in Figure 5, and soaked for 24 h–72 h. After the soaking period, the PVA solution was drained, and the mixture was washed with clean water. The mixture was then put on an iron plate for drying for subsequent use in tests.

2.2.2. Mix Proportion and Specimen Fabrication. The design aggregate grading refers to the grading range of cement-stabilized aggregate specified in the construction guidelines. RC and RB are designed with grading A and B, respectively.

Figure 4: PVA.

Figure 5: PVA solution soaking recycled aggregate.

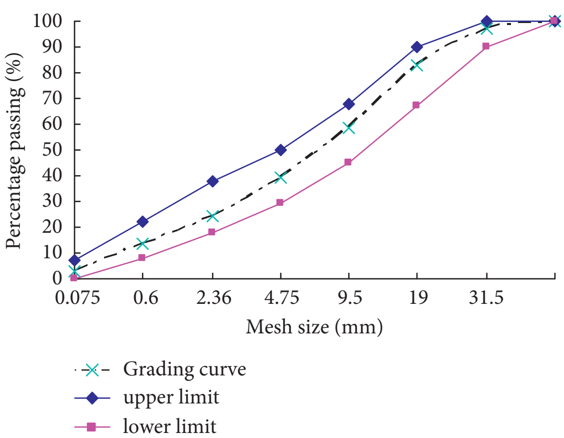

Figure 6: Grading RCA.

The proportion of coarse aggregate in grading B is relatively high. Two gradings of RC aggregate (hereinafter referred to as RCA and RCB) are shown in Figures 6 and 7. The proportions of the coarse, medium, and fine aggregates of RCA and RCB are 30%, 45%, and 25% and 40%, 40%, and 20%, respectively. The RB aggregate was screened, and then the aggregates with different particle sizes were selected to prepare aggregates with two grades A and B (hereafter referred to as RBA and RBB), as shown in Figures 8 and 9. The RBA grading curve was close to the median value of the grading range, and the RBB grading curve was close to the lower limit.

According to the design proportion, the recycled aggregate of each particle size was evenly weighed and mixed. Then, half of the required water was added, and the mixture was thoroughly mixed again and allowed to stand for 4 hrs. Cement was subsequently added along with the remaining half of the mixing water. The mixture was evenly mixed again. The duration for each mix was 90 seconds.

The methods of making cement-stabilized macadam specimens include compaction, vibration, and static

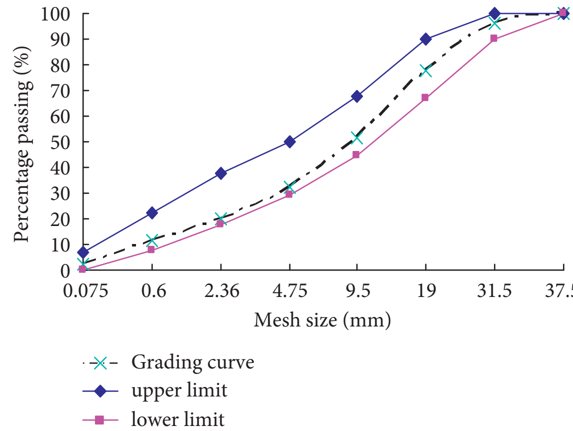

Figure 7: Grading RCB.

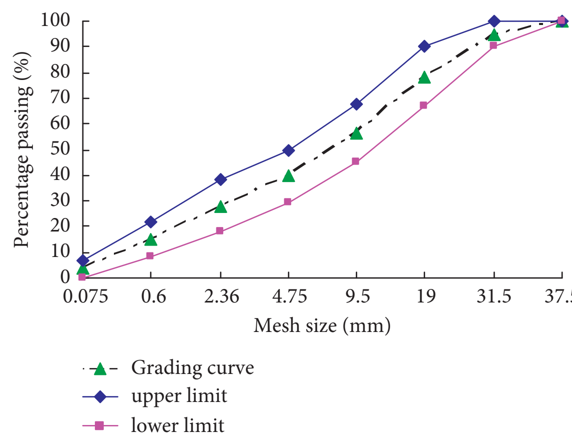

Figure 8: Grading RBA.

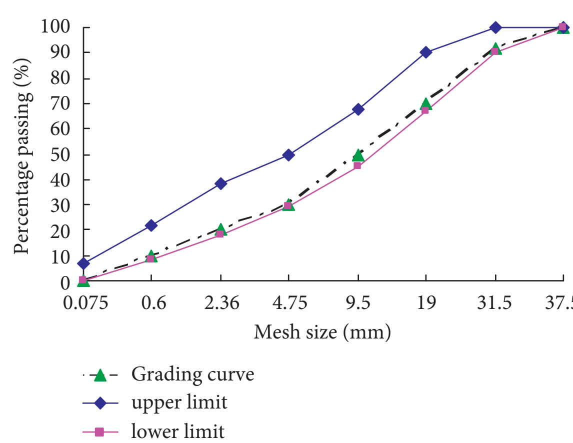

Figure 9: Grading RBB.

pressure. The unconfined compression strength test specimens were cylindrical specimens with a diameter and a height of 150 mm. In the beginning, the compaction method was used for molding. It was found that part of the brick aggregate was struck during the compaction process, and the molded specimens were incomplete. It was easier to form the test piece by vibration, compaction, and static pressure methods, and the integrity of the test piece was better. After comparison, the two methods were used to form the specimens in subsequent tests.

The vibration, compaction, and static pressure methods were used to make the test specimens. The mixture was evenly loaded into the test molds in three layers and gently tamped with a tamping rod. A vibration compactor was used to compact the specimens. The surface pressure and vibration frequency were set as 0.1 MPa and 28–30 Hz, respectively. The universal testing machine was used to apply the static pressure to form the test piece. The loading rate of 1 mm/min (strain-controlled action) was selected. The load was applied until all the specimens were pressed into the mold, and the pressure was maintained for 2 minutes. Afterwards, the specimens were demolded and cured in a standard curing chamber for six days. The specimens were later soaked in water for 24 h. The unconfined compressive strength for 7 days was then subsequently measured.

Four kinds of recycled aggregate were added with 5% PO42.5 cement, respectively, to form four different mixtures. Each mixture was added with mixing water at a 0.5% water consumption interval, and five groups of specimens with different water content were made by vibration compaction and the static pressure method. The water content was measured for the control group, and the corresponding dry density was calculated as a reference for the optimal water content. After the 7 d curing of the specimens with different gradations and moisture contents, the 7 d unconfined compressive strength was measured. The water content of the specimens with the maximum compressive strength was taken as the optimal water content. The test setup is shown in Figure 10.

2.2.3. Unconfined Compressive Strength Test. After six days of standard curing and 24 h of immersion in water, the specimens were tested for a 7-day unconfined compressive strength. The test specimens were removed from the water, and the surface water was wiped off. The specimen was placed in the universal testing machine and was aligned with the indenter. Then, the test machine was started to make the indenter of the testing machine come into contact with the specimen. The pressure tester was adjusted to run at 1 mm/min. The pressure was recorded when the specimen started showing damage, and the unconfined compressive strength was calculated. The number of specimens in each group will be at least 3. If the unconfined compressive strength difference of the same group of test pieces was greater than 15%, then double the number of test pieces had to be made and retested. The test process is shown in Figure 11.

2.2.4. Freeze-Thaw Cyclic Test. The minimum temperature in winter in Central China is lower than 0°C, and the minimum temperature is about −15°C, which has certain requirements on the frost resistance of pavement base materials. The freeze-thaw test can be used to test the frost resistance of recycled cement-stabilized macadam at low temperatures. After 7 days of curing, the surface moisture of the test specimens was wiped. The specimens were weighed, measured, and then placed in the freeze-thaw chamber for the freeze-thaw cycles, as shown in Figure 12. In order to adapt to the characteristics of the Central Plains region, the freezing and thawing cycle were set at a low temperature of −18°C, a normal temperature of 20°C, a low temperature of 16 hours, a normal temperature of 8 hours, and a freezing and thawing cycle time of 7 days. Six test specimens in each group were tested, and the number of specimens used for each index test before and after the freeze-thaw cycle was at least three. The test indicators include the unconfined compressive strength of the specimen before and after the freeze-thaw cycle. The strength ratio was calculated, and then the durability of recycled cement-stabilized macadam was evaluated.

3. Results

3.1. Strengthening Effect and Influencing Factors of PVA. The strength of the two kinds of recycled aggregates soaked in PVA solution of different concentrations with different soaking durations is shown in Figures 13 and 14. Table 1 shows the changes in physical and mechanical properties of recycled aggregate strengthened with the optimal soaking concentration and time.

The test results show that when RC and RB are strengthened with PVA of different concentrations and soaked for different durations, the corresponding strength increases, whereas the crushing value decreases to varying degrees. The optimal soaking concentration of RC and RB is found to be 10%, while the optimal soaking time is determined as 24 h and 60 h, respectively. RB requires a longer soaking time than RC. The crushing values of reinforced RC and reinforced RB are 24.95% and 29.40%, respectively, which meet the strength requirements of cement-stabilized macadam base for heavy traffic class I highways and class II highways, respectively.

3.2. Strength of Cement-Stabilized Recycled Aggregate. Unconfined compressive strength is an important index of road performance for cement-stabilized macadam. Highway traffic shows a significant growth trend of overloaded and overweight vehicles, which has become an important factor in pavement structure damage. Therefore, the 7 d unconfined compressive strength of cement-stabilized material base course for the heavy traffic of class I highways and class II highways required in the construction rules are 4 MPa ∼5 MPa and 3 MPa ∼5 MPa as the strength design goal of cement-stabilized recycled aggregate. The optimum water content is determined according to the principle that the cement-stabilized recycled aggregate made according to the design mix proportion has the best molding effect and the maximum compressive strength. The unconfined compressive strength test results are shown in Table 3.

The unconfined compressive strength test results of cement-stabilized recycled aggregate (before and after strengthening) show that the unconfined compressive strength of cement-stabilized SRC prepared with PO42.5

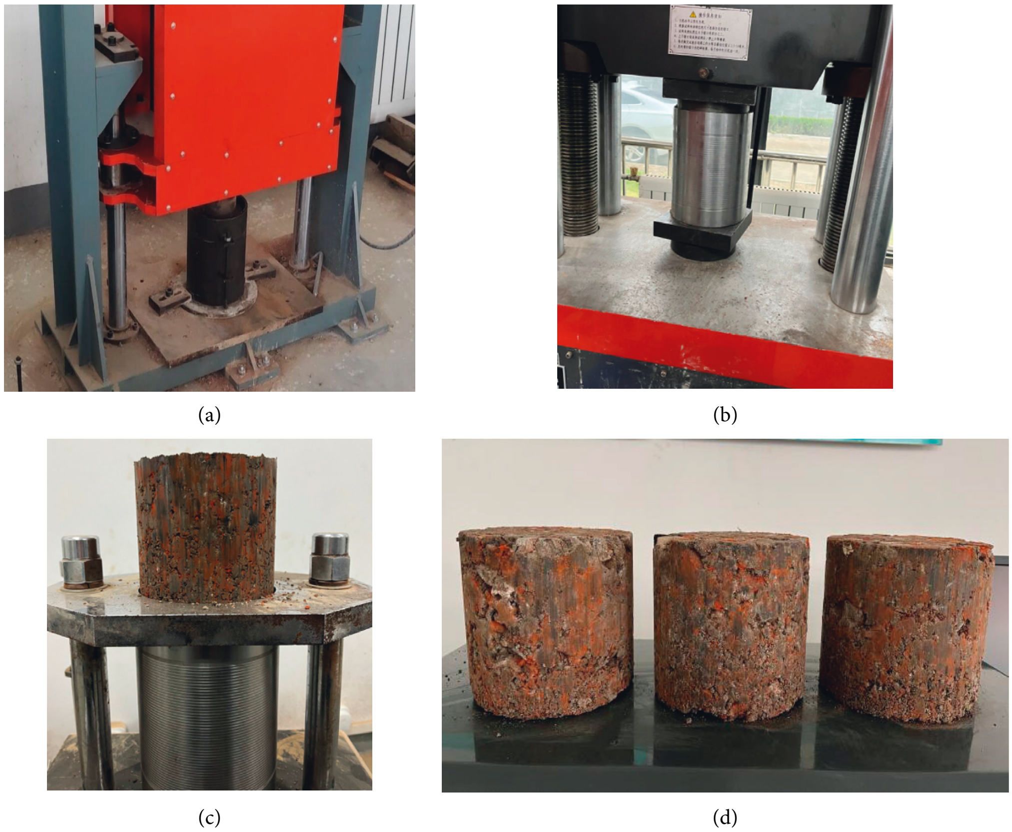

Figure 10: Specimen preparation. (a)Vibratory compaction, (b)static pressure, (c) specimen demolding, and (d) specimen after demoulding.

Figure 11: Unconfined compression test: (a)Unconfined compression test starts and (b)specimen is crushed.

cement meets the design requirements of class I highway. The strength increases by 18%~22% than that of before strengthening. The cement-stabilized RB prepared with PO42.5 cement has low unconfined compressive strength before strengthening, which only meets the class II highway subbase requirements. After strengthening, the strength is increased by 36~39%, which can meet the technical requirements of class II highway heavy traffic base, and the scope of application is expanded. Compared with cement-stabilized SRC, cement-stabilized SRB has a more significant effect on the strength improvement of the two kinds of recycled aggregates after strengthening treatment. The reason is that compared with recycled concrete aggregate, brick slag has lower strength and larger pores. After PVA solution strengthening treatment, the internal structural defects are filled and strengthened to improve their strength. The effect of cement-stabilized SRB strength improvement is more significant.

Figure 12: Freeze-thaw cycle test.

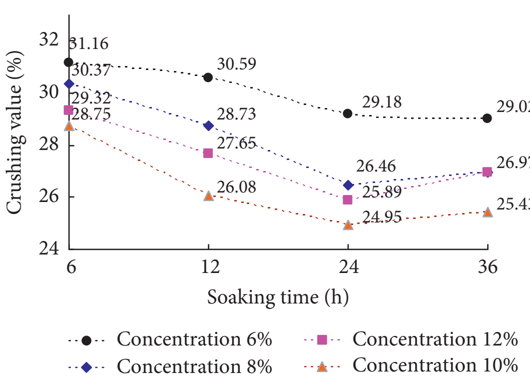

Figure 13: Crushing value of SRC.

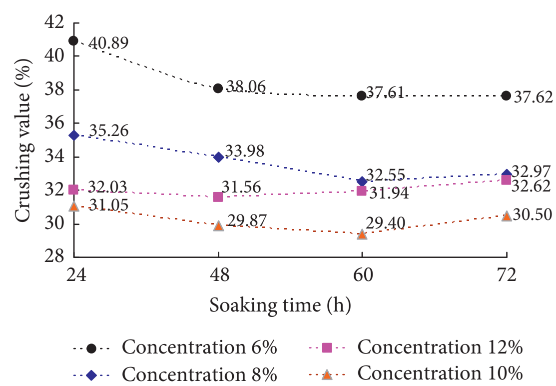

Figure 14: Crushing value of SRB.

3.3. Freeze-Thaw Cyclic Test Results. The freeze-thaw test can detect the water damage resistance of pavement structures. It is also an important index to evaluate the durability of cement-stabilized macadam. The test specimen of cement-stabilized recycled mixture made by adding 5% cement to grade A aggregate was subjected to the freeze-thaw cycle test. The test results are shown in Table 4.

The test results show that after the freeze-thaw cycle test, the strength loss of the cement-stabilized recycled mixture is less, reaching more than 70% of the design strength, indicating excellent durability. The durability of the cement-stabilized recycled mixture after strengthening is not significantly improved.

4. Discussion

It is seen from the results of the unconfined compressive strength test of unreinforced cement-stabilized recycled aggregate that the optimum moisture content of RCA, RCB, RBA, and RBB specimens made by vibratory compaction and static pressure is the same, which is 11.0%, 10.5%, 16.5%, and 16.0%, respectively. The optimum moisture content of RBA and RBB was significantly higher than that of RCA and RCB. The optimum moisture content of RCA was slightly higher than that of RCB. The optimum moisture content of RBA was slightly higher than that of RBB. The reason is that the water absorption of brick slag in recycled aggregate is the highest. After adding water and cement, more water will be absorbed during mixing and stewing, so the optimal water content of RCA and RCB is significantly lower than that of RBA and RBB. The larger the particle size of recycled aggregate, the smaller the water absorption in a certain period. Therefore, the optimal water content of RCB and RBB is slightly lower than that of RCA and RBA.

From the unconfined compressive strength test results of reinforced cement-stabilized recycled aggregate, it can be seen that the optimum water content of SRCA, SRCB, SRBA, and SRBB is 10.5%, 10.0%, 15.5%, and 15.0%, respectively. Compared with the recycled cement-stabilized macadam prepared with unreinforced aggregate, the optimum water content decreased in varying degrees, and SRBA and SRBB decreased more, reaching 1%. The reason is that after

Table 3: Unconfined compressive strength test results.

Aggregate type	Pressing methods	Optimum water content/%	Maximum unconfined compressive strength/MPa	Aggregate type	Pressing methods	Optimum water content/%	Maximum unconfined compressive strength/MPa
RCA	Vibratory compaction	11.0	3.41	RBA	Vibratory compaction	16.5	2.31
	Static compaction		3.49		Static compaction		2.46
SRCA	Vibratory compaction	10.5	4.08	SRBA	Vibratory compaction	15.5	3.13
	Static compaction		4.25		Static compaction		3.41
RCB	Vibratory compaction	10.5	3.38	RBB	Vibratory compaction	16.0	2.18
	Static compaction		3.39		Static compaction		2.34
SRCB	Vibratory compaction	10.0	4.01	SRBB	Vibratory compaction	15.0	3.06
	Static compaction		4.07		Static compaction		3.19

Table 4: Freeze-thaw cycle test results.

Mixture type	Test piece without freeze-thaw cycle	Test specimen after 7-day freeze-thaw cycles	
	Unconfined compressive strength R_0 (MPa)	Unconfined compressive strength R_3 (MPa)	Strength ratio = $R_3//R_0$ (%)
RCA	3.49	2.85	81.7
SRCA	4.25	3.37	79.3
RBA	2.46	1.98	80.5
SRBA	3.41	2.68	78.6

soaking in PVA solution, the pores of recycled aggregate are filled, the water absorption of aggregate is reduced after condensation, and the water consumption is reduced. The brick in recycled aggregate has the highest water absorption, the strength of the brick is low, and it is easier to produce more microcracks in the crushing process. Therefore, the optimal water content of SRBA and SRBB is significantly higher than that of SRCA and SRCB. The larger the particle size of recycled aggregate, the smaller the water absorption in a certain period. Therefore, the optimal water content of SRCB and SRBB is slightly lower than that of SRCA and SRBA.

The unconfined compressive strength test results of the cement-stabilized recycled aggregate of the same type and different gradations show that cement-stabilized RC and RB are within the upper and lower gradation limits. Also, the strength of the gradation composition close to the lower limit is slightly lower. Since the recycled aggregate has large pores, the internal structural defects are filled and strengthened after the PVA solution strengthening treatment. This is why the strength has significantly improved. Grade A, which is close to the median value of the grading range, is similar to the dense suspension structure, while grade B, which is close to the lower limit, is similar to the dense skeleton structure. The coarse aggregate content in dense suspension structures is less, and its strength mainly comes from the binding of cement and fine aggregate. The dense skeleton structure contains a large amount of coarse aggregate, and their strength is mainly composed of the impaction of coarse aggregate and the cementation of cement and fine aggregate. Due to the low strength of recycled coarse aggregate-containing bricks, the skeleton function of the structure is insufficient. The aggregate is crushed by vibratory compaction and static pressure forming, which impacts the strength.

The comparison of the strengths of cement-stabilized recycled aggregate formed by different forming methods reveals that the strength of the specimen made by static pressure forming is higher than that by vibration forming. In constructing a cement-stabilized macadam base, the compaction process includes initial compaction ⟶ re-compaction ⟶ final compaction. Static pressure, vibration compaction, and static pressure are adopted, respectively, which is more than the single forming method in the laboratory. In theory, the compaction effect is better, and it should not be lower or even higher than the strength of the test specimen made by the single static pressure or vibration forming method in the laboratory. Therefore, the strengthening scheme obtained in the laboratory can be applied in road engineering.

5. Conclusions

The following conclusions can be drawn from the study on the strengthening method of recycled aggregate and the grading, mix proportion design, strength, and durability test of cement-stabilized recycled aggregate.

(1) After the recycled aggregate is strengthened by PVA solution, the strength is improved to a certain extent, and RB is more significantly improved than RC.

(2) When RB and RC are stabilized by cement, the optimum moisture content of the former is higher than that of the latter; the optimum moisture content of grade A is slightly lower than that of grade B.

(3) After PVA strengthening treatment, the strength of RC and RB can meet the requirements of aggregate for the cement-stabilized crushed stone base of heavy traffic class I highways and class II highways. Moreover, relatively higher strengths can be obtained by adopting grade A and the static pressure method.

(4) After the freeze-thaw cycle test, the strength loss of the stabilized recycled aggregate is small, and the durability is good; the durability of recycled aggregate is not significantly improved after strengthening.

Data Availability

The data supporting the current study are given in the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

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