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Research Article

Laboratory Evaluation and Design of Construction and Demolition Wastes for Granular Base

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Using recycled aggregate from construction and demolition (C&D) wastes as a construction material is a potential method for solving the disposal of C&D wastes, which can reduce the exploitation of natural aggregate. In this study, extensive laboratory tests were carried out to investigate the reliability of the C&D wastes used as road base material. Meanwhile, the gradation design and the dominant aggregate size range were considered, and a physical disposal method was proposed to enhance the structural performance of the recycled material by replacing the skeleton of the recycled aggregate (RA) with high-quality limestone. The test results showed that (1) given the high absorbency and fragility of C&D wastes, its RA was not enough to provide the strength and stability required by the base; (2) the compaction characteristics of the RA are quite different from that of the limestone aggregate, but the final compaction effect is basically the same; (3) the replacement treatment proposed in this study is an effective approach to improve the performance of the recycled granular base because the breakage rate decreased by at least 28.2% and the mechanical properties increased by approximately 50% compared with that of the untreated specimen; and (4) when the limestone content reached 75%, the California bearing ratio and the resilient modulus of the graded B specimen exceeded 120% and 200 MPa, respectively, satisfying the pavement requirement in medium traffic.

1. Introduction

The construction and demolition (C&D) wastes is one of the secondary resource materials that are widely collected from construction residue and building demolition, which include waste rock, brick slag, cement detritus, etc. [1]. With the rapid development of the urban infrastructure construction, the amount of C&D waste resource is at the giddy growth and has occupied plenty of space for landfill. Open-air stacking or landfilling of C&D wastes did not develop its use value and caused a type of potential threat to the environment [2]. Actually, more than 1.7 billion tons of C&D wastes has been produced yearly in China since 2018, and the utilization rate of converting it into recycled resources was less than 10%. The low utilization rate demonstrates that it has a promising prospect of recycling C&D wastes, which means a sustainable solution for its application is necessary for building materials. Furthermore, with the increasing shortage of river sand and the soaring cost of crushed stone in natural quarries, urgently, many projects need to find an alternative product to decrease economic and environmental risks in civil works [3]. Leite et al. [4] and Zhang et al. [5] promoted C&D wastes as recycled aggregate (RA) in road engineering. They suggested that C&D wastes may be reused for the construction of granular base and subgrade in urban (low-volume) pavements since geotechnical properties of C&D aggregates are lower than the natural stone. It has a great potential to further transform C&D wastes into high-performance RA for solving the problem of C&D waste disposal while reducing the exploitation of natural sand and stone [6].

A flexible pavement consists of three main elements from top to bottom: (a) the surface course which directly bears traffic loading is constituted by asphalt binder and

high-strength aggregate; (b) the base course is composed of unbound granular materials, which is overlaid by asphalt mixture and absorbs the upper stress; and (c) the subgrade is the solid foundation for the pavement structure and always compacted with suitable soil or low-quality aggregate [7, 8]. It is acknowledged that a reliable flexible pavement should have enough strength to resist the deformation suffered by wheel loads [9]. However, most of the practices to utilize C&D aggregates in pavement engineering are still limited by empirical methods related to ordinary granular materials and even without design [10]. Considering the feasibility of C&D materials in road engineering structure, numerous studies have been carried out to characterize the physical property and mechanical behavior of C&D aggregates [11, 12]. Sobhan et al. [13] analyzed the fatigue performance of recycled aggregate concrete under both wet-dry cycles and repeated loads and confirmed the possibility of RA application in the pavement structure. Barbudo et al. [14] studied the mechanical properties of 27 RAs produced from C&D wastes and found that most of them have different composition and performance. Pasandín et al. [15, 16] used coarse RA prepared from C&D wastes and mixed it into hot-mix asphalt mixture in different proportions and studied the performance of the recycled mixture. The result showed that the mixture has poor durability but good resistance to permanent deformation. Arulrajah et al. [17] conducted laboratory tests to evaluate the physical characteristics and shear behaviors of six types of RA derived from different C&D materials. Tavira et al. [18] used a mixed material by C&D aggregates and soil as sub-base in testing road section and found that its pavement performance obtained in situ display well and acceptable in a long term. From the above studies, it is proved that there is no standardized reference for the testing and design of C&D materials at different regions and it is necessary for C&D construction to identify various sources of wastes in detail. Moreover, it also highlighted that the RA from C&D wastes has a higher water absorption rate and lower strength than natural aggregates and its structural composition plays a key role in physical and mechanical properties [19].

The application of C&D wastes with enhanced treatments is an interesting topic for researchers and road engineers. Compared with natural aggregate, C&D aggregate exhibits low-quality material properties and is easy to be broken because of fragile and porous particles (e.g., clay bricks and shattered concrete) [20]. Two main methods were proposed to obtain higher mechanical properties of C&D mixtures, such as chemical stabilization and physical enhancement. For chemical stabilization, Xuan et al. [21] mention that the elastic modulus of C&D bases can be improved after a curing time by means of cement treatment; Disfani et al. [22] carried out fatigue performance tests to study the enhancement effect on recycled concrete aggregates supplemented with crushed brick and 3% cement. Liu et al. [23] proposed a normalized characterization method for the fatigue behavior of cement-treated aggregates based on the yield criterion, which eliminates the influence of test methods on the characterization of fatigue properties. However, these common chemical approaches depend on cement treatments or polymer agents, which also results in raising the risk of carbon emission and soil contamination [24, 25]. Thereby, it needs further research studies to find a suitable substitute or take into consideration the low-cost physical solution [26]. In terms of physical enhancement, Saberian et al. [27] reported the effect of crumb rubber on the permanent behavior of recycled concrete aggregate and waste rock; Yaghoubi et al. [28] investigated changes of size distribution, soil-water characteristics, and resilient behavior of C&D aggregates in the compaction process of both the impact method and the static method; additionally, mixture design is also an important factor which directly acts on the stability and anisotropy of unbound granular materials [29, 30].

In this study, a series of laboratory experiments were performed to systematically evaluate the performance and applicability of RAs for granular base, taking into account enhanced treatments by gradation and composition design. The content of this paper is classified as follows: The forthcoming section introduces the composition of RA and its physical properties compared with limestone aggregate. In Section 3, three gradations of RA mixture are designed with the maximum density curve and a new physical treatment of RA is proposed through replacement of main skeleton of RA into high-quality limestone at dominant aggregate size range (DASR). After that, results of experiments are presented in Section 4, such as compaction test with particle breakage, California bearing ratio test, and resilient modulus tests. Finally, some findings are documented in conclusions.

2. Materials and Physical Properties

2.1. Materials. The natural aggregates and coarse RAs used in the experiment were produced by a renewable technology company in Changsha, China. The process flow of RA production is shown in Figure 1. The coarse RA mainly consists of exposed gravel, brick slag, surface-coated mortar gravel, brick slag, pure cement mortar block, and a small amount of impurities (ceramics, glass, wood chips). Three piles of samples were randomly selected from the material site, and the proportion of their components was determined, as shown in Table 1. The RA was mainly composed of 34% natural stone, 36% brick, 23% concrete, and a small amount of impurities.

2.2. Physical Properties. The material characteristics and gradation of aggregates contribute significantly to its mechanical properties, so the performance test of RA is carried out to select the most suitable materials for pavement base. Aggregates play a role of filling and supporting concrete as loose granular materials, which can improve the durability and stability of concrete. According to the Test Methods of Aggregate for Highway Engineering (JTG E42-2005) in China, aggregates are divided into coarse and fine aggregates according to their particle sizes. The particle sizes between 0.15 and 4.75 mm belong to fine aggregates, and those between 4.75 and 9.0 mm belong to coarse aggregates. Limestone is widely used in construction and industrial raw materials. It has a compact structure, no micro pores, no

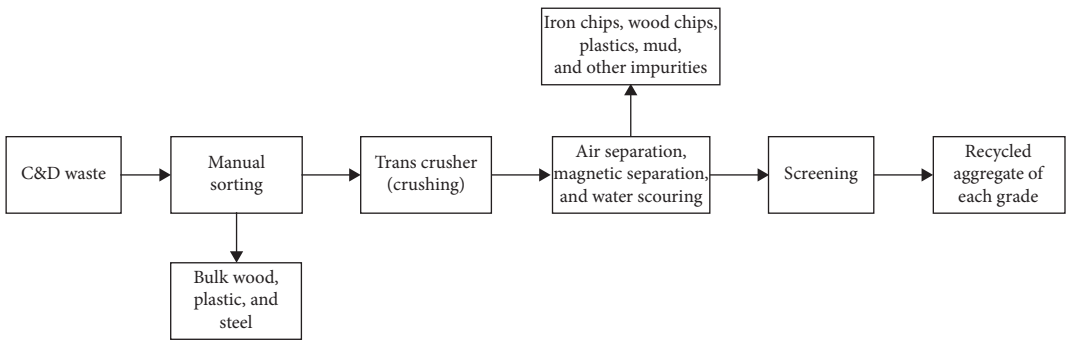

Figure 1: Production process of the RA.

Table 1: Component percentages of the RA.

Component	Measure 1	Measure 2	Measure 3	Average
Natural stone (%)	34	35	33	34
Brick (%)	38	34	36	36
Concrete (%)	21	22	25	23
Impurities (%)	7	9	6	7
Sum (%)	100	100	100	100

water absorption, strong durability, and a certain strength. Compared with general materials, limestone has better construction and workability features and is the main raw material of graded crushed stone for roadbeds. Thus, this study used limestone as the control. The basic physical properties of the RA and limestone are shown in Tables 2 and 3, respectively:

(a) Coarse aggregate: Table 2 summarizes the physical properties of coarse RA and limestone coarse aggregate. The table shows that only the percentages of flat and elongated grains meet the standard requirements. Compared with limestone, the Los Angeles abrasion of the RA is relatively large, and the water absorption is 21.9 times that of limestone. Los Angeles abrasion and water absorption affect the strength of the aggregate.

(b) Fine aggregate: Table 3 summarizes the physical properties of fine RA and fine limestone aggregate. The percentage of grains less than 0.075 mm and the plasticity index of fine RA do not meet the specifications, and the water absorption rate is also higher than that of limestone. Meanwhile, through the above analysis, most of the physical properties of the coarse and fine aggregate cannot satisfy the requirements. Therefore, further attempts were carried out by mix design and component replacement to improve the mechanical properties of the RA base materials.

3. Packing Theory and Mix Design

In addition to good mechanical properties, the pavement base should also have a good drainage, which can timely discharge the water on the subgrade surface to avoid various road diseases caused by free water. In this way, the water immersed in the subgrade surface layer can be discharged in time to avoid the various road diseases caused by excessive free water. The mechanical properties of the pavement base mainly include the strength of the aggregate, the frictional resistance, and the embedding force between the aggregates. The strength of the aggregate depends on its own material, the friction resistance, and the squeezing force, which are mainly determined by the irregular angularity and gradation of the crushed stone.

3.1. Maximum Density Curve. The maximum density curve is an ideal curve proposed by experiment. The theory holds that solid particles are arranged in a regular way according to the particle size and the mixture with the largest density and the smallest porosity can be obtained. Meanwhile, the closer the particle gradation curve is to the parabolic maximum density curve, the greater the density is. According to Thabo theory, the formula of the maximum density curve can be expressed as an n-power formula as follows:

$$P(d_i) = 100\left(\frac{d_i}{d_{\max}}\right)^n, \tag{1}$$

where P is the passing percentage of aggregate at a certain level; d_i is the particle size of aggregate at a certain level; $d_{\max}$ is the maximum particle size of aggregate; and n is the gradation index, usually 0.3~0.7. According to this formula, the throughput of various particles at the maximum density can be calculated. It is generally believed that in engineering practice, the maximum density curve is used to design gradation and the aggregate density is maximum when n is 0.45. Therefore, n equals to 0.45 in this experiment is considered as the optimal gradation density.

3.2. Dominant Aggregate Size Range. Dominant aggregate size range (DASR) refers to the particle size range of interaction in the continuous contact particle interaction network [29]. The DASR forms the main structure network of the aggregate. Intermediate component (IC) is used to fill the gap between the DASR, mainly including particles of size smaller than the DASR. For a well-graded granular material, the proportion of particles larger than DASR is very small. These large particles just float in the aggregate matrix and do

Table 2: Physical properties of coarse aggregate.

Testing	C&D	Limestone	Standard	Method
Bulk density (g/cm^3)	2.43	2.75	Min. 2.5	T0304-2005
Water absorption (%)	11.61	0.53	Max. 3.0	T0304-2005
Percentage of grains less than 0.075 mm (%)	1.7	0.6	Max. 1.5	T0310-2005
Percentage of grains flat and elongated (%)	7.3	8.5	Max. 25.0	T0312-2005
Percentage of breakage (%)	28.8	20.5	Max. 26.0	T0316-2005
Los Angeles abrasion (%)	45.1	19.6	Max. 35.0	T0317-2005

Table 3: Physical properties of fine aggregate.

Testing	C&D	Limestone	Standard	Method
Bulk density (g/cm^3)	2.35	2.68	Min. 2.3	T0304-2005
Water absorption (%)	13.04	4.7	—	T0304-2005
Percentage of grains less than 0.075 mm (%)	4.7	0.9	Max. 2.0	T0310-2005
Plasticity index	7.3	4.6	Max. 6.0	T0312-2005
Liquid limit (%)	29.2	19.7	—	T0316-2005

not play a major role in the aggregate structure because their interaction with other particles is negligible or even nonexistent. Therefore, if the skeleton composed of the DASR is strong enough, the granular material will remain stable under high stress.

The porosity of the mixture is affected by many factors, such as particle arrangement, size, shape, gradation, aggregate content, and porosity, indicating that the accumulation type of the DASR structure can be inferred from the DASR porosity. Given that the porosity of the particle combination does not exceed 50% under normal loose packing, the DASR porosity can be used to evaluate the structure type of the coarse aggregate in the laboratory and the field. Utilizing the DASR porosity, the contact of the particles in the mixture could be analyzed to determine if it is enough to generate the appropriate interaction between adjacent particles. If a certain porosity exists under a given aggregate gradation, then the porosity of any DASR can be calculated. According to the derivation of Guarin et al. [31], the calculation formula of DASR porosity is as follows:

$$\eta_{\text{DASR}} = \frac{V_{V\,(\text{DASR})}}{V_{T\,(\text{DASR})}} = \frac{V_{T\,(\text{IC})} + \text{VMA}}{V_{\text{TM}} - V_{T\,(>\text{DASR})}}, \tag{2}$$

where V_V (DASR) is the volume of void in DASR (including the volume of IC aggregate and the volume of effective aggregate plus the volume of air) and V_T (DASR) is the total volume of DASR particles, which can be calculated by subtracting the volume of particles larger than DASR from the total volume of aggregate.

3.3. Mix Design and Component Optimization. To study the law of mechanical properties of the graded crushed stone between different N values in more detail, the n value could be refined into three groups, i.e., 0.35, 0.45, and 0.55, and specific continuous grading could be designed for analysis and verification. The particle size distribution of the three gradations and their upper and lower limits are shown in Table 4. The table shows that the mesh passing rate of the three gradations could basically meet the requirements of the upper and lower limits, and some of them that did not meet the requirements were corrected in the subsequent tests.

The DASR porosity of the three gradations above is calculated as shown in Table 5. As presented, the particle size distribution of the skeleton structure corresponding to different n values varies. In addition, the previous discussion indicates that the strength of the RA is not enough to share the high pressure from the overlying load on the base structure. Therefore, this study used the limestone aggregate to replace the RA at the DASR to enhance the performance of the graded base materials. The relative contents of the limestone aggregate are 0%, 25%, 50%, 75%, and 100%.

4. Tests and Results

4.1. Compaction Test and Particle Breakage. As light compaction tests were only applicable to cohesive soil with particle size less than 5 mm, standard heavy compaction tests were used in this study to determine the optimal moisture content and maximum dry density of the RA and the limestone aggregates. According to the fitting relationship between dry density and average water content, the maximum dry density and the optimal water content of the RA and limestone samples with different gradations were obtained. The results are shown in Figure 2. In the compaction test, the optimal water content of the RAs ranged from 12.4 to 14.6, and the maximum dry density of RAs ranged from 1.87 to 2.06. The optimal water contents of the RAs with different gradations were higher than those of the limestone aggregates by 171%, 166%, and 186%. Moreover, compared with the maximum dry density of the limestone aggregates, the maximum dry density of the RAs decreased by more than 10%. This result can be attributed to the high content of brick slag and the large porosity of the aggregate. The compacted porosity (p) of the RA can be calculated as follows:

$$p = 100\left(1 - \frac{\rho_b}{\rho_d}\right), \tag{3}$$

where ρ_d is the dry density and ρ_b is the apparent density.

Table 4: Particle size distribution of granular base by maximum density curve.

Sieve size (mm)	Passing percentage by mass				
	Upper limit	Gradation A ($n = 0.35$)	Gradation B ($n = 0.45$)	Gradation C ($n = 0.55$)	Lower limit
31.5	100	100.0	100.0	100.0	100
26.5	100	94.1	92.5	90.9	90
19	95	83.8	79.7	75.7	75
16	88	78.9	73.7	68.9	66
13.2	82	73.8	67.6	62.0	59
9.5	71	65.7	58.3	51.7	46
4.75	55	51.6	42.7	35.3	30
2.36	40	40.4	31.2	24.0	18
1.18	32	31.7	22.8	16.4	13
0.6	25	25.0	16.8	11.3	9
0.3	20	19.6	12.3	7.7	6
0.15	13	15.4	9.0	5.3	3
0.075	7	12.1	6.6	3.6	0

Table 5: Mix design by adding limestone.

Gradation	Bulk porosity (%)	DASR (mm)	DASR porosity (%)	DASR mass percentage	Relative adding limestone (%)
A	18.83	4.75~9.5	48.96	14.2	
B	13.81	4.75~13.2	45.08	24.9	0, 25, 50, 75, 100
C	21.76	4.75~16	46.85	33.6	

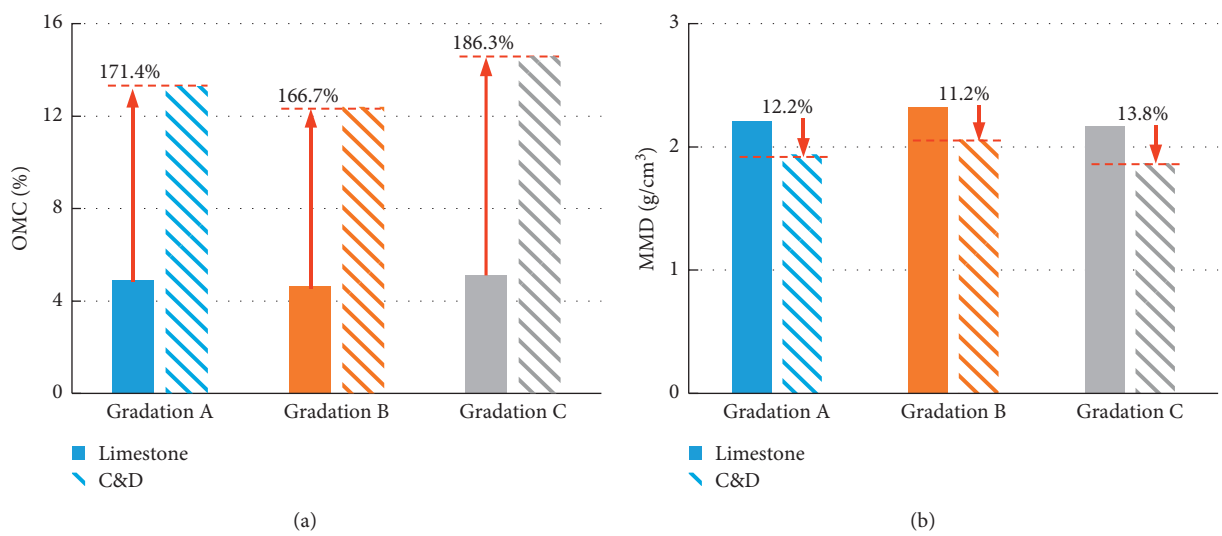

Figure 2: Results of compaction tests: (a) optimum moisture content (OMC) and (b) maximum dry density (MDD).

The calculated compaction porosities of the RAs were 18.83%, 13.81%, and 21.76%, corresponding to 18.75%, 14.71%, and 21.76% of the limestone aggregates. The compaction porosity and the maximum dry density indicate that the compaction degree of the specimen under the gradation B condition is obviously better than those under the two gradation conditions. The test indicates that although the maximum dry density and the optimal moisture content of the two materials have a large gap, their final compaction effects (porosity) are consistent for the same gradation. Therefore, this experiment incorporated limestone in the RA for the subsequent research.

To evaluate the particle breakage, taking gradation A as an example, the RA after compaction and crushing was screened and analyzed. Figure 3 shows the particle size distribution of broken recycled aggregate particles after the compaction test. The results show that the passing rate of each particle size increased slightly with the limestone content after compaction. Given its small change, the fractal dimension (D) and the breaking rate were introduced to evaluate the degree of particle breakage.

Fractal dimension is a quantitative index of the fractal distribution characteristics of the soil particle size. Through the change in particle size of the soil before and after

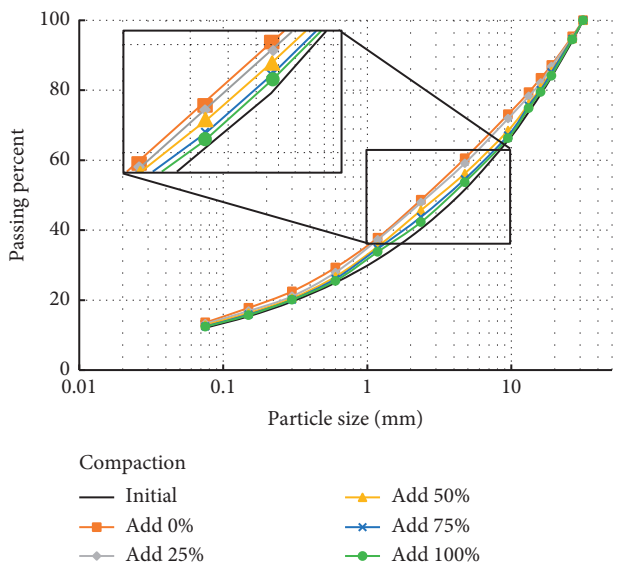

Figure 3: Particle breakage after impact compaction for Gradation A.

compaction, the degree of particle breakage is characterized. Based on the proposed fractal theory, the standardized equation of mass and aperture relationship was proposed by Tyler et al. [32] to derive the following equation:

$$\lg\left[\frac{M_1(di)}{M_T}\right] = (3-D)\lg\left(\frac{d_i}{d_{\max}}\right), \tag{4}$$

where M_1 (d_i) is the total number of materials under a certain particle size of the sieve and M_T is the total mass of the sample. M_1 $(d_i)/M_T$ can be obtained by particle screening statistics, $d_{\max}$ is the maximum particle size of the sample, and d_i is the calculated particle size. According to the equation, the influence of different amounts of limestone addition on the fractal dimension of particle fragmentation under three gradations is shown in Figure 4(a).

Figure 4(a) shows a good linear relationship between D and limestone addition, indicating that the particle size distribution of the three gradation specimens used in the test had good fractal characteristics after particle fragmentation, and fractal dimension D was 2.4728–2.7043. After the addition of limestone, the fractal dimension after crushing was nearer to that of the initial gradation. In terms of internal structure, the high-strength limestone part replaced the coarse aggregate skeleton and enhanced the strength of the coarse particles in the original mixture, reducing the particle fragmentation and leading to small gradation change.

In the process of impact compaction, aggregate particles extrude each other under the action of external load, resulting in the fracture or damage of the structure and then the splitting into multiple particles with uneven particle sizes. Crushing occurs between coarse particles, and grinding occurs between coarse and fine particles. The quantitative statistics of different particle size compositions before and after the entire sample test determines the particle breakage degree. In this study, the breaking rate (B_g) defined by Marsal [33] was used as a measure of the breaking degree of particles in the test. The formula is as follows:

$$B_g = \sum \left| W_{ki} - W_{kf} \right|, \tag{5}$$

where B_g is the sum of the positive values of the difference between the masses of the particle sizes before and after the test; W_{ki} is the mass fraction of a certain particle group on the gradation curve before the test; and W_{kf} is the mass fraction of the same particle group on the gradation curve after the test.

Figure 4(b) intuitively shows that the breaking rate decreased with the increase in limestone content. When the limestone blending amount reached a certain value, the crushing rate decreased significantly, indicating that a certain amount of limestone can significantly improve the aggregate strength of the RA to resist crushing between coarse particles and the grinding between coarse and fine particles. The figure also shows that among the three gradations, the gradation B specimen had the lowest breaking rate, also indicating that gradation B had better stability than the other two gradations.

4.2. California Bearing Ratio Test. The California bearing ratio (CBR) test is an index of the load bearing capacity of roadbed soil and pavement materials and is one of the main parameters of flexible pavement design. Simultaneously, the compression deformation under local load could be evaluated by this index. To a certain extent, this index can reflect the relationship between the load and deformation of graded crushed stone at a certain deformation level to characterize the strength and stiffness characteristics of graded crushed stone. The CBR test results of gradations A, B, and C with different limestone contents are shown in Figure 5. To ensure the reliability and accuracy of the results, three groups of tests were performed for comparison (the maximum value of CBR is shown in parentheses). The two tests above clearly indicate that gradation B is better than the other two gradations and the skeleton is more reliable. To ensure the accuracy of the test data, gradation B is used for subsequent tests.

4.3. Laboratory Bearing Plate Test. Most of the time, the CBR cannot fully reflect the changes of graded gravel materials in the entire deformation process. The modulus of static resilience is an important parameter in the current asphalt pavement design in China because it can directly represent the stiffness characteristics of graded crushed stone materials. It is also the main design index needed for the structural design of asphalt pavement, which has a significant impact on the surface deflection and pavement thickness design. The resilient modulus of the base course indicates the ability of the base course to resist vertical deformation in the elastic deformation stage under vertical load. Therefore, the resilient modulus is used as the index of the base compressive strength in the pavement design. The resilient modulus of the gradation B specimen was tested through the bearing plate test, and the resilient modulus of each level of load could be obtained from Table 6. With the increase of the loading stress, the specimen aggregate

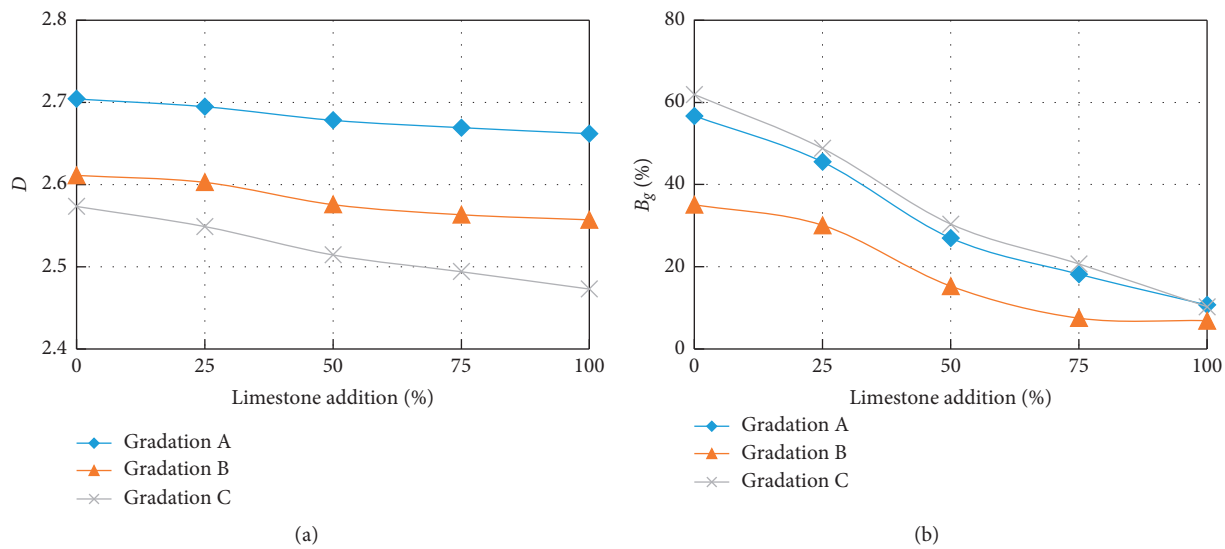

Figure 4: Evaluation of particle breakage with different limestone addition: (a) fractal dimension D and (b) breakage rate B_g.

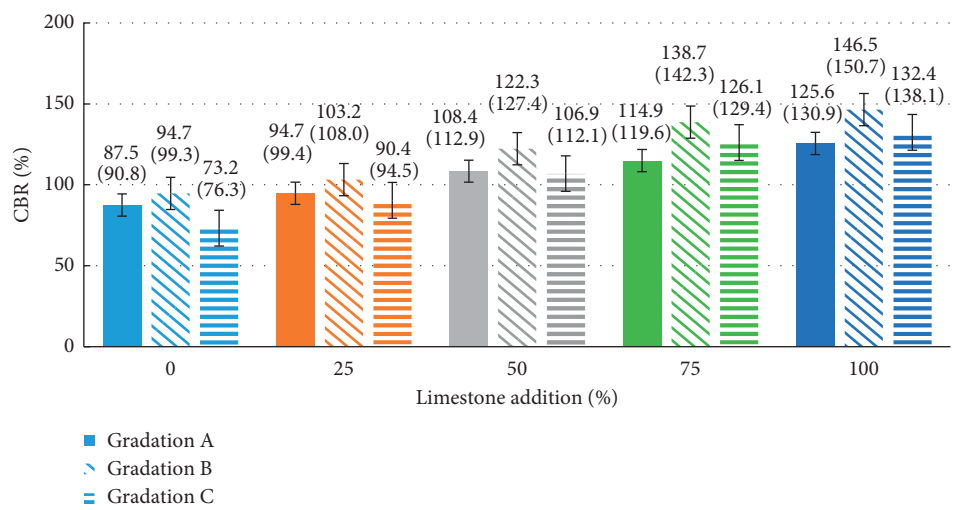

Figure 5: Results of California bearing ratio test.

became more compact and the contact between aggregates nearer, increasing the friction resistance and the resilient modulus of the material substantially. Table 6 shows that the test data of the gradation B specimen are stable, and the modulus value is between 137.4 and 213.6. By adding limestone, the performance of RA improved. When RA was replaced by 100% limestone, the resilient modulus of the specimen was 55.5% higher than that of the untreated sample. Owing to the actual effect of shear pressure, the contact point wear between particles resulted in a small friction coefficient and a limited shear resistance, indicating that the deformation was large and the elastic modulus was low during loading.

4.4. Data Analysis. The laboratory test of the CBR indicates that the CBR value of a single RA base was greatly affected by the gradation, ranging from 73.2% to 94.9%, which is far less than the standard value of general gravel materials. In addition, the single RA base also displayed a poor ability in the bearing plate test, with a resilient modulus of only 137.4 MPa. The comparison and analysis of the above test data show that the RA is not enough to provide the strength and stability required by the base pavement.

In this study, by adding limestone to replace the aggregate skeleton, the performance of the recycled base could be significantly improved, and the maximum CBR value could be increased to approximately 146.5%. In the mechanical empirical design of flexible pavement, the static modulus value of the granular base is usually around 200 MPa. With the comprehensive effect of the gradation design and the limestone replacement, the new design of the recycled base could satisfy the performance requirements of the pavement in medium traffic. When the limestone content reached 75%, the CBR value and resilience modulus of the graded B specimen exceeded 120% and 200 MPa, respectively. Considering the

Table 6: Resilient modulus results of gradation B.

Loading stress (kPa)	Resilient modulus (MPa)				
	0% addition	25% addition	50% addition	75% addition	100% addition
25	144.1	153.6	188.6	203.7	210.4
50	134.9	144.3	173.4	191.6	207.3
75	134.5	146.8	177.5	189.4	199.5
100	132.8	149.4	177.1	197.7	211.6
125	131.7	157.2	174.6	194.3	228.1
150	137.8	153.5	173.9	195.5	226.3
200	137.1	154.8	179.2	201.4	210.4
300	146.3	155.1	180.5	208.3	215.4
Average	137.4	151.8	178.1	197.7	213.6

mechanical and economic requirements, the design with gradation B and the minimum content of 75% of the limestone aggregate may be recommended.

5. Conclusions

This study aims to reveal the reliability of C&D wastes used in road base materials. Thus, the gradation design and the DASR were studied, and compaction, CBR, and bearing plate tests were performed on RA specimens with different limestone contents. On the basis of the results, the following conclusions can be drawn:

(1) The performance of the RA from C&D wastes was poor. According to the physical properties of the material, most of the properties of the RA cannot satisfy the requirements, such as water absorption and Los Angeles abrasion because of the large proportion of natural stones and bricks, greatly affecting the RA strength.

(2) The compaction characteristics of the RA are quite different from that of the limestone aggregate, but the final compaction effect is basically the same. When $n = 0.45$, the optimum moisture content was low and the maximum dry density was high. The optimum moisture content of the RA was 166% higher than that of limestone, and the maximum dry density of the RA was 11.2% lower than that of limestone. Under the same gradation condition, the final voids of the two were basically the same.

(3) Replacing the RA at the DASR with high-quality limestone could significantly improve the stiffness of the RA base materials. The breakage rate of the specimen replaced with 100% limestone after compaction was at least 28.2% lower than that of the untreated specimen. With the addition of limestone aggregate from 0% to 100%, the CBR values of the three graded specimens increased by 38.1%, 51.8%, and 59.2%, respectively. Under the optimal grading condition, the elastic modulus of 100% limestone-replaced specimens was 55.5% higher than that of the untreated specimens.

(4) Given the many defects of C&D wastes, its RA is not enough to provide the strength and stability required by the base pavement. However, according to the replacement method proposed in this study, when the limestone content reached 75%, the CBR value and resilience modulus of the graded B specimen exceeded 120% and 200 MPa, respectively, which can be applied to the road base pavement with medium traffic volume.

It is worth mentioning that the replacement method proposed in this paper is universally applicable. Concretely, when the replacement method is applied to C&D wastes, it can better improve the CBR value and resilient modulus of the specimen to meet the requirements of road use. Taking into account that in many countries the C&D wastes recycling is carried out, the method proposed in this paper can provide an important reference for the application of C&D wastes in road engineering.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

Conceptualization of the study was done by Jin Yi. Data curation was done by Chenghao Liang and Junfeng Qian. Formal analysis was performed by Junfeng Qian and Jue Li. Resources and funds needed for this study were obtained by Jin Yi and Yongsheng Yao. Jin Yi and Chenghao Liang investigated the study. Methodology of the study was designed by Jin Yi. Project administration was done by Jin Yi. Jue Li developed the software program required for this study. Yongsheng Yao supervised the study. Chenghao Liang validated the study results. Data presentation was done by Junfeng Qian and Jue Li. Jin Yi and Chenghao Liang wrote the original draft. Chenghao Liang reviewed and edited the article for intellectual content.

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