Research on Mix Design of Cement Stabilized Recycled Aggregate Pavement Base

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Abstract. In this paper, the compaction test of the mixture with different cement content and different replacement rate of recycled aggregate is studied by vibration compaction method. Through the research on the mix design of cement stabilized recycled aggregate pavement base, the optimum content of cementitious materials is determined, and the maximum dry density and optimum water content of each test scheme are obtained. The influence of cement content and recycled aggregate content on the maximum dry density and optimum water content of the mixture is analyzed.

Keywords: Cement stabilized recycled aggregate, mix proportion design, maximum dry density, optimum water content.

1. Research background
Using recycled aggregate instead of natural sandstone in road base of highway engineering can not only reduce the exploitation of raw materials, protect the natural environment, but also save economic costs. Because there are differences between recycled aggregate and natural aggregate, it requires us to study the mix design of cement stabilized recycled aggregate, so as to provide some reference for pavement structure design and construction of highway engineering. In 2010, Yu Hongjie and Yao Yanhong et al. [1] conducted an experimental study on the mix proportion of recycled concrete with 100% coarse aggregate replacement rate, in order to discuss the influence of water consumption per unit volume, water-cement ratio, sand ratio and fly ash content on the strength of recycled aggregate concrete. Liu Bing et al. [2] made a systematic study on the molding method, basic mechanical properties and road performance of cement stabilized recycled aggregate specimens. The research results show that the compaction effect of cement stabilized recycled aggregate pavement base is better by vibration compaction molding. In 2010, Zhang Daning [3] and Li Yuejiu and others [4] studied a series of mix design, indoor test and outdoor road test, and thus developed a mix scheme of cement stabilized recycled aggregate base which meets the engineering application requirements. On the basis of previous studies, I have carried out the compaction test of cement stabilized recycled aggregate, and studied the mix design of cement stabilized recycled aggregate pavement base.
2. Vibration compaction test

2.1. Raw material

(1) Cement
This paper selects 42.5 ordinary Portland cement produced by Fujian Jianyang Conch Cement Co., Ltd..

(2) Aggregate
It is difficult for the crushed aggregate to meet the grading requirements specified in the national specification "Technical Rules for Construction of Highway Cement Concrete Pavement" (JTG/T F30-2014). For this reason, through analysis and calculation, it is finally determined that the synthetic ratio between the three grades of aggregates, 10–30mm, 5–10mm and 0–5mm, is designed to be 4: 3: 3, which can meet the continuous gradation required by this specification. The basic physical and mechanical properties of aggregate are shown in Table 1.

| Aggregate category | Apparent density (g/cm³) | Water absorption (%) | Crushing value (%) | Wear value (%) | Content of needle-like particles (%) |
|--------------------|--------------------------|----------------------|-------------------|---------------|-------------------------------------|
| Natural aggregate  | 2.682                    | 1.281                | 8.07              | 18.65         | 11.99                               |
| Recycled aggregate | 2.613                    | 3.275                | 18.27             | 27.35         | 8.98                                |
| Normative value    | ≥ 2.5                    | ≤ 3.0                | ≤ 22              | ≤ 30          | ≤ 18                                |

2.2. Test device
The vibration forming method can simulate the field compaction method to the maximum extent, and the detection standard obtained by indoor test using the formed specimen is basically consistent with the field inspection results. Therefore, LHZD-6 vibratory compaction molding machine (Fig. 1) and LQ-T150D demoulding machine (Fig. 2) are used for vibratory compaction test.

Figure 1. LHZD-6 type vibration compaction molding machine
Figure 2. LQ-T150D model stripper

2.3. Test plan
This paper mainly studies the influence of cement content and recycled aggregate content on the mechanical properties of cement stabilized aggregate base mixture, so the variables are cement content and recycled aggregate content. In the construction of cement stabilized pavement base, the specification [5] requires that the cement content is generally between 3% and 7%. In this paper, 4%, 5%, 6% cement content is selected as variable to do compaction test of natural aggregate base mixture and recycled aggregate base mixture, and 5% cement content and 0%, 30%, 60%, 100% recycled aggregate replacement rate are selected as variable to do compaction test of base mixture. The mix proportion scheme of concrete compaction test mixture is shown in Table 2.

Table 2. Mixture compaction test plan

| Test number | Cement: aggregate (recycled aggregate content) | Remarks description |
|-------------|-----------------------------------------------|---------------------|
| 0-4         | 4 : 100 (0)                                   | 4% cement content and 100% natural aggregate |
| 0-5         | 5 : 100 (0)                                   | 5% cement content, 100% natural aggregate |
| 0-6         | 6 : 100 (0)                                   | 6% cement content, 100% natural aggregate |
| 100-4       | 4 : 100 (100)                                 | 4% cement content, 100% recycled aggregate |
| 100-5       | 5 : 100 (100)                                 | 5% cement content, 100% recycled aggregate |
| 100-6       | 6 : 100 (100)                                 | 6% cement content, 100% recycled aggregate |
| 30-5        | 5 : 100 (30)                                  | 5% cement content, 30% recycled aggregate (0–5mm recycled aggregate replaces 0–5mm natural aggregate) |
| 60-5        | 5 : 100 (60)                                  | 5% cement content, 60% recycled aggregate (0–5mm, 5–10mm recycled aggregate instead of natural aggregate) |

Note: in specimen number 0-4, 0 means that the recycled aggregate content is 0%; 4 means that the cement content is 4%.

3. Test results and analysis
The dry density and moisture content data obtained from the compaction test of each group of mixture ratios are fitted with a one-variable quadratic function. The best water content \( w_{\text{opt}} \) and the maximum dry density \( \rho_d \) of each mixture ratio can be obtained, as shown in Table 3.
Table 3. Results of compaction and fitting test of mixtures of various mixture ratios

| Test number | Optimum moisture content $W_{opt}$ (%) | Maximum dry density $\rho_d$ (g/cm³) |
|-------------|---------------------------------------|--------------------------------------|
| 0-4         | 6.75                                  | 2.14                                 |
| 0-5         | 7.32                                  | 2.19                                 |
| 0-6         | 7.6                                   | 2.16                                 |
| 100-4       | 8.54                                  | 1.96                                 |
| 100-5       | 9.42                                  | 2.0                                  |
| 100-6       | 9.79                                  | 2.03                                 |
| 30-5        | 9.0                                   | 2.03                                 |
| 60-5        | 9.2                                   | 2.01                                 |

According to the compaction fitting test results of each mixture shown in Table 3, in order to show more clearly the influence of cement content and recycled aggregate content on the maximum dry density and optimum water content of cement stabilized aggregate base mixture, the relationship curves between them and cement stabilized aggregate base mixture are drawn with cement content and recycled aggregate content as independent variables. As shown in Figure 3 and Figure 4.

![Figure 3](image1.png)

(a) Mixture with 0% recycled aggregate content

![Figure 4](image2.png)

(b) Mixture of 100% recycled aggregate

**Figure 3.** The influence of cement content on the parameters of the mixture compaction test
According to the data of mixture compaction fitting results shown in Table 3 and the influence of cement content on mixture compaction test parameters shown in Figure 3, it can be seen that the optimum water content of cement stabilized aggregate mixture increases with the increase of cement content. The higher the content of cement in the base mixture, the greater the amount of hydration reaction and the greater the water consumption required for the reaction. Therefore, the optimum water content of the mixture will increase. In addition, for recycled aggregate, it contains a considerable amount of hardened cement mortar (containing a small amount of unreacted cement particles). Therefore, under the same cement content, the optimum water content of cement stabilized recycled aggregate mixture is greater. According to the relationship between recycled aggregate content and compaction results shown in Figure 4, it can be seen that under the premise of a certain cement content, the higher the recycled aggregate content, the greater the optimal water content. When 30% (equivalent to fine aggregate) is added, the growth rate of the optimum water content is the largest, and the growth rate slows down with the increase of recycled aggregate content (particle size of recycled aggregate increases). It also shows that in a certain range of particle size, the larger the particle size of recycled aggregate, the lower the content of hardened cement mortar adhered to the surface of recycled aggregate under the same quality.

From the data of mixture compaction fitting results shown in Table 3, combined with the influence of cement content on mixture compaction test shown in Figure 3, it can also be seen that the maximum dry density of cement stabilized macadam base mixture increases first and then decreases with the increase of cement content, while the maximum dry density of cement stabilized recycled aggregate base mixture is positively correlated with cement content. There are a lot of microcracks in recycled aggregate due to crushing and transportation, and there are a lot of pores in hardened cement paste. Therefore, with the increase of cement content, a large amount of cement mortar will be mixed into these cracks and pores, which will increase the overall quality of base course mixture and the maximum dry density at the same volume. Natural aggregate has low porosity because of few cracks. When cement mortar is mixed into these cracks and pores and reaches saturation, redundant hardened mortar is distributed among aggregates. This makes the volume of aggregate decrease while the volume of hardened mortar increases while the density of hardened mortar is obviously smaller than that of natural aggregate. Therefore, the maximum dry density of cement stabilized macadam mixture will also decrease. According to the relationship curve between recycled aggregate content and compaction test parameters of mixture shown in Figure 4, with the increase of recycled aggregate content, aggregate crack and porosity gradually increase, so the maximum dry density of mixture gradually decreases. When the particle size is within a certain range, the larger the particle size of recycled aggregate, the lower the hardened cement mortar content under the same quality. Therefore, in Figure 4, the higher the content of recycled aggregate, the slower the decrease of the maximum dry density.
density of the mixture.

4. Conclusion
Based on the vibration compaction test of cement stabilized aggregate base mixture and the 7-day unconfined compressive test of mixture specimens, this paper studies the influence of cement content and recycled aggregate content on the optimum water content, maximum dry density and 7-day unconfined compressive strength of base mixture, and further analyzes the above influence mechanism, and draws the following conclusions:

(1) For cement stabilized aggregate mixture, the optimum water content increases with the increase of cement content and recycled aggregate content.

(2) The maximum dry density of cement stabilized recycled aggregate mixture has a positive correlation with cement content, while the maximum dry density of cement stabilized macadam mixture increases first and then decreases with the increase of cement content. With the increase of recycled aggregate content, the maximum dry density of cement stabilized aggregate mixture will decrease, which is confirmed to be within a certain particle size range to some extent. With the increase of particle size of recycled aggregate, the content of hardened cement mortar of recycled aggregate will decrease under the same quality.

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