Experimental study on the tensile performance of cement stabilized recycled aggregate pavement base

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Abstract. As the main bearing stratum of pavement, the base mixture is equivalently subject to external shear stress when unevenly stressed, so the splitting performance is an important parameter to measure its engineering characteristics. The results of splitting and splitting rebound test showed that the strength and rebound modulus of cement stabilized macadam and cement stabilized recycled aggregate increased exponentially with age. Through comparative analysis, it was found that the splitting and tensile properties of cement stabilized recycled aggregate were slightly inferior to that of cement stabilized macadam. Finally, the strength calculation formula of the mixture was derived, which could provide reference for practical engineering.

1. Introduction

In recent years, the application research of recycled aggregate has been gradually extended to highway engineering. Mashnad M [1] and Sobhan K [2-4] et al. studied the elastic modulus and fatigue cumulative damage characteristics of cement-fly ash stabilized recycled aggregate base under repeated flexural load through laboratory tests. Arulrajah A [5] and Behiry E M [6] et al. compared the performance of RCA with the requirements of road management departments, and discussed the applicability of recycled aggregate as base material through experiments. Park T [7] and Chi S P [8] et al. carried out triaxial test on the base mixture by using the 15MPa-75MPa waste concrete, and concluded that the content of soft particles and flat and elongated particles in the recycled aggregate would significantly affect the rebound modulus of the mixture. As pavement base, the cement stabilized aggregate base mixture is often affected by the temperature difference between day and night, which could produce a dilatation stress within the material, and as the main bearing stratum of pavement, the base mixture is equivalently subject to an external shear stress when unevenly stressed; therefore, the base mixture should be provided with not only a certain compressive strength, but also a certain tensile strength. In this paper, on the basis of previous studies, the splitting tensile and splitting rebound test tests were conducted on the base mixture, so as to study the cement stabilized recycled aggregate base.
2. Base mixture test

According to the actual situation, 4%, 5%, and 6% was selected as the cement content in this experiment, and then the experimental comparative study was conducted on the base mixture with 0% and 100% recycled aggregate. Based on the Ф 150 mm x 150 mm cylinder concrete specimens, and 42.5 ordinary Portland cement produced by Lisnshi Cement Factory of Fujian Cement Co., Ltd. in the experiment, it was very difficult for the crushed aggregate to meet the grading requirements of national standards, so it was finally determined through analysis and calculation that, when the combination ratio of the three grades of aggregate (10–30 mm, 5-10 mm, 0–5 mm) was 4:3:3, the continuous grading meeting the standard requirements could be achieved, with the basic physical and mechanical properties of the aggregate shown in Table 1.

In order to simulate the field compaction method to the greatest extent, the vibration compaction test was selected to determine the optimal moisture content and maximum dry density of the mixture, and the specimen was made by the vibration molding method. The compaction test results of the mixture are shown in Table 2.

Tab.1 Aggregate physical and mechanical properties

| Aggregate category | Apparent density (g/cm³) | Crushing value | Los Angeles Abrasion Value | Needle flake granule content |
|--------------------|--------------------------|----------------|---------------------------|-----------------------------|
| Natural aggregate  | 2.69                     | 8.07           | 18.65                     | 11.99                       |
| Recycled aggregate | 2.61                     | 18.27          | 27.35                     | 8.98                        |

Tab.2 Mixture vibration compaction test results

| Mixture type                    | Cement content | $\omega_{opt}$ (%) | $\rho_{max}$ (g/cm³) |
|---------------------------------|----------------|--------------------|----------------------|
| Cement stabilized macadam       | 4%             | 6.75               | 2.14                 |
|                                 | 5%             | 7.32               | 2.19                 |
|                                 | 6%             | 7.6                | 2.16                 |
| Cement stabilized recycled aggregate | 4%     | 8.54               | 1.96                 |
|                                 | 5%             | 9.42               | 2.0                  |
|                                 | 6%             | 9.79               | 2.03                 |

Pavement base is the bearing stratum in the entire road structure, so it must be provided with certain compressive strength to resist vehicle load, so unconfined compressive strength is the initial indicator of base mixture performance design, and the base mixture can resist vehicle load, and other performance requirements can be put forward only when it is provided with certain strength. Therefore, it is required in the specification that 7 d unconfined compressive strength is an important indicator for mixture material design, with the test results shown in Table 3.

Tab.3 Mixture 7d unconfined compressive strength test

| Number       | 0-4 | 0-5 | 0-6 | 100-4 | 100-5 | 100-6 |
|--------------|-----|-----|-----|-------|-------|-------|
| Strength (MPa) | 2.42 | 3.89 | 4.96 | 2.75  | 3.21  | 3.91  |
| Specification (MPa) | 3.0–5.0MPa | | | | | |

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Note: In the specimen No.0-No.4 0-- cement stabilized macadam, 4 -- cement content; in 100-4, 100--cement stabilized recycled aggregate; 4--cement content; the numbering rules for the rest are the same as above.

At present, the important performance indexes to measure the tensile strength and stiffness of materials are the splitting strength and splitting rebound modulus, so they are also the main indexes of pavement structure design. The test results obtained according to the standard requirements are shown in Table 4 and Table 5.

### Tab.4 Mixture splitting tensile test results

| Number | $R$ / MPa | 7d | 28d | 90d |
|--------|-----------|----|-----|-----|
| 0-4    | 0.234     | 0.381 | 0.474 |
| 0-5    | 0.312     | 0.469 | 0.6  |
| 0-6    | 0.39      | 0.588 | 0.726 |
| 100-4  | 0.24      | 0.31  | 0.421 |
| 100-5  | 0.288     | 0.451 | 0.554 |
| 100-6  | 0.353     | 0.556 | 0.668 |

### Table 5 Mixture splitting tensile and springback test result

| Number | $E$ / MPa | 7d | 28d | 90d |
|--------|-----------|----|-----|-----|
| 0-5    | 1849.96   | 2019.08 | 2241.68 |
| 100-5  | 1637.96   | 1928.32 | 2111.9 |

### 3. Analysis of test results

The composition of recycled aggregate is mainly in three forms, namely, aggregate-mortar mixture, original natural aggregate, and pure hardening cement mortars. From the perspective of external influence factors, the biggest difference between recycled aggregate and natural aggregate lies in that plenty of hardened cement mortar adheres to all kinds of energy the surface of recycled aggregate, thereby resulting in more rough aggregate surface, as well as more edges and corners; from the perspective of internal influence factors, the recycled aggregate is subject to all kinds of energy in the process of production and transportation, thereby causing cumulative damage and initiation of micro cracks in the recycled aggregates, so the internal defect in this kind of aggregate is also great difference between recycled aggregate and natural aggregate. It can be seen from the physical and mechanical performance test values of aggregate shown in Table 1 that, although the performance of recycled aggregate is slightly inferior, it is still within the scope of standard requirements.

The split tensile strength of base mixture is mainly reflected in two aspects: 1. the cement mortar is distributed between the coarse aggregates by the cement hydration products wrapping around fine aggregates, so as to connect the coarse aggregate to a compact whole, thus forming the overall strength; 2. the holding-on and bonding between aggregate and cement in the transition zone of cement-aggregate interface can improve the tensile strength of interface transition zone. According to the splitting tensile strength data of base mixture shown in Table 4, the relation curve between the cement content and the splitting strength of base mixture is drawn with cement as the independent variable, as shown in Fig 1, so as to more clearly reflect the effect of cement content and recycled aggregate on the splitting strength of base mixture. By referring to the theories of relevant experts and scholars about the law of strength increasing with age, the power exponent fitting was used in this experiment, with the fitting results shown in Table 6.
Fig. 1 Relationship between cement dosage and strength

Tab. 6 Mixture age and the splitting tensile numerical fitting results

| Number | Exponential fitting $y = ax^b$ |
|--------|---------------------------------|
|        | $a$    | $b$    | $R^2$ |
| 0-4    | 0.1507 | 0.2590 | 0.94  |
| 0-5    | 0.1986 | 0.2480 | 0.98  |
| 0-6    | 0.2586 | 0.2328 | 0.96  |
| 100-4  | 0.1504 | 0.2265 | 0.98  |
| 100-5  | 0.1900 | 0.2419 | 0.94  |
| 100-6  | 0.2385 | 0.2338 | 0.92  |

The corresponding fitting curve is shown in Fig. 2. As could be seen from Fig 1 and Fig 2, the splitting strength increased with the increasing cement content and age, and under the condition of same cement content, the splitting strength of cement stabilized recycled aggregate was lower than that of cement stabilized macadam. The main reason was that there was a large number of old cement wrapping on the surface of recycled aggregates, and the unfavorable factors, such as cracks and etc. would appear in the transition region interface between old cement and original aggregate because the recycled aggregates would be subject to the action of various energy in the process of production and transportation, thereby making the mixture have weak interface, which could produce stress concentration under the action of external force, and then cause fracture preferentially; thus, the overall strength of mixture was reduced. When the cement content was increased, the new cement paste would be mixed into the cracks, thus improving the tensile strength of interface transition zone, so the strength of cement stabilized recycled aggregate with 5% cement content was better than that of cement stabilized macadam with 4% cement content, and the strength of cement stabilized recycled aggregate with 6% cement content was greater than that of cement stabilized macadam with 5% cement content. It showed that, the splitting performance of cement stabilized recycled aggregate was slightly lower than that of cement stabilized macadam under the same conditions, but the appropriate increase of cement content could bridge this gap.

It could be seen from the fitting curve in Fig. 2 that, the strength of the mixture increased rapidly in the early stage (7d–28d), and increased slowly in the later stage along with the age. By the deformation of the fitting formula, $y = ax^b$, it could be concluded that:

$$\frac{y(28)}{y(27)} = \frac{a \times 28^b}{a \times 3^b} = 7^b$$  \hspace{1cm} (1)

$$y(28) = a \times 28^b$$  \hspace{1cm} (2)
Then, the coefficients $b$ and $a$ of the fitting formula could be obtained, as shown in Formula (3) and Formula (4):

$$b = \frac{\lg y(28) - \lg y(7)}{\lg y(7)}$$  \hspace{1cm} (3)
$$a = \frac{y(28)}{28}$$  \hspace{1cm} (4)

Therefore, as long as we know the mixture strength in the early stage (7d, 28d), we could calculate the fitting coefficients $b$ and $a$, and then estimate the later strength of the mixture, thus providing a reference for the design, construction and testing of the project.

Fig. 2 Age and Strength curve

4. Conclusions

In this paper, in order to study the tensile strength and tensile deformation of cement stabilized recycled aggregate base, and make recycled aggregate better applied in highway engineering, the experiments of splitting tensile strength and splitting rebound modulus were carried out. The following conclusions are obtained after experimental analysis:

1) Under the same conditions, the splitting performance of cement-stabilized recycled aggregate is slightly lower than that of cement-stabilized macadam, but the difference can be made up by appropriately increasing the cement content.

2) The strength and modulus of the mixture increased fast in the early stage (7 d, 28 d) and increased slowly in the later stage along with the age, and the effect of power exponent fitting was impressive. Through the power exponent fitting, as long as we know the early (7 d, 28 d) strength of the mixture, the fitting coefficients $b$ and $a$ can be calculated, and then the later strength of the mixture can be estimated, so as to provide reference for project design, construction and detection, etc in the later stage.

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