Study and Application of Gneiss in Preparation of Graded Gravel Base Material

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Abstract: Because a lot of abandoned tunnel slag is produced in road engineering construction and the using rate is low, based on the Shijiazhuang section of the Xifu section of the Taihang mountain highway, the lithology of abandoned tunnel slag is analyzed. Its physical and mechanical properties are evaluated by laboratory tests, and its feasibility as an aggregate of graded gravel base is demonstrated. The gradation of the crushed stone mixture is composed of fine aggregate limestone mixed with abandoned tunnel gneiss, and the related characteristics are studied. The results show that the strength of the mixture could be significantly improved by replacing the fine aggregate with limestone, and the California load ratio (CBR) value of the crushed stone mixture with 0~3 mm and 3~5 mm limestone could reach 377.2%, and the unconfined compressive strength could reach 1.2 MPa.

1. Introduction
With the continuous increase of highway construction mileage in China, highway construction in mountainous areas is also increasing. In the process of constructing mountain expressways, the proportion of tunnels is increasing. Due to the improper disposal method, a lot of abandoned dregs generated by tunneling, however, have caused damage to the surrounding ecological environment. On the other hand, the paving of the pavement base and surface layer requires a large amount of purchased stone, which is neither in line with the concept of green development nor scientific and reasonable [1]. It not only increased the construction cost of the construction unit, but it must spend more funds to ensure the smooth implementation of the construction project.

The results of the investigation and analysis of the application of abandoned dregs in different areas show that the dregs are mostly used for filling roadbed or processing sand and gravel. These applications do not consider the tunnel dregs rational to use as high-quality road materials, as the using rate is low at only about 20%. The aggregate amount of asphalt pavement in the course of paving accounts for about 73%, and is an important potential layer for the application of tunnel slag.

Due to its good gradation and small void ratio, the base course on graded gravel has a good anti-deformation capacity and diffusion load capacity, which could effectively alleviate the reflection of the cracking of semi-rigid base asphalt pavement [2], and is widely used in cold areas in the north.
By studying the lithology, aggregate characteristics, mix ratio design, mechanical index, and other aspects of the abandoned slag rock in the tunnel, this paper, therefore, analyzes the feasibility of its application to the base course of graded gravel to save construction cost, protect the local ecological environment, reduce the pavement reflection crack and extend the service life.

2. Lithological analysis of abandoned dregs in tunnel

2.1. Classification of geological soil
The slag-stone samples of the tunnel were mostly hemp green, but the proportion of mineral species in the slag-stone samples was quite different. In aggregate 1, the rock has a scaly granular crystalline structure, with the mineral composition consisting of 65% plagioclase, 20% ~ 25% quartz, 10%~15% biotite, and a small amount of iron, apatite. In aggregate 2, the rock has a plate-like columnar metamorphic structure with a mineral composition of tremolite 55%, carbonate 20%~25%, Muscovite 10%~15%, quartz 8%~9%, and iron 1%~2%. In aggregate 3, the rock has a columnar granular metamorphic structure with a mineral composition of 50% plagioclase, 25%~30% amphibole, 20%~25% quartz, and a small amount of iron, apatite. In aggregate 4, the rock has a squamous granular crystalline structure with a mineral composition of 75%~80% potassium feldspar, 10%~15% sericite, and 10% quartz. In aggregate 5, the rock has a scaly granular crystalline structure, and the mineral composition is 45%~50% potassium feldspar, 20% plagioclase, 20%~25% quartz, 10% biotite and a small amount of iron. In conclusion, it is determined that the lithology of abandoned dregs is gneiss.

![Figure 1. Microscopic observation of stone samples](image)

2.2. Uniaxial saturated compressive strength classification
In highway engineering, rocks are divided into three categories according to the uniaxial saturation compressive strength index, as shown in Table 1.

| Rock types          | Uniaxial saturation compressive strength (MPa) | Representative rock                                      |
|---------------------|-----------------------------------------------|---------------------------------------------------------|
| Hard rock           | ≥60                                           | Granite etc.                                            |
| Medium hard rock    | 30 ~ 60                                       | Marble etc.                                             |
| Soft rock           | 5 ~ 30                                        | Argillaceous sandstones, chiphyllite, schist, etc.       |

According to the uniaxial compressive strength test (T0221–2005) in the highway engineering rock test code (JTGE41-2005), the compressive strength was tested by drilling core, and the average value of the test result was 131MPa, indicating that the rock was hard rock [3].

According to the above analysis, the lithology of abandoned dregs in the tunnel supporting engineering, therefore, is gneiss, which is a metamorphic rock with a medium-coarse granulose crystal structure and gneiss or banding structure. The uniaxial saturated compressive strength is also divided into hard rocks to meet the requirements of highway engineering.
3. Analysis of the characteristics of abandoned slag aggregate in tunnel

3.1. Physical properties of abandoned slag aggregate in tunnel

This paper conducted tests according to the highway geotechnical test code (JTG E42-2005) to analyze the physical characteristics of the abandoned slag aggregate in the tunnel. The test detected the crushing value of the coarse aggregate, needle plate, and fine aggregate liquid limit, plasticity index and other indicators. The results are shown in Table 2 and Table 3.

| Project                      | Unit       | Test value | Technical requirements |
|------------------------------|------------|------------|------------------------|
| Crush value                  | %          | 23.8       | ≤26                    |
| Needle flake                 | %          | 3.4        | ≤18                    |
| Dust content below 0.075mm   | %          | 0.82       | ≤2                     |
| Content of soft rock         | %          | 2.3        | ≤3                     |

Table 3. Test results of the fine aggregate index of abandoned slag in tunnel

| Project                        | Unit | Test value | Technical requirements |
|--------------------------------|------|------------|------------------------|
| Apparent relative density      | -    | 2.735      | ≥2.50                  |
| Water washing method <0.075 mm particle content | % | 8.5        | ≤15                    |
| Sand equivalent                | %    | 45         | ≥50                    |
| Methylene blue content         | g/kg | 1.65       | ≤1.5                   |
| Sulfate content                | %    | 0.01       | ≤0.25                  |
| Liquid limit                   | %    | 26         | ≤28                    |
| The plastic index              | %    | 13         | ≤9                     |

(1) The project relies on the traffic level of the project for heavy traffic. From the test results, the coarse aggregate of abandoned slag in the tunnel has good physical properties, and the crushing value, needle flake, dust content below 0.075 mm, and soft stone content are all in line with the provisions of the technical rules for the construction of highway pavement base course (JTGT F20-2015). The coarse aggregate of abandoned slag in the tunnel, therefore, could be used as graded gravel[4].

(2) The physical indexes of the fine aggregate of abandoned slag in the tunnel meet the requirements of the code, but the plasticity index is greater than 9%. Currently, there is no regulation on the sand equivalent and methylene blue content of graded gravel fine aggregate in the current specification. It is required that the sand equivalent is not less than 50% and the methylene blue content is not more than 1.5 g/kg based on the engineering technical guidelines[5] to ensure the cleanliness of fine aggregate. From the table, it can be seen that the sand equivalent and methylene blue content of fine slag abandoned in the tunnel do not meet the requirements of the technical guidelines, which indicates that there are many impurities in the fine slag abandoned in the tunnel.

3.2. Single file aggregate screening results of abandoned dregs in tunnel

The strength and stability of graded crushed stone mixture are not only influenced by the type and performance of aggregate but also related to the maximum particle sizes of 4.75 mm, 0.6 mm and 0.075 mm passing mass percentage. The water stability of the material is related to the passing mass percentage and plasticity index of the material below 0.6 mm. According to the requirements of the highway engineering aggregate test code (JTGE42-2005), this paper, therefore, carried out the tunnel slag
screening test. The percentage of the passing mass of each sieve hole is shown in Table 4, and the specification of aggregate used for the graded gravel base mixture is shown in Table 5.

Table 4. Screening results of abandoned slag aggregate in tunnel

| Specifications (mm) | Percentage of mass through the following screen (mm) (%) |
|---------------------|---------------------------------------------------------|
|                     | 31.5 | 26.5 | 19  | 16  | 13.2 | 9.5  | 4.75 | 2.36 | 1.18 | 0.6  | 0.3  | 0.15 | 0.075 |
| 20~25               | 100.0| 100.0| 9.9 | 7.7 | 1.0  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1   |
| 15~20               | 100.0| 100.0| 91.4| 29.3| 1.5  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1   |
| 10~15               | 100.0| 100.0| 100.0| 100.0| 93.4 | 9.6  | 0.2  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1   |
| 5~10                | 100.0| 100.0| 100.0| 100.0| 100.0| 76.3 | 0.4  | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  | 0.3   |
| 3~5                 | 100.0| 100.0| 100.0| 100.0| 100.0| 76.3 | 0.4  | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  | 0.3   |
| 0~3                 | 100.0| 100.0| 100.0| 100.0| 100.0| 100.0| 91.6 | 74.9 | 59.1 | 36.8 | 17   |

Table 5. Specification requirements of aggregate for graded crushed stone base mixture

| Specifications (mm) | Percentage of mass through the following screen (mm) (%) |
|---------------------|---------------------------------------------------------|
|                     | 31.5 | 26.5 | 19  | 13.2 | 9.5  | 4.75 | 2.36 | 1.18 | 0.6  | 0.3  | 0.075 |
| 20~25               | 100.0| 90~100| 0~10| 0~5 | -    | -    | -    | -    | -    | -    | -    |
| 15~20               | -    | 100.0| 90~100| 0~10| 0~5 | -    | -    | -    | -    | -    | -    |
| 10~15               | -    | -    | 100 | 90~100| 0~10| 0~5 | -    | -    | -    | -    | -    |
| 5~10                | -    | -    | -   | 100 | 90~100| 0~10| 0~5 | -    | -    | -    | -    |
| 3~5                 | -    | -    | -   | -   | 100 | 90~100| 0~15| 0~5 | -    | -    | -    |
| 0~3                 | -    | -    | -   | -   | -   | 100 | 90~100| -   | 0~15 | -    | -    |

Table 4 and Table 5 show that the aggregate percentage by basic meets the requirements of different specifications, but the specification of 0~3 mm aggregate by 0.075 mm mesh quality percentage is 17%, specifications for 3~5 mm aggregate through 2.36 mm mesh quality percentage is 34.2%. This goes beyond the technical conditions for the construction of the highway pavement base (JTGT F20-2015) with an intermediate macadam mixture aggregate specification limit.

Based on the physical properties of the aggregate and screening results, the indexes and screening results of the coarse aggregate meet the requirements. In fine aggregate, there are more fine materials below 0.075 mm, the plastic index exceeds the standard, and the content of impurities such as viscous soil is high. Fine aggregate significantly influences the strength and water stability of graded gravel. When the content of fine aggregate is small, the plasticity index has little effect on the strength. When the content of fine particles increases, the influence of the plasticity index, however, will increase.

The larger the liquid limit and plasticity index of particles below 0.5 mm, the worse the water stability. With the increase of the plasticity index, the CBR value of aggregate decreases rapidly. At the same time, fine materials with a high plasticity index tend to expand when exposed to water due to their high clay content, which reduces the permeability and water stability of the materials and increases the freezing sensitivity.

This paper, therefore, discusses the feasibility of the slaggy aggregate in the graded gravel base by replacing some slaggy aggregate in the tunnel to make full use of the slaggy gneiss aggregate in the tunnel.

4. Performance analysis of crushed stone mixture with fine limestone aggregate replacing abandoned slag in tunnel

This paper adopted the vibration molding method to shape the specimen to be like field construction to
fully embed the coarse aggregate with each other and to better the strength of the skeleton. A CBR test was used to evaluate the material performance to study the performance of limestone fine aggregate replacing tunnel slag-graded crushed stone mixture. On the other hand, the vibration-compaction specimen could be formed by stripping, and the unconfined compressive strength test of graded gravel base material was used to evaluate its compressive strength. The technical performance requirements of the support project are CBR ≥ 300 and unconfined compressive strength ≥0.7 mpa.

4.1. Grading optimization

The stability and strength of the graded crushed stone mixture are affected by its gradation. In general, the CBR value of the graded crushed stone mixture with high compactness and continuous gradation is relatively high, and the permanent deformation capacity is relatively good.

According to the screening results of the slag-abandoning aggregate in each channel above, to optimize the appropriate mixture gradation, five gradations were preliminarily determined to carry out the test of the optimal water content, maximum dry density and CBR\(^4\). The five gradation mixing ratios are shown in Table 6, the synthetic gradation is shown in Table 7, and the optimal water content and maximum dry density are shown in Table 8.

Table 6. Proportion of aggregate admixture in five gradations

| Screen size (mm) | Grade 1 | Grade 2 | Grade 3 | Grade 4 | Grade 5 |
|-----------------|---------|---------|---------|---------|---------|
| 20–25           | 20      | 22      | 24      | 20      | 24      |
| 15–20           | 12      | 13      | 14      | 12      | 14      |
| 10–15           | 12      | 13      | 14      | 12      | 14      |
| 5–10            | 16      | 16      | 16      | 21      | 13      |
| 3–5             | 17      | 16      | 14      | 17      | 13      |
| 0–3             | 23      | 20      | 18      | 18      | 22      |
| Total           | 100     | 100     | 100     | 100     | 100     |

Table 7. Five synthetic gradations

| Screen size | 26.5 | 19 | 16 | 13.2 | 9.5 | 4.75 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 |
|-------------|------|----|----|------|-----|------|------|------|-----|-----|------|-------|
| Synthesis of grading 1 | 100.0 | 82.8 | 73.1 | 66.2 | 53.7 | 39.3 | 28.9 | 20.2 | 13.6 | 8.4 | 4.1 | 2.4 |
| Synthesis of grading 2 | 100.0 | 81.2 | 70.5 | 63.0 | 49.8 | 35.3 | 25.5 | 17.6 | 11.8 | 7.3 | 3.6 | 2.1 |
| Synthesis of grading 3 | 100.0 | 79.5 | 68.0 | 59.9 | 45.9 | 31.4 | 22.9 | 15.8 | 10.7 | 6.6 | 3.3 | 1.9 |
| Synthesis of grading 4 | 100.0 | 82.8 | 73.1 | 66.2 | 52.5 | 34.3 | 23.9 | 15.9 | 10.7 | 6.6 | 3.3 | 2.0 |
| Synthesis of grading 5 | 100.0 | 79.5 | 68.0 | 59.9 | 46.6 | 34.5 | 26.5 | 19.3 | 13.0 | 8.0 | 3.9 | 2.3 |
| Grading limit | 100.0 | 85.0 | 77.0 | 67.0 | 58.0 | 40.0 | 30.0 | 20.0 | 16.0 | 11.0 | 8.0 | 5.0 |
| Graded lower limit | 100.0 | 77.0 | 66.0 | 56.0 | 46.0 | 30.0 | 20.0 | 12.0 | 10.0 | 5.0 | 3.0 | 2.0 |
Table 8. Optimal moisture content and maximum dry density of different grades

| Grading       | Grade 1 | Grade 2 | Grade 3 | Grade 4 | Grade 5 |
|---------------|---------|---------|---------|---------|---------|
| Optimum moisture content (%) | 5.7     | 5.3     | 5.7     | 5.3     | 5.4     |
| Maximum dry density (g/cm³)     | 2.146   | 2.115   | 2.146   | 2.122   | 2.158   |

In this paper, according to the CBR test method T0134–1993 as per the highway geotechnical test code (JTG e40–2007), the specimen forming method was the vibration-compaction forming, and the CBR of different matching specimens was tested, as shown in Table 9.

Table 9. CBR test results

| Test item | No soaking CBR (2.5 mm) | No soaking CBR (5.0 mm) | Soaking CBR (2.5 mm) | Soaking CBR (5.0 mm) |
|-----------|-------------------------|-------------------------|----------------------|----------------------|
| Grade 1   | 197.1                   | 241.8                   | 175.0                | 211.1                |
| Grade 2   | 168.1                   | 204.9                   | 126.2                | 163.7                |
| Grade 3   | 198.3                   | 214.6                   | 133.9                | 170.4                |
| Grade 4   | 136.8                   | 187.9                   | 102.7                | 144.9                |
| Grade 5   | 202.1                   | 245.7                   | 179.8                | 220.8                |

From the above test results, the CBR value of 5 at the intermediate level of the five gradation mixtures is the largest, and the CBR value of 4 is the smallest, so it is better to choose 5 as the best gradation.

4.2. Limestone fine aggregate replacement method

Although the CBR value of gradation 5 is the largest, it still fails to meet the requirement of CBR ≥ 300. Limestone fine aggregate was used to replace the tunnel slag-graded gravel mixture to improve the CBR value of the tunnel slag-graded gravel mixture, and the performance difference between the substitute mixture and limestone-graded gravel mixture was compared and analyzed. There are two alternative methods for fine limestone aggregate. The first method replaces 0~3 mm with limestone, and the second type, 0~3 mm and 3~5 mm are replaced by limestone. The limestone-graded gravel mixture is set as a contrast. For the convenience of description, 0~3 mm is replaced with limestone as plan 1, 0~3 mm and 3~5 mm are both replaced with limestone as plan 2, and limestone-graded gravel is denoted as plan 0.

4.2.1. Technical indicators of fine limestone aggregate

According to JTG E42-2005, the technical indicators and screening of fine limestone aggregates were tested, as shown in Tables 10 and 11.

Table 10. Technical requirements for fine aggregate of limestone

| Project               | Unit | Test value | Technical requirements |
|-----------------------|------|------------|------------------------|
| Apparent relative density | -    | 2.803      | ≥2.50                  |
| Sand equivalent       | %    | 67.5       | ≥50                    |
| Methylene blue content | g/kg | 1.2        | ≤1.5                   |

Table 11. Screening results of fine limestone aggregates 0~3 mm and 3~5 mm

| Specifications (mm) | Percentage of mass through the following screen (mm) (%) |
|---------------------|---------------------------------------------------------|
| 3~5                 | 31.5 26.5 19 16 13.2 9.5 4.75 2.36 1.18 0.6 0.3 0.15 0.075 |
| 0~3                 | 100.0 100.0 100.0 100.0 100.0 90.1 62.2 42.0 31.7 23.8 20.5 |

4.2.2. Limestone adjusted mix design
(1) Synthetic gradation

Figure 2 shows the gradation curves of the gravel mixture graded in scheme 1, scheme 2, and scheme 0.

![Figure 2. Grading diagram](image)

(2) Optimal moisture content and maximum dry density

The optimal water content and maximum dry density of the graded crushed stone mixture of the three schemes that were determined by the test method of the vibration compaction, and the results are shown in Table 12.

| Gradation of different aggregates | Project 1 | Project 2 | Project 0 |
|-----------------------------------|-----------|-----------|-----------|
| Optimum moisture content (%)      | 5.1       | 5.2       | 5.7       |
| Maximum dry density (g/cm³)       | 2.235     | 2.258     | 2.146     |

4.3. Comparison of performance of graded crushed stone mixture with different replacement methods

A CBR test and an unconfined compressive strength test were conducted under the condition of optimal water content and maximum dry density. The graded crushed stone mixture of the three schemes was compared with the graded crushed stone mixture of abandoned dregs in the tunnel. Figures 3 and 4 show a summary of the test results.
The above result shows that the CBR value and limestone grading macadam mixture unconfined compressive strength meet the technical requirements of the graded crushed stone base. The tunnel abandons slag grading macadam mixture and scheme 1 replacement (0~3 mm) limestone mixture is slightly tall. The CBR value is at the same time a Project 2 replacement (0~3 mm and 3~5 mm limestone) of graded gravel tunnel-abandoned slag of CBR value, which is slightly lower on average. From the perspective of unconfined compressive strength, plan 0 (limestone-graded gravel mixture) is higher than the tunnel slag-graded gravel mixture but slightly lower than the tunnel slag-graded gravel mixture of Project 1 and Project 2, which also meets the requirement of unconfined compressive strength of graded gravel base.

According to the above experimental studies, using fine limestone aggregate instead of the original fine slag aggregate could significantly improve the strength of the mixture, and Project 2 is better to replace 0~3 mm and 0~5 mm limestone at the same time.
5. Conclusion
This study first analyzed the lithology of the abandoned slag in the tunnel and then analyzed its aggregate characteristics. It then compared the performance of the graded crushed stone mixture with different fine aggregates and studied its applicability as the base of the graded crushed stone. The results showed that:

1) The lithology of abandoned slag rocks in the Xifu expressway tunnel is gneiss, which is divided into hard rocks according to hardness, which could meet the lithology requirements of the graded gravel base of highway engineering.

2) According to the technical rules for construction of highway pavement base course (JTGT F20-2015), the coarse aggregate of abandoned slag in this tunnel meets the technical requirements. The plasticity index of fine aggregate is greater than 9% and there are many impurities. After the test and comparison analysis, the fine aggregate of abandoned slag in the tunnel could be replaced and used for the base course of graded gravel.

3) Using limestone fine aggregate instead of tunnel slag fine aggregate could significantly improve the strength of the mixture. Using limestone simultaneously replaces the tunnel slag 0~3 mm and 3~5 mm fine aggregate. A CBR not less than 300, unconfined compressive strength not less than 0.7 mpa, could be used as the base of highway grading gravel.

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