Pavement Performance of Cement Stabilized Slag Base
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Abstract: In order to study the influence of power plant slag on the mechanical properties of cement stabilized macadam base, the cement stabilized macadam mixture was prepared by replacing natural stone with slag according to different proportion, and the compaction characteristics, unconfined compressive strength, splitting strength and compressive modulus of elasticity of the mixture were tested. The results show that the larger the amount of slag, the larger the optimal moisture content of the mixture and the smaller the maximum dry density; the 7-day unconfined compressive strength of the semi-rigid base layer increases first and then decreases with the amount of slag. Both the crack strength and frost resistance index decrease with the increase of slag content. The results prove that slag can be used as a substitute for aggregates in semi-rigid base course, which provides a test basis for the application of slag in road engineering.

Introduction
In recent years, with the continuous deepening of China's industrialization process, industrial solid waste has been increasing year by year. As the main body of China's energy industry, coal-fired power plants not only cause huge pressure on the surrounding environment, but also cause waste of resources. Slag is a voluminous ash active substance such as SiO₂ and Al₂O₃, which is a by-product of coal combustion. It can replace aggregates in semi-rigid substrates and stimulate the mechanical properties of semi-rigid substrates. Therefore, it is feasible to study the influence of slag on the mechanical properties of semi-rigid base using slag as the raw material for preparing semi-rigid base.

In this paper, slag is used as the replacement material of stone in semi-rigid base, the influence of slag on the mechanical properties of semi-rigid base is studied, the seven day unconfined compressive strength, splitting strength and compressive resilient modulus of semi-rigid base are tested, and the influence of slag on the mechanical properties of base is discussed.

Test Materials and Test Methods
Test Materials
(1) Slag: Taken from Shan'xi Huadian Yuheng Coal Power Co., Ltd., the appearance is gray solid powder or block, apparent density is 2.603g / cm³, and the main components are silicon dioxide, aluminum oxide, and iron oxide. The chemical composition of the slag is shown in Table 1, and the screening results are shown in Table 2.

| compositions | CaO | Al₂O₃ | Fe₂O₃ | SiO₂ | SO₃ | loss on ignition |
|-------------|-----|-------|-------|------|-----|-----------------|
| Content[%]  | 4.44| 13.26 | 9.37  | 66.12| 0.68| 0.53            |

| Mesh size [mm] | 19  | 9.5 | 4.75 | 2.36 | 0.6 | 0.075         |
|----------------|-----|-----|------|------|-----|---------------|
| Passage Rate[%]| 100.0| 75.8| 48.2 | 30.9 | 19.4| 0.0           |
According to the screening results of power plant slag, the size of 9.5mm sieve takes up about 25%, indicating that there are some large particles formed by combustion in slag, and the size of 4.75mm takes up the largest proportion, 27.6%, while the size of other materials takes up the same proportion as that of stone debris.

(2) Cement: Huaxin P.O 42.5 cement is used for cement. See Table 2 for setting time and strength of cement.

| Setting time | Compressive strength [MPa] | Folding strength [MPa] |
|--------------|-----------------------------|------------------------|
| Initial setting | Final setting | 3d  | 28d  | 3d  | 28d |
| 245          | 390            | 28.3 | 52.3 | 5.88 | 8.2 |

Test Method

Suspended-dense structure is used to test the road performance of the semi-rigid base course. The mixture is shown in Table 3. In accordance with relevant regulations such as "Testing Rules for Inorganic Binder Stabilizing Materials for Highway Engineering" (JTG E51-2009) and "Technical Details for Construction of Highway Pavement Base Course" (JTGT F20-2015), determine the maximum dry density and optimal water content of the mixture, as shown in Table 4. Cylindrical sample of φ150 mm × 150 mm were produced. Each group of sample was compacted by the static pressure method according to its optimum water content, and the compaction degree was 0.98. After the sample is formed, place it at (20 ± 2) °C and humidity ≥95% for standard curing, Saturate the sample with water before the measurement of unconfined compressive strength and splitting strength of the sample. The height of the water surface is required to exceed the height of the sample. Test the compressive strength and split strength after the sample is completely saturated. Frost resistance test was performed according to T8582-2009, and the test sample had a curing period of 28 days.

| Number | 10-30[mm] gravel | 10-20[mm] gravel | 5-10[mm] gravel | 3-5[mm] gravel | 0-3[mm] chip | slag [%] |
|--------|------------------|------------------|-----------------|---------------|-------------|---------|
| 1      | 17               | 21               | 15              | 14            | 33          | 0       |
| 2      | 24               | 21               | 15              | 0             | 30          | 10      |
| 3      | 24               | 21               | 15              | 0             | 20          | 20      |
| 4      | 24               | 21               | 15              | 0             | 10          | 30      |
| 5      | 24               | 21               | 15              | 0             | 0           | 40      |
| 6      | 20               | 18               | 12              | 0             | 0           | 50      |
Table 4. Compaction test results.

| different mixing amount of slag [%] | optimum water content [%] | maximum dry density [g/cm$^3$] |
|-----------------------------------|---------------------------|--------------------------------|
| 0                                 | 2.291                     | 5.2                            |
| 10                                | 2.287                     | 5.6                            |
| 20                                | 2.188                     | 6.6                            |
| 30                                | 2.090                     | 7.2                            |
| 40                                | 1.991                     | 7.8                            |
| 50                                | 1.891                     | 8.9                            |

Test Results and Discussion

Seven-day Unconfined Compressive Strength

The seven-day unconfined compressive strength test results of semi-rigid base with different mixing amount of slag are shown in Figure 2.

As can be seen from the above figure, as the mixing amount of slag increases, the unconfined compressive strength of 7d initially increases and then decreases. This is because the slag will have a certain crushing process during the molding process. During the compression molding process, this crushing process will help the mixture sample to be denser and the porosity will become smaller. As the mixing amount of slag continues to increase, the slag exists as a skeleton after filling the gap. The slag skeleton has weaker compression strength than the crushed stone skeleton, so the compressive strength shows a decreasing curve at 10%-50%. The mixing amount of slag is 50%, and the compressive strength still meets code requirement.

Splitting Strength

The results of the split test are shown in Figure 3. It can be seen from Fig. 3 that with the increase of mixing amount of slag aggregate in the same curing period, the splitting strengths of the Sample at 28d and 90d showed a decreasing trend. The splitting strength of the 50% slag-mixed mixture is about 60% without addition, and the strength is reduced by about 40%. With the increase of the curing period, the splitting intensity increased, but the increase was not obvious.

Frost Resistance Test

The frost resistance was evaluated by the frost resistance index. The freeze resistance index is the ratio of the compressive strength of the Sample after freeze-thaw to the compressive strength before freeze-thaw. The larger the frost resistance index, the better the freeze resistance of the Sample. The results of the freeze-thaw test are shown in Table 5. It can be seen from Table 5 that the frost resistance index of cement stabilized slag macadam is generally lower than that of cement stabilized macadam. When the mixing amount of slag is less than 30%, the frost resistance index is higher.
than 90%. When the mixing amount of slag is 40% and 50%, the frost resistance index is lower than 90%. This is because the slag aggregate has more pores than natural stone, and the sample has a large water absorption rate, which intensifies water invasion and frost heave. When the mixing amount of slag aggregate is less than about 30%, the sample has the best frost resistance and can be used in seasonal freezing areas.

Summary
Slag is a kind of material with low surface density and low porosity. It contains active materials such as SiO2 and has pozzolanic activity. It can be used as a material for preparing Semi-rigid Base.

Cement stabilized slag can be used as the pavement base filler, which can meet its strength requirements. With the increase of the amount of slag, the strength of cement stabilized slag filler increases first and then decreases.

For seasonal frozen areas, considering frost resistance, it is recommended that the mixing amount of slag is less than 30%.

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References
[1] Zhang Juan, Qiu Chengji, Zhu Yu. Research on the Performance of Slag Cement Stabilized Base Materials [J]. Journal of Highway and Transportation Research and Development (Application Technology Edition).

[2] Ministry of Transport of the People's Republic of China. FTG E51-2009 Test Rules for Stable Materials of Inorganic Binding Materials for Highway Engineering [S]. Beijing: People's Communications Press, 2009.

[3] Cui Suping, Gu Xueci, Wang Ziming, et al. Effect of gypsum types on properties of Portland cement [J]. Cement Technology, 2005 (2): 29-32.

[4] Liu Dong, Li Lihan, Cui Huajie. Road performance of cement stabilized slag crushed stone base course [J]. Journal of Tongji University (Natural Science), 2005 (3): 405-409.