Research on Steel Slag Resin Mixture Used in Rapid Repair of Pavement Damage

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Abstract. In order to explore the pavement performance of steel slag for pavement damage repair, steel slag, river sand and resin binder are mixed in proportion to prepare steel slag mixture. The test results show that the steel slag mixture has excellent high temperature stability, water stability, low water absorption and low expansibility. The engineering application shows that the steel slag resin mixture has no quality problem after being used to repair the pavement damage for half a year. At the same time, it can also solve the problem of environmental pollution caused by the solid waste of steel slag, which has good social benefits.

Keywords. Steel slag, steel slag resin mixture, pavement damage, pavement performance.

1. Introduction

With the development of China's iron and steel industry, steel slag as a by-product of steelmaking has increased year by year. According to statistics, the cumulative storage of steel slag in China has reach 1 billion tons [1]. The utilization rate of steel slag in developed countries is almost 100%. However, the domestic steel slag treatment process is less, and the utilization rate is only about 30%. In China, the utilization of steel slag is mainly concentrated in filling road base and subbase. The utilization rate of steel slag with small particle size and high crushing value is low [2].

In recent years, with the increase of traffic volume and road service life, many kinds of pavement diseases appear frequently, especially the cement concrete pavement appears damage, pit, gnawing edge and other diseases. For the pavement with high traffic pressure and serious damage, it is necessary to strengthen pavement maintenance [3-4]. At present, there are mainly inorganic materials and organic materials used for damage repair. Based on the research of modified epoxy resin mixture in the field of road maintenance in recent years, this paper mainly uses modified epoxy resin material combined with inorganic aggregate to prepare mixture for pavement damage repair. On the one hand, this paper makes use of the properties of epoxy materials, such as fast curing speed, high bond strength, boiling resistance, acid and alkali corrosion resistance, on the other hand, the compressive properties of materials are supplemented by inorganic materials [5].

At present, China's highway industry is in rapid development, and the demand for natural sand and stone resources is increasing. However, sand and stone resources are not renewable resources. Excessive exploitation may lead to the destruction of the original ecological environment. Through the research on the utilization of steel slag, combined with modified resin materials, the mixture is prepared and applied to the pavement damage repair in this paper. It can not only solve the problems of steel slag occupation and environmental pollution, but also reduce the dependence on sand and
2. Raw Material Test

Steelmaking process. The test material selected in this paper comes from Yangjiang Qiaojiang Environmental Protection Technology Co., Ltd., which is produced by "rkef" process to produce ferronickel alloy. Rkef process is the most advanced and practical pyrometallurgical process for smelting laterite nickel ore. This process has been widely used in the world. The steel slag prepared by this method has relatively uniform particle size and good stability [7].

2.2. Chemical Composition of Steel Slag

The chemical composition content of steel slag is mainly determined by production process, production equipment and target product, but the main chemical composition is similar. In this test, three samples are collected from the upper, middle and lower parts of steel slag pile of Yangjiang Qiaojiang Environmental Protection Technology Co., Ltd. Then the chemical composition is detected, and the test results are shown in table 1.

It can be seen from the test data in table 1 that the chemical composition of the three groups of samples is close, and all of them are mainly SiO₂ and MgO. The content of SiO₂ is 50.94%, and the content of magnesium compound is 18.88%. The content of calcium compound is less, which meets the requirement that free CaO should not be more than 3.0%. Less free calcium oxide can prevent the steel slag aggregate from swelling after meeting water and cause aggregate pulverization. Therefore, the analysis and test results show that the steel slag has good chemical stability.

### Table 1. Composition analysis of samples.

| Test items | SiO₂/% | Ca/% | Mg/% | Na₂O/% | K₂O/% | Al₂O₃/% | Si/% | Ni% | Fe% | Mn/% |
|------------|--------|------|------|--------|-------|---------|------|-----|-----|-----|
| Sample 1   | 47.48  | 0.73 | 20.42| 0.088  | 0.031 | 5.92    | 0.024| 0.057| 7.76| 0.5 |
| Sample 2   | 53.46  | 1.42 | 18.12| 0.09   | 0.058 | 4.95    | 0.048| 0.044| 6.2 | 0.52|
| Sample 3   | 51.87  | 1.51 | 18.09| 0.094  | 0.086 | 5.71    | 0.059| 0.042| 6.1 | 0.55|
| Average value | 50.94 | 1.22 | 18.88| 0.031  | 0.058 | 5.53    | 0.044| 0.048| 6.69| 0.52|

2.3. Physical and Mechanical Properties of Steel Slag

In order to test the performance of steel slag as aggregate to replace part of natural aggregate. The physical and mechanical properties of steel slag fine aggregate are tested and compared with the common emery aggregate according to the standard "highway engineering aggregate test specification" (JTG E42-2005) . The test results are shown in table 2. The appearance of Yangjiang steel slag is dark green with fine particles and uniform distribution. 90% of the particles are concentrated in 1.18 ~ 4.75mm. According to the specifications, the physical and mechanical properties of steel slag are measured according to the "highway engineering aggregate test specification" (JTG E42-2005). The test results are shown in table 2. It can be seen from table 2 that the physical test results of steel slag are close to those of common aggregate emery. The apparent relative density of steel slag is 3.05, for it contains more metal compounds, the relative density is higher. The moisture content, abrasion loss, water absorption and expansion rate can meet the requirements of technical specification for construction of highway asphalt pavement (JTG F40-2004).
Table 2. Aggregate technical index.

| Index                      | Emery test results | Steel slag test results | The technical requirements | The test method |
|----------------------------|--------------------|-------------------------|----------------------------|-----------------|
| Apparent relative density | 2.6                | 3.05                    | ≥2.9                       | T0308           |
| Water content/%            | 0.56               | 0.81                    | ≤3.0                       | T0305           |
| Wear loss/%                | 28                 | 34                      | ≤35                        | T0317           |
| Water absorption rate/%    | 1.30               | 1.18                    | ≤3.0                       | T0307           |
| Expansion rate/%           | 0                  | 0.15                    | ≤2.0                       | T0348           |
| Granularity/mm             | 1.18–4.75          | 1.18–4.75               | -                          | T0302           |

2.4. Radioactivity of Steel Slag
Since the steel slag comes from the smelting of laterite nickel ore, it may contain a small amount of heavy metals, toxic substances and even radioactive elements. It may be harmful to contact personnel when it is applied to repair pavement damage. Therefore, it is necessary to detect the radioactivity of steel slag to ensure traffic safety and prevent radiation pollution. The specific structure of radioactivity detection is shown in table 3. The results show that the radioactivity is small and meets the specification requirements.

Table 3. Steel slag radioactivity.

| Test items                      | Test results | “Radionuclide limits for building materials” | Standard level |
|--------------------------------|--------------|---------------------------------------------|----------------|
| Internal Exposure Index (I<sub>Ra</sub>) | 0.01         | I<sub>Ra</sub>≤1.0                          | Reach the standard |
| External Exposure Index (I<sub>r</sub>)     | 0.02         | I<sub>r</sub>≤1.0                           | Reach the standard |

2.5. Ratio of Epoxy Resin Adhesive and Mixture
(1) Epoxy cement
The epoxy resin binder consists of a component of resin, component B of curing agent and component C of inorganic filler, and the mass ratio is 1:0.5:0.3. Epoxy resin cement has the characteristics of high strength, fast curing time and good durability. It can be widely used in the repair of cement concrete road and asphalt road. The mechanical properties of cement are shown in table 4.

Table 4. Main technical indicators of epoxy resin binder.

| Performance                      | Technical requirements | Test results | Reference standards |
|---------------------------------|------------------------|--------------|---------------------|
| Tensile strength /MPa           | ≥20                    | 25           | GB/T 1040.3-2006    |
| Bonding strength /MPa           | ≥2.5 (concrete failure)| 3.30 (concrete failure)| GB/T 16777-2008 |
| Steel-steel bonding strength /MPa| ≥15                    | 17.5         | GB/T 6329-1996      |
| Steel-steel tensile shear strength /MPa| ≥12          | 14.5         | GB/T 124-2008       |
| Water absorption (%)            | <1                     | 0.15         | ASTM D 570 2005     |
2.6. Aggregate Grading Screening

Based on the previous research of the research group, the appropriate gradation is selected by preparing Marshall Specimen and testing its water absorption and Marshall Stability. The results show that the best ratio of glue to aggregate is 1:8. In this paper, steel slag and fine sand are selected as aggregate, modified epoxy resin adhesive is used as binder, and the mass ratio is 1:8. By testing the change trend of water absorption and Marshall Stability, the appropriate proportion of steel slag and river sand is selected. The test results are shown in figure 1.

![Figure 1. Influence of steel slag and river sand blending ratio on water absorption and stability.](image)

It can be seen from figure 1 that with the increase of the quality of river sand, the Marshall stability strength of steel slag mixture increases first and then decreases, and the water absorption first decreases and then increases. When the mass ratio of steel slag to river sand is 50:50, the stability reaches 47.66kN, and the water absorption rate is the lowest, only 2.07%. The main reason is that a small amount of steel slag with a diameter of 754.1 mm exists after the preparation of resin. With the addition of river sand, the porosity of the mixture gradually decreases, so the stability gradually increases and the water absorption rate decreases. When the amount of river sand is more than 50%, the mechanical strength and stability of the mixture decrease when the content of fine sand is too high. Therefore, the mass ratio of steel slag to river sand is 1:1, and the mass ratio of resin glue to aggregate is 1:8.

3. Road Performance Research

3.1. High Temperature Stability

According to T0703 in "test specification for asphalt and asphalt mixture of Highway Engineering" (JTG E20-2011), the rutting specimens with length of 300 mm × width of 300 mm × thickness of 50 mm are prepared for testing. As the control group, the modified asphalt mixture is prepared with commercial asphalt and commercial aggregate AC-13 grade. After the mixture is cured and kept warm for 6 h, this paper simulates the use of high temperature heavy traffic at 60 °C and wheel pressure of 0.7 MPa, The results are shown in table 5.

| Project                      | Modified asphalt mixture | Steel slag resin Mixture | Technical requirements |
|------------------------------|--------------------------|--------------------------|------------------------|
| Dynamic stability/(times/mm)| 4169                     | 9091                     | ≥1000                  |
3.2. Water Stability

The ratio of the stability before and after immersion is taken as the water stability index. The immersion Marshall specimens are prepared according to t0709 method in “test specification for asphalt and asphalt mixture of Highway Engineering” (JTG e20-2011), and soaked for 48 h at 60 ℃, and the rest are the same as the standard Marshall test method. The test results are shown in Table 6. It can be seen from the data in Table 6 that the residual stability of modified asphalt mixture and steel slag resin mixture meets the requirements of technical specifications which is more than 80%. The residual stability is 99.1% and the water absorption rate is 2.07%. The results show that the steel slag resin mixture has good stability and high water stability, which can fully meet the pavement application resistance to water damage.

| Sample                  | Water absorption/% | Marshall stability/KN Conventional immersion | Residual stability/% | Technical requirements |
|-------------------------|--------------------|---------------------------------------------|----------------------|------------------------|
| Modified asphalt mixture| 2.25               | 11.6                                        | 10.1                 | 86.5                   |
| Steel slag resin Mixture| 2.07               | 47.7                                        | 47.2                 | 99.1                   |

3.3. Compressive Strength

The compressive strength test is conducted according to the cement mortar cube compression test method in “JTG e30-2005 highway engineering cement and cement concrete test specification”, and 70.7 mm × 70.7 mm × 70.7 mm cube specimen is prepared. It can be seen from the results in Table 7 that 19.4 Mpa can be reached after curing for 5 h. Generally, the pavement temperature in the south is higher than the room temperature, so the maintenance time is generally 2 ~ 3 h before the traffic can be opened. After curing at 23 ℃ for 2 days, the compressive strength can reach 51.7 MPa. It can be seen that steel slag resin mixture has the advantages of high compressive strength and short maintenance time, which can be applied to the rapid repair of pavement damage.

| Sample                  | Compressive strength/MPa |
|-------------------------|--------------------------|
|                         | 23℃5h     | 23℃2d     |
| Steel slag resin mixture| 19.4       | 51.7       |

3.4. Expansibility

According to the t0348-2005 method in "highway engineering aggregate test specification" (JTGE42-2005), the main step is to prepare three Marshall specimens of steel slag mixture according to the standard operation method to test its volume. After soaking in 60 ℃ water for 3 days, the volume is measured and the volume change rate is calculated.

Due to the different sources and processes of steel slag, the content of free calcium oxide is different, resulting in different expansibility after immersion. According to the chemical composition analysis in table 1, the steel slag studied in this paper contains less free calcium oxide. It can be concluded from the test results in Table 8 that the volume of steel slag mixture has almost no change after immersion and expansion, which can be applied to the repair of pavement potholes and meet the specification requirements of steel slag for wear resistant asphalt pavement (GB / T24765-2009).

| Sample                  | Expansibility | Technical requirements |
|-------------------------|---------------|------------------------|
| Steel slag resin mixture| 0.1%          | ≤2.0%                  |
3.5. Engineering Application

The construction site is Huangpuyong Bridge of Guangzhou ring expressway. The steel slag mixture is used to repair the damaged road. Firstly, the damaged position of the original road is chiseled out, and the loose plate and surrounding floating dust are cleaned up. Then apply glue at the bottom and pour the prepared steel slag mixture into the pit and groove, and then compact it. The construction process is shown in figures 2 and 3. After half a year of construction, there is no quality problem in the follow-up visit, and the application effect is good.

![Figure 2. Before construction (after base surface treatment).](image1)

![Figure 3. After construction.](image2)

4. Conclusion

(1) The test shows that the moisture content, wear loss, water absorption and expansion rate of steel slag aggregate can meet the requirements of the specification "standard specification for construction and acceptance of highway asphalt pavement " (JTG F40-2004). The chemical composition analysis shows that the chemical stability is good. The radioactivity test shows that the steel slag is non-radioactive and has no impact on the environment.

(2) The test shows that the steel slag mixture has excellent high temperature stability, water stability, low water absorption and low expansibility. Under the temperature of 60℃ and wheel pressure of 0.7MPa, the high temperature stability is tested and the dynamic stability is 9091 times/mm, Marshall Stability is 47.7kN, residual stability is 99.1%, water absorption rate is 2.07%, and expansion property was 0.1%. The test high temperature stability obtains the dynamic stability of 9091 times/mm, the Marshall stability of 47.7kN, the residual stability of 99.1%, the water absorption rate of 2.07%, and the expansibility of 0.1%. The test shows that the mixture can be used to repair road damage and has the characteristics of simple construction, good durability and fast traffic opening.

(3) By using waste steel slag as aggregate to repair pavement damage, it can not only solve the problems of solid waste solids occupying land and environment polluting, but also reduce excessive exploitation of natural sand and gravel resources, which has good social benefits.

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