Study on Preparation and Performance of Steel Slag Asphalt Mixture Based on Steel Slag Aggregate

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Abstract. The comprehensive utilization of steel slag has always been a worldwide problem. Under the background of vigorous development of highways in China, the application technology of steel slag in asphalt concrete will make the steel slag resources hopefully get a large number of reasonable utilization. Based on the application of steel slag in asphalt concrete, the basic physical and chemical properties of different types of steel slag were investigated. The blast furnace slag was used as the aggregate to prepare the asphalt mixture. The mixture was tested by research and test. The uniaxial compression test and the indirect tensile test were used to evaluate the low temperature crack resistance and fatigue resistance. The test results show that the surface texture of steel slag is rough and the embedding effect is good, which is beneficial to enhance the adhesion with asphalt and improve the shear resistance. The steel slag asphalt mixture has good low temperature deformation ability and small expansion ratio, which can be paved to meet the driving conditions. Required asphalt concrete pavement.

1. Introduction
In China, with the continuous deepening of steel slag research in recent years, steel slag as a road material to replace natural gravel and sand has become the research content of many research institutions and institutions [1]. Therefore, how to effectively handle the use of steel slag is a serious and difficult task before us. In road engineering, steel slag can partially replace natural aggregate to improve concrete wear resistance. However, the use of steel slag in building materials is mainly limited by its high alkalinity and internal free calcium, magnesium and other unstable components [2]. China's highway construction is in a stage of rapid development, and it consumes a lot of energy and resources. If steel slag is used as an aggregate in pavement engineering, it is of great significance to improve the utilization of steel slag and reduce environmental pollution [3]. In addition, with the rapid development of highway construction in China, high-quality road stone resources are increasingly scarce, and the development of the highway industry also urgently needs to find other materials that can replace road stone. Practice has proved that most of the steel slag can be controlled under 3.5%, which can meet the technical specifications of highway asphalt pavement construction. In addition, the asphalt film can also play a role in restraining the expansion of steel slag [4]. With the implementation of the national sustainable development strategy and the industrialized production of iron and steel enterprises in China, how to utilize steel slag wastes as resources and high value has become a continuing research hot spot at home and abroad.
2. Methodology

2.1 Raw Material
The main chemical composition of steel slag from converter steelmaking is shown in Table 1, and P. O42.5 cement is selected as cement, and its chemical composition and main performance index are shown in Table 2. Natural coarse aggregate: construction stone with particle size of 6 to 32.5mm, limestone gravel; natural fine aggregate: construction sand with particle size of 0 to 5.5mm, siliceous river sand.

| Table 1 | Experimental raw material chemical composition / wt.% |
|---------|--------------------------------------------------------|
|         | CaO         | SiO2        | Al2O3      | Fe2O3      |
| Cement  | 50.36%      | 21.37%      | 7.81%      | 3.31%      |
| Slag    | 45.61%      | 15.77%      | 4.59%      | 19.24%     |

| Table 2 | Ordinary Portland cement (42.5) performance index |
|---------|--------------------------------------------------|
| Stability | Setting time/min | Specific surface area/m2/Kg | Flexural strength/MPa | Compressive strength/MPa |
| Qualified | Initial setting | Final setting | 315 | 4d | 24d | 4d | 24d |
|          | 193 | 297 | 3.4 | 5.5 | 19.2 | 40.18 |

2.2 Test Method
There are some differences between the appearance of steel slag and traditional stone. The surface of steel slag is gray-black with abundant edges and corners, and there are many surface pores. The steel slag was crushed and grinded by jaw crusher and ball mill, and then sifted through 0.5mm pore size. The steel slag powder under sieve was taken as raw material for carbide aggregate. After further processing, steel slag with particle size greater than 4.33 nm is usually used as aggregate for asphalt concrete and cement concrete. The remaining tailings will be further processed into steel slag powders by adding them to the washing ball mill. The maximum load is obtained by loading at a rate of 60 mm/min until the specimen is destroyed. After forming and demoulding, the sample is put into the carbonization kettle, vacuum is pumped to -0.2 MPa and CO2 gas is injected to adjust the carbonization pressure and time. Compared with the indexes of limestone used in the test, it is obvious that the water absorption rate of the steel slag reaches 2.5%, which is nearly three times that of the limestone. This also indicates that the pores inside the steel slag are more and the steel slag is easy to absorb water. Features [5]. In the process of sewage discharge, the steel slag debris will be precipitated at the edge of the sedimentation tank due to its own importance. In this part of the ball-milling tailings, the content of the steel slag is extremely high, and a small amount of dust coated on the raw steel slag aggregate is also contained.

After confirming the selection of converter drum steel slag as a follow-up test, the stability of the converter drum steel slag was further tested. Since the asphalt concrete is a semi-rigid material and has a certain void ratio, the stability test of the steel slag permeable concrete used is carried out to test the stability of the steel slag of the converter drum. The main factors affecting the carbonization of steel slag are water content, molding pressure, carbonization temperature, carbonization pressure, carbonization time, etc. The factors affect each other, so the experimental results cannot be analyzed by single factor [6]. According to the influencing factors of this experiment, the range of values of each parameter is designed, as shown in Table 3. Because asphalt mixture is a kind of viscoelastic material, its composition is more complex, and its pavement performance is closely related to temperature change, load action, holding time, water and other factors. The accumulated ball mill tailings not only occupy a large amount of land, but also pose a potential threat to the environment. The tailings are actually a mixture of steel slag debris and dust, and the maximum nominal particle size is not more than 2.35 mm.
Therefore, fine aggregates smaller than 4.33mm in blast furnace slag have larger specific surface area, which can effectively adsorb asphalt and reduce the content of effective asphalt in asphalt mixture.

Table 3 Experimental parameters

| Water content/% | Forming pressure/MPa | Carbonization temperature/°C | Carbonization pressure/MPa | Carbonization time/h |
|----------------|----------------------|-------------------------------|---------------------------|---------------------|
| 11             | 8                    | 40                            | 0.21                      | 3                   |
| 10             | 6                    | 50                            | 0.33                      | 5                   |
| 13             | 9                    | 60                            | 0.47                      | 7                   |

The pore structure and pore volume of steel slag aggregate before and after carbonization were measured by mercury intrusion method. By means of X-ray diffraction analysis, thermogravimetric analysis, scanning electron microscopy and energy spectrum analysis, the composition change, element composition and micro-morphology of carbide aggregate were investigated. The experimental results show that the relative density of steel slag powder is higher than that of limestone powder, which is consistent with the regularity of steel slag aggregate. This is mainly because steel slag powder is ground by steel slag aggregate, and its physical and chemical properties have not changed [7]. Therefore, the road performance of the asphalt mixture was comprehensively evaluated by testing the high temperature stability, low temperature crack resistance, water damage resistance and water immersion expansion properties of the test materials. Since the ratio of the oil-stone ratio is the ratio of the mass of the asphalt to the mass of the aggregate, and the density of the steel slag is larger than that of the limestone, the aggregate mass of the aggregate incorporating the steel slag is larger under the same aggregate volume. Steel slag is easier to pulverize during cooling. The pulverized steel slag carries a large amount of dust, and if it is used as a fine aggregate, it will be detrimental to the normal operation of the asphalt mixture production equipment.

3. Result Analysis and Discussion

Since the volume expansion of f-CaO in the steel slag is caused by water, and the volume inside the structure is unstable, it is necessary to test the expansion amount of the mixture prepared by the steel slag. The total effective porosity of the blast furnace steel slag is the largest, which indicates that the blast furnace steel slag is a porous material although its surface texture is hard. When the carbonized steel slag aggregate concrete is pressed and the aggregate is broken, in the liquid phase environment, the clinker-like mineral inside the steel slag hydrates to produce a gel to fill the cracks and voids, thereby achieving the purpose of repairing micro-cracks in the concrete [8]. The stability of the steel slag asphalt mixture is higher than that of the gravel aggregate. The reason is that the shape of steel slag is uniform, the edges and corners are many, the particles can be well embedded, the surface texture is rough, and the steel slag and asphalt can effectively adhere. The actual asphalt content of steel slag asphalt mixture is larger than that of limestone asphalt mixture even if the asphalt-stone ratio is the same, which also shows that the porous characteristics of steel slag lead to the strong absorption ability of steel slag to asphalt. Usually, the main reason for the poor high temperature stability is the insufficient shear strength. The shear strength of asphalt mixture mainly comes from the cohesive force and the internal friction of asphalt.

Steel slag contains more f-CaO and MgO. If it is crushed directly as aggregate, it will expand hydration in hardened concrete, which seriously affects the volume stability of concrete. The carbonized steel slag is prepared according to the optimal process parameters, and the specific process performance of the measured steel slag aggregate is shown in Table 4 and Figure 1 below.

Table 4 Optimal group of experimental results

| Group                  | Compressive strength/MPa | Depth of carbonization/mm |
|-----------------------|--------------------------|---------------------------|
| According to strength | 150.33                   | 10                        |
| According to f-CaO content | 140.18                 | 15                        |
When steel slag is directly replaced, the volume parameters of the mixture have changed greatly, and the gradation of the replaced mixture needs to be adjusted again. The adjustment is based on two principles: one is that the adjusted volume parameters meet the requirements of the code; the other is to use more steel slag on the premise of meeting the requirements of the code. The formation process of blast furnace slag is that high temperature liquid slag is separated and smashed by pressure and water in the process of flowing out and descending, and the high temperature slag is cracked by stress concentration due to rapid contraction of water. At the same time, heat exchange is carried out to granulate the slag in the water curtain. Therefore, whether the carbonized steel slag aggregate can be broken in the concrete and the aggregate hydration performance will directly affect the repair effect of the carbonized steel slag aggregate. The water damage of the asphalt concrete pavement is caused by looseness, falling particles and the like caused by repeated dynamic loading under the action of freezing and thawing cycles or water. Therefore, it is necessary to define the amount of asphalt in the same volume of asphalt mixture in order to make the steel slag asphalt mixture comparable to the limestone asphalt mixture.

The apparent relative density of the steel slag coarse aggregate for asphalt mixture must be greater than 2.83, the water absorption rate is relaxed to 3.5%, and the wear loss in Los Angeles must not exceed 25%. This is an selection criterion for the wear resistance of steel slag and its significant characteristics. The Marshall test performance of the steel slag asphalt mixture after the individual replacement and the mixed replacement can meet the specification requirements, and the initial stability of the fine material replacement and the comprehensive replacement is greatly improved. The specific road performance changes need to pass through the following. Performance tests to determine. The blast furnace steel slag asphalt mixture has the highest vehicle stability, and its high temperature stability is superior to the asphalt mixture using the other two aggregates. Through tolerance analysis, about 45% of the fracture area is in the transition zone of aggregate interface, the rest of the fracture is from the cement matrix, and the cracks appear at the aggregate edge, which is directly related to the weak transition zone of aggregate interface, and the aggregate polyhedron structure also promotes the aggregation of cracks in the transition zone [9]. The failure strength increases with the increase of temperature before the brittle point, but it shows the opposite trend after the brittle point. The higher the temperature, the more obvious the decrease of the splitting strength. In asphalt pavement, the expansion stress produced by this reaction process will lead to cracking of pavement. This shows that different gradations of steel slag mixtures play different roles. In skeleton structure, the direct contact between steel slag aggregates can give full play to its advantages of strong internal friction resistance.

![Fig. 1 Optimal group of experimental results](image-url)
4. Summary

In this paper, the physical and mechanical properties, chemical composition and morphology of steel slag aggregate are analyzed. The problems of density conversion and effective density in the design of slurry are solved, and the steel slag asphalt mixture is prepared. The basic characteristics of steel slag and various minerals were studied. The converter drum steel slag was selected as the research object of asphalt mixture by using safety performance indexes such as leaching of harmful elements and stability test. In fresh water, steel slag aggregate concrete samples can withstand about 350 freeze-thaw cycles, compared with ordinary concrete, less than 150 cycles, the freeze-thaw resistance is better. The steel slag aggregate has many edges and corners, which is conducive to extrusion and makes the steel slag asphalt mixture have better deformation resistance at high temperature. The comparison of the performance of limestone asphalt mixture shows that the steel slag asphalt mixture designed in this paper is superior to limestone asphalt mixture in high temperature stability and water stability. The asphalt content loss prediction model of the corresponding asphalt mixture can be established by the linear fitting method through the composition content of the asphalt mixture aggregate and its asphalt absorption characteristics. There is also a large amount of steel slag with expansion properties that cannot be used in asphalt concrete, which may become a research hot spot in the future.

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