Preparation and characterization of coal gangue modified road asphalt

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Abstract. Coal gangue is one of the largest industrial wastes in China, a large number of coal gangue accumulation not only occupies too much land area, but also causes surrounding land and air pollution. In this paper, the coal gangue samples were activated at first, and then the coal gangue powder was modified by adding coal gangue powder to road asphalt with the ratio of 0.5 and 1.2, and the penetration, softening point and ductility of the modified asphalt were tested. The results show that the viscosity, strength and softening temperature of modified asphalt can be improved by adding coal gangue powder into asphalt. With the increase of the amount of coal gangue powder in asphalt, the change of penetration and softening point of asphalt will be greater, and the strength of asphalt will also increase, but it will also make the toughness of asphalt worse. By adjusting the powder-binder ratio, the modified asphalt can adapt to different environments and use conditions, so that it can be widely used.

Keywords: coal gangue; modified road asphalt; penetration; ductility; softening point.

1. Introduction
With the development of the times, cars have gradually become an indispensable means of transportation in people’s life, and the number of cars is increasing year by year, and the problem of road damage caused by it is becoming more and more serious. Asphalt pavement is a common pavement structure in urban roads, which has the advantages of low noise, smooth driving, easy maintenance, no joints and so on [1]. However, due to vehicle overloading, climatic conditions, construction defects, design defects and lack of management, as well as the asphalt pavement structure itself is easy to deform, aging, and poor high-temperature stability, as a result, there are potholes, rutting, loosening, spalling, waves, oil flooding, collapse and other damage phenomena of urban road asphalt pavement in China, which seriously affect the performance and service life of asphalt pavement. One of the main ways to improve the performance and service life of road asphalt is to prepare modified asphalt with excellent performance based on the current asphalt raw materials, so as to meet the requirements of high-grade road. The most attractive modified asphalts are Styrene Butadiene Rubber modified asphalt and Styrene-Butadiene-Styrene Triblock Copolymers modified asphalt, which are widely used because of their excellent performance, but the raw material cost is too high. Moreover, due to the different climate and environment in different regions, the requirements for asphalt performance are also different. For example, in the south area, road asphalt with higher softening point and lower hardness is needed, while...
in the north, road asphalt with lower softening point and higher hardness is needed. Therefore, how to modify asphalt has become a difficult problem at present. In recent years, inorganic filler modified asphalt has been developed to a certain extent, such as limestone powder, cement, hydrated lime, talc powder, diatomite, fly ash, volcanic ash, carbon black and so on. This kind of modifier has been widely concerned by road researchers because of its wide range of sources, easy processing, low cost and so on [2]. The study shows that adding inorganic fillers to asphalt mixture can effectively improve the stability and durability of asphalt mixture, and has good economic and environmental benefits.

Coal gangue is a by-product in the process of coal mining and coal washing, and it is one of the largest industrial solid wastes in China. According to statistics [3], the discharge of coal gangue in China is about 300-400 million tons per year, but the comprehensive utilization of coal gangue is less than 20%. If a large number of coal gangue is not used effectively, it will occupy a lot of land resources, affect the growth of vegetation, destroy the ecological environment and endanger human health. Although in recent years, China has begun to attach importance to the resource utilization of coal gangue, but the overall level is not high [4-5]. Therefore, there is still a lot of research space for reprocessing and resource utilization of coal gangue. At present, the application of coal gangue in road building materials is mainly focused on cement firing and aggregate for pavement and roadbed paving, but the research on the modification of asphalt with coal gangue as filler is rare. In view of the fact that there are a large number of kaolin series minerals in coal gangue, proper activity can be produced after grinding and calcination, so as to improve the interface properties between coal gangue and asphalt, and the macroscopic properties of asphalt mortar and asphalt mixture. It has become a new material to be studied in the field of asphalt modification.

Based on the above situation, in this paper, coal gangue is activated by crushing, ball milling and calcination, and the activated coal gangue powder is used as asphalt admixture to modify road asphalt. and study the change law of penetration, softening point and ductility of modified asphalt under different powder-binder ratio, in order to provide theoretical basis for improving the performance of road asphalt.

2. Experimental Method and Process

2.1. Raw materials
The coal gangue selected in the experiment is Panzhihua coal gangue in Sichuan Province. The average particle size of the original coal gangue is about 5-6mm, and there are more large pieces of coal gangue, as shown in Figure 1 before and after calcination. As can be seen from the picture, compared with the uncalcined coal gangue, the color of the calcined coal gangue changes from black-brown to yellow. This is because the excess water and carbon in the coal gangue are consumed during high temperature calcination, and the rest is activated coal gangue. According to the XRF analysis in Table 1, the main components of activated coal gangue are Al2O3 and SiO2, which indicates that the coal gangue selected in the experiment belongs to kaolinite type, which provides the possibility for coal gangue to be mixed with modified road asphalt. The asphalt used in the test is No. 70 road asphalt produced by Shanxi Dongfang paint Co., Ltd.

![Figure 1. Photos of coal gangue before (a) and after (b) calcination.](image_url)
Table 1. Composition content of coal gangue

| Sample            | Na₂O | MgO  | Al₂O₃ | SiO₂  | CaO  | K₂O  | Fe₂O₃ | SO₃  | TiO₂ | LOI |
|-------------------|------|------|-------|-------|------|------|-------|------|------|-----|
| Coal gangue       | 0.19 | 3.13 | 20.86 | 47.07 | 1.87 | 3.84 | 5.46  | 0.31 | 1.23 | 16.04 |

2.2. Experimental process

First, coal gangue was put into jaw crusher for crushing treatment, and the particle size of coal gangue reached 1-2mm after crushing. Then the broken coal gangue powder was placed in a 105 °C constant temperature drying oven and dried to a constant weight. After that, the gangue powder was ground by ball mill for 2 h, and the gangue powder treated by ball mill was calcined in muffle furnace at 750 °C for 2 h to obtain activated gangue powder. Asphalt mortar was added to the activated coal gangue powder and stirred, the powder-binder ratio was 0.5 and 1.2, and the temperature was controlled at (150 ±5) °C. After the surface of the solution is uniform, the modified asphalt mortar can be prepared by high-speed shear instrument, and the coal gangue doped modified asphalt mortar can be prepared. The experimental flow chart is shown in Figure 2.

Figure 2. Experimental flow chart of coal gangue modified asphalt

According to the Test Code for Highway Engineering Asphalt and Asphalt mixture (JTG E20-2011), the penetration, ductility and softening point of sample 1 (unmodified No. 70 road asphalt), sample 2 (powder-binder ratio 0.5 modified asphalt) and sample 3 (powder-binder ratio 1.2 modified asphalt) were tested respectively.

3. Performance Analysis of Modified Road Asphalt

3.1. Penetration degree test

The penetration of samples was tested at 25 °C, the experimental data are shown in Table 2.

Table 2. Test data of needle penetration of coal gangue modified asphalt

| Sample | test 1 (mm) | test 2 (mm) | test 3 (mm) | test 4 (mm) | Average penetration (mm) |
|--------|-------------|-------------|-------------|-------------|--------------------------|
| 1      | 65.6        | 65          | 66.5        | 66.4        | 65.88                    |
| 2      | 49.0        | 49.5        | 50.9        | 49.3        | 49.68                    |
| 3      | 33.3        | 32.8        | 32.1        | 33.2        | 32.85                    |

Penetration index is used to describe the viscosity of asphalt, which can indirectly show the hardness of asphalt. The greater the hardness of the asphalt, the smaller the penetration value. It can be seen from the experimental data that compared with sample 1, the penetration of sample 2 decreased by 24.6%, and that of sample 3 decreased by 50.1%, indicating that adding coal gangue powder into asphalt can effectively reduce the penetration of asphalt so as to improve the strength performance of asphalt.

3.2. Ductility test

Ductility is an important index to evaluate asphalt. The higher the ductility of asphalt is, the better its ductility is. Different types of road asphalt have different ductility, so they are suitable for different areas.
The ductility of three kinds of samples were tested at 5 °C and 25 °C respectively. The results are shown in Table 3.

| Sample | Amount of stretching at 5 °C (cm) | Amount of stretching at 25 °C (cm) |
|--------|----------------------------------|-----------------------------------|
| 1      | 0.2                              | 30.5                              |
| 2      | 3.3                              | 6.5                               |
| 3      | 1.1                              | 1.9                               |

From the experimental data, it can be seen that compared with the No. 1 sample without coal gangue, the ductility of No. 2 sample increases by about 15 times and that of No. 3 sample increases by about 5 times at 5 °C. At 25 °C, the ductility of sample 2 decreased by about 78.6%. The ductility of sample 3 decreased by about 93.7%, which indicated that the addition of coal gangue powder would have a serious impact on the ductility of road asphalt. Comparing sample 2 and sample 3, it is found that the ductility of road asphalt with coal gangue powder changes little at 5 °C and 25 °C, and the more coal gangue powder is added, the smaller the effect of temperature on ductility.

3.3. Softening point test

The softening point data of asphalt reflect the high temperature stability of asphalt, and the asphalt with different softening point is suitable for different areas. The test of asphalt softening point of three prepared samples was carried out. The results are shown in Table 4.

| Sample | Test result 1(°C) | Test result 2(°C) | Average temperature (°C) |
|--------|-------------------|-------------------|--------------------------|
| 1      | 47.6              | 47.6              | 47.6                     |
| 2      | 50.7              | 51                | 50.85                    |
| 3      | 58.3              | 59.3              | 58.8                     |

As can be seen from the experimental data, compared with the undoped No. 1 sample, the softening point temperature of No. 2 sample increased by about 6.8%, and the softening point of No. 3 sample increased by about 23.5%. This shows that the adulterated coal gangue powder has an obvious effect on the softening point temperature of asphalt, and the softening point temperature will increase with the increase of the amount of coal gangue powder. At the same time, it also indirectly shows that the strength of modified asphalt mixed with coal gangue will be improved. This also provides the possibility for coal gangue modified asphalt.

4. Conclusion

Adding coal gangue powder into asphalt can properly improve the viscosity, strength and softening temperature of modified asphalt. With the increase of the amount of coal gangue powder in asphalt, the change of penetration and softening point of asphalt will be greater, and the strength of asphalt will also increase, but it will also make the toughness of asphalt worse. Compared with the traditional modified asphalt, the advantage of using coal gangue modified asphalt is that the cost is relatively cheap, and the powder-binder ratio can be adjusted to adapt to different environments and use conditions, so this kind of asphalt modified method has a wide range of application.

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