Experimental study on high-temperature stability of rubber powder-modified Asphalt mixture

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Abstract. Waste rubber powder-modified asphalt can not only improve the asphalt pavement performance but can also solve the environmental pollution problem caused by waste tires. In this paper, through rutting tests, the effects of three different factors, the rubber powder content, rubber powder mesh number, and hydrogen peroxide content, on high-temperature stability of the mixture are systematically studied. The results reveal that the optimum rubber powder mesh is 60 mesh and the best rubber powder content is 21% for high-temperature stability of a rubber-modified asphalt mixture. At the same time, hydrogen peroxide can improve the high-temperature stability of the asphalt mixture.

1. Introduction
Over the years, road structures have begun to be deteriorated more rapidly due to increases in service traffic density, axle loading and low maintenance services. To minimize the damage to the pavement surface and increase the durability of flexible pavement, conventional bitumen needs to be improved with regards to performance related properties, such as resistance to permanent deformation (rutting) and fatigue cracking. Modifications of the bituminous binder have been explored over the past few years to improve the road pavement performance properties. There are many modification processes and additives are currently used in bitumen modifications. However, it is believed that the application of recycled automobile tires will not only solve the environmental problem associated with these industrial solid wastes but also act as a very promising modifier for the improvement of asphalt pavement material[1]. The use of crumb rubber in asphalt pavements has shown promising results in previous studies[2-4].

The rubber asphalt preparation parameters (rubber mesh number, rubber content, and hydrogen peroxide) have an important influence on the road performance of the mixture. Memon Ghulam Mohammed first found that the stability and rheological properties of modified asphalts prepared with hydrogen peroxide oxidized rubber powder were improved[5-7]. Based on the research of domestic and international scholars, the road performance of a modified asphalt mixture prepared by mixing rubber powder into asphalt has been improved to different extents, depending on the amount of rubber powder added, the mesh number of the rubber powder, and the amount of hydrogen peroxide used. There are some differences in the effects of the road performance[8-13]. The main purpose of this study is to determine the effects of different factors of a rubber powder-modified asphalt mixture on high-temperature stability of the mixture via a rutting test.
2. Experimental section

2.1. Raw materials and test plans

70#A grade road petroleum asphalt was chosen as the base asphalt. For rubber powder selection, market-bias tire rubbers of 20 mesh, 40 mesh, 60 mesh and 80 mesh were chosen. For the coarse aggregate and the fine aggregate, diabase and diabase clastic was separately selected; for the mineral powder, limestone mineral powder was selected; and for oxygen water, 30% hydrogen peroxide from the mark was selected. All of the materials were tested by experiment to meet the requirements of the specifications.

The variables for preparing the rubber powder-modified asphalt mainly include the amount of waste rubber powder, the mesh of waste rubber powder and the content of hydrogen peroxide. The dosages of waste rubber powder were 15%, 18%, 21%, and 24%. The meshes of the waste rubber powder were 20 mesh, 40 mesh, 60 mesh, and 80 mesh. The contents of hydrogen peroxide were 0 ml and 10 ml. The tests were divided into 30 groups.

2.2. Mix ratio design

In this study, continuous grade AC-13 is selected as the target grade. After the design adjustment, the ratio of the amount of each raw material is: 1# material: 2# material: 3# material: mineral powder = 35:36:25:4.

2.3. Determination of the best oil-stone ratio

The asphalt-aggregate ratio of the AC-13 rubber powder-modified asphalt mixture was selected to be from 4% - 6%, and 0.5% was used as the interval change. The Marshall Test pieces were molded with asphalt-aggregate ratios of 4.0%, 4.5%, 5.0%, 5.5%, and 6.0%. The standard Marshall Test pieces were molded 50 times on both sides. Through experiments, the relative bulk density ($\gamma_f$), porosity (VV), asphalt saturation (VFA), porosity (VMA), stability (MS) and flow value (PL) of the mixture sample were measured. The results are shown in Table 1.

Table 1. AC-13 Marshall test results

| Whetstone ratio (%) | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 |
|--------------------|-----|-----|-----|-----|-----|
| Maximum theoretical density | 2.536 | 2.518 | 2.500 | 2.483 | 2.467 |
| Gross volume density (g/cm³) | 2.344 | 2.367 | 2.381 | 2.383 | 2.371 |
| Void ratio (%) | 7.400 | 5.700 | 4.500 | 3.800 | 3.600 |
| Asphalt saturation (%) | 54.300 | 63.500 | 71.500 | 76.500 | 78.400 |
| Mineral gap rate (%) | 16.100 | 15.700 | 15.700 | 15.900 | 16.800 |
| Stability (KN) | 11.830 | 13.460 | 14.360 | 14.150 | 12.010 |
| Flow value(0.1 mm) | 20.200 | 25.300 | 29.300 | 33.400 | 37.000 |

After calculation, the best oil-stone ratio of AC-13 rubber powder-modified asphalt mixture was 5.1%.

3. Results and analysis

3.1. Effect of the rubber powder content on high-temperature stability

In this study, the content of the rubber powder is 15%, 18%, 21% and 24%. The experimental data are analyzed according to the corresponding relation between the different contents of the rubber powder and dynamic stability. The relationship between the dynamic stability (DS) and content of the rubber powder is shown in Figure 1.
Analyzing the data in the chart determines that:

1) The dynamic stability values of the asphalt mixture obtained by the test are all greater than 3000 times/mm. The experimental results all meet the requirements of the relevant designs and specifications, and the asphalt mixture has good high-temperature stability.

2) Taking 60 mesh rubber powder and 0 ml of hydrogen peroxide as an example, the dynamic stability of the rubber powder increased from 3387 times/mm to 3874 times/mm during the process of increasing the rubber powder content from 15% to 24%. Other types of mixtures show the same trend. The amount of rubber powder has a certain influence on the dynamic stability of the asphalt mixture. Under the same conditions, with an increase in the amount of rubber powder, the dynamic stability of the asphalt mixture also gradually increases because the viscosity of the rubber asphalt increases with the increase of the amount of rubber powder and increase of the amount of rubber powder filled between mineral aggregates, resulting in an increase in the insertion force and friction between mineral aggregates. The effects of both ensure that the asphalt mixture has a higher elasticity; thus, the high-temperature stability of the asphalt mixture is also improved with the increase of the amount of rubber powder.

3) Taking a content of 0 ml hydrogen peroxide with 40 mesh rubber powder as an example, the dynamic stability of the mixture increased from 3247 times/mm to 3705 times as the dosage gradually increased from 15% to 21% at intervals of 3%. The value increased by 458, and the increase of the curve as larger. When the rubber powder increased from 21% to 24%, the dynamic stability of the mixture increased from 3705 times/mm to 3758 times/mm. The curve grows very little and almost stabilizes. Other types of mixtures show the same trend. Under the same conditions, the dynamic stability of the asphalt mixture increases with the increase in the rubber powder content. When the rubber powder content increases to 21%, the growth rate decreases because the rubber powder is gradually incorporated into the matrix asphalt. In the saturated state, excessive rubber powder incorporation will reduce the strength of the asphalt mixture. Therefore, the comprehensive analysis performed in this paper considers that the optimum rubber powder content is 21%.
3.2. Effect of the mesh of rubber powder on high-temperature stability

The meshes of the rubber powders selected in this study are 20 mesh, 40 mesh, 60 mesh, 80 mesh. The experimental data are analyzed according to the corresponding relation between the different mesh of the rubber powder and the flat between the dynamic stability and dynamic stability (DS). The mesh of the rubber powders is shown in Figure 2.

![Dynamic stability diagram of a 0 ml mixture of hydrogen peroxide](image1)
![Dynamic stability diagram of a 10 ml mixture of hydrogen peroxide](image2)

Figure 2: Asphalt mixture rutting test results of different rubber powder meshes

Analyzing the data in the chart determines that:

1. The dynamic stability values of various asphalt mixtures under different rubber powder counts are all greater than 3000 times/mm. The experimental results all meet the requirements of the relevant designs and specifications, and the asphalt mixture exhibits good high temperature stability.

2. Taking 21% rubber powder with 0 ml hydrogen peroxide as an example, when the mesh of rubber powder increases from 20 mesh to 80 mesh, the dynamic stability of the mixture increases from 3559 times/mm to 3913 times/mm. Other types of mixtures show the same trend. The mesh number of the rubber powder has a certain influence on the dynamic stability of the asphalt mixture. Under the same conditions, as the mesh of the rubber powder increases, the dynamic stability of the mixture increases because the rubber powder particles are finer. The distribution in the matrix asphalt and specific surface area increase, so the swelling reaction is more sufficient. The two areas have a positive impact on the anti-rutting ability of the mixture, so the high temperature stability of the mixture is improved.

3. With a 21% rubber powder content of 0 ml hydrogen peroxide as an example, when the mesh of the rubber powder is increased from 20 to 60 mesh, the dynamic stability of the mixture increases from 3559/mm to 3865/mm, and the growth trend is steeper, while the mesh of the rubber particles increases from 60 to 80 mesh, the dynamic stability is only increased by 48, and the growth curve is almost smooth. Other different types of mixtures show the same trend. Under the same conditions, the tangent value of the dynamic stability curve of the mixture becomes smaller with the increase in the mesh number of rubber particles, that is, the dynamic stability of the mixture significantly initially increases when the mesh number of rubber particles is more than 60 mesh; then, the increase in the range is reduced because the fine powder particles on the structure of the skeleton and the desulfurization and degradation reaction have adverse effects. Therefore, the best mesh of the rubber powder is 60 mesh.
3.3. Effect of the hydrogen peroxide content on high temperature stability

The hydrogen peroxide content (HPC) selected in this experiment is 0 ml and 10 ml. The experimental data are analyzed according to the corresponding relationship between the hydrogen peroxide content and dynamic stability. Taking 60 mesh rubber powder as an example, the relationship between the dynamic stability (DS) and hydrogen peroxide content is shown in Figure 3.

![Figure 3. Rutting test results of the 60 mesh asphalt mixture with different hydrogen peroxide contents](image)

Analyzing the data in the chart determines that:

1. The dynamic stability values of various asphalt mixtures under different hydrogen peroxide contents are more than 3000 times/mm. The experimental results all meet the requirements of the relevant designs and specifications, and the asphalt mixture shows good high-temperature stability.

2. Comparing the dynamic stability of the mixture with the same dosage of the same mesh and different hydrogen peroxide contents, the dynamic stability of the mixture with 21% of 60 mesh rubber powder added with 10 ml of hydrogen peroxide is 4256 times/mm and the dynamic stability of the mixture with 21% of 60 mesh rubber powder added with 0 ml of hydrogen peroxide is 3865 times/mm, with a difference of approximately 400 times/mm. After calculation and analysis, the dynamic stability of all of the rubber powder-modified asphalt mixtures prepared with hydrogen peroxide oxidized rubber powder is approximately 400 times/mm different from that of the ordinary rubber powder-modified asphalt mixture, which indicates a great improvement. The higher the dynamic stability is, the stronger the rutting resistance of asphalt mixture is. Hydrogen peroxide can improve the interfacial bonding strength between the rubber powder and asphalt and promote the formation of the asphalt colloid stable structure of the rubber powder and asphalt, thereby improving the high-temperature stability of the modified asphalt mixture.

4. Conclusions

The effects of three different factors, namely, the rubber powder content, rubber powder mesh number, and hydrogen peroxide content, on the pavement performance of mixtures are systematically studied via several indoor experiments. Some conclusions are as follows:

(i) With the increase in the rubber powder content and the mesh number of rubber powder, the high-temperature stability of the asphalt mixture is increased. When the amount of rubber powder is more than 21% and the mesh number of rubber powder is increased by more than 60 mesh, the high-temperature stability of asphalt mixture decreases. Therefore, the best-recommended rubber powder content is 21%, and the best mesh number of rubber powder is 60 mesh.
(ii) The dynamic stability of the modified asphalt mixture with hydrogen peroxide is obviously higher than that of the ordinary modified asphalt mixture, which indicates that hydrogen peroxide has a positive effect on the high-temperature stability of the improved mixture.

**Acknowledgments**

The material in this paper is based upon work supported by the Natural Science Foundation of China:“Monitoring the hydration behavior of cement-based materials by electrical resistivity method and thermodynamic modelling at different temperatures”(51608402).

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