The water stability research of the rubber powder-modified asphalt mixture

Jie Sun¹*, Xi Lv¹, Yao Zhang¹ and Jing Yang²

¹ College of Urban Construction, University of Wuhan Science and Technology, Wuhan, Hubei, 430046, China
² Wuhan Hanyang Municipal Construction Group Corporation, Wuhan, Hubei, 430050, China

*Corresponding author E-mail: sunjie@wust.edu.cn

Abstract. In recent years, research shows that crumb rubber modified asphalt can not only improve the pavement performance, but also reduce the pollution of waste tires. Therefore, based on the freeze-thaw test, the influence of hydrogen peroxide, rubber powder mesh number and rubber powder content on the stability of rubber modified asphalt mixture is studied. The results show that when the rubber powder content is 21% and the number of rubber powder mesh is 60, the rubber powder modified asphalt mixture has good stability, and hydrogen peroxide can improve the water stability of rubber powder modified asphalt mixture.

1. Introduction

With the rapid development of China's economy, the transportation industry has developed rapidly; China will face a large number of waste tire treatment problems. At the same time, the pavement structure is also damaged by the increase of axle load. For improving the stability of asphalt pavement and reducing the pollution of waste tires to the environment, it is very promising for asphalt pavement modifier to process waste tires into rubber powder and produce modified asphalt[1]. The results show that the addition of rubber powder in asphalt pavement can improve the high temperature stability, low temperature performance and water stability of modified asphalt mixture, and obtain great economic, social and environmental benefits. It has a good application price[2-4]. American scholar Memon Ghulam Mohammed used hydrogen peroxide to oxidize the surface of waste tire rubber powder and used it to prepare modified asphalt. The results show that the rheological properties and water stability of modified asphalt mixture can be improved by hydrogen peroxide [5-7]. Most studies have shown that the performance of crumb rubber modified asphalt mixture in pavement use is mainly related to three factors, namely, the amount of hydrogen peroxide, the number of rubber powder mesh and the amount of rubber powder. The different dosage of each factor has a different improvement on road performance[8-13]. Therefore, through the rutting test and freeze-thaw splitting test, the influence of the amount of hydrogen peroxide, the number of rubber powder mesh and the amount of rubber powder on the water stability of modified asphalt mixture is studied. The test data and results provide theoretical guidance for the application and design of rubber powder modified asphalt mixture.
2. Material parameters

2.1. Experimental materials and related plan

The asphalt mixture was prepared with the amount of rubber powder, mesh number of rubber powder mesh and hydrogen peroxide as the main variables. 70 grade petroleum asphalt is selected for road surface course. Rubber powder is a kind of bias tire rubber sold on the market. The number of rubber powder mesh ranged from 20 mesh to 80 mesh, which was divided into four groups with 20 mesh interval. The amount of rubber powder used ranged from 15% to 24%, with 3% as the interval. Fine aggregate and coarse aggregates are diabase detritus and diabase respectively; limestone is the main ore powder. Oxygen water is 30% hydrogen peroxide, the content is 0 ml and 10 ml respectively. A total of 30 groups of tests were conducted. According to the standard, the above materials are tested and all meet the requirements of the specification. The influencing factors are shown in Table 1.

|   | Amount of rubber powder | Number of rubber powder mesh | The content of hydrogen peroxide |
|---|------------------------|------------------------------|---------------------------------|
| 1 | 15                     | 20                           | 0                               |
| 2 | 18                     | 40                           |                                 |
| 3 | 21                     | 60                           | 10                              |
| 4 | 24                     | 80                           |                                 |

2.2. Mix proportion parameters

In the study, the continuous grade AC-13 is the target level. The mineral aggregate screening results are shown in Table 2. The rubber grade of the modified asphalt mixture AC-13 synthetic grade is shown in Table 3.

| Gradation type | Percentage by mass of the following sieve (%) |
|----------------|-----------------------------------------------|
|                | 16 | 13.2 | 9.5 | 4.75 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 |
| AC-13          | 100 | 90~100 | 68~ | 38~ | 24~ | 15~ | 10~ | 7~ | 5~ | 4~8 |
| 1#             | 100 | 93.4 | 47.2 | 27.6 | 12.3 | 4.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| 2#             | 100 | 100 | 94.5 | 50.3 | 36.3 | 31.0 | 22.8 | 13.9 | 7.2 | 3.7 |
| 3#             | 100 | 100 | 100 | 91.7 | 47.5 | 23.1 | 12.4 | 7.3 | 4.1 | 2.2 |
| Mineral        | 100 | 100 | 100 | 100 | 100 | 100 | 98.5 | 92.1 | 79.2 |

Table 3. Synthetic grade of rubber powder-modified Asphalt mixture AC-13

| Size of sieve | 16 | 13.2 | 9.5 | 4.75 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 |
|---------------|----|------|-----|------|------|------|----|----|------|------|
| High limit of grading | 100 | 100 | 85 | 68 | 50 | 38 | 28 | 20 | 15 | 8 |
| Lower limit of grading    | 100 | 90 | 68 | 38 | 24 | 15 | 10 | 7 | 5 | 4 |
| Gradation median              | 100 | 95 | 77 | 53 | 37 | 26.5 | 19 | 14 | 10 | 6 |
| Synthetic grading              | 100 | 97.7 | 79.5 | 54.7 | 33.2 | 22.4 | 15.7 | 11.2 | 7.7 | 5.4 |

The proportion of 1#, 2#, 3# and mineral is 35:36:25:4. The synthetic gradation curve of the rubber powder-modified asphalt mixture AC-13 is shown in Figure 1.
2.3. Determine the best oil ratio
Marshall compaction method was used to determine the best asphalt content. The aggregate ratio of crumb rubber modified asphalt is 4% - 6%, and Marshall compaction test is carried out at 0.5% pitch oil spacing. The diameter of Marshall standard specimen is 101.6 mm ± 0.2 mm, and the height is 63.5 mm ± 1.3 mm. The two sides of the specimen are pressed 50 times. The indexes of asphalt mixture are stability (MS), flow value (PL), porosity (VV) and asphalt saturation (VFA). The best asphalt aggregate ratio of the mixture is 5.1%.

3. Result analysis and research

3.1. Influence of rubber powder content on water stability of mixture
The content of rubber powder was between 15% and 24%, and the test was carried out at the interval of 3%. Based on the correlation between the change of rubber powder content and the splitting strength ratio, the experimental data were analyzed. The ratio of splitting strength ratio (TSR) to rubber powder dosage is shown in Figure 2.

Figure 2. Experimental data analysis of freeze-thaw splitting of asphalt mixture when rubber powder content changes.
Some results can be obtained from Figure 2:

- When the rubber powder content is different, the freeze-thaw splitting strength ratio of various asphalt mixtures is more than 80%, the water stability of asphalt mixture is better, and the test data and results meet the requirements of the specification.
- Taking the hydrogen peroxide content of 0ml and rubber powder mesh of 60 mesh as an example, the freeze-thaw splitting strength ratio increases first and then decreases, with an interval of 3% each time. As the rubber powder content changed from 15% to 21%, the ratio of freeze-thaw splitting strength reached 83.5%. The freeze-thaw splitting rate increased from 21% to 24%, and the freeze-thaw splitting rate was 82.9%. The change of rubber powder content affects the freeze-thaw splitting strength ratio, and the rest of the mixture has the same trend. When other conditions remain unchanged, the freeze-thaw splitting strength ratio of the mixture increases first and then decreases with the increase of rubber powder content. The reason is that the rubber powder has a certain viscosity, the more rubber powder content in asphalt, the higher the viscosity of mixture, and the water stability of mixture is gradually improved. When the content of rubber powder is 21%, the molecular weight of free radical asphalt decreases, the semi-solid continuous phase system gradually forms, and the viscosity decreases. As the rubber powder content increases, more matrix asphalt is absorbed, the thickness of the asphalt film on the surface of the mineral material decreases, and the adhesion between the rubber asphalt and the aggregate increases. When there are too many rubber powder particles, during the freezing process at a negative temperature, the shrinkage volume of the rubber powder particles decreases, which causes the void ratio of the mixture to increase. The above reasons are combined and generate the freeze-thaw splitting strength ratio, which has adverse effects on the decline. Therefore, the optimal rubber powder content selected is 21%.

3.2. Influence of rubber powder mesh on water stability of mixture

The number of rubber powder mesh is between 20-80 mesh, which is divided into four groups according to the interval of 20 mesh. Based on the correlation between the change of rubber powder content and the splitting strength ratio, the experimental data were analyzed. The ratio of splitting strength ratio (TSR) to rubber powder dosage is shown in Figure 3.

![Figure 3](image)

Some results can be gotten from Figure 3:

- When the rubber powder mesh is different, the freeze-thaw splitting strength ratio of various asphalt mixtures is greater than 80%, the water stability of asphalt mixture is better, and the test data and results meet the requirements of the specification.
• For the hydrogen peroxide content of 0ml and rubber powder content of 21%, the number of rubber powder nets ranged from 20 mesh to 80 mesh, and they were divided into 4 groups according to the spacing of 20 mesh. The dynamic stability of each group was 82.4%, 82.7%, 83.5% and 83.9%, respectively. It shows that the number of rubber powder mesh has a certain influence on the dynamic stability of mixture, and the other mixtures have the same trend. When the other conditions are the same, the freeze-thaw splitting strength ratio of the mixture will gradually increase with the increase of the number of rubber particles, because the smaller the mesh number of plastic powder, the larger the particle size of powder. When the size of the powder particles and effects of thermal expansion and contraction cannot be ignored, the test process of the freezing and hot water bath process on the strength of the asphalt mixture will be adversely affected, so the finer the powder particles, the smaller the negative effect and the greater the freeze-thaw splitting strength. Therefore, this study determines that the best rubber powder is 60 mesh.

3.3. Influence of hydrogen peroxide dosage on water stability of mixture
In this study, the hydrogen peroxide content is 0 ml and 10 ml. On the basis of the correspondence between the splitting strength ratio and the hydrogen peroxide content, the experimental data are analyzed. For example, for 60 mesh rubber powder, Figure 4 shows that TSR changes with hydrogen peroxide dosage and rubber powder content.

![Figure 4. Analysis of freeze-thaw splitting test data of mixture with different hydrogen peroxide content (60 mesh rubber powder mesh)](image)

Some results can be obtained from Figure 4:
• When the content of hydrogen peroxide changes, the freeze-thaw splitting strength ratio of asphalt mixture also changes and is greater than 80%, which indicates that the water stability of asphalt mixture is good, and the test results meet the standard.
• When the amount of rubber powder is the same and the content of hydrogen peroxide is different, the freeze-thaw splitting strength of asphalt mixture is different. For example, the ratio of freeze-thaw splitting strength of the mixture is 88.1% when the content rubber powder is 21%, rubber powder mesh is 60 mesh and the dosage hydrogen peroxide is 10ml. But the ratio of freeze-thaw splitting strength of mixture is 83.5% under the same rubber powder mesh and content without hydrogen peroxide. Through the analysis of the test data, it is found that the freeze-thaw splitting strength of the modified asphalt mixture prepared by hydrogen peroxide oxidation method is greatly improved. The results show that the increase of hydrogen peroxide content can enhance the bonding strength of rubber powder and asphalt, make the structure of asphalt and rubber powder more stable, and improve the water stability of asphalt mixture.
4. Conclusions

Based on the above research, the following conclusions can be made.

- When the amount of rubber powder changes from 15% to 21%, the freeze-thaw splitting strength ratio of asphalt mixture gradually increases to the highest value. When the dosage of rubber powder is more than 21%, the strength ratio will decrease, which indicates that the water stability of the mixture can be improved within a certain range of rubber powder dosage, but more than 21% will have adverse effects. According to the test results, the optimum dosage is 21%.

- The tangent value of freeze-thaw splitting strength curve decreases with the increase of mesh number of rubber powder, and the water stability of mixture decreases. Compared with the cost and the test results, the recommended size of rubber powder mesh is 60 mesh.

- The results of freeze-thaw splitting test with and without hydrogen peroxide show that the water stability of modified asphalt mixture with hydrogen peroxide is significantly improved.

Data Availability

Data from this manuscript may be made available upon request to the authors.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

[1] Abu.A.A. (2016) Int J Ther Env Eng, 12:61-66.
[2] Shafabakhsh, G.H., Sadeghnjad, M, Sajed, Y.(2014) Case Studies in Construction Materials, 1: 69-76.
[3] Hossain, Z., Bairgi, B., Zaman, M., et al. (2016) Proc. of 95th Transportation Research Board Annual Meeting, pp.10-14.
[4] Hu, C.Y., Wang, X.P., Jia, D.M. (2020) Journal of Chemical Engineering, 1: 214-221.
[5] Memon, G.M. the US, 5704971, 1998.
[6] Memon, G.M. the US, 5927620, 1999.
[7] Memon, G.M. the US, 6444731, 2002.
[8] Guan, H.X., Zhang, Q.S., Xu, C. (2010) Journal of Highway and Transportation Research and Development, 27:38-42.
[9] Zhou, H.P., Holikattis, Vacura P., (2014) Journal of Traffic and Transportation Engineering, 1:39-48.
[10] Jeong, K.D., Lee, S.J., Amirkhanian, S.N., et al., (2010) Construction and Building Materials, 24:824-831.
[11] Li, X.Y., Ping, L., Wang, H.N. (2015) Journal of Traffic and Transportation Engineering, 15:10-17.
[12] Mull, M.A., Stuart, K., Yehia, A. (2002) Journal of Materials Science, 37:557-566.
[13] Ameli, A., Babagoli, R., Aghapou, M. (2016) J. Petrol. Sci. Technol, 34:449-453.