Water Susceptibility and Raveling Resistance of Polyurethane Mixture

Ke Zhong¹,², Meng Zhang¹,²*, Mingzhi Sun¹,², Shengkai Sun³ and Xue Wang³

¹ Research Institute of Highway Ministry of Transport, Beijing, 100088, China
² Key Laboratory of Transport Industry of Road Structure and Material, Beijing, 100088, China.
³ Chongqing Jiaotong University, Chongqing, China

* Corresponding author’s e-mail: zhang.meng@rioh.cn

Abstract: The amount of different rubber particles has a certain influence on the water stability and raveling resistance of polyurethane mixture. The more rubber particles are, the better the water stability and raveling resistance. Different grades have a certain influence on the water stability and raveling resistance. The addition of fine aggregate is conducive to improving the water stability of polyurethane mixture. Different kinds of polyurethane binders can change the polyurethane water stability and raveling resistance of the mixture.

1. Introduction

Polyurethane mixture is composed of polyurethane adhesive, rubber particles and aggregate in a certain proportion to form a multi new pavement material [1]. Because polyurethane adhesive has certain elastic property and high bending tensile strength after curing, its service performance in the pavement is better than that of ordinary asphalt mixture [2-3]. Polyurethane is used in the mixture instead of the traditional asphalt binder. Through the tensile test, dynamic mechanical analysis and mixture performance test of polyurethane, the addition of polyurethane can improve the durability and fatigue resistance of the mixture [4].

In recent year, more and more polyurethane mixtures have been developed and used in the road. Bazmara studied the modified asphalt with thermoplastic polyurethane and synthetic polyurethane as modifiers, which greatly improved the high-temperature and low-temperature properties of the modified asphalt mixture [5]. Torzs T will replace the traditional asphalt with polyurethane and mix it into the mixture to understand and quantify the relevant hydraulic characteristics of polyurethane combined pavement materials [6]. In order to overcome the shortcomings of durability and fatigue life of traditional asphalt bonded OGFC mixture, Cong Lin carried out tensile test and dynamic mechanical analysis on polyurethane [7]. Sun Min has prepared polyurethane modified asphalt. It is found that polyurethane modified asphalt has excellent high-temperature and anti-aging properties than ordinary SBS modified asphalt [8].

It is found that the water stability and raveling resistance of polyurethane mixture are poor [9]. In order to study the influencing factors, this paper studies the influencing factors of water stability and raveling resistance in three aspects of different rubber particle content, different gradation and different polyurethane binder. Its water stability was studied by immersion Marshall test and freeze-thaw splitting test, and its spalling resistance was studied by immersion dispersion test.
2. The effect of rubber particles content on water damage

2.1. Water susceptibility

In order to explore the influence of rubber particles on water stability, in this test, the rubber particles of 0%, 12.5% and 25% of PERS polyurethane mixture were replaced by soaked Marshall stability test and freeze-thaw splitting test. Specifically, the residual Marshall stability (MSR) was calculated by formula 1, and the tensile strength ratio (TSR) was calculated by formula 2.

\[
MSR = \frac{MS_{0.5h}}{MS_{48h}}
\]  

(1)

Where \(MS_{0.5h}\) represents the Marshall stability of specimens after 0.5 hours’ water bath at 60℃ (kN); \(MS_{48h}\) represents the Marshall stability of specimens after 48 hours’ water bath at 60℃ (kN).

\[
TSR = \frac{R_0}{R_{FT}}
\]  

(2)

Where \(R_0\) represents the tensile strength of specimens without freeze-thaw cycle (kN); \(R_{FT}\) represents the tensile strength of specimens after one freeze-thaw cycle (kN).

The specific test results are shown in figure 1.

![Figure 1. Effect of different amount of rubber particles on moisture susceptibility](image)

It can be seen from Figure 1 that with the increasing content of rubber particles, MSR becomes larger and larger. As for freeze-thaw splitting test results, With the increase of rubber particle content, the TSR value of pers polyurethane mixture is increasing, which indicates that the freeze-thaw splitting strength of polyurethane mixture is improved by adding rubber particles.

2.2. Raveling resistance

In this test, 0%, 12.5% and 25% rubber particles were replaced by per polyurethane mixture by Cantabro test. The initial mass (\(m_0\)) and final mass (\(m_1\)) of Marshall specimen were measured before and after Cantabro test respectively. The mass loss (\(R_m\)) can be utilized to characterize the raveling resistance of mixture, which was calculated by formula 3. The Cantabro test results are shown in Fig. 2.

\[
R_m = \frac{m_0 - m_1}{m_0}
\]  

(3)
Figure 2. Effect of different amount of rubber particles on raveling resistance

It can be seen from Figure 2 that with the increase of the amount of rubber particles, the mass loss of polyurethane mixture is smaller and smaller, and the raveling resistance is better and better, indicating that rubber particles can improve the raveling resistance of polyurethane mixture.

3. The effect of different types of water damage

3.1. Water susceptibility

In order to explore the influence of different gradation on water stability, four polyurethane mixtures of different gradation, PERS, PAC-13-I, PAC-13-II and OGFC, were used in this test to carry out soaked Marshall stability test and freeze-thaw splitting test. The four gradations are shown in Table 1, 2, 3 and 4. The specific test results are shown in Figure 3.

Table 1. Gradation of PERS

| Aggregate Type | Basalt Aggregate | Optimum Asphalt Content (%) |
|----------------|------------------|-----------------------------|
| Sieve size (mm) | 13.2 9.5 4.75 2.36 1.18 | 4.5                          |
| Percentage by weight (%) | 5.2 22.1 46.7 13.8 11.2 |                             |

Table 2. Gradation of PAC-13-I

| Aggregate Type | Basalt Aggregate | Mineral powder | Optimum Asphalt Content (%) |
|----------------|------------------|----------------|-----------------------------|
| Sieve size (mm) | 16 13.2 9.5 4.75 2.36 1.18 0.6 0.3 0.15 0.075 | 4.8 | 4.5 |
| Percent Passing (%) | 100 94.8 55.7 17.4 13.4 11.8 9.1 7.4 5.9 4.8 | 4.5 |
| Percentage by weight (%) | 0 5.2 39.1 38.3 4 1.6 2.7 1.7 1.5 1.1 | 4.5 |

Table 3. Gradation of PAC-13-II

| Aggregate Type | Basalt Aggregate | Mineral powder | Optimum Asphalt Content (%) |
|----------------|------------------|----------------|-----------------------------|
| Sieve size (mm) | 16 13.2 9.5 4.75 2.36 1.18 0.6 0.3 0.15 0.075 | 4.8 | 4.5 |
| Percent Passing (%) | 100 95 55.5 28 18 6 2 4 3 3 | 3 4.5 |
| Percentage by weight (%) | 0 5 39.5 27.5 10 10 2 1 1 1 | 4.5 |
Table 4: Gradation of OGFC

| Aggregate Type | Basalt Aggregate | Mineral Powder | Optimum Asphalt Content (%) |
|----------------|------------------|----------------|----------------------------|
| Sieve size (mm) | 16 13.2 9.5 4.75 2.36 1.18 0.6 0.3 0.15 0.075 | 0 5 25 49 5 4 2.5 2 2 1.5 |
| Percent Passing (%) | 100 95 70 21 16 12 9.5 7.5 5.5 4 | 4 4 4.5 |
| Percentage by weight (%) | 0 5 25 49 5 4 2.5 2 2 1.5 | 0 5 10 15 20 25 30 35 40 45 50 |

Figure 3. Effect of different types on moisture susceptibility

In Figure 3, the MSR value of PAC-13-I and PERS is slightly lower than that of PAC-13-II and OGFC, which indicates that PAC-II and OGFC have good water stability. As for freeze-thaw splitting test results, the TSR value of polyurethane mixtures graded with PAC-13-I, PAC-13-II and OGFC is higher than that of PERS, which indicates that the three graded polyurethane mixtures have better freeze-thaw resistance and are suitable for seasonal freezing area. The TSR value of PERS grading is low, the cycle of freeze-thaw resistance is poor.

3.2 Raveling resistance

In order to explore the influence of different gradations on raveling resistance, this test uses four different gradations of polyurethane mixture, namely PERS, PAC-13-I, PAC-13-II and OGFC, to conduct Cantabro test, and the test results are shown in Figure 4.

Figure 4. Effect of different types on raveling resistance

The mass loss of polyurethane mixture with PAC-13-I, PAC-13-II and OGFC gradations is smaller than that with PERS gradations, which shows that the addition of fine aggregate is beneficial to improve the raveling resistance of polyurethane mixture.
4. The effect of different polyurethane of water damage

4.1. Water susceptibility

In order to explore the influence of different polyurethane on water stability, five kinds of polyurethane were used as binders (named PU-I, PU-II, PU-III, PU-IV, PU-V respectively) in this test. PAC-13-II grading was used to replace 20% rubber particles by equal volume, and then soaked Marshall stability test and freeze-thaw splitting test were carried out. The specific test results are shown in Figure 5.

![Figure 5. Effect of different polyurethane on moisture susceptibility](image)

All of the five materials are higher than the required value (75%) of "technical specifications for construction of highway asphalt pavement" for the residual stability of common asphalt mixture soaked in water, meeting the requirements of the specifications. The MSR of PU-III is the highest, reaching 90.9%, indicating that the material has good water stability. As for freeze-thaw splitting test results, the TSR values of the four polyurethane materials are almost the same, basically maintained at about 77%, indicating that the four materials have good freeze-thaw cycle resistance. The TSR value of PU-IV polyurethane material is only 56.7%, and its freeze-thaw resistance is poor.

4.2. Raveling resistance

In order to explore the influence of different polyurethane on raveling resistance, five kinds of polyurethane were used as binders (named PU-I, PU-II, PU-III, PU-IV, PU-V respectively) in this test. PAC-13-II grading was used to replace 20% rubber particles by equal volume, and then Cantabro test were carried out. The specific test results are shown in Figure 6.

![Figure 6. Effect of different polyurethane on raveling resistance](image)

As shown in Fig. 6, PU-III and PU-V polyurethane have the lowest mass loss, indicating that the two materials have good peeling resistance, and PU-IV polyurethane has large flying loss, indicating that the material has poor peeling resistance.
5. Conclusions

(1) With the increase of the content of rubber particles, the water stability and anti flaking property of polyurethane mixture increase in varying degrees, which shows that the addition of rubber particles is beneficial to improve the water stability of polyurethane mixture.

(2) It can be seen from the test of influence factors of water stability of four different gradation pairs that OGFC gradation and PAC-13-II gradation are better than PAC-13-I gradation, and the three are obviously better than PERS, which shows that the addition of fine aggregate is conducive to improving the water stability of polyurethane mixture; and it can be seen that the smaller the void ratio, the better the water stability.

(3) According to the water stability test of the above five different polyurethane materials, different polyurethane materials have certain influence on the water stability, of which PU-V has the best performance and PU-III has the worst performance.

Acknowledgments

The research work described herein was funded by the Fundamental Research Funds for the Central Research Institute (Grant No. 2019-0121). This financial support is gratefully acknowledged.

References

[1] Liu, M., Han, S., Shang, W. (2019) New polyurethane modified coating for maintenance of asphalt pavement potholes in winter-rainy condition. Progress in Organic Coatings 133: 368-375.
[2] Chen, J., Yin, X. J., Wang, H. (2018) Evaluation of durability and functional performance of porous polyurethane mixture in porous pavement. Journal of Cleaner Production 188: 12-19.
[3] Wang, D. W., Liu, P. F., Leng, Z. (2017) Suitability of PoroElastic Road Surface (PERS) for urban roads in cold regions: Mechanical and functional performance assessment. Journal of Cleaner Production 165: 1340-1350.
[4] Gao, J. F., Wang, H. N., Chen, J. K. (2019) Laboratory evaluation on comprehensive performance of polyurethane rubber particle mixture. Construction and Building Materials 224: 29-39.
[5] Bazmara, Behrokh, Taheravan, et al. (2018) Influence of thermoplastic polyurethane and synthesized polyurethane additive in performance of asphalt pavements. Construction and Building Materials 166: 1-11.
[6] Torzs, T., Lu, G., Monteiro, A. O. (2019) Hydraulic properties of polyurethane-bound permeable pavement materials considering unsaturated flow. Construction and Building Materials 212: 422-430.
[7] Cong, L., Yang, F., Guo, G. H. (2019) The use of polyurethane for asphalt pavement engineering applications: A state-of-the-art review. Construction and Building Materials 225: 1012-1025.
[8] Sun, M., Zheng, M. L., Bi, Y. F. (2019) Modification mechanism and performance of polyurethane modified asphalt. Journal of Traffic and Transportation Engineering 19(2): 49-58.
[9] Lu, G. Y., Liu, P. F., Wang, Y. H. (2019) Development of a sustainable pervious pavement material using recycled ceramic aggregate and bio-based polyurethane binder. Journal of Cleaner Production 220:1052-1060.