Influence of Wood Fiber on the Laboratory Road Performance of Recycled Asphalt Pavement (RAP) Asphalt Mixture

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Abstract. The influence of wood fiber content on the road performance of asphalt mixture with high recycled asphalt pavement (RAP) content was studied based on the Marshall test, high temperature rutting test, low temperature crack resistance test and water stability test. And the optimum wood fiber content in RAP asphalt mixture with high RAP content was recommended. The results show that the dynamic stability and low temperature bending strain of RAP asphalt mixture increased and then decreased with the increase of wood fiber content. When the content of wood fiber is 0.3 %, the road performance of RAP asphalt mixture is the best. Compared with RAP asphalt mixture without wood fiber, the Marshall stability and low temperature flexural tensile strain of RAP asphalt mixture with 0.3% wood fiber increase by 7.1% and 4.6%, respectively, and the high temperature rutting resistance and water stability decreases.

1. Introduction
In order to solve the problem of recycled asphalt pavement (RAP) obtained during the maintenance of asphalt pavement, road engineers at home and abroad mostly adopt recycling, crushing and screening of waste asphalt mixture, then mixing it with new aggregate, new asphalt and recycling agent in proper proportion to prepare recycled asphalt mixture [1, 2]. Zhou et al investigated the effect of reclaimed asphalt pavement (RAP) on the rheological properties of a polymer modified binder and the fatigue cracking performance of polymer modified asphalt mixture [3]. Zhang et al using the binder blending chart to select a performance grade of the virgin binder may not be applicable for mixtures containing more than 25% reclaimed asphalt pavement (RAP) [4]. Most studies on the design and construction of RAP asphalt mixture with RAP materials content less than 25%; thus, information about the performance of recycled asphalt mixture with high RAP content is limited, and it is difficult to meet the pavement performance requirements under special circumstances [5].

In order to improve the performance of asphalt mixture, road engineering researchers have carried out a series of studies on fiber reinforced asphalt mixture. The addition of fibers can effectively improve the low temperature crack resistance and fatigue resistance of asphalt mixture, and improve the durability of asphalt pavement. Wood fibers are mainly used in SMA mixtures, while the application of wood fibers in cold recycled asphalt mixtures is less. The performance of high RAP content mixtures, the influence of wood fiber content on the performance of asphalt mixtures with high RAP content was
studied through Marshall test, high temperature rutting test, low temperature crack resistance test and water stability test. The optimum wood fiber content in asphalt mixtures with high RAP content was recommended.

2. Materials and methods

2.1. Materials

Table 1 shows the general specifications of AH-90 asphalt which obtained from Karamay, Xinjiang, China. The recycled asphalt pavement (RAP) materials for this study were obtained from the reconstruction project of Wusu to Sailimu Lake first class highway in Urumqi, Xinjiang, China. The virgin aggregate (VAG) was obtained from Urumqi, Xinjiang, China, and it was graded into six types of coarse aggregates, fine aggregate and mineral powder with the following sizes: 23-30 mm, 18-23 mm, 10-18 mm, 5-10 mm, 0-5 mm and mineral powder. Their technical indicators which tested according to the technical requirements of Technical Specification for Construction of Highway Asphalt Pavements (JTG F40-2004) are omitted. The technical indicators of wood fiber are shown in Table 2. The mineral gradation of the AC-25 mixture is listed in Table 3, and the RAP materials content is 45%.

| Tested Item                             | Tested results | Specified value |
|-----------------------------------------|----------------|-----------------|
| Penetration(25°C,100g,5s) (0.1mm)       | 89             | 80~100          |
| Penetration index (PI)                  | 0.13           | -1.0 ~ +1.0     |
| Ductility(5cm/min,15°C) (cm)            | 151            | ≥100            |
| Softening point(°C)                     | 48             | ≥46             |
| Mass loss (%)                           | -0.24          | -0.8 ~ +0.8     |
| Residual penetration ratio (%)          | 72.5           | ≥61             |
| Ductility(10°C) (cm)                    | 31             | ≥6              |

Table 2. General index of wood fiber

| Fiber types    | Fiber length (mm) | Ash content (%) | Oil absorption rate (%) | Water content (%) |
|----------------|-------------------|-----------------|-------------------------|-------------------|
| Wood fiber     | ≤5                | 16              | 7 time fiber mass       | ≤4                |

Table 3. Mineral aggregate gradations of AC-25 RAP asphalt mixture

| Gradating    | Percentage passing(%) for sieve size (mm) |
|--------------|-------------------------------------------|
| Study Gradation | 31.5 26.5 19 16 13.2 9.5 4.75 2.36 1.18 0.6 0.3 0.15 0.075 |
| Upper limit    | 100 97.3 85.1 77.1 68.6 54.6 38.9 25.6 19.2 15.9 11.0 6.7 5.4 |
| Lower limit    | 100 90 75 65 57 45 24 16 12 8 5 4 3 |

2.2. Test methods

The preparation steps of RAP asphalt mixture specimens are as follows: (1) The RAP materials were placed in an oven for 2 hours with an air temperature of 110 oC; (2) The VAG and asphalt were separated place in two oven for 4 hours with an air temperature of 190 oC and 150 oC, respectively; (3) The throwing order of materials was wood fiber, RAP, aggregates, asphalt and mineral powder. The stirring time was controlled within 90 seconds after the aggregates, asphalt and mineral powder added, respectively. And the total stirring time was controlled within 270 seconds.

To adequately study the effect of the wood fiber content on the road performance of RAP asphalt mixture, five possible content of wood fiber were chosen: 0, 0.2 %, 0.3 %, 0.4 % and 0.5 %, and the corresponding optimum asphalt-aggregate ratio were 4.9 %, 5.3 %, 5.4 %, 5.6 % and 5.7 %.
The performance evaluation indicators in this study include volumetric property, Marshall stability (MS), and road performance. Volumetric property indicators include the volume of air void (VV), voids filled with asphalt (VFA), voids in mineral aggregate (VMA). Road performance measures include dynamic stability (DS), which is the indicator used to evaluate the high temperature rutting resistance of RAP asphalt mixtures. The freeze-thaw splitting strength ratio (TSR) was used to evaluate the water stability of RAP asphalt mixtures. Flexural tensile strength (RB) and flexural tensile strain (εB) were used to evaluate the low temperature performance of RAP asphalt mixture. The VV, VMA, VFA, MS, TSR, RB, and εB of asphalt mixture were all measured according to the Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011).

3. Test results and discussion

3.1. The Marshall index test results of RAP asphalt mixtures

Table 4 shows the Marshall index test results of RAP asphalt mixtures with different wood fiber content.

| Wood fiber content (%) | optimum asphalt-aggregate ratio (%) | VV (%) | VMA (%) | VFA (%) | MS (kN) | FL (mm) |
|------------------------|-------------------------------------|--------|---------|---------|---------|---------|
| 0                      | 4.9                                 | 4.2    | 13.2    | 67.0    | 9.1     | 3.6     |
| 0.2%                   | 5.3                                 | 4.4    | 13.4    | 67.0    | 9.5     | 3.5     |
| 0.3%                   | 5.4                                 | 4.5    | 13.7    | 67.2    | 9.8     | 2.9     |
| 0.4%                   | 5.6                                 | 4.5    | 14.0    | 69.2    | 9.4     | 3.0     |
| 0.5%                   | 5.7                                 | 4.6    | 14.4    | 68.1    | 9.2     | 3.6     |

As shown in Table 4, compared with the RAP asphalt mixture, which wood fiber content is 0, the Marshall index test results were different based on different wood fiber content. With the wood fiber content of mixture increased, the optimum asphalt-aggregate ratio, VV and VMA increased, and the MS increased to peak values then decreased, however the VFA decreased to lower values then increased.

3.2. The high temperature rutting resistance of RAP asphalt mixtures

The high temperature rutting test results of RAP asphalt mixtures with different wood fiber content were shown in the table 5, and the relationship between wood fiber content of RAP asphalt mixtures and deformation difference, DS were shown in the Figure 1.

| Wood fiber content (%) | Optimum asphalt-aggregate ratio (%) | 45min deformation (mm) | 60min deformation (mm) | Deformation difference (mm) | DS (times/mm) |
|------------------------|-------------------------------------|-----------------------|------------------------|-----------------------------|---------------|
| 0                      | 4.9                                 | 2.895                 | 3.187                  | 0.292                       | 2154          |
| 0.2%                   | 5.3                                 | 4.058                 | 4.322                  | 0.264                       | 2387          |
| 0.3%                   | 5.4                                 | 3.993                 | 4.310                  | 0.317                       | 1986          |
| 0.4%                   | 5.6                                 | 3.714                 | 4.078                  | 0.364                       | 1732          |
| 0.5%                   | 5.7                                 | 4.239                 | 4.672                  | 0.433                       | 1456          |
As shown in the Table 5 and Fig.1, the 45 and 60 min deformation of RAP asphalt mixtures increased with the increasing of wood fiber content of RAP asphalt mixture.

It is also observed from the Table 5 and Fig.1 that with the wood fiber content of mixture increased, the deformation difference decreased to lower values then increased, and DS of RAP asphalt mixtures increased to peak values then decreased, which is proof that the high temperature rutting resistance of RAP asphalt mixtures increases as the wood fiber content increases to a maximum at the optimum point (0.2 %). These results could be due to the wood fiber is flocculent structure, which cannot be well distributed in the mixture when the content reaches a high value, so the high temperature rutting resistance of RAP asphalt mixtures decreased with the high wood fiber content. And the wood fiber content of RAP asphalt mixtures should be controlled within 0.3 %.

3.3. The water stability of RAP asphalt mixtures

The water stability test results of RAP asphalt mixtures with different wood fiber content were shown in Table 6, and the relationship between wood fiber content of RAP asphalt mixtures and freeze-thaw splitting strength ratio (TSR) was shown in the Fig.2.

| Wood fiber content (%) | Optimum asphalt-aggregate ratio (%) | Freeze-thaw splitting strength(MPa) | Splitting strength(MPa) | Freeze-thaw splitting strength ratio (%) |
|-----------------------|-------------------------------------|------------------------------------|-------------------------|----------------------------------------|
| 0                     | 4.9                                 | 1.089                              | 1.296                   | 84.0                                   |
| 0.2                   | 5.3                                 | 1.049                              | 1.352                   | 77.6                                   |
| 0.3                   | 5.4                                 | 1.038                              | 1.396                   | 74.3                                   |
| 0.4                   | 5.6                                 | 0.994                              | 1.415                   | 70.2                                   |
| 0.5                   | 5.7                                 | 0.938                              | 1.359                   | 69.0                                   |

Fig. 1 Wood fiber content of RAP asphalt mixtures versus deformation difference and DS of RAP asphalt mixtures

Fig. 2 Wood fiber content of RAP asphalt mixtures versus TSR of RAP asphalt mixtures
As shown in the Table 6 and Fig. 2 that compared with splitting strength of RAP asphalt mixtures specimens without wood fiber, the splitting strength of RAP asphalt mixtures specimens with wood fiber was increased. And compared with splitting strength of RAP asphalt mixtures specimens without wood fiber after freeze-thaw cycle, the splitting strength of RAP asphalt mixtures specimens with wood fiber after freeze-thaw cycle was decreased.

It is also observed from the Table 6 that with the wood fiber content of mixture increased, the freeze-thaw splitting strength ratio decreased, and compared with the freeze-thaw splitting strength ratio of RAP asphalt mixtures without wood fiber, the freeze-thaw splitting strength ratio of RAP asphalt mixtures with 0.2 % wood fiber was decreased about 11.9 %.

### 3.4. The low temperature performance of RAP asphalt mixtures

The low temperature performance test results of RAP asphalt mixtures with different wood fiber content were shown in the Table 7, and the relationship between wood fiber content of RAP asphalt mixtures and flexural tensile strength, flexural tensile strain were shown in the Figure 3.

**Table 7.** The low temperature performance of RAP asphalt mixtures with different wood fiber content

| Wood fiber content (%) | Optimum asphalt-aggregate ratio (%) | Maximum load (N) | Midspan deflection (mm) | Flexural tensile strength (MPa) | Flexural tensile strain (με) | Stiffness modulus (MPa) |
|------------------------|------------------------------------|------------------|-------------------------|-------------------------------|----------------------------|------------------------|
| 0                      | 3.9                                | 924              | 0.553                   | 7.63                          | 2905                       | 2627                   |
| 0.2                    | 5.3                                | 965              | 0.590                   | 7.66                          | 2984                       | 2567                   |
| 0.3                    | 5.4                                | 879              | 0.610                   | 7.48                          | 3091                       | 2420                   |
| 0.4                    | 5.6                                | 932              | 0.611                   | 7.35                          | 3134                       | 2345                   |
| 0.5                    | 5.7                                | 810              | 0.622                   | 6.61                          | 3227                       | 2048                   |

**Fig. 3** Wood fiber content of RAP asphalt mixtures versus flexural tensile strength and flexural tensile strain of RAP asphalt mixtures

It is observed from the Table 7 and Figure 3 that with the wood fiber content of mixture increased, the flexural tensile strength decreased, thus the flexural tensile strain increased. And compared with the flexural tensile strain of RAP asphalt mixtures without wood fiber, the flexural tensile strain of RAP asphalt mixtures with 0.2 % wood fiber was increased a little. However, compared with the flexural tensile strain of RAP asphalt mixtures with 0.2 % wood fiber, the flexural tensile strain of RAP asphalt mixtures with 0.3 % wood fiber was increased 3.6%. That shows that the low temperature performance of RAP asphalt mixture can be improved when the content of wood fiber reaches a certain level, but the effect is not significant. When the content of wood fiber exceeds a certain amount, the tensile property of the RAP asphalt mixture decreases and the strain resistance improves.
4. Conclusion
The effect of the wood fiber content on the road performance of RAP asphalt mixture were studied, and the optimum wood fiber content of high RAP content asphalt mixtures was recommended. Based on the results the following conclusions can be drawn:

(1) With the wood fiber content of mixture increased, the optimum asphalt-aggregate ratio, VV and VMA increased, and the MS and FL increased to peak values then decreased, however the VFA decreased to lower values then increased.

(2) The addition of wood fibers can improve the high temperature and low temperature performance of RAP asphalt mixtures; however the improvement of water stability performance of v mixtures is not enough. It is suggested that the RAP asphalt mixture with wood fibers can be used in high temperature areas under more economical and reasonable conditions, and the content of wood fibers should be controlled within 0.3%.

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