Study on pavement performance of cotton straw cellulose modified asphalt

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Abstract
To improve the pavement performance of heavy traffic asphalt pavement, two modifiers, cotton straw powder and cotton straw cellulose, were added to matrix asphalt. Through the tenacity test, dynamic shear rheological test, multi-stress creep recovery test and bending beam rheological test of asphalt, the tenacity, high temperature properties, viscoelastic properties and low temperature properties of three kinds of asphalt, including matrix asphalt, cotton straw powder modified asphalt and cotton straw cellulose modified asphalt, were evaluated. Scanning electron microscopy and synchronous thermal analyzer were used to analyze the microstructure and thermal stability of modified asphalt. The results show that both cotton stalk powder and cotton stalk cellulose can effectively improve the tenacity, temperature sensitivity and rheological properties of asphalt. The comprehensive improvement effect of 1% cotton straw cellulose is the best, but its low temperature performance has not been improved significantly. Cotton straw cellulose and asphalt form a more stable system, thereby improving the stability of asphalt. The increase of asphaltene content and the decrease of aromatic content are due to the good oil absorption of cotton straw cellulose, and the high temperature performance of asphalt is improved.

1. Introduction
Due to the complexity of environmental changes and the gradual increase of traffic load, cracks, rutting, pits, loosening, biting and other diseases have successively appeared on asphalt concrete pavement. Adding different types of modifiers in asphalt to improve its road performance has become an indispensable mission for road workers. Cotton, as a large crop in China and even in the world, is more and more used in many ways, but the energy utilization rate of straw is very low [1]. In this paper, straw cellulose is extracted from cotton straw and added to asphalt as a modifier to use, thus greatly improving the utilization rate of cotton straw. Relevant studies have shown that the addition of fibers can significantly improve the road performance of asphalt pavement, which is conducive to solving various diseases of asphalt pavement [2–6]. Polypropylene fiber modified asphalt improves Marshall stability value, which helps to reduce flow and strengthen pavement layer [7]. Mineral fiber can effectively improve the high-temperature stability and low-temperature crack resistance of asphalt, and its improvement mechanism is viscosifying, crack resistance and toughening, which saves the road cost [8]. Lignin fiber is a potential green biological resource with good source and high aromatic content [9]. By testing the tensile strength, shear strength, permeability and indirect tensile strength of fiber asphalt mixture, it is found that fiber can increase the viscoelasticity of asphalt, reduce the stiffness and permeability of asphalt pavement, and improve the
In summary, many scholars have studied the application of cellulose, but there are few studies on cellulose in asphalt, and there is a lack of systematic research on the mechanism of cotton straw cellulose enhancing asphalt from a micro perspective. In this paper, cellulose was extracted from cotton stalk, and on the basis of determining that its performance meets the use requirements, a series of experimental analysis and comparison were conducted on the road performance of matrix asphalt, cotton straw powder modified asphalt and cotton straw cellulose modified asphalt. The mechanism of cotton straw fiber reinforced asphalt pavement performance was further studied by scanning electron microscopy and TGA/DSC analysis from the microscopic level, which has laid the foundation for different kinds of excellent modifiers to gradually appear on the stage of modified asphalt development.

### 2. Materials

#### 2.1. Cotton straw cellulose

Adding cotton straw cellulose and cotton straw powder into asphalt should have favorable physical properties which can be used for modified asphalt, and the basic physical properties are shown in Table 1.

#### 2.2. Asphalt

The asphalt used in this paper is No. 70 A grade asphalt provided by Qilu Branch of Sinopec, and its performance index test is carried out according to the test procedure (JTG E20–2011) [23]. The test results are shown in Table 2. According to the technical requirements in the specification (JTG F40–2004) [24], it can be seen that the asphalt specification meets the requirements.

### 3. Preparation method

#### 3.1. Preparation of cotton straw powder

Firstly, the cotton straw (from Zhengzhou, Henan Province) was cut off and cut into 8 ~ 10 cm each section. The treated cotton straw strip was put into a high-speed multifunctional pulverizer by dry method for crushing treatment to obtain the cotton stalk powder, as shown in Figure 1.

| Table 1. Basic technical performance. |
|---------------------------------------|
| Material varieties | Length/(mm) | Fineness/(μm) | Color | Breaking strength/(cN) | fracture elongation(%) |
|---------------------|-------------|---------------|-------|------------------------|------------------------|
| Cotton straw powder | 8 ~ 10      | About 30      | Light yellow | 2.6                    | 7.68                   |
| Cotton straw cellulose | 4 ~ 6     | 16 ~ 20       | Shading yellow | 3.4                    | 2.21                   |

| Table 2. Basic performance index of asphalt. |
|---------------------------------------------|
| Performance index | Test results | Technical requirements |
|-------------------|--------------|------------------------|
| Penetration (25 °C, 100 g, 5 s)/mm | 68 | 60 ~ 80 |
| Softening point (ball and ring method)/°C | 48.5 | ≤46.0 |
| Ductility (5 cm min⁻¹, 10 °C)/cm | 24 | ≤15 |
| Ductility (5 cm min⁻¹, 15 °C)/cm | >100 | ≤100 |
| Flash point/°C | 269 | ≤260 |
| Density/(g/cm³) | 1.026 Actual measurement |
| Solubility/(%) | 99.7 | ≤99.5 |
| Dynamic viscosity (60 °C)/Pa·s | 184 | ≤180 |

low-temperature cracking resistance of asphalt pavement [10–14]. In response to the national environmental protection policy, it has become a major trend to link waste crop straw with road fibers. The study on rice straw fiber show that its average length is 60 mm, and its fineness is 6 ~ 15 μm. It has a large aspect ratio, and its fracture strength is close to that of flax fiber. Adding rice straw fiber into asphalt can significantly improve its compressive strength [15, 16]. 0.3% coconut fiber can effectively improve the engineering performance of SMA mixture and reduce the segregation between binder and aggregate, thereby improving water stability [17, 18]. Cotton stalk fiber, as a potential substitute for cellulose fiber, can reduce the penetration of modified asphalt and increase the shear strength, which has the advantages of energy saving, environmental protection and abundant resources [19, 20]. The study on the physical and mechanical behavior of corn straw fiber modified asphalt shows that corn straw fiber has good uniformity in asphalt binder. The addition of corn straw fiber can improve the viscosity of asphalt binder and reduce the temperature sensitivity of asphalt binder [21, 22].
3.2. Preparation of cotton straw cellulose
A certain mass of straw powder was taken and added into the nitric acid solution with mass fraction of 4.5% at a solid-liquid ratio of 1: 8. After heating in water bath at 95 °C for 110 min, it was cooled and filtered until the filtrate was neutral, the oven was dried at 60 °C ± 5 °C. The powder obtained after drying was added in 3.5% sodium hydroxide solution with solid-liquid ratio of 1 : 9. After heating in water bath at 90 °C for 90 min, it was cooled and filtered until the filtrate was neutral. Finally, put into the oven, 60 °C ± 5 °C drying, drying straw cellulose, as shown in figure 2.

3.3. Preparation of cotton straw cellulose modified asphalt
The cellulose was slowly added to the matrix asphalt heated to 160 °C ± 2 °C. Firstly, it was stirred at 1500 r·min⁻¹ for 15 min at low speed. After the naked eye could not see the cellulose powder, it was stirred at
5000 r·min\(^{-1}\) for 40 min at high speed. Finally, in order to eliminate the bubbles generated in the process of high speed stirring, it was stirred at 1000 r·min\(^{-1}\) for 10 min at low speed. Finally, the cotton straw cellulose modified asphalt was prepared.

4. Test method

4.1. Tenacity test
The tenacity of modified asphalt as a method for evaluating the pavement performance of modified asphalt was first proposed by Benson of Japan in 1955. China also formally formulated the standard method of asphalt viscosity and toughness evaluation in the petrochemical industry in 2003. In this paper, a SYD-0624 asphalt visco-ductility tester was used, the tenacity of six modified asphalts at 25 °C was tested, according to the T 0624-2011 in the test procedure (JTG E20-2011)\(^{[23]}\).

4.2. Dynamic shear rheological test
According to the T 0628-2011 in the test procedure (JTG E20-2011)\(^{[23]}\), the selected temperature scanning frequency was 10 rad/s (1.59 Hz), frequency scanning frequency was 0.1 rad s\(^{-1}\) ~ 100 rad s\(^{-1}\). When the test temperature was higher than 46 °C, for asphalt samples without aging and short-term aging, 25 mm diameter of the parallel plate was selected, and kept the distance between the upper and lower was 1 mm. In this experiment, the strain control mode with strain level controlled at about 10% was adopted. The interval temperature of temperature scanning test was 6 °C, and the temperature range was 46 °C ~ 88 °C. The complex shear modulus, phase angle, rutting factor and fatigue factor of modified asphalt with different sample types were tested by dynamic shear rheometer. The high temperature performance of cotton straw powder and cotton straw cellulose modified asphalt was studied. Frequency scanning test temperature was 40 °C, 64 °C, 88 °C. The dynamic shear modulus and phase angle of modified asphalt with different sample types at different temperatures and frequencies were analyzed by dynamic shear rheometer. The deformation resistance of cotton straw powder and cotton straw cellulose modified asphalt was studied.

4.3. Multiple stress creep recovery test
Two stress levels of 100 Pa and 3200 Pa were selected to study the creep recovery ability of asphalt under continuous loading at different levels of low stress and high stress. Ten creep recovery cycles were carried out at each stress level. Each cycle was loaded for 1 s and unloaded for 9 s, and each loading and unloading process can be divided into two processes: creep and recovery, as shown in Figure 3.

During each creep cycle, the initial strain value is \(\gamma_0\), the peak value of strain is \(\gamma_p\), the residual strain value is \(\gamma_u\), and the stress is \(\tau\). Unrecoverable creep compliance \(J_{nr}\) and creep recovery rate \(R\) are calculated by Formulas (1) and (2).

\[
J_{nr} = \frac{\gamma_u}{\tau}
\]
The average unrecoverable creep compliance \( J_{\text{nr}}(\tau, N) \) and average creep recovery rate \( R(\tau, 10) \) of 10 creep recovery cycles are calculated. As shown in (3), (4).

\[
J_{\text{nr}}(\tau, 10) = \frac{\sum_{i=1}^{10} J_{\text{nr}}(\tau, N)}{10}
\]

\[
R(\tau, 10) = \frac{\sum_{i=1}^{10} R(\tau, N)}{10}
\]

Formula : N is the number of creep cycles, from 1 to 10.

The difference ratio of unrecoverable flexibility \( J_{\text{nr}} \) at different stress levels \( J_{\text{nr}, \text{diff}} \) can be used to characterize the stress dependence of asphalt materials. As shown in (5).

\[
J_{\text{nr}, \text{diff}} = \frac{J_{\text{nr}, 3.2} - J_{\text{nr}, 0.1}}{J_{\text{nr}, 0.1}} \times 100\%
\]

4.4. Bending beam rheological test
According to the T 0627-2011 in the test procedure (JTG E20-2011) [23]. Under the test temperature of \(-12^\circ C, -18^\circ C, -24^\circ C\), the asphalt was prepared into a sample of \(140 \text{ mm} \times 12.5 \text{ mm} \times 6.35 \text{ mm} \) in size, by loading, unloading and dead load control, bending rheological tests were carried out on asphalt, cotton straw powder modified asphalt and cotton straw cellulose modified asphalt to determine bending creep stiffness modulus and creep curve slope, the low temperature crack resistance of asphalt was studied.

4.5. Test of SEM
In this paper, JSM-7500F field emission scanning electron microscope was used to collect images of cotton straw cellulose modified asphalt. The size of the sample was \(2 \text{ cm} \times 2 \text{ cm} \times 1 \text{ cm} \), which was due to the magnification of the scanning electron microscope and the relatively small volume of the copper table. Considering that the specimen should have sufficient conductivity, The scanning electron microscope observation was carried out after the gold was sprayed at 40 mA for 15 s by the JFC-1600 automatic magnetron sputtering instrument of Jieoulu Company. The scanning electron microscope morphology of cotton straw powder modified asphalt and cotton straw cellulose modified asphalt were analyzed. The magnification of cotton straw powder modified asphalt were 200 times and 1000 times, and the magnification of cotton straw cellulose modified asphalt were 100 times and 500 times.

4.6. Test of TGA/DSC
Differential scanning calorimetry can measure the heat flow in the material with the phase transition of temperature and time, and provide qualitative or quantitative physical and chemical information such as the phase transition of material or the change of heat capacity, which can reflect the change of aggregation state of asphalt material within a certain temperature range. In this paper, TGA/DSC-1 synchronous thermal analyzer was adopted, the temperature rise rate was 10 \(^\circ \text{C} \text{ min}^{-1} \) and the temperature range was \(0^\circ \text{C} \sim 100^\circ \text{C} \).

5. Results and discussion

5.1. Tenacity analysis
The tenacity of six kinds of modified asphalt at \(25^\circ \text{C} \) were tested. The test results are shown in table 3.

As can be seen from table 3, the tenacity and toughness of cotton straw powder modified asphalt and cotton straw cellulose modified asphalt are improved, the results show that cotton straw powder and cotton straw cellulose have improved the tenacity and toughness of asphalt. The tenacity and toughness of 1% cotton straw powder modified asphalt are the maximum, when the content is 2% and 3%, the tenacity value decreases and tends to be stable, while the toughness value decreases sharply, cotton straw cellulose modified asphalt also has the same change rule. The main difference between the two is that when the dosage is 1%, the tenacity and toughness of cotton straw cellulose modified asphalt increase by 6 times and 25 times, while the tenacity and toughness of cotton straw powder modified asphalt increase by only 1.5 times and 8 times. The improvement effect is close in other dosage. Thus, 1% cotton straw powder and cotton straw cellulose can improve the toughness of asphalt, and the improvement effect of cotton straw cellulose is more obvious.
5.2. Temperature scanning

5.2.1. Viscoelastic analysis

The phase angle and dynamic shear modulus of modified asphalt with different types and contents at different temperatures were tested, as shown in figures 4–7.

**Table 3.** Tenacity of different modified asphalt.

| Types of asphalt samples | 70# asphalt | Cotton straw powder content/% | Cotton straw cellulose content/% | Standard deviation |
|--------------------------|-------------|-------------------------------|----------------------------------|-------------------|
|                          | 1           | 2                             | 3                                | 1                 | 2               | 3               |                  |
| Tenacity/N·m             | 4.7         | 11.5                          | 8.7                              | 8.5               | 33.7            | 8.5             | 7.9              | 9.1              |
| Toughness/N·m            | 0.8         | 8.8                           | 2.3                              | 1.1               | 21.5            | 3.4             | 1.8              | 6.9              |
According to figures 4–7, at lower temperature, the dynamic shear modulus of asphalt is larger and the phase angle is smaller, the elasticity of asphalt is stronger, and its deformation resistance is better. With the increase of temperature, the dynamic shear modulus decreases, the phase angle increases, the viscosity of asphalt is enhanced, and its deformation resistance is weakened. For cotton straw powder modified asphalt, the dynamic shear modulus change is not particularly obvious at high temperature, but at low temperature, it shows that when the content of cotton straw powder is 2%, the complex modulus is the largest, which shows that when the content of cotton straw powder is 2%, the mechanical properties of asphalt are improved greatly and the deformation resistance is the best. For cotton straw fiber modified asphalt, the same dynamic shear modulus value changes little at high temperature, when the temperature is low, the dynamic shear modulus is maximum when the content is 3%. However, when the content is 1%, the dynamic shear modulus also increases compared with that when the content is 2%. Comprehensive analysis shows that when the cellulose content is 1%, the mechanical properties of asphalt relatively well. With the change of dosage, it can be seen that the phase angle of 2% cotton straw powder modified asphalt is the smallest, and the phase angle of 3% cotton straw cellulose modified asphalt is the smallest. Thus, with the increase of cotton straw powder content, the elastic characteristics of modified asphalt will not increase linearly. With the increase of cotton straw cellulose content, modified asphalt shows more significant elastic characteristics.
5.2.2. High temperature stability analysis

The rutting factors of modified asphalt with different types and contents at different temperatures were tested, as shown in figures 8 and 9.

According to figures 8 and 9, it can be seen that at the same temperature, the rutting factor of matrix asphalt is the smallest, the rutting factor of cotton straw powder modified asphalt is the largest when the content is 2%, and the rutting factor of cotton straw cellulose modified asphalt is the largest when the content is 3%. With the gradual increase of temperature, the rutting factor of cotton straw powder and cotton straw cellulose modified asphalt with different contents decrease rapidly, mainly because the asphalt becomes soft and tends to viscous flow with the increase of temperature, so the high temperature resistance deformation ability is weakened, and the temperature has a great influence on the rutting resistance of modified asphalt.

As shown in figure 10, the temperature of modified asphalt at rutting factor of 1 kPa under different types and dosages. The inactive temperature of base asphalt is 69.1 °C, with the increase of cotton straw powder and cellulose content, the inactive temperature is also increasing. The deactivation temperatures are increased by 5.6% and 7.1% by adding 3% straw powder and cotton straw cellulose to the matrix asphalt, respectively. Thus, adding cotton straw cellulose and cotton straw powder can significantly improve the high temperature resistance of asphalt.
5.3. Frequency scanning

The phase angle and dynamic shear modulus of asphalt, cotton straw powder modified asphalt and cotton straw cellulose modified asphalt at different temperatures and frequencies were tested, as shown in figures 11 and 12.

According to figure 11, with the increase of the dosage of cotton straw powder modified asphalt, the angular frequency of 90° corresponding to the phase angle is also gradually increasing. It can be seen that the viscoelastic range of high content of cotton straw powder modified asphalt is wider. When the content of cotton straw cellulose modified asphalt is 1%, the corresponding angular frequency value of 90° is the largest. Therefore, the viscoelastic range of cotton straw cellulose modified asphalt with low content is wider.

According to figure 12, asphalt, cotton straw powder modified asphalt and cotton straw cellulose modified asphalt with the increase of angular frequency, dynamic shear modulus increases gradually at the same temperature. Further comparison shows that at the same temperature, the dynamic shear modulus values in the low-frequency region and the high-frequency region show the following law: cotton straw cellulose modified asphalt > cotton straw powder modified asphalt > asphalt. With the change of cotton straw cellulose content, no matter in high frequency or low frequency, dynamic shear modulus change is not obvious. The dynamic shear modulus of cotton straw cellulose modified asphalt increases by 1 times and 0.5 times in low frequency and high frequency respectively. It can be concluded that the addition of cotton straw powder and cotton straw cellulose can effectively improve the deformation resistance of asphalt under high speed or low speed vehicle load shear, and the effect of cotton straw cellulose is better.

5.4. Analysis of multiple stress creep recovery

The creep recovery ability of modified asphalt with different types and contents under different stress levels were tested, as shown in table 4.

According to table 4, the average creep recovery rate R (100) and R (3200) of asphalt are small, which show that the creep recovery rate of asphalt is poor at 64 °C. With the increase of cotton straw powder and cellulose content, the creep recovery rate increases, the effect of cotton straw cellulose modified asphalt with 3% content is the most obvious, which is 4.6 times and 7.7 times higher than that of matrix asphalt under the stress of 100 Pa and 3200 Pa, respectively. This shows that cotton straw powder, cotton straw cellulose and asphalt components fully combined to improve the elastic properties of asphalt. By observing the data of Jnr (100) and Jnr (3200) in table 4, it can be seen that with the increase of the dosage of cotton straw powder, the value of Jnr gradually decreases, which decreases by 41.9% when the dosage is 3%. After adding cotton straw cellulose, the Jnr value is the smallest when the content is 1%, which is 37.1% lower than that of asphalt. This shows that 3% cotton straw powder and 1% cotton straw cellulose can significantly reduce the unrecoverable creep compliance of asphalt, effectively improve the plastic deformation resistance of asphalt at 64 °C and improve the high temperature performance of asphalt.

The difference ratio of unrecoverable creep compliance (Jnr\textsuperscript{diff}) represents the sensitivity of non-recoverable compliance to heavy loads. The smaller the Jnr\textsuperscript{diff} value is, the weaker the sensitivity of non-recoverable compliance of asphalt to heavy load is, and the stronger the creep recovery ability of asphalt under heavy load is. It can be seen from table 4 that with the incorporation of cotton straw powder and cellulose, Jnr\textsuperscript{diff} values are all increasing. Among them, the addition of cotton straw powder is more obvious, when the content reaches 3%, the Jnr\textsuperscript{diff} value is twice as large as that of asphalt. After the addition of 1% cotton stalk cellulose, the Jnr\textsuperscript{diff} value increases slightly, only by 4%. As a result, through the incorporation of cotton straw powder and cotton straw...
cellulose, the sensitivity of asphalt unrecoverable creep compliance to heavy load is increased, and the creep recovery ability of asphalt under heavy load is also reduced, but the effect of 1% cotton straw cellulose on asphalt is not obvious.

Figure 11. Phase angles of different types of modified asphalt at different frequencies.
5.5. Analysis of bending beam

The low temperature performance of modified asphalt with different types and contents was tested, as shown in table 5.

Figure 12. Dynamic shear modulus of different types of modified asphalt at different frequencies.
According to Table 5, the stiffness modulus of cotton straw powder modified asphalt and cotton straw cellulose modified asphalt are larger than that of asphalt. With the decrease of temperature, the increase of stiffness modulus of both modified asphalts are larger than that of asphalt, which is due to the oil absorption of fibers. Aromatic and saturated components with viscous properties in asphalt are absorbed by fibers, and the content of asphaltene and resin components increase relatively, thus increasing the stiffness modulus of modified asphalt. However, since the fiber does not have temperature sensibility, it can still maintain toughness and flexibility at low temperatures. Even if the stiffness modulus of modified asphalt is very large at low temperature, its low temperature crack resistance is also improved. In addition, the creep rates of cotton straw powder modified asphalt and cotton straw cellulose modified asphalt are smaller than that of asphalt. Under the same conditions, the creep rates of cotton straw cellulose modified asphalt are higher than that of cotton straw powder modified asphalt, which indicates that cotton straw cellulose modified asphalt has stronger stress relaxation ability than cotton straw powder modified asphalt. In summary, the incorporation of cotton straw powder and cotton straw cellulose cannot effectively improve the low-temperature crack resistance of asphalt.

### Table 4. MSCR test results of different modified asphalt.

| Types of asphalt samples       | R(100) | R(3200) | Jnr(100) | Jnr(3200) | Jnrdiff |
|-------------------------------|--------|---------|----------|-----------|---------|
| 70# Asphalt                   | 0.928  | 0.113   | 0.542    | 0.597     | 10.148  |
| 1% cotton straw powder modified asphalt | 1.579  | 0.443   | 0.384    | 0.436     | 13.542  |
| 2% cotton straw powder modified asphalt | 2.249  | 0.519   | 0.326    | 0.387     | 18.712  |
| 3% cotton straw powder modified asphalt | 4.387  | 0.954   | 0.315    | 0.379     | 20.317  |
| 1% cotton straw cellulose modified asphalt | 2.441  | 0.627   | 0.341    | 0.377     | 10.557  |
| 2% cotton straw cellulose modified asphalt | 4.119  | 0.955   | 0.370    | 0.412     | 11.351  |
| 3% cotton straw cellulose modified asphalt | 5.217  | 1.133   | 0.353    | 0.397     | 12.465  |

### Table 5. Bending creep stiffness test results of different modified asphalts.

| Types of asphalt samples                        | Creep stiffness modulus S/MPa | Creep curve slope m |
|------------------------------------------------|------------------------------|--------------------|
|                                                 | −12 °C | −18 °C | −24 °C | −12 °C | −18 °C | −24 °C |
| 70# Asphalt                                    | 131.4  | 375.0  | 649.0  | 0.434  | 0.307  | 0.247  |
| 1% cotton straw powder modified asphalt        | 148    | 406    | 660    | 0.431  | 0.306  | 0.244  |
| 2% cotton straw powder modified asphalt        | 181    | 493.4  | 719.2  | 0.426  | 0.304  | 0.240  |
| 3% cotton straw powder modified asphalt        | 190.2  | 502.7  | 736.8  | 0.393  | 0.280  | 0.219  |
| 1% cotton straw cellulose modified asphalt     | 142    | 411    | 658    | 0.432  | 0.305  | 0.243  |
| 2% cotton straw cellulose modified asphalt     | 180.5  | 489.9  | 714.3  | 0.428  | 0.302  | 0.239  |
| 3% cotton straw cellulose modified asphalt     | 186.5  | 503    | 732.6  | 0.394  | 0.278  | 0.216  |
5.6. Morphology analysis of cotton straw powder/cellulose modified asphalt

The morphology of cotton straw powder modified asphalt and cotton straw cellulose modified asphalt were analyzed by scanning electron microscopy. The results are shown in figures 13–16.

According to figures 13 and 14, the cotton straw powder is distributed in the asphalt in fibrous form, and the ‘wrinkle’ is formed at the contact surface between the end of the cotton straw powder and the asphalt. This is because the fibrous cotton straw powder is wrapped by asphalt. When it is protruding on the surface of the asphalt, it will cause the linkage of the surrounding asphalt. At the same time, due to the strong oil absorption of the cotton straw powder, wrinkles will occur at the end and around. But as can be seen from figure 15, the fiber formed by cotton straw powder has been partially raised, and the fiber neck formed by some cotton straw powder is not tightly combined with asphalt. It can be seen that the compatibility between cotton straw powder and asphalt is general, but the combination effect of its ends in asphalt is good, which shows that cotton straw powder has played a good ‘reinforcement’ role and helps to improve the stability of asphalt, but may show insufficient durability.

As can be seen in figures 15 and 16, after adding cotton straw cellulose, asphalt surface changes obviously, intricate and dense hemp ‘fold’ is formed. This is because cellulose itself has a high oil absorption, after full adsorption of asphalt around the ‘saturated’ state, the formation of a vacancy around the ‘fold’ phenomenon, which plays a good adsorption. It can be inferred that cotton straw cellulose and asphalt have good compatibility. But after wrapping cellulose by asphalt, there is not too much protrusion, because cotton straw cellulose and
asphalt formed a stable system, cellulose itself has good mechanical properties, so it is not easy to be destroyed. Therefore, in practical application, the content of cellulose should be reduced while ensuring road performance.

In conclusion, the compatibility between cotton straw cellulose and asphalt is better by analyzing the wrinkle degree of asphalt surface, the protrusion of asphalt surface and the combination with asphalt. Cotton straw powder and cotton straw cellulose can make the structural stability of modified asphalt better.

5.7. Thermal stability analysis
The thermal stability of cotton straw powder modified asphalt and cotton straw cellulose modified asphalt were analyzed, and the results are shown in figure 17.

According to figure 17, asphalt, cotton straw powder modified asphalt and cotton straw cellulose modified asphalt all form an endothermic peak at high temperature and low temperature respectively, and the heat absorption peak intensity and total heat absorption of high temperature zone and low temperature zone are smaller than that of base asphalt. This shows that the phase transition occurs within the modified asphalt, resulting in the decrease of heat absorption of asphalt. The combination of the groups of cotton stalk cellulose and the free groups between asphalts causes the change of a certain component content in asphalt, which hinders the transformation between phases. According to the asphalt colloid theory, asphaltene is the dispersed phase,
colloid is the adhesive solvent, and oil is the disperse medium. In asphalt, the polarity of asphaltene is the strongest, which directly affects the indicators of asphalt and determines the viscosity. It is also the largest component of relative molecular weight. After the incorporation of cotton straw cellulose, due to the high oil absorption of cotton stalk cellulose, it exists in the free state with asphalt, and the oil is a dispersion medium, which is difficult to completely absorb. In the process of not reaching ‘saturation’, it also absorbs a large number of asphaltene, so that some of the cotton straw cellulose is wrapped by asphaltene, thereby increasing the overall content of asphaltenes, while the quality of aromatic components is relatively reduced, thereby improving the thermal stability of asphalt.

The mechanism of cotton straw powder modified asphalt and cotton straw cellulose modified asphalt is similar, because its adsorption with asphalt is mainly caused by physical combination, however, in the complex change process of high-speed shear, some free groups on the surface of cotton straw powder are also combined with asphalt, causing the change of phase state, resulting in the change of asphalt composition, and thus improving the thermal stability of asphalt. However, due to this is also partly caused, so the higher the cotton straw powder content is, the closer the ‘saturation’ effect of cotton straw cellulose is, which is consistent with the macroscopic conclusion.

6. Conclusion

(1) Cotton straw cellulose modified asphalt and cotton straw powder modified asphalt can improve the viscosity and toughness of asphalt. The viscosity and toughness of cotton straw cellulose modified asphalt with 1% content are the strongest, which are 6 times and 25 times higher than that of matrix asphalt, respectively. The viscosity and toughness of cotton straw powder modified asphalt with 1% content are increased by 1.5 times and 8 times.

(2) When the content of cellulose is 1%, the mechanical properties of modified asphalt is improved by 64% and the viscoelastic range is wider. The anti-rutting performance is improved by 4.2% ~ 7.1% by adding cotton straw cellulose. Cotton straw powder and cotton straw cellulose cannot effectively improve the low-temperature performance of asphalt.

(3) Cotton straw cellulose modified asphalt and cotton straw powder modified asphalt can improve the ability of asphalt to resist permanent deformation. The content of 3% cotton straw cellulose improves the elastic performance significantly, which is 7.7 times higher than that of matrix asphalt under the stress of 3200 Pa.

(4) Cotton straw powder and cotton straw cellulose have high oil absorption, which can achieve the adsorption effect of asphalt. Compared with cotton straw powder, cotton straw cellulose has better compatibility with asphalt, and cellulose itself has better mechanical properties, which can significantly improve the stability of asphalt.

(5) The good oil absorption of cotton straw cellulose increases the overall content of asphaltene and decreases the quality of aromatic components, which improves the thermal stability of asphalt. The mechanism of the two modified asphalts is similar, but due to the different number of free groups that can be absorbed and combined, cotton straw powder needs a large number of raw materials.

(6) Chemical activation of cotton straw cellulose to a more suitable physical form or to improve the performance of asphalt may be considered. The main results of this paper are carried out in the laboratory, and the next step can be considered to pave the test section to analyze the related performance of cotton straw cellulose modified asphalt in the actual road environment.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

CRediT authorship contribution statement

Z Li: Conceptualization, Project administration, Supervision, Writing-Review & Editing. T Guo: Conceptualization, Formal analysis, Methodology, Visualization. Y Chen: Supervision, Project administration, Data curation, Formal analysis. J Liu: Conceptualization, Writing-Original Draft, Supervision, Investigation. J Ma: Conceptualization, Supervision, Writing-Original Draft. J Wang: Conceptualization, Project administration, Super-vision, Investigation. L Jin: Funding acquisition, Investigation.
Declaration of competing interest

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