Design of Asphalt Light Component Pre-filled Filler Based on Oil Shale Waste Residue

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ABSTRACT: The asphalt light component pre-filled filler is prepared based on oil shale waste residue. The performance of the light component pre-filled filler is evaluated based on ultimate and fatigue failure parameters, such as the ultimate bending failure strength and strain of asphalt mastic, and the bending creep stiffness variation ratio of asphalt mastic. Test results show that the light component pre-filled filler can weaken the effect of aging on the asphalt property parameters, which is a feasible measure of the anti-aging of asphalt.

1. INTRODUCTION

The exploitation and utilization of oil shale is a hot issue in the energy field. China has rich oil shale resources. The oil refining technology of oil shale is also gradually maturing. Oil shale is exploited in Jilin Province, Liaoning Province, and other provinces, then further refined. A large amount of oil shale waste residue is produced after refining crude oil, which causes a certain degree of environmental pollution [1].

Asphalt in an asphalt mixture ages under the combined action of heat, light, and oxygen during the construction and service stages [2–4]. Asphalt is usually aged in two ways: one is the volatilization of light components, such as aromatics and saturates in asphalt, and the other is the oxidation of light components and their subsequent transformation into asphaltene and resin. These aging methods eventually lead to a gradual reduction in the proportion of light components in the asphalt, but the contents of asphaltene and resin are gradually increased [5–8]. After aging to a certain degree, the low-temperature anti-cracking and moisture damage resistance property of asphalt mixture decrease significantly, and the relevant pavement performance of the mixture decreases [9–11].

To reduce the negative influence of asphalt aging effect on the pavement performance of the mixture, researchers have attempted to delay the aging process of asphalt by using anti-aging agents and other materials [12–13]. The working principle of anti-aging agents is to inhibit the oxidation of asphalt in the natural environment and reduce the proportion of the light components that change into asphaltene and resin to achieve the anti-aging effect [14–16]. The practice has proved that the performance of anti-aging agent was limited because it failed to reduce the significant volatilization effect of asphalt light component in construction stage.

The following ideas are put forward to conduct this research work: Asphalt light components can be pre-implanted in a carrier that is rich in micro-pore structures. The carrier is added as a general filler during the preparation stage of the mixture. As a result, light components that are lost during the asphalt aging process can be effectively supplied through a continuous, dynamic, and complete process. If achieved, then this method is a direct and effective anti-aging measure.

During the previous research process, we found that oil shale waste residue produced a large number of micro-pores during the crude oil refining process; these micro-pores are an ideal carrier for the asphalt light components.

This study uses oil shale waste residue particles as the carrier, in which light components are pre-implanted to form a functional filler, and the performance of light component pre-filled filler is examined.

2. EXPERIMENTAL MATERIALS

The oil shale waste residue material was obtained from an oil shale waste residue storage area in Huadian City, Jilin Province, China. After undergoing crushing...
and sieving, the particles with a size below 0.075 mm sieve are chosen as the carrier materials of the light components. The remarkable characteristic of this material is that it is highly porous (Figure 1), which provides an important opportunity for application in this study.

The materials used in this research are asphalt, oil shale waste residue, and diesel oil that are rich in aromatics and saturates. Two types of asphalt exist, namely, CNOOC 90# (China National Offshore Oil Corporation 90#) asphalt and SBS(Styrene-Butadiene-Styrene)-modified asphalt. The basic property parameters of the two types of asphalt are shown in Table 1.

3. RESEARCH METHOD

3.1. Preparation of Aging Asphalt Samples

The aging asphalt was prepared by oven heating in this research because the aging asphalt samples were usually limited by traditional aging test (RTFOT + PAV, Rotating Thin Film Oven Test + Pressure Aging Vessel) [17–20]. This method can make the asphalt reach the standard of long-term aging level, and it can use numerous aging asphalt samples in testing asphalt strength and deformation. The oven temperature was 160°C and the heating time was 42 h. The asphalt was fully stirred for 30 s every 20 min to ensure the volatility of the light components. Results indicate that this method ensures consistency between the aging state of asphalt samples and that obtained with traditional aging test (RTFOT + PAV).

3.2. Asphalt Mastic Bending Test

The beam bending test is used in this study for mechanical analysis of the asphalt mastic under low-temperature conditions. The ultimate bending failure strength and ultimate bending failure strain of the specimen are calculated according to Equations (1) and (2). The size of the asphalt mastic beam specimen is 250 mm × 30 mm × 35 mm, and the loading rate is 50 mm/min.

\[
R_B = \frac{3LP_B}{2bh^2} \tag{1}
\]

\[
\varepsilon_B = \frac{6hd}{L^2} \tag{2}
\]

where \(R_B\) is the ultimate bending failure strength when the specimen is destroyed, MPa; \(\varepsilon_B\) is the ultimate

<table>
<thead>
<tr>
<th>Asphalt Type</th>
<th>Penetration (0.1 mm)</th>
<th>Ductility at 15°C (cm)</th>
<th>Softening Point (°C)</th>
<th>Brookfield Viscosity (pa.s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNOOC 90# asphalt</td>
<td>7.5 88.2</td>
<td>97</td>
<td>48.9</td>
<td>0.26</td>
</tr>
<tr>
<td>SBS-modified asphalt</td>
<td>7.1 87.8</td>
<td>111</td>
<td>49.5</td>
<td>0.29</td>
</tr>
</tbody>
</table>

Figure 1. Micro-pore structure of oil shale waste residue under scanning electron microscope: (a) 5 µm and (b) 2 µm.
bending failure strain when the specimen is destroyed; $b$ is the midspan cross section width, mm; $L$ is the mid-span cross section height, mm; is the span of the specimen, mm; $P_B$ is the peak load when the specimen is destroyed, N; and $d$ is the midspan bending when the specimen is destroyed, mm.

The asphalt mastic beam mold used in this experiment is shown in Figure 2. The equipment used in this test is shown in Figure 3.

3.3. Asphalt Mastic Bending Beam Rheological Test (BBR)

This study focuses not only the ultimate failure state of the asphalt mastic, but also the anti-fatigue performance. Rheological property is an important mechanical characteristic of asphalt mastic and is closely related to the anti-fatigue performance of asphalt mastic. Low-temperature rheological property was tested by using BBR in this study. The stiffness characteristic of the asphalt mastic beam specimen under the creep load was tested based on the beam theory. The creep stiffness $S$ and the variation rate $m$ of creep stiffness with time as the indexes during the test. This study focused on the asphalt mastic creep stiffness variation rate $m$. A greater value of $m$ under low-temperature condition indicated stronger stress relaxation and anti-fatigue failure of asphalt mastic [21–24].

4. DESIGN OF LIGHT COMPONENT PRE-FILLED FILLER

4.1. Working Principle of Light Component Pre-filled Filler

To avoid a reduction in the high-temperature performance of the asphalt binder as a result of the increased proportion of light components in the asphalt, a reasonable design for a light component pre-filled filler should include light components that are released slowly from the cavity interior at a certain temperature. In this manner, the light components are supplied into the surrounding oil film in a continuous, dynamic, and complete way. As a result, the four components constitute a reasonable proportion of the asphalt binder and ultimately have an anti-aging effect. The working principle of the proposed light component pre-filled filler is shown in Figure 4.

4.2. Determination of the Additive Content of the Light Component Pre-filled Filler

The carrier adsorption capacity of light components was determined through a comparison between the carrier quantity before and after absorbing the light components. The quantity of the oil shale waste residue particles before absorbing the light components was 20.0 g, the quantity of the oil shale waste residue particles after absorbing the light components was 31.7 g, so the light component quantity absorbed by each gram of oil shale waste residue was 0.6 g.

The test result of asphalt components after long-term aging indicates that the proportion of light components decreased from 49.2% to 36.6%, and the proportion of light components loss was 12.6%, that is, 100 g asphalt after long-term aging lost 12.6 g of light components.
In accordance with the ability of the oil shale waste residue particles to adsorb light components, 1 g oil shale waste residue particles can adsorb 0.6 g of light components. On the basis of the above rules, if 21 g of light component pre-filled filler were mixed into 100 g asphalt, then the light component proportion of this asphalt mastic can still be maintained within a reasonable range during the long-term aging process to maintain a better pavement performance. The above quantitative analysis indicates that the content of the light component pre-filled filler was 21% of the asphalt quantity in this study.

5. EVALUATION OF WORKING PERFORMANCE OF LIGHT COMPONENT PRE-FILLED FILLER

5.1. Preparation of Asphalt Mastic

To evaluate the working performance of the light component pre-filled filler, the two types of asphalt, namely, the CNOOC 90# asphalt and SBS-modified asphalt, were doped with ordinary limestone power and light component pre-filled filler to prepare the asphalt mastic under the ordinary state and the long-term aging state (through oven heating for 42 h). Then, comparative analysis was performed on a series of properties.

Given the significant difference in the density of the ordinary limestone filler and that of the light component pre-filled filler (the density of the limestone filler and the light component pre-filled filler is 2.7 and 1.6 g/cm³, respectively), to ensure the same distribution of the filler in different asphalt mastics prepared by different fillers, the mixed volume of the two types of filler should be strictly consistent, that is, the volume of the ordinary limestone filler and light component pre-filled filler mixed into the asphalt should be the same. In summary, the content of the light component pre-filled filler is 21% of the asphalt quantity for the asphalt mastic mixed with light component pre-filled filler, and the content of the limestone power is 35% for the asphalt mastic mixed with ordinary limestone filler.

5.2. Effect of the Light Component Pre-filled Filler on the Basic Performance Parameters of Asphalt Mastic

To facilitate the production of analysis diagrams and tables, the CNOOC 90# asphalt doped with ordinary limestone filler and light component pre-filled filler were defined as mastic A⁻ and mastic A⁺, respectively.

The SBS-modified asphalt doped with ordinary limestone mineral filler and light component pre-filled filler were defined as mastic B⁻ and mastic B⁺, respectively. The basic parameters of the test include softening point and ductility, the test results are shown in Table 2.

For the general asphalt, adding the mineral filler will increase the softening point and decrease the ductility at the same time. As shown in Table 2, for the asphalt mastic mixed with ordinary limestone filler, the softening point increased significantly. For the asphalt mastic mixed with light component pre-filled filler, after long-term aging, the softening point also exhibited a certain degree of increase, but the increase proportion is far less than that of the asphalt mastic mixed with ordinary limestone filler. After long-term aging, the ductility of mastic A⁻ and mastic B⁻ mixed with ordinary limestone filler decreased significantly. However, the ductility decreased proportion of the asphalt mastic mixed with light component pre-filled filler is far lower than the asphalt mastic mixed with ordinary limestone filler.

The effect of the light component pre-filled filler on the softening point and ductility of the asphalt mastic indicates that the working performance of the light component pre-filled filler is significant. The light component pre-filled filler has a significant effect on the basic performance parameters of the asphalt mastic. Thus, the light component pre-filled filler can be speculated to have a beneficial effect on the mechanical properties of the asphalt mastic.

5.3. Effect of the Light Component Pre-filled Filler on the Mechanical Parameters Under Asphalt Mastic Bending Failure Conditions

To analyze the effect of the light component pre-filled filler on the mechanical parameters under ultimate failure of the asphalt mastic, asphalt mastic bending failure tests of different categories of asphalt mastic under different states were carried out to determine the influence law of the light component pre-filled filler.
on the ultimate bending strength and ultimate bending strain of the asphalt mastic. In the test, the asphalt mastic types were mastic A–, mastic A+, mastic B– and mastic B+. The aging states of asphalt mastic were normal state and long-term aging state. The test temperatures were 0, –10, and –20°C. The test results of the ultimate bending strength and ultimate bending strain of different kinds of asphalt mastic in different aging states under different temperature conditions are shown in Table 3 and Table 4.

The results shown in the Figures 5, 6, 7, and 8 indicate that the influence law of the asphalt mastic prepared by the CNOOC 90# asphalt is the same as that of the asphalt mastic prepared by SBS-modified asphalt.

With the test results of asphalt mastic prepared by the CNOOC 90# asphalt as an example, the results of the asphalt mixed with ordinary limestone filler (mastic A–) in the normal state were compared with the test results after long-term aging. Results show that the ultimate bending strength of the asphalt mastic increased by 48% at 0°C, the ultimate bending strain decreased by 42.5%, the ultimate bending strength of the asphalt mastic increased by 27.9% at –10°C, and the ultimate bending strain decreased by 46.7% because of the aging and low-temperature. The embrittlement temperature of asphalt is about –20°C, Thus the ultimate bending strength of the asphalt mastic decreased by 26.7%, and the ultimate bending strain decreased by 37.5% at –20°C.

The results of the asphalt mixed with light component pre-filled filler (mastic A+) in the normal state were compared with the test results after long-term aging. The ultimate bending strength of the asphalt mastic increased by 20.3% at 0°C, and the ultimate bending strain decreased by 15.2%; the ultimate bending strength of the asphalt mastic increased by 9.8% at –10°C, and the ultimate bending strain decreased by 12.8%; the ultimate bending strength of the asphalt mastic decreased by 12.3% at –20°C, and the ultimate bending strain decreased by 12.5%. Thus, the application of this material can weaken the effect of aging on the mechanical parameters.

For the beam bending test, aging will increase the hardness of asphalt materials, increase the modulus, and weaken the anti-deformation ability, thereby increasing the ultimate bending strength of the asphalt material and decreasing the ultimate bending strain. The proposed light component pre-filled filler can supply light components that are lost during the asphalt aging process in a continuous, dynamic, and complete way. Thus, the application of this kind of material can weaken the effect of aging on the mechanical parameters under asphalt mastic bending failure conditions.

### 5.4. Effect of the Light Component Pre-filled Filler on the Low-temperature Creep Stiffness Variation Ratio of Asphalt Mastic

The bending creep stiffness $S$, bending creep stiffness variation ratio $m$ of mastic A–, mastic A+, mastic B–, and mastic B+ in the normal state and long-term aging state were tested by the BBR test. The test temperature was –12°C. The test results are shown in Table 5.

Generally, as a result of aging, the bending creep stiffness $S$ will increase, and the bending creep stiffness variation ratio $m$ will decrease. $m$ can reflect the dissipative

<table>
<thead>
<tr>
<th>Table 3. Test Results of the Ultimate Bending Strength and Ultimate Bending Strain (CNOOC 90# asphalt).</th>
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<tbody>
<tr>
<td>Mastic Type</td>
</tr>
<tr>
<td>(A–) Asphalt mastic in normal state</td>
</tr>
<tr>
<td>(A+) Asphalt mastic in long-term aging state</td>
</tr>
<tr>
<td>(B–) Asphalt mastic in normal state</td>
</tr>
<tr>
<td>(A+) Asphalt mastic in long-term aging state</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>(B+) Asphalt mastic in long-term aging state</th>
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<tbody>
<tr>
<td>1.48</td>
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<tr>
<td>0.067</td>
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<tr>
<th>Table 4. Test Results of the Ultimate Bending Strength and Ultimate Bending Strain (SBS-modified asphalt).</th>
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</thead>
<tbody>
<tr>
<td>Mastic Type</td>
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<tr>
<td>(B–) Asphalt mastic in normal state</td>
</tr>
<tr>
<td>(B+) Asphalt mastic in long-term aging state</td>
</tr>
<tr>
<td>(B+) Asphalt mastic in normal state</td>
</tr>
<tr>
<td>(B+) Asphalt mastic in long-term aging state</td>
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<tr>
<td>(B+) Asphalt mastic in long-term aging state</td>
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</table>
stiffness ability of asphalt mastic. Thus, the creep stiffness variation ratio \( m \) can be used to reflect the anti-fatigue capability of asphalt mastic. The \( m \) values of four types of asphalt mastic in different aging states were statistically analyzed in this study. The regularity of the two types of asphalt was basically the same. The asphalt mastic prepared by the CNOOC 90# asphalt is given as an example. After long-term aging, the bending creep stiffness variation ratio \( m \) of the asphalt mastic mixed with the ordinary limestone filler is decreased by 31.9%, but the bending creep stiffness variation ratio \( m \) of the asphalt mastic mixed with the light component pre-filled filler decreased by only 10.9%. Hence, the light component pre-filled filler can effectively inhibit the asphalt aging effect, and it has great significance to the improvement of the anti-fatigue performance of the asphalt mastic and asphalt mixture.

6. DISCUSSION

Asphalt ages during the preparation of asphalt mixture, transportation, paving, rolling, and service stage. The pavement performance of the asphalt mastic and asphalt mixture decreases because the effect of aging
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is inevitable. Selecting an effective anti-aging measure to improve the performance of asphalt pavement is important.

Oil shale waste residue is rich in micro-pore structures. Thus, this material is a good carrier of asphalt light components. According to the working principle of this material, as shown in Figure 4, when the asphalt light components are pre-implanted in the micro-pore structure, the light components will supplement the surrounding oil film in a continuous, dynamic, and complete manner, thereby keeping the light components (aromatics and saturates) of the asphalt within a reasonable range, which ensures the good pavement performance of the asphalt mastic and asphalt mixture at low temperature.

Two types of control parameters are selected to analyze the influential effect of the light component pre-filled filler on the low-temperature performance of asphalt mastic. One is the mechanical parameters that reflect the ultimate failure performance of asphalt mastic; these parameters are ultimate bending failure strength and ultimate bending failure strain under different temperatures, which are tested by the beam bending test of asphalt mastic. The second is the mechanical parameters that reflect the fatigue damage performance of asphalt mastic, that is, the asphalt mastic bending creep stiffness variation ratio \( m \) tested by the asphalt mastic bending beam rheological test. The test result indicates that the working performance of the light component pre-filled filler, which is investigated based on the indexes of ultimate damage and fatigue damage, is representative.

The experimental results clearly show that the effect of aging on the basic performance parameters of asphalt mastic (softening point and ductility), mechanical parameters of ultimate failure (the ultimate bending failure strength and ultimate bending failure strain), and fatigue failure parameter (asphalt mastic bending creep stiffness variation ratio \( m \)) is weakened by the proposed light component pre-filled filler, thereby indicating that the filler is an effective anti-aging measure.

The focus of this study is the effect of the light component pre-filled filler on the low-temperature performance of asphalt mastic. Whether the application of this light component pre-filled filler will negatively affect the high-temperature properties of asphalt mastic or not is also a concern by the research team. Given the release of light components, which is a slow process in the pore of oil shale waste residue, a sudden and significant attenuation effect on the high-temperature performance of asphalt mastic is not produced. On the basis of the asphalt mastic high-temperature adhesion test (water boiling method) and high-temperature viscosity test, the adhesion level of the mastic does not change, and the high-temperature viscosity does not change too.

The asphalt light component pre-filled filler based on oil shale waste residue has significant engineering value and social value. On the one hand, it can reduce the aging effect on the low-temperature performance of asphalt mastic; on the other hand, it has a positive effect on environmental protection based on rational utilization of oil shale waste residue.

### 7. CONCLUSION

Waste residue particles rich in micro-pore structures can be obtained from oil shale after refining crude oil. Thus, these particles can be used as the carrier of asphalt light components. Combined with the construction feasibility problem, the light component pre-filled filler is designed, and the working performance is evaluated.

In accordance with the change of light component proportion after long-term aging and the oil shale waste residue particle adsorption capacity of light components, the proportion of this light component pre-filled filler is determined; this method of determining mixing proportion is universal.
Compared with the asphalt mastic mixed with ordinary limestone filler, the application of the light component pre-filled filler could weaken the effect of aging on the basic performance parameters of asphalt mastic, the mechanical parameters of ultimate failure, and fatigue failure parameter. Thus, it is a simple and feasible anti-aging measure for asphalt.

On the basis of the effect of the light component pre-filled filler on the anti-aging property of asphalt mastic, the application of this material can produce a beneficial effect on the low-temperature performance of asphalt mixture.

8. ACKNOWLEDGEMENT

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9. REFERENCE