Laboratory evaluation of PE modified asphalt mixture containing reclaimed asphalt pavement

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This study evaluated the pavement performances of polyethylene (PE) modified asphalt mixture (PEHMA) containing reclaimed asphalt pavement (RAP). A series of RAP (80-100 wt%) were added into PEHMA to replace natural aggregate for the manufacture of RAP–PEHMA. Marshall design method was employed to prepare related specimens to determine the permanent deformation, water sensitivity, low temperature crack resistance and fatigue properties. The results show that RAP–PEHMA performs better rutting resistance than the PEHMA (control mixture), which means that the RAP could improve the high temperature performance of PEHMA. Conversely, RAP–PEHMA made with PE and RAP displays worse water stability, low temperature stability, fatigue performance than that of PEHMA, but all of them could satisfy the current mixture requirements in China.

Keywords: Asphalt mixture, Reclaimed asphalt pavement, Polyethylene, Pavement

Along with more and more asphalt pavements have been stepping into the maintenance stage, an increase in the numbers of deteriorated roadways are needed to reconstruction and maintenance. So amounts of RAP generated in China have been continuously rising1. Because RAP will cause environmental problems and material waste, recycle using the old asphalt pavement material (RAP)2 is necessary.

Many researches have concluded that adding reclaimed asphalt pavement (RAP) into hot mix asphalt (HMA) pavements could beneficial to reduce initial costs, conserve natural resources, and avoid disposal problems3-5. Furthermore, the properties of reasonable designed recycled asphalt concrete materials have been proven to be comparable to new asphalt pavements6. Several researchers state that diverse methods for recycling asphalt pavements are suitable including: hot recycling in plant, hot-recycling "in situ", cold-recycling "in situ", and others7. Nevertheless, hot recycling method, which virgin materials and RAP are combined in different proportions and sizes, is one of the most widely techniques used at present8. Although the advantages of economic and environmental are obvious for adding RAP to virgin HMA mixtures, there is a concern about long-term performance of HMA pavements containing RAP9.

Conventional asphalt material is difficult to meet the needs of increasing traffic and heavy traffic loading. So many polymers have been incorporated into asphalt binders to mitigate the major causes of asphalt pavement failures such as permanent deformation at high temperatures and cracking at low temperatures10. The most commonly used polymer for asphalt modification is styrene butadiene styrene (SBS)11, followed by other polymers such as crumb rubber10, styrene butadiene rubber (SBR)12, ethylene vinyl acetate (EVA)13. These polymer mixtures also have been used with success at high-stress locations such as interstates, intersections, and airports.

In addition, packaging technology has made a great contribution to daily life, but its by-product, packaging waste, has generated a serious pollution problem14. China is one of the world's top 10 producers and consumer of plastic products. Plastic wastes are responsible for the visual pollution, and moreover, they will threaten global ecology as their non-degradable molecular structure15. Without doubt that the waste polyethylene (PE) is a major source of pollution16.

Considering the fact that PE is also a polymer, many researchers tried to use PE as a modifier to improve asphalt properties. At present, some progress has been made on PE modified bitumen, however,
there appears to be a gap in the knowledge on performance of PE modified asphalt mixture incorporating different RAP contents. Therefore, the objective of this study is to investigate the engineering properties of PE modified asphalt mixture incorporating RAP. Laboratory experiments such as wheel tracking test, freeze-thaw splitting test, bending beam test and indirect tensile fatigue tests were carried to characterize the high temperature rutting resistance, water damage resistance, low temperature anti-crack property and fatigue life of RAP–PEHMA.

Experimental Procedure

Materials

One pure asphalt (AH-70) was selected in this study in accordance with weather and construction conditions, volume of traffic, highway classification, etc. The properties of the asphalt binder are shown in Table 1. A kind of commercially PE particle with 2-4 mm size is used in this research, which has gravity of 55.3 g/cm³, elongation at break of 378%, flexural modulus of 513 MPa and thermal deformation temperature of 44.3°C.

Two sources of aggregates were used within this project. The natural aggregates were sampled from a central producer including coarse aggregates, fine aggregate, and limestone-based mineral filler. Table 2 shows the characterizations of natural aggregates. The filler has CaO content of 47.6%, SiO₂ content of 1.44% and specific gravity of 2.735 g/cm³.

RAP aggregate was designed to replace natural aggregates. The RAP was separated into individual sizes among the 0.075 mm to 19 mm with a maximum nominal particle size of 16 mm. The gradation of AC-16 with 100% RAP in Fig.1 was the grain size distribution of the RAP aggregates. Meanwhile, the extracted aggregate bulk specific density of RAP was 2.613 g/cm³.

Rejuvenating agent composed of rubber oil was used to restore the reclaimed asphalt binder properties to a consistency level appropriate for the pavement performance. It was added at a rate of 5% by weight of the RAP.

PE modified asphalt preparation

PE modified binders were prepared by using a rotation mixer at 3000 r/min. First the asphalt about 100 g was heated to fluid at around 170°C. Then, the appropriate amount of PE (6 wt% of asphalt) was added into these hot liquid asphalt slowly and blended for 60 min to promote it could be dispersed well in binders.

Marshall mix design

Marshall mix-design procedure was employed to design mixture since it is the standard mix-design method adopted in Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011) of China. A common dense-graded asphalt mixture (AC-16) was selected to prepare PEHMA as it is widely used in the middle layer. The aggregate gradation had a maximum nominal particle size of 16 mm and a 4% mineral filler content. Similar gradations were set to design RAP-PEHMA. Percentages of 100%, 95%, 90%, 80% RAP by weight of total aggregate were studied. Figure 1 was the gradation result of asphalt mixture with different RAP dosages.

Table 1 — Physical properties of asphalt binder

<table>
<thead>
<tr>
<th>Test items</th>
<th>Unit</th>
<th>Value</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration at 25°C</td>
<td>0.1 mm</td>
<td>63.6</td>
<td>T0604</td>
</tr>
<tr>
<td>Ductility at 15°C</td>
<td>cm</td>
<td>&gt;100</td>
<td>T0605</td>
</tr>
<tr>
<td>Ductility at 10°C</td>
<td>cm</td>
<td>41.2</td>
<td>T0605</td>
</tr>
<tr>
<td>Softening point (°C)</td>
<td>°C</td>
<td>47.5</td>
<td>T0606</td>
</tr>
<tr>
<td>Mass loss (%)</td>
<td>%</td>
<td>0.16</td>
<td>T0609</td>
</tr>
<tr>
<td>Residual penetration ratio (%)</td>
<td>%</td>
<td>71.3</td>
<td>T0604</td>
</tr>
<tr>
<td>Ductility at 10°C</td>
<td>cm</td>
<td>15.3</td>
<td>T0605</td>
</tr>
</tbody>
</table>

Table 2 — Properties of the natural aggregate

| Aggregate specific gravity (g/cm³) | Test results | ASTM C-127 | 2.813 |
| Coarse aggregate absorption (%)   | ASTM C-127   | 0.34       |
| Fine aggregate specific gravity (g/cm³) | ASTM C-128   | 2.811      |
| Fine aggregate absorption (%)     | ASTM C-128   | 0.42       |
| Abrasion loss (loss angles) (%)   | ASTM DC-131  | 8.3        |

Fig. 1 — Aggregate gradation of different asphalt mixture
The laboratory mixing temperature and compaction temperature were 170°C and 160°C, respectively. Cylindrical specimens 101.6 mm in diameter and 63.5 mm in height were formed using the marshall compactor (with 75 blows on each side). The optimum asphalt content (OAC) was determined based on the results of marshall stability (MS), flow (FL), air voids (VV) and voids in the mineral aggregate (VMA) in accordance with the JTG F40-2004. Table 3 shows the composition and marshall design results of these asphalt mixtures.

**Wheel tracking test**

Loaded wheel tester was conducted to evaluate the resistance of RAP-PEHMA to permanent deformation. This experiment condition was standardized as loading for 0.7 MPa, temperature for 60°C and wheel running speed for 42 cycles/min, with a rubber wheel of 50 mm width. Dynamic stability (DS), which is used widely to characterize the rut resistance of asphalt mixture, can be calculated by Eq. (1) (JTG F40-2004).

\[ DS = \frac{(t_2 - t_1)}{d_2 - d_1} \times C_1 \times C_2 \quad \ldots (1) \]

Where \( DS \) is dynamic stability, times/mm; \( d_1 \) is deformation at \( t_1 = 45 \) min, mm; \( d_2 \) is deformation at \( t_1 = 60 \) min, mm; \( C_1, C_2 \) are machine type coefficient and specimen type coefficient.

**Residual stability test and freeze-thaw splitting test**

Residual stability test and freeze-thaw splitting test were used to evaluate the moisture sensitivity of RAP-PEHMA. In the residual stability test, Residual Marshall Stability (RMS) is considered to be an evaluating indicator of water stability, and large RMS value indicates better water stability. Eight asphalt mixtures specimens with a diameter of 101.6 mm and a height of 63.5 mm were divided into two groups. One control subset group was tested after immersed in 60°C water bath for 30 min; while the other test group immersed in water in a vacuum box for 15 min first, and then freeze for 16 h in a -18°C environment box, after that, these specimens were saturated in a water bath for 24 h at the 60°C. The tensile strength of the specimens in each subset was then determined to calculate TSR as Eq. (3). This testing method is similar to the method specified in AASHTO T 283-03 (Standard Method of Test for Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage), but the experiment parameters are a little different.

\[ TSR = \frac{R_2}{R_1} \times 100 \quad \ldots (3) \]

Where TSR is the tensile strength ratio (%); \( R_1 \) is the tensile strength without freeze–thaw circles (MPa); \( R_2 \) is the tensile strength under freeze–thaw circle (MPa).

**Low temperature bending beam test**

Bending test was conducted to evaluate the low temperature cracking resistance of asphalt mixture specimens following the standard test method JTG E20-2011. Specimens with 250 mm×30 mm×35 mm were monotonically loaded to failure along the midpoint of span at the constant rate of 50 mm/min at

<table>
<thead>
<tr>
<th>Mixture types</th>
<th>Natural:RAP</th>
<th>MS (kN)</th>
<th>FL (mm)</th>
<th>VV (%)</th>
<th>VMA (%)</th>
<th>OAC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC-16 with 0% RAP</td>
<td>100:0</td>
<td>17.93</td>
<td>3.01</td>
<td>4.6</td>
<td>13.4</td>
<td>4.60</td>
</tr>
<tr>
<td>AC-16 with 100% RAP</td>
<td>0:100</td>
<td>11.52</td>
<td>5.15</td>
<td>2.5</td>
<td>15.6</td>
<td>4.20</td>
</tr>
<tr>
<td>AC-16 with 95% RAP</td>
<td>5:95</td>
<td>12.97</td>
<td>4.67</td>
<td>3.2</td>
<td>15.2</td>
<td>4.25</td>
</tr>
<tr>
<td>AC-16 with 90% RAP</td>
<td>10:90</td>
<td>13.54</td>
<td>4.18</td>
<td>4.3</td>
<td>14.7</td>
<td>4.32</td>
</tr>
<tr>
<td>AC-16 with 80% RAP</td>
<td>20:80</td>
<td>14.78</td>
<td>3.44</td>
<td>4.5</td>
<td>14.3</td>
<td>4.40</td>
</tr>
</tbody>
</table>
the temperature of -10°C. The bending strain at failure can be calculated as Eq. (4).

$$\varepsilon = \frac{6hd}{L^2} \quad \ldots (4)$$

Where $h$ is the height of specimen at mid-span section (mm); $L$ is the span of specimen (mm); $d$ is the mid-span deflection at failure (mm); $\varepsilon$ is the bending strain at failure.

**Fatigue test**

Indirect tensile test (IDT) was used to evaluate the fatigue life of asphalt mixture. Cylinder specimens with a diameter of 101.6 mm and a height of 63.5 mm were prepared using the Marshall compaction method. Then the constant tension levels (350 kPa, 450 kPa and 550 kPa) was applied to achieve a series of stress ratios (0.2-0.6) for all PE modified asphalt mixtures with and without RAP. The produced strain at these stress ratios (0.2-0.6) could cover the actual strain ranges of the pavement. Then, numbers of loading cycles corresponding to the specimen fracture was denoted as the fatigue life of asphalt mixture. Equation (5) represents the regression equations of fatigue life.

$$N_f = k\left(\frac{1}{\sigma}\right)^n \quad \ldots (5)$$

Where $N_f$ is the number of sample subjected to constant stress to failure; $\sigma$ is the applied constant stress amplitude; $k$, $n$ are the test-related parameters.

**Results and Discussion**

**Permanent deformation**

Figure 2 shows the results from the wheel tracking test of the PE modified asphalt mixture with and without RAP. It can be seen that the PE–RAP mixtures performed a greater dynamic stability (DS) than the corresponding virgin mixtures (PEHMA) for all RAP percentages. Moreover, as the RAP content increases, the DS values show a trend of growth. As a higher DS reflects an excellent anti-rutting performance, this result shows that RAP will benefit the high temperature performances. Especially, it can be found that in Fig. 2, all asphalt mixture specimens had final DS values higher than 2000 (cycle/mm), which is the minimum specified in the technical specifications (JTG F40-2004).

**Moisture damage**

The results of the moisture sensitivity of the PE modified asphalt mixture with and without RAP are shown in Figs 3 and 4. RMS results for evaluation of PEHMA in terms of the moisture susceptibility are...
shown in Fig. 3. It can be found that RMS values decrease with RAP increases. Furthermore, all RMS values obtained were greater than 80%, which is the requirement established in the Chinese specifications for HMA. This means the water stability of RAP-PEHMA can be guaranteed.

The freeze-thaw splitting test results for evaluation of the asphalt mixtures in terms of moisture susceptibility are shown in Fig. 4. Similar to residual stability test, it was concluded that adding RAP resulted in a decreased moisture resistance. TSR of the PE-RAP mixtures showed a same trend as the freeze-thaw test results exhibited for the RMS. The TSR values of the RAP-PEHMA investigated passed the 75% minimum specified in the technical specifications (JTG F40-2004).

Low temperature cracking

Results from the bending beam test of all mixtures are shown in Fig. 5. Failure strain results showed that the low temperature cracking resistance is sensitive to RAP dosage. Especially, RAP-PEHMA showed an obvious decrease as compared to the corresponding virgin mixtures (PEHMA) in terms of $\varepsilon_{B}$. This means that the introduction of RAP will cause an increased low temperature cracking potential. Furthermore, it was also found that the $\varepsilon_{B}$ values of RAP-PEHMA could meet the specifications (JTG F40-2004) requirement of $\varepsilon_{B}$ which is 2000 $\mu$e.

Fatigue test

Fatigue resistance was assessed by indirect tensile test. As shown in Fig. 6, the RAP-PEHMA performed lower fatigue resistance than that PE modified mixture produced without RAP at different stress ratios. The fatigue test results indicated RAP caused a negative effect on the fatigue resistance.

It can be found from Fig. 6, the relationship between fatigue life and stress ratio produced an excellent correlation in the logarithmic scale. A fatigue equation for RAP-PEHMA has been plotted for comparison with that of control mixture in this study. The correlation coefficients ($R^2$) of 0.998, 0.999 are an indication that the equation could describe the fatigue laws of tested mixtures. Furthermore, the fatigue life of these mixtures could be estimated according to the fatigue equations at any stress ratios.

Conclusions

The main issue of this study was to evaluate the PE modified asphalt mixture containing reclaimed asphalt pavement (RAP). The results from this study show that the using of RAP in PEHMA has a positive effect on the better rutting resistance and negative effects on the moisture resistance, low temperature cracking resistance and fatigue resistance. The moisture resistance, low temperature cracking resistance and fatigue resistance reduced following RAP dosages, the reasons could be attributable to the fact of RAP may prevent aged bitumen from mixing thoroughly with the new bitumen. Furthermore, the high temperature performance improved because harden and stiffen effect of aged bitumen preventing the deformability of mixture. The evaluation of properties of the RAP-PEHMA analyzed in this study shows that it is possible to use up to 95% RAP content in mix preparation for PE modified mixture.
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References
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