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Study on permanent deformation of asphalt mixtures by single penetration repeated shear test

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Abstract

The problem of asphalt pavement rutting is getting worse, which affects driving safety seriously and reduces pavement life greatly. Through comparative analysis, a single penetration repeated shear test (SPSFT) for a research on asphalt mixture permanent deformation was put forward. Many SPSFT tests on different load levels were did with four kinds of most commonly used asphalt mixtures in the upper and middle layer of asphalt pavements. Some conclusions were the followings: (1) The three-stage permanent deformation behavior of asphalt mixtures on loads could be got by SPSFT. (2) The bigger the load, the faster the permanent deformation of asphalt mixtures increases, and the smaller the fatigue life. (3) Mixtures with modified asphalt had a greater ability resistance to shear deformation than with conventional asphalt. (4) Large load (≥1.3MPa) made the large deformation with not large load cycles and the mixture broke; but the smaller load (≤1.1MPa) got very slow increase of the deformation, which was stably in the second stage of three-stage permanent deformation and didn’t broke. (5) The asphalt mixtures with bigger shear strength had a greater ability resistance to shear deformation. (6) Load stress levels had an equivalence to load cycles.

1. Introduction

The vehicle load is one of the key factors affecting road life. It is generally characterized by the total vehicle weight, axle load or wheel weight and has a permissible value (Yuan, 2009). In recent years, Chinese highways survey showed overload problem was very serious. It has three characteristics of the high degree of overload, the high tire pressure and the high proportion of heavy vehicles (Yin, 2009). With the occurrence of these problems, asphalt pavement rutting deformation is getting more serious, which results in premature failure of the pavement
and greatly affect the driving safety (Zhou et al., 2004). So it is necessary to study permanent deformation of asphalt mixture under different load levels with appropriate test methods before its application.

There are many test methods to study permanent deformation of asphalt mixture, such as mini tread test, large ring road test, large accelerated loading test, creep test, the axial stress test, repeated load permanent deformation test, simple shear test and so on (Du, 2006). A report (Sousa et al., 1991) from SHRP proposed a test method for studying permanent deformation of asphalt mixture should have following features: 1) Asphalt pavement permanent deformation is caused by the mixture shear flow. So the shear stress under load in the specimen should be similarly equal to the stress in pavement. 2) The load should be repeated or dynamic. 3) Mechanical behavior of the deformation can be obtained. 4) Specimens are prepared easily and can be got by coring from the road. 5) Test simple and spend less. Accelerated loading test (Zhou et al., 2004) in North America confirmed permanent deformation of asphalt mixtures are generally divided into three stages (Figure 1): 1) Initial stage is rapid compaction deformation once the load works. 2) The second stage is the stable shear deformation developed by the shear stress. 3) The third stage is the failure stage. The shear deformation exacerbates and shear failure occurs on the road. Therefore whether or not to get the three stages is also an important reference for test choosing (Yuan, 2009).

![Fig. 1. Three-stage permanent deformation curve of asphalt mixture](image)

Triaxial repeated load test use repeated load and apply fixed confining pressure on cylindrical specimens. It investigates the shear resistance of the mix through providing axial pressure force. NCHRP (Cooperative Highway Research Organization) recommended the use triaxial repeated loading tests on asphalt mixture permanent deformation, and elaborate test methods (Witczak, 2002). The Huang Xiaoming research group triaxial repeated load permanent deformation test carried out research, and based on this test mixes bomb sticky plastic - damage mechanics model (Zhang, 2008). In triaxial test, however, not only the stress distribution is different from the actual road surface but cannot determine the size of the side pressure (confining pressure). In pavement structure, material possesses the ability to resist shear, because the bond strength of asphalt, aggregate interlocking force between lateral and peripheral material binding. And the peripheral force changes with asphalt mixtures and load levels (Sun, 2005).

In order to simulate the actual road force state, Bi Yufeng (2004) introduced a new test method - single penetration test. The test simulated the road model under a single round Load a certain size of the cylinder and a certain load is applied on it. Used in the experiment of 28.5mm or 42.0mm in diameter steel pressure head, corresponding to the dimensions of test pieces were $\Phi100mm \times 100mm$ and $\Phi150mm \times 100mm$, pressure head, respectively, and test pieces of the two sets of size applied to the nominal maximum particle diameter of 13.2mm and the 13.2mm above asphalt mixture, loading rate for 1mm/min. Through single penetration test to maximize poured into the pressure, multiplied by the corresponding strength parameters, the shear strength of the asphalt
mixture specimen can be obtained. Compared to other tests, single penetration test has the following characteristics: 1) Force mode of the steel head penetrated into mixture is similar to wheels on the pavement. The maximum shear stress both is similar and the depth is also. 2) As the indenter size is much smaller than the diameter of the specimen, the confining pressure of the force part asphalt is naturally provided by the surrounding mixture and confining pressure change with the load and different mixes constraints not fixed like triaxial test. 3) The test method is easy to operate, need simple equipment, and convenient to use.

The single penetration test can be used to study the permanent deformation of asphalt mixture under repeated shear load. It is called single penetration repeated shear test. Shao Xianzhi (2005) had a research on AC13 gradation asphalt mixture with the single penetration repeated shear test. He got the three-stage permanent deformation and defined the number of load at the exchanging point between the second and third stage fatigue life of asphalt mixture, which was called flow number (FN) in North America. Yuan Jun (2009) also used this test to study AC13 gradation asphalt mixture. She proposed that as load cycles and test temperature raised the permanent deformation of asphalt mixture increased. Actual pavement survey found that the surface layer of asphalt pavement rutting deformation occurs mainly in the upper and middle asphalt layer. The upper and middle asphalt layer of High-grade roads mostly use modified asphalt. Therefore, this paper did some study for several of the most commonly used on the surface layer of asphalt mixture to explore the impact of different load level for permanent deformation of asphalt pavement.

2. Experimental process and result analysis

2.1. Experimental preparation

As surface material, asphalt mixtures are directly under various vehicle loads. So the load level is the most important factor affecting its deformation properties. Therefore, the paper did tests under different load level for permanent deformation of asphalt pavement.

The loads applied on the mixtures are five levels considering the actual road load. Indenter contact pressures were 0.7MPa, 0.9MPa, 1.1MPa, 1.3MPa, 1.5MPa. The rutting mostly occurred in the summer. So test temperature was 60°C. Fig 2 is the test photo.
Have sine wave loading was used and the frequency was 10Hz. Intended load was crest value of the load level and trough value was 0.1MPa prevent indenter void. Before loading was 10 second pre-loading. Load Limit times was set to one million. Types and shear strength of the asphalt mixtures were shown in Table 1. In order to ensure the comparability of the test results, the unified test indenter 42mm in diameter and the specimen size high 100mm, diameter 150mm were prepared

Table 1. 4 types of asphalt mixtures for test

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Grading</th>
<th>Asphalt type</th>
<th>Asphalt aggregate ratio/%</th>
<th>Void/%</th>
<th>Shear stress/MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AC13</td>
<td>SBS modified</td>
<td>4.9</td>
<td>4.1</td>
<td>0.978</td>
</tr>
<tr>
<td>2</td>
<td>AC20</td>
<td>SBS modified</td>
<td>4.3</td>
<td>4.0</td>
<td>1.010</td>
</tr>
<tr>
<td>3</td>
<td>SMA13</td>
<td>SBS modified</td>
<td>6.0</td>
<td>3.6</td>
<td>0.847</td>
</tr>
<tr>
<td>4</td>
<td>AC20</td>
<td>70# conventional</td>
<td>4.4</td>
<td>4.3</td>
<td>0.490</td>
</tr>
</tbody>
</table>

2.2. Test results and analysis

Permanent deformation of Asphalt mixture under different load levels

The four asphalt mixtures under different loads shear deformation along with an increase in the number of loads of variation were shown in Figure 3 to 6.
Some test results were got from Fig 3 to 6.

(1) Four different types of asphalt mixtures all show the full three-stage deformation with single penetration repeated shear test, when load level was bigger and load time was longer.
(2) Load level was very significant for permanent deformation of asphalt mixtures. The shear deformation increased with load level at the same number of load times. For the three mixtures with SBS modified asphalt, if the load $P \leq 1.1\text{MPa}$ deformation increased slightly and was stable in the second phase of the shear deformation with the times increasing; if the load $P \geq 1.3\text{MPa}$ the deformation had the full three stages. Load level was bigger, deformation increased faster. For the mixture with conventional asphalt, at a very small number of load times the deformation got into the third stage and broke.

(3) The type of asphalt used had a great effect on the deformation. For the mixtures with SBS modified asphalt the load times when deformation got into the third stage were above 100,000 at $P=1.5\text{MPa}$. But for the mixture with conventional asphalt the load times were just 3,000.

Relation between shear strength and deformation resistance
Shear strength with single penetration test can well reflect the shear behavior of asphalt mixture (Shao, 2005). Figure 7 is a comparison of deformation of three mixtures with different shear strength at 1.5MPa. Black vertical intersection of the horizontal axis is obtained by linear approximation method the second and third stages of the transition point corresponding to the number of loads. This number of times is the fatigue life of the mix or flow number. At the same number of load times the asphalt mixture with smaller shear strength had bigger shear deformation and the asphalt mixture with bigger shear strength had bigger fatigue life and flow number. Therefore the asphalt mixture with bigger shear strength had a better resistance to deformation.

![Fig. 7. Deformation of 3 types of modified asphalt mixtures on the load of 1.5MPa](image)

Relation between load level and times
Fig 8 to 11 showed the deformation with different load levels at the same number of load times.

![AC13(SBS)](image)
Number of loads and load levels had a combined effect on permanent deformation of asphalt mixtures. The effect with bigger load level and smaller number of loads was the same to the one with smaller load level and bigger number of loads. It is called equivalent.
3. Conclusions

The single penetration test is a very reasonable testing method of evaluate asphalt mixture shear resistance because it well simulate wheels load on actual roads. A test that repeated load was applied to the indenter can study the permanent deformation of asphalt mixture under shear stress. It was called single penetration repeated shear test.

The rutting occurred mainly in the upper and middle asphalt layer. The paper did the study on the mostly used four kinds of asphalt mixtures with single penetration repeated shear test. The conclusions obtained are as follow:

1. The three-stage permanent deformation behavior of asphalt mixtures on loads could be got by single penetration repeated shear test.
2. The bigger the load was, the faster permanent deformation of asphalt mixtures increased and the smaller the fatigue life was.
3. Mixtures with modified asphalt had a greater ability resistance to shear deformation than with conventional asphalt.
4. Large load (≥1.3MPa) made the large deformation with not large load cycles and the mixture broke; but the smaller load (≤1.1MPa) got very slow increase of the deformation, which was stably in the second stage of three-stage permanent deformation and didn’t broke.
5. The asphalt mixtures with bigger shear strength had a greater ability resistance to shear deformation.
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