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Research on interfacial shear characteristics of crumb rubber modified asphalt concrete bridge deck pavement structure

WANG Lan, WU Zhi-yang*, HUANG Wen-bin

College of Civil Engineering, Inner Mongolia University of Technology, Hohhot 010051, China

Abstract

The interfacial shear characteristics and the influence of overloading on the structure of SBS (styrene-butadiene-styrene) and crumb modified asphalt bridge deck pavements are studied in this paper. Crumb rubber modified asphalt bridge deck pavement is applicable to Inner Mongolia cold regions. These pavements are evaluated through the indoor asphalt concrete bridge deck pavement interfacial shear contrast test. The results indicate that for the interfacial shear strength between asphalt pavement structure of lower layer and concrete bridge deck pavement, the strength of SBS modified asphalt pavement is slightly greater than the crumb rubber modified asphalt pavement. For the interfacial shear strength between asphalt pavement structure of upper layer and lower layer, the strength of crumb rubber modified asphalt pavement under the overload less than 50% is slightly greater than SBS modified asphalt pavement shear strength. The interfacial shear strength between the lower layer and the concrete bridge deck pavement of two kinds of modified asphalt pavement structure is less than the interfacial shear strength between the upper layer and the lower layer. The interfacial shear deformation of crumb rubber modified asphalt is greater, and the interfacial shear deformation between the lower layer and the concrete bridge deck pavement of two kinds of modified asphalt pavement structure is less than the interfacial shear deformation between the upper layer and the lower layer under the vertical stress less than 1.05MPa. Finally, the shear stress of crumb rubber modified asphalt concrete bridge deck pavement structure under the standard load is calculated by the finite element software ABAQUS. Comparing and analyzing the experimental results shows that the bridge deck pavement meets the shear requirements.

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Keywords: bridge deck pavement; interfacial shear; SBS modified asphalt; crumb rubber modified asphalt;

1. Introduction

* Corresponding author.
E-mail address: 916530571@qq.com
The vehicle load is one of the key factors to affect the service life of the bridge deck pavement. In the recent years, the number of heavy-duty vehicles has increased significantly, the axle load from the rated 100KN has increased to more than 180KN and the tire inflation pressure from 0.7 MPa has increased to more than 1.1MPa, which brings a severe test to asphalt concrete bridge deck pavement. How to analysis of the asphalt pavement layer bearing capacity accurately and prolong its service life has the obviously technical and economic significance. Using the crumb rubber modified asphalt for bridge deck pavement can enhance the pavement performance in the low temperature and the interfacial bonding properties, while the waste was utilized to reduce the black pollution, which have great economic and social benefits for the development of recycling economy and protecting the environment[1]. According to the crumb rubber modified asphalt deck pavement which is applicable to Inner Mongolia cold regions, the interfacial shear strength on pavement structure of crumb rubber modified asphalt pavement and SBS modified asphalt pavement which are in the same ratio is studied by the interfacial shear contrast test.

2. The Interfacial Shear Experiment of Bridge Deck Pavement Structure

The interfacial shear strength of asphalt concrete bridge deck pavement structure consists of two parts[2], one part is from the interfacial adhesive, the other part is from the interfacial material surface roughness of friction.

2.1. Introduction to the shear experimental apparatus and the experiment

Homemade instrument used in the experiment is shown in Figure 1, the instrument is composed mainly by the upper and lower sets of fixtures, horizontal force and vertical force were applied through two pairs of proving rings, the shear deformation was tested by centigrade meter which was placed in the center of the upper fixture and on the shear direction. The appropriate proving rings were selected by the trial desired vertical pressure and the shear strength and installed in two directions. The vertical pressure was applied first, then a horizontal force was applied to the speed in 1mm/min, and different horizontal shear force and the corresponding horizontal displacement were recorded.

Fig. 1. The experimental apparatus for shear

2.2. Specimen preparation

For the simulation of the real bridge deck pavement[3], two interfaces of two kinds of modified asphalt bridge deck pavement are the interface of coarse asphalt mixture pavement layer (AC - 20) with concrete bridge deck and the interface of medium-grained asphalt mixture pavement (AC - 16) with coarse modified asphalt mixture pavement (AC - 20), the ratio of two kinds of modified asphalt mixture is the same. The concrete deck layer is
made of the concrete specimens, the surface of the concrete specimens need to be cleared the laitance, napped, cleaned and brushed waterproof adhesive layer, then they are paved modified asphalt mixture and shaped by Marshall compaction method\cite{4}, the specimens' diameter are 101.6 mm. Figure 2 is forming two interfaces of composite specimens.

![Fig. 2. The two interfaces of composite specimens](image)

2.3. Experimental program

Research shows that\cite{5} the interfacial shear strength has great relationships with the temperature at the test, the vertical load and the shear speed, the higher the temperature is, the lower shear strength is; The greater the vertical load is, the greater the shear strength is; The faster the shear speed is, the greater the shear strength is. Asphalt was used as bonding material for interfacial treatment, which is a kind of viscoelastic material, the stiffness modulus has relationships with the loading time and the temperature, thus the temperature and loading speed should be controlled strictly in the experiment.

Test temperature was room temperature, the vertical stresses were taken as followed: 0MPa, 0.70MPa, 1.05MPa and 1.4MPa, 1.75MPa and 2.1MPa, which were no vertical load, the standard vertical load, overload 50%, 100%, 150% and 200% than the standard vertical load. The horizontal load was applied in the speed of 1mm/min, the maximum horizontal load after the specimen damaged as the shear force and each displacement before the loading were recorded to calculate the shear strength and deformation.

3. Analysis of Experimental Results

Calculation of interfacial shear stress is according to the formula below:

$$T = \frac{Q}{A_s} \quad (1)$$

In the formula: $T$ is the interfacial shear stress, unit M Pa; $Q$ is the maximum horizontal shear, unit KN; $A_s$ is the shear area, unit $m^2$.

3.1. The influence of pavement materials on the interfacial shear strength

Figure 3 is the interfacial shear stress and deformation under the vertical pressure curve of two kinds of modified asphalt pavement and concrete deck. As can be seen, the interfacial shear stress increases with the increasing of the vertical pressure, and the values of SBS modified asphalt pavement are slightly greater than the
crumb rubber modified asphalt pavement; The shear deformation of crumb rubber modified asphalt pavement structure is greater than the value of SBS modified asphalt pavement with the increasing of the vertical pressure; The interfacial shear stress of SBS modified asphalt pavement and concrete bridge deck under no vertical compressive stress is 0.74MPa, and the interfacial shear stress of crumb rubber modified asphalt pavement and concrete bridge deck under no vertical compressive stress is 0.69MPa, and the interfacial shear strength under no vertical compressive stress mainly is due to the interfacial adhesive strength. Therefore, through the above test analysis, it shows that the interfacial shear of SBS modified asphalt pavement structure and the concrete bridge deck is greater than the crumb rubber modified asphalt pavement structure, which mainly is due to that the bonding performance between SBS modified asphalt pavement and concrete bridge deck is better.

Fig. 3. The interfacial shear stress and deformation curve of pavement and concrete bridge deck

Fig. 4. The interfacial shear stress and deformation curve of upper layer pavement and lower layer pavement
Figure 4 is the upper layer and the lower layer interfacial shear stress and deformation under the vertical pressure curve of two kinds of modified asphalt pavement structure. As can be seen, the interfacial shear stress of crumb rubber modified asphalt pavement structure is slightly greater than the value of SBS modified asphalt pavement structure in the vertical compressive stress of no more than 1.05MPa, and the shear deformation of the crumb rubber modified asphalt pavement structure is greater than the value of SBS modified asphalt pavement. Through the interfacial bond-slip theory \cite{6} can be known that the upper layer and the lower layer interfacial shear failure of crumb rubber modified asphalt pavement structure more tends to slip failure, and the upper layer and the lower layer interfacial shear failure deformation of SBS modified asphalt pavement structure is smaller, thus the upper layer and the lower layer interfacial shear failure of SBS modified asphalt pavement structure more tends to bond failure.

From figure 3 and figure 4 contrast can be seen, two interfaces’ interfacial shear strength of two kinds of modified asphalt pavement increase along with the vertical force, but the interfacial shear strength between two kinds of modified asphalt pavement and concrete bridge deck are less than the value of two kinds of modified asphalt pavement structure between upper layer and the lower layer, and when the vertical stress is less than 1.05MPa, the interfacial shear deformation between two kinds of modified asphalt pavement and concrete bridge deck is less than the value of two kinds of modified asphalt pavement structure between the upper layer and lower layer. This is because that the asphalt pavement and concrete bridge deck bonding performance is not as good as the bonding performance between the upper layer pavement and the lower layer pavement, and the latter more tends to bond failure. By the interfacial shear deformation, it can be known that the interlayer between the asphalt pavement and concrete bridge deck in the small deformation will occur shear failure. Therefore, the treatment of cement concrete bridge deck surface and choice of waterproof adhesive layer’s materials in the construction should be noted.

3.2. The influence of vertical pressure on the interfacial shear strength

Figure 5 is the modified asphalt pavement and concrete bridge deck interfacial shear stress under the vertical pressure contrast curve of two kinds of modified asphalt concrete bridge deck pavement. The linear regression can be seen, the interfacial shear stress curve of the SBS modified asphalt pavement and concrete bridge deck is linear under the vertical compressive stress and the correlation is 0.9729, the interfacial shear stress curve of the crumb rubber modified asphalt pavement and concrete bridge deck is also linear under the vertical compressive stress and the correlation is 0.9756, the vertical loads with shear stresses show a good linear relationship between them. According to Coulomb-Moor’s law, the shear strength of material consists friction resistance and cohesive force two parts, the friction resistance is proportional to the normal force which vertically acts on the shear plane, the cohesive force is intrinsic material properties, so it can be plotted into curves in different vertical stress with the material shear strength, and in a certain range it can be approximated using a straight line representation, and the intercept is the cohesion \cite{7}. The linear regression formula of SBS modified asphalt pavement and concrete bridge deck interfacial shear stress curve can be obtained:

\[
ys = 0.2354xs + 0.5127
\]

(2)

In the formula: \(ys\) is interfacial shear stress, \(xs\) is the vertical stress, SBS modified asphalt pavement and concrete bridge deck cohesion is 0.5127MPa; The same to the linear regression formula of crumb rubber modified asphalt pavement and concrete bridge deck interfacial shear stress curve can be obtained:

\[
yj = 0.2166xj + 0.4553
\]

(3)

In the formula: \(yj\) is interfacial shear stress, \(xj\) is the vertical stress, crumb rubber modified asphalt pavement and concrete bridge deck cohesion is 0.455 MPa, therefore, as can be seen, the SBS modified asphalt pavement and concrete bridge deck interfacial bonding performance is slightly better than the crumb rubber modified asphalt concrete bridge deck pavement.
Figure 6 is the upper layer and the lower layer interfacial shear stress under the vertical pressure contrast curve of two kinds of modified asphalt concrete bridge deck pavement. As can be seen, when the vertical compressive stress is among 0 Mpa to 0.7 Mpa, the upper layer and the lower layer interfacial shear stress with vertical compressive stress is linear growth, when the vertical compressive stress is upper than 0.7 Mpa, the interfacial shear stress is nonlinear growth. When the vertical compressive stress is among 0Mpa to 0.7 Mpa, the data correlation of two kinds of material’s linear regression analysis is very good, when it is upper than 0.7 Mpa, the interfacial shear stress of crumb rubber modified asphalt pavement changed into a slowdown trend growth curve, but the interfacial shear stress of SBS modified asphalt pavement continues to rapid growth trend and the values are greater than the crumb rubber modified asphalt pavement interfacial shear stress. It indicates that: In the heavy-load situations, the upper layer and lower layer interfacial shear performance of SBS modified asphalt pavement structure is slightly better than the crumb rubber modified asphalt pavement structure, which dues to that SBS modified asphalt waterproof adhesive layer combination with isotropic SBS modified asphalt pavement structure again under the large vertical force making the interface bonding closer and increasing the interfacial frictional resistance; In the cases of normal load and overload less than 50%, the interfacial shear performance between the upper layer and the lower layer of crumb rubber modified asphalt pavement structure is better than the SBS modified asphalt pavement structure, this is because that the interfacial shear strength under no vertical load of crumb rubber modified asphalt pavement structure is greater, namely the interfacial cohesive force is greater.

4. Finite Element Analysis of the Interfacial Shear Characteristics of Crumb Rubber Modified Asphalt Concrete Bridge Deck Pavement Structure

The paper did the finite element analysis for interfacial shear characteristics of the crumb rubber modified asphalt concrete bridge deck pavement [14][15] which was applicable to Inner Mongolia cold regions. Assuming the asphalt concrete bridge deck pavement between the upper layer and lower layer was completely continuous and between the lower layer and the hollow concrete deck was also completely continuous. To analysis shear stress characteristics with span respectively in 13 meters, 16 meters, 20 meters of simply supported hollow slab bridge under the loads, and the bridge deck as an elastic three-layer system was simplified, the first layer of pavement was crumb rubber modified asphalt upper layer, the second layer of pavement was crumb rubber modified asphalt lower layer and the third layer was reinforced concrete hollow slab. The contact relationship of the upper layer
pavement and lower layer pavement was surface-to-surface contact, the upper layer was the main surface and the lower layer was the following surface. The lower layer and the bridge deck is also the surface-to-surface contact, the bridge deck was the following surface and lower layer was the main surface. The standard axle load and the horizontal braking force were used in loading. The material parameters of structure layer are shown in Table 1.

Table 1. The table of structure layer material parameters

<table>
<thead>
<tr>
<th>Structure Layer</th>
<th>Structure Layer Thickness (cm)</th>
<th>Modulus of Elasticity (M Pa)</th>
<th>Poisson's Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavement structure of upper layer</td>
<td>4</td>
<td>2000</td>
<td>0.3</td>
</tr>
<tr>
<td>Pavement structure of lower layer</td>
<td>5</td>
<td>2500</td>
<td>0.3</td>
</tr>
<tr>
<td>Hollow concrete board</td>
<td>75 / 85/ 95</td>
<td>34500</td>
<td>0.17</td>
</tr>
</tbody>
</table>

In the loading and calculating model, the vertical load and horizontal load were both taken into account, the loading area was $0.2 \times 0.6 \, \text{m}^2$, and the emergency brake coefficient of friction $f = 0.8$ was selected. The vertical load was taken $0.7 \, \text{Mpa}$, the horizontal load at maximum braking force was taken $0.5 \, \text{Mpa}$. Loading position along the longitudinal bridge respectively in $L/2$, $3L/8$, $L/4$ and $L/8$, fulcrum place were arranged with load position 1, load position 2, load position 3 and load position 4, load position 5; In the transverse direction of the bridge were respectively arranged with load position 6, load position 7, load position 8 and load position 9 which were starting from the edge of 0.5m and moving at 1m step to the middle of the bridge. Load location layout plan is shown in figure 7.

By calculating and analyzing the most unfavorable position of shear stress, it was the bearing namely was the load position 5, in load position 8 and 9 which were perpendicular to the direction of the most unfavorable longitudinal position 5 were loaded to determine the most unfavorable shear stress of transverse position. The calculated results of maximum interfacial shear stress are listed in table 2 and table 3.
Table 2. The transverse shear stress of asphalt concrete bridge deck pavement upper layer

<table>
<thead>
<tr>
<th>Span</th>
<th>13m</th>
<th>16m</th>
<th>20m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load position</td>
<td>$T_{1\text{zmax}}$ MPa</td>
<td>$T_{1\text{zmax}}$ MPa</td>
<td>$T_{1\text{zmax}}$ MPa</td>
</tr>
<tr>
<td>5</td>
<td>0.2945</td>
<td>0.3197</td>
<td>0.3004</td>
</tr>
<tr>
<td>8</td>
<td>0.3063</td>
<td>0.3212</td>
<td>0.3184</td>
</tr>
<tr>
<td>9</td>
<td>0.3125</td>
<td>0.3268</td>
<td>0.3193</td>
</tr>
</tbody>
</table>

Table 3. The transverse shear stress of asphalt concrete bridge deck pavement lower layer

<table>
<thead>
<tr>
<th>Span</th>
<th>13m</th>
<th>16m</th>
<th>20m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load position</td>
<td>$T_{2\text{zmax}}$ MPa</td>
<td>$T_{2\text{zmax}}$ MPa</td>
<td>$T_{2\text{zmax}}$ MPa</td>
</tr>
<tr>
<td>5</td>
<td>0.1352</td>
<td>0.1315</td>
<td>0.1308</td>
</tr>
<tr>
<td>8</td>
<td>0.1363</td>
<td>0.1321</td>
<td>0.1324</td>
</tr>
<tr>
<td>9</td>
<td>0.1425</td>
<td>0.1386</td>
<td>0.1393</td>
</tr>
</tbody>
</table>

$T_{1\text{zmax}}$ - The maximum longitudinal shear stress of upper layer pavement
$T_{2\text{zmax}}$ - The maximum longitudinal shear stress of lower layer pavement

From the table 2 can be seen, among the three spans, the interfacial shear stress under the standard load between the crumb rubber modified asphalt upper layer pavement and lower layer pavement of simply supported hollow slab bridge with 16m span in the load position 9 is maximum, and it is 0.3268MPa less than the interfacial shear strength of 1.45MPa in the experiment; From the table 3 can be seen, among the three spans, the interfacial shear stress under the standard load between the crumb rubber modified asphalt pavement and the concrete bridge deck of simply supported hollow slab with 13m span in the load position 9 is maximum, and it is 0.1425MPa less than the interfacial shear strength of 0.95MPa in the experiment, it indicates that the crumb rubber modified asphalt concrete pavement structure under the standard load won’t appear interfacial shear failure.

5. Conclusions

According to the crumb rubber modified asphalt and the SBS modified asphalt, two kinds of modified asphalt concrete bridge deck pavement interfacial shear strength were tested and researched, and various working conditions of the interfacial stress and deformation were analyzed, mainly get the following conclusions:

1. The interfacial cohesion value of SBS modified asphalt pavement and the concrete bridge deck is greater than crumb rubber modified asphalt pavement; The interfacial shear stress of bridge deck pavement structure increases with the increasing of vertical compressive stress and it shows a good linear relationship between them; In different range of compressive stress, the interfacial shear stress is influenced by different mainly factors.

2. In the cases of standard load and overload less than 50 %, the interfacial shear strength of crumb rubber modified asphalt pavement structure is greater than the value of SBS modified asphalt pavement structure; The interfacial shear stress between two kinds of modified asphalt pavement and concrete bridge deck is less than the value of two kinds of modified asphalt between the upper layer pavement and the lower layer pavement, when the vertical stress is less than 1.05MPa, the interlayer between asphalt pavement and concrete bridge deck in the small deformation will occur shear failure, therefore, the treatment of cement concrete bridge deck surface and choices of waterproof adhesive layer’s materials in the construction should be noted.
3. The analyzed results of finite element software are compared with experimental results, it indicates that crumb rubber modified asphalt concrete pavement structure won't appear interfacial shear failure under the standard load, which further verifies the applicability of crumb rubber modified asphalt deck pavement and provides the basis for the choice of bridge deck pavement materials.

References