Study on fatigue self-healing properties of basalt fiber asphalt mixture

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Abstract: Asphalt concrete pavement will age gradually and produce fatigue damage under the repeated load and environment. Under the repeated action of driving load and the continuous influence of external environment, it will gradually age and produce fatigue damage. It is found that the asphalt mixture has self-healing characteristics, and it is of positive significance to improve the service life of asphalt pavement by giving full play to the self-healing characteristics of asphalt mixture. With the extensive application of basalt fiber asphalt mixture, its self-healing characteristics have become an urgent problem to be studied. In this paper, according to the four-point bending fatigue test of basalt asphalt mixture, the slope ratio of fatigue curve is selected as the recovery. The effects of basalt fiber asphalt mixture on its self-healing ability under three factors, such as damage degree, healing time and healing temperature, were analyzed by orthogonal test, and compared with matrix asphalt mixture and SBS modified asphalt mixture. The results showed that the self healing capacity of asphalt mixture was inversely proportional to the damage degree and time. When the damage degree is more than 50%, the healing performance of the matrix asphalt mixture decreases obviously, and the SBS modified asphalt mixture almost does not heal, while the healing performance of the basalt fiber asphalt mixture is the best.

1. Overview

The asphalt mixture has some self-healing characteristics, but the traditional asphalt pavement research mostly ignores the performance of the asphalt mixture. The self-healing test results of Qiu show that the healing ability of asphalt concrete depends on the healing time and temperature. Huang Weidong et al, through the four-point bending fatigue test controlled by strain, shows that the immediate self-healing of asphalt mixture is accompanied by loading, and temperature, load and time play a positive role in the healing ability of asphalt mixture. And the degree of injury played a certain reverse effect.

The existing asphalt mixture self-healing research is based on the matrix asphalt, and the commonly used fiber asphalt mixture research is less. In this paper, the self-healing performance of basalt road fiber asphalt mixture with stable chemical property, natural environmental protection and low price is studied systematically. From the point of view of composite material, the self-healing property of basalt fiber asphalt mixture was studied by combining the anti-cracking characteristic of basalt fiber material with the self-healing property of asphalt material.

2. General situation of test

The effects of three factors on self-healing properties of basalt fiber asphalt mixture were investigated by using AASHTO T321 experimental standard for strain-controlled four-point bending experiments. The effects of three factors on self-healing properties of basalt fiber asphalt
mixture were investigated by three factors: rest time (2h, 4h, 6h), healing temperature (15°C, 35°C, 55°C) and degree of injury (30%, 50%, 70%).

2.1 Design and molding of asphalt mixtures

The test was carried out with 0 ~ 3 mm ~ 3 mm ~ 5 mm ~ 10 ~ 20 mm basalt gravel and limestone ore powder. According to the construction technical specification of JTGF40-2004 highway asphalt pavement, the median value of composite AC-16 gradation of block aggregate is selected as test gradation. The design and matching of asphalt mixture are as follows:

| Mesh size /mm | 26.5 | 19 | 16 | 13.2 | 9.5 | 4.75 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 |
|---------------|------|----|----|------|-----|------|------|------|-----|-----|------|------|
| Throughput rate /% | 100 | 100 | 95 | 86 | 76 | 50 | 31 | 24 | 18 | 12 | 8 | 4 |

The modified asphalt with A grade 90# road asphalt and SBS modifier content of 4.5% is used in the test. The basalt fiber index is shown in Table 2-2. The basalt fiber mixture with 0.3% mass fraction is mixed into the matrix asphalt mixture by dry mixing method to make basalt fiber mixture. The results of Marshall test show that the base asphalt and basalt fiber asphalt mixture are 4.5 and 4.6 SBS modified asphalt mixture is 4.8. The mixture is formed by the shear compaction instrument produced by ASC, Italy. The bulk volume density is chosen as the control index. Cutting the shearing compaction plate with a large cutting machine 380mm × 63.5mm × 50mm trabecular specimen. Before fatigue test, the temperature of each specimen should be kept above 4 hours in the incubator to ensure that the temperature will not affect the test.

2.2 Experimental programme

| Index | Test value |
|-------|------------|
| Fibre length (mm) | 6 |
| Diameter (μm) | 10~13 |
| Relative density (g/cm³) | 2.7 |
| Break strength (Mpa) | 3200 |
| Modulus of elasticity (Gpa) | 8.6 |
| Elongation at break (%) | 2.5~2.8 |

In order to investigate the self-healing performance of basalt fiber asphalt mixture and matrix SBS modified asphalt mixture under healing time, healing temperature and different damage degree, 27 trabecular specimens were prepared. Among them, 9 groups of AC-16C matrix asphalt mixture and 9 groups of SBS modified asphalt mixture were prepared by 90# base asphalt, and 9 groups of basalt fiber asphalt mixture. There are 3 parallel specimens in each group, using the "fatigue healing again fatigue" test method. The degree of damage is defined as \( \left( 1 - \frac{\text{Residual stiffness modulus}}{\text{Initial stiffness modulus}} \right) \times 100\% \).

When the residual modulus of stiffness reaches a preset percentage, the first fatigue test is completed, the rest period is entered, the differential healing temperature and time are set, and the second fatigue test stage is reached after healing. The degree of damage is reduced again to the first test, that is, damage, the end of the test. The orthogonal test was used to explore the influence of various factors on the self-healing performance of the mixture. The orthogonal table is as follows:

| List | Time (h) | Degree of injury (%) | Healing temperature (°C) |
|------|----------|----------------------|-------------------------|

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2.3 Determination of evaluation indicators for healing

In order to accurately study the self-healing ability of asphalt mixture, it is necessary to determine a reasonable evaluation index.

Wang Haopeng and Yang Jun of Southeast University put forward a new evaluation index: damage rate $D$ (damage), formula is as follows:

$$D = \frac{S_0 - S_t}{t}$$

Where $D$ is the proportion of damage that reaches a predetermined degree of damage, $S_0$ as the initial stiffness modulus, $S_t$ as the modulus of stiffness for termination, $T$ is the time required to change the modulus of stiffness from $S_0$ to $S_t$.

The damage rate is the inclination of the drawn fatigue curve, and each fatigue curve represents the fatigue performance of a bituminous mixture. After the analysis of the difference of the fatigue curve of the mixture before and after the healing, it can be more intuitively and accurately evaluated the influence of different factors on the asphalt mixture. Therefore, the ratio of damage rate $HI_D$ is chosen as the index to evaluate the healing ability of the mixture.

$$HI_D = \frac{D_{\text{before}}}{D_{\text{after}}} \times 100\%$$

The advantage of the ratio of damage rate to stiffness modulus is that the ratio of damage rate can be used to characterize the self-healing performance of asphalt mixture by comparing the slope of fatigue curve. The fatigue curve can counteract the change of stiffness modulus, such as temperature, which does not belong to structural damage, thus more accurately characterizing the self-healing performance of the mixture. $HI_D$ is close to 1 and two healing fatigue curve closer, better healing properties.

3. Experimental results and analysis

3.1 Results and analysis of orthogonal experiment on self-healing of basalt fiber asphalt mixture

| Test code | Time(s) | Number of times | Initial schedule modulus(Pa) | Termination stiffness modulus(Pa) | Damage rate | Healing index |
|-----------|---------|----------------|-----------------------------|----------------------------------|-------------|--------------|
| 1         | 747     | 7470           | 7843                        | 5490                              | 3.15        | 71.00%       |
| 1         | 530     | 5300           | 7838                        | 5487                              | 4.44        |              |
| 2         | 2994    | 29940          | 6964                        | 3482                              | 1.16        | 66.14%       |
Range Analysis is the most commonly used method in orthogonal analysis. The effects of various factors on the experimental results are analyzed by calculating $K_i$, $\overline{K}_i$, $R$. The detailed calculation process is as follows:

$K_i$: represents the sum of the test results corresponding to any column with a horizontal number $I$ ($I = 1/2$ or 3).

$\overline{K}_i$: Represents the average of the test results obtained from a given level of factors in a particular column.

$R$: called extreme difference, on any column as $R = \max\{K_1, K_2, K_3\} - \min\{K_1, K_2, K_3\}$.

According to the magnitude of range $R$, the influence of various factors on the test index can be judged. The larger the $R$ value and the greater the $R$ value, the greater the influence on the index. The more important the factor is, the smaller the $R$ value is. In this experiment, the result is evaluated by the healing rate, so the bigger the test index, the better the experimental effect. The results of the range analysis are as follows:

| Time | Degree of injury | Healing temperature | Error |
|------|-----------------|---------------------|-------|
| K1   | 1.78            | 2.97                | 1.58  | 1.78 |
| K2   | 2.03            | 1.85                | 2.13  | 2.08 |
| K3   | 2.17            | 1.16                | 2.27  | 2.12 |
| K1'  | 0.59            | 0.99                | 0.53  | 0.59 |
| K2'  | 0.68            | 0.62                | 0.71  | 0.69 |
| K3'  | 0.72            | 0.39                | 0.76  | 0.71 |
| range R | 0.13        | 0.60                | 0.23  | 0.11 |

The range $R$ in Table 3-2 shows that among the three factors affecting the self-healing performance of basalt fiber mixture, the degree of damage is $>$ the healing temperature $>$ the time. The self-healing behavior of asphalt mixture is essentially the recovery of cracks after stopping the repeated load, and
the greater the damage degree is, the more the number of loads is, the larger the internal cracks are. The healing temperature and healing time are both the means to enhance the recovery of cracks, so the effect on the healing rate is not as significant as the degree of injury.

3.2 Comparison and Analysis of Self-Healing performance of Basalt Fiber modified SBS and Matrix Asphalt mixture

In order to determine the effect of fiber addition on the self-healing of asphalt mixture, the preparation of SBS modified asphalt mixture was carried out under the same conditions. The final results are as follows:

| Test number | Experimental factor | Bear fruit |
|-------------|---------------------|------------|
|             | time(h) | level(%) | temperature (°C) | AC | BF | SBS |
| 1           | 1 (2h)  | 1 (30%)  | 1 (15°C)         | 0.74 | 0.71 | 0.73 |
| 2           | 1       | 2 (50%)  | 2 (35°C)         | 0.90 | 0.62 | 0.14 |
| 3           | 1       | 3 (70%)  | 3 (55°C)         | 0.36 | 0.45 | 0.17 |
| 4           | 2 (4h)  | 1       | 2                | 0.86 | 1.09 | 1.1 |
| 5           | 2       | 2       | 3                | 0.93 | 0.65 | 0.07 |
| 6           | 2       | 3       | 1                | 0.19 | 0.29 | 0.06 |
| 7           | 3 (6h)  | 1       | 3                | 0.94 | 1.17 | 1.08 |
| 8           | 3       | 2       | 1                | 0.60 | 0.58 | 0.22 |
| 9           | 3       | 3       | 2                | 0.22 | 0.42 | 0.05 |

Note: AC represents matrix asphalt mixture and BF represents basalt fiber asphalt mixture. SBS represents SBS modified asphalt mixture.

Test results analysis:

In this paper, the effects of 9 conditions (2h, 4h, 6h), damage degree (30%, 50%, 70%), healing temperature (15, 35, 55) on the self healing of SBS modified asphalt, matrix bitumen and basalt fiber asphalt mixture are investigated. The results are as follows:

The main results are as follows:

(1) The healing rate of SBS modified asphalt mixture and basalt fiber asphalt mixture is higher than 100 under condition 4 and 7, which indicates the fatigue performance of SBS modified asphalt mixture and basalt fiber asphalt mixture after healing under certain conditions. Will pass before healing. According to some research results of fatigue characteristics of metal materials, after a certain number of loads are used (but at the same time below the upper limit), after resting for a period of time, when the loading cycle begins again, Compared with the previous fatigue test, the remaining fatigue life of the fatigue life has been greatly improved, this phenomenon is called "exercise effect". Asphalt mixing Material is also a kind of material, some properties are similar to metal materials, so we can use "exercise effect" to explain the phenomenon that the fatigue ability after healing exceeds that before healing.

(2) The base asphalt mixture has the best healing performance under the experimental condition of 2: 5%, which indicates that the self-healing performance of the matrix asphalt mixture is better than that of SBS modified asphalt in the damage degree of 30% or 50%. Both basalt fiber modified asphalt and basalt fiber modified asphalt are higher than base asphalt in terms of fatigue resistance. However, the healing performance of the base asphalt mixture is inferior to that of the base asphalt mixture when the fatigue test recommends 50% damage degree. This is because SBS modified asphalt mixture is a mixed system, SBS modifier can not be completely dissolved in asphalt, it can only use some kind of asphalt. The size of the particles is mixed in the asphalt. As a kind of fiber modifier, basalt fiber is reinforced by "bridging" a kind of heterogeneous disorderly structure in the mixing process to form a
three-dimensional network structure between the aggregate of the mixture to enhance the performance of the mixture. On the one hand, these reinforcements enhance the performance of asphalt mixture in various ways, on the other hand, they change the structure of asphalt mixture. When 50% fatigue damage occurs, the internal crack of asphalt mixture has already begun to expand, and the macroscopic crack has already begun to appear. Through the above mechanism analysis, we can know that the corresponding modification of SBS modified asphalt in healing process. The agent reduces the normal movement of the bitumen molecules, and the basalt fiber fibers in the middle of the mixture will also affect the movement of the bitumen molecules, which will cause the bitumen's mobility not to be completely carried out and the cracks are reduced to the matrix bitumen mixture. Therefore, the healing performance of SBS modified asphalt and basalt fiber asphalt is relatively poor.

3) The best self-healing test of basalt fiber asphalt mixture is No. 3, 6, 9. The common point of these tests is that the degree of damage is large (70%), and the fatigue damage of asphalt mixture has a critical point, and when the damage does not exceed the critical point, it shows microscopic damage. When the critical point is beyond the critical point, the micro cracks begin to penetrate each other, forming macroscopic cracks, and the damage degree rises to 70. When the three kinds of asphalt mixture appear cracks, but the basalt fiber asphalt mixture cracks are small. This is because the basalt fiber is mixed with asphalt mixture to form a random three-phase spatial network structure. Under the action of external force, the internal crack began to develop. The crack will be blocked by a large number of fibers in the developing stage, and the further crack propagation will be restrained, thus improving the self-healing ability of basalt fiber asphalt mixture.

4. Conclusion
The main results are as follows:
1) Among the three factors affecting the self-healing performance of basalt fiber mixture, the degree of damage is > the healing temperature > the time. The healing temperature has a positive effect and the degree of injury has a negative effect.
2) After the asphalt mixture with strong fatigue properties such as SBS and basalt fiber is subjected to slight damage, the fatigue resistance of asphalt mixture under proper curing conditions is better than that before healing.
3) The healing performance of matrix asphalt mixture is better than that of basalt fiber asphalt mixture and SBS modified asphalt mixture, no matter how the healing temperature changes, when the damage degree is 30% or 50%.
4) When the damage degree is more than 50%, the healing performance of the matrix asphalt mixture decreases obviously, and the SBS modified asphalt mixture almost does not, and the basalt fiber asphalt mixture has the best healing performance.

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