Low Temperature Crack Resistance and Fatigue Properties of Asphalt Mixture with Pre-buried Heat Conduction Tube

Chuanyi Zhuang, Xiaotong Zhao* and Yali Ye
School of Transportation and Civil Engineering, Shandong Jiaotong University, Jinan, Shandong, China
Email: 289580166@qq.com; tong22aichen@vip.qq.com

Abstract. In order to study the effect of geothermal heat transfer tube on the asphalt pavement performance, a heat transfer tube with a diameter of 8 mm was used, which was placed in an AC-16 hot mix asphalt mixture and crushed into a ruthenium plate test piece, using MTS-810 hydraulic servo test. The system evaluates the low temperature crack resistance and fatigue performance, and compares the performance with the asphalt mixture test piece without the heat conduction tube. The results show that after the heat transfer tube is buried, the failure strain of the asphalt mixture is reduced by 40.9%, and the repeated load of the three-point bending fatigue test is reduced by 53.9%. The low temperature crack resistance and fatigue performance are both larger. The degree is reduced.

Keywords. Asphalt Pavement, Buried Heat Transfer Tube Asphalt Mixture, Heat Transfer Tube, Low Temperature Crack Resistance, Fatigue Performance.

1. Introduction
When the asphalt mixture pavement is subjected to repeated effects of heavy traffic and low temperature environment, the pavement will have serious diseases such as fatigue cracking and low temperature cracking. The service life of the pavement will be drastically reduced, and the driving comfort cannot be effectively guaranteed. Therefore, further research is needed on how to further improve the low temperature crack resistance and fatigue performance of asphalt pavement. The low temperature crack resistance and fatigue performance of asphalt mixture have an important influence on the road performance of asphalt mixture.[1] The asphalt mixture has good low temperature crack resistance and fatigue performance. It is the asphalt mixture pavement which can keep the heat conduction tube and asphalt mixed. The composite component composed of the material has good bonding performance, which is the basic premise for ensuring the thermal conductivity of the buried pipe asphalt mixture, the excellent pavement performance and durability. [2]At present, domestic and foreign scholars' research on the pre-buried heat conduction tube for geothermal resource heat conduction automatic snowmelt pavement mainly focuses on the conduction research of geothermal resources and the simulation of temperature field, and the low temperature crack resistance of composite members for heat conduction tube and asphalt mixture. There are few studies on sexual and fatigue performance. Therefore, it is one of the urgent problems to be studied and solved to study the low temperature crack resistance and fatigue performance of buried asphalt mixture.[3]
2. Test Material and Mix Design

2.1. Test Materials
The test used 70-A matrix asphalt, the coarse aggregate was granite gravel, and the fine aggregate was granite mechanical sand and limestone mineral powder. The test results of each material are shown in tables 1-3.

| Test Items                  | Penetration (25 °C, 100 g, 5 s)/(0.1mm) | Softening Point/°C | 15 °C Ductility (cm) | Asphalt density (15 °C)/(g.cm⁻³) |
|-----------------------------|----------------------------------------|--------------------|----------------------|-----------------------------------|
| Results of testing Skills Requirement | 65                                     | 46.5               | 149                  | 0.991                             |

Table 1. 70-A asphalt performance index test results.

| Test Items             | Apparent Density | Water Content/% | Size Range |
|------------------------|------------------|-----------------|------------|
| results of testing     | 2.630            | 0.42            | <0.6mm     |
| skills requirement     | ≥2.5             | ≤1.0            | <0.15mm    |
|                        |                  |                 | ≤0.075mm   |

Table 2. Test results of mineral powder performance indicators.

| Material          | Aggregate | Mineral Powder |
|-------------------|-----------|----------------|
| Apparent relative density | 2.677     | 2.630          |
| Gross volume relative density | 2.638     | -              |

Table 3. Aggregate density test results.

It can be seen from the test results that the materials used in the test meet the requirements of the technical specifications.

2.2. Mix Design
The gradation design of mineral materials is shown in table 4.

| Gradation Range | Screen Pass Rate/% |
|-----------------|--------------------|
| Design Level    | 19 16 13.2 9.5 4.75 2.36 1.18 0.6 0.3 0.15 0.075 |

Table 4. AC-16 mix design.

According to table 4, the optimal grading of AC-16 is determined as follows: (crushed stone 10-16 mm): (crushed stone 5-10 mm): (crushed stone 3-5 mm): (crushed stone 0-3 mm): Mineral powder = 31%: 36%: 5%: 25%.

At the same time, for the mixture AC-16, the estimated oil-stone ratio is 4.8%, and the oil-stone ratio is 3.8%, 4.3%, 5.3% and 5.8%. The volume index and mechanical index test results of Marshall test pieces with different oil-stone ratio AC-16 are shown in table 5.
Table 5. Marshall test results of different oil-stone ratio AC-16 asphalt mixture.

| Whetstone Ratio (%) | Gross Volume Relative Density | Void Ratio (%) | Mineral Gap Rate (%) | Asphalt Saturation (%) | Stability (KN) | Flow Value (mm) |
|---------------------|-------------------------------|----------------|----------------------|------------------------|---------------|----------------|
| 3.8                 | 2.288                         | 5.84           | 15.39                | 59.42                  | 8.18          | 2.93           |
| 4.3                 | 2.306                         | 5.55           | 15.32                | 64.12                  | 9.06          | 3.66           |
| 4.8                 | 2.307                         | 5.45           | 15.07                | 65.27                  | 9.43          | 3.75           |
| 5.3                 | 2.315                         | 4.93           | 14.76                | 68.66                  | 8.79          | 3.33           |
| 5.8                 | 2.342                         | 3.61           | 14.57                | 74.71                  | 9.63          | 4.43           |

Based on the test results, the optimum ratio of oil to stone was determined to be 5.1%.

3. Study on Low Temperature Crack Resistance and Fatigue Properties of Buried Pipe Asphalt Mixture

According to JTG E20-2011, the asphalt mixture is subjected to bending test. The prism beam is 250 mm±2.0 mm, width 30 mm±2.0 mm and height 35 mm±2.0 mm. The trabe test piece is made of 300 mm*300 mm*50 mm rut plate. The test piece is cut. [4]

3.1. Study on Low Temperature Crack Resistance of Buried Pipe Asphalt Mixture

3.1.1. Test Method. The low-temperature crack resistance of buried asphalt mixture was evaluated by trabe low-temperature bending test. The low-temperature bending test of -10 °C for AC-16 unburied asphalt mixture girders and buried pipe asphalt mixture was tested by MTS-810. The three-point bending test was carried out with a midpoint, and the loading frequency was 0.5 cm/min.[5]

3.1.2. Test Results. The test results are shown in table 6.

Table 6. Results of low temperature crack resistance test.

| Mixing Type                        | Inter-Span Deflection d (mm) | Maximum Load at Failure/N | Maximum Bending Strain | Bending Stiffness Modulus (MPa) |
|------------------------------------|-----------------------------|---------------------------|------------------------|--------------------------------|
| Unburied heat transfer tube asphalt mixture | 0.345                       | 417.8                     | 1159.2                 | 3674.94                       |
| Buried heat conduction tube asphalt mixture | 0.204                       | 350.1                     | 685.44                 | 5208.33                       |

It can be seen from table 6 that the average mid-span deflection of the pre-buried heat transfer tube specimen is 0.204 mm, the average maximum load at the time of failure is 350.1 N, and the average mid-span deflection of the specimen without the heat-conducting tube is 0.345 mm, and the average at the time of failure. The maximum load is 417.8N. It can be seen that the deflection is reduced by 40.8% after embedding the heat transfer tube, and the maximum load reduction is 83.7% of the comparative test piece. The embedding of the heat conduction tube reduces the tensile strength of the trabecular beam, increases the modulus of the bending stiffness, and reduces the maximum bending strain. Under the applied external force, the bending strength exceeds the maximum value and cracking occurs.[6] The low temperature crack resistance of the pre-buried heat transfer tube specimen is deteriorated due to the principle of thermal expansion and contraction of the material. Due to the viscoelastic properties of the asphalt, the shrinkage of the asphalt is higher than that of the heat transfer tube at low temperature.[7]
3.2. Study on Fatigue Performance of Buried Pipe Asphalt Mixture

3.2.1. Test Methods. With the help of MTS-810 test machine, the mid-point loading, stress control mode is adopted, and the fatigue damage test is carried out. According to the research of Harbin University of Architecture, the temperature of the most unfavorable period of the pavement structure is generally 13 °C-15 °C. Therefore, 15 °C is selected, and the average value of the failure load is determined according to the requirements of the T0715 asphalt mixture bending test in JTG E20-2011 "Testing Regulations for Asphalt and Asphalt Mixtures for Highway Engineering". Finally, the 10% failure load is used as the bending creep. The test load was loaded (stress ratio of 0.1) until the trabecular specimen broke.[8]

3.2.2. Test Results. It is known from table 7. As the test strain increases, the fatigue life of the pre-buried heat transfer tube test piece and the unburied heat transfer tube test piece are greatly reduced, and the asphalt mixture of the heat transfer tube is buried under the same strain level. The fatigue life of the test piece decreased more obviously, and the embedding of the heat transfer tube had a great influence on the fatigue performance of the asphalt mixture.[9] This is because the asphalt mixture has been fully wrapped in the asphalt mixture during the mixing process, and the asphalt cement adhered on the surface of the heat transfer tube during the molding process of the test piece is less, and the heat transfer tube is a circular structure, and the asphalt mixture is tested. The part is easy to move during molding, so the heat transfer tube becomes a weak area of the asphalt mixture, and the buried heat transfer tube easily causes concentrated stress on the asphalt road surface, and also adversely affects the fatigue performance of the asphalt mixture.[10]

| Mixing Type                        | Destructive Load (N) | Start Bending Strain | Starting Stiffness Modulus (MPa) | End Bending Strain | End Stiffness Modulus (MPa) | Load Times |
|------------------------------------|----------------------|----------------------|----------------------------------|-------------------|----------------------------|------------|
| Unburied heat transfer tube asphalt mixture | 42                   | 0.009                | 4.44                             | 1.40              | 0.03                       | 20356      |
| Buried heat conduction tube asphalt mixture | 35                   | 0.933                | 0.03                             | 0.934             | 0.025                      | 9384       |

4. Conclusion
(1) After the heat transfer tube is buried in the asphalt mixture, the fracture deflection, critical failure load and bending strain of the asphalt mixture test specimen are lower than those of the heat transfer tube asphalt mixture, indicating the embedding of the heat transfer tube. The asphalt mixture has low temperature crack resistance.

(2) After embedding the heat transfer tube, the bending stiffness modulus of the asphalt mixture beam test piece has been greatly reduced, indicating that the pre-embedded heat transfer tube reduces the stiffness of the asphalt mixture, thus the asphalt mixture Fatigue performance has an adverse effect.

(3) With the number of loading times as the evaluation index, the strain rate of the trabecular specimens gradually increases, and the stiffness modulus decreases gradually. The number of repeated loadings of the unburied asphalt mixture specimens is much higher than that of the buried asphalt mixture. The embedding of the heat transfer tube has a great influence on the fatigue life of the asphalt mixture.

Acknowledgements
This paper was financially supported by a Project of Shandong Province Higher Educational Science and Technology Program (Grant No. J18KA209).

References

[1] Nian Lianghong, Wang Xiong, Deng Wenjun, Shao Kun, Yao Erhua. Fatigue Performance of Warm Mix Recycled Asphalt Mixture [J]. Journal of Highway and Transportation Technology, 2018, 14(10): 138-141.

[2] Lu Pengcheng, Gu Qianxi, Wu Yuhao, Xia Yan, Shi Yu, Yuan Yijin, Wang Tian. Experimental Study on Fatigue Properties of Basalt Fiber Asphalt Mixture [J]. Value Engineering, 2019, 38(17): 263-265.

[3] Bai Wei. Experimental analysis of heat transfer performance of asphalt pavement [D]. Chang'an University, 2012.

[4] ZHANG Jun, ZHANG Hui, ZHANG Hong, ZHUANG Jun. Application research of geothermal heat pipe snow melting system [J]. Acta Energia Sinica, 2011, 32(12): 1822-1826.

[5] Wang Peng. Study on the Influence of Heat Exchange Pipes on the Performance of Solar Collecting Asphalt Pavement [D]. Wuhan

[6] Li Wei. Research on the application of geothermal energy technology based on U-type piles in road snowmelt [D]. Chongqing Jiaotong University, 2013.

[7] Xu Da. Research on Performance of Asphalt Mixture Based on Thermal Conduction Theory [J]. 2014(02): 88-90.

[8] Zhang Liang. Research Status of Road Geothermal Snow Melting Ice [A]. China Refrigeration and Air Conditioning Industry Association, China Refrigeration Society. Proceedings of the 13th National Heat Pump and System Energy Saving Technology Conference [C]. China Refrigeration and Air Conditioning Industry Association, China Refrigeration Society: China Refrigeration Society, 2008: 5.

[9] Lin Yanyan. Experimental study on snowmelt system based on soil source heat pump road [D]. Harbin Institute of Technology, 2011.

[10] Geng Zengjun. Analysis of Factors Affecting Thermal Conductivity of Asphalt Pavement Materials [J]. Journal of Highway and Transportation Technology (Apps & Technology Edition), 2017, 13(08): 109-112.