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Study on rutting stress resistance of asphalt concrete for municipal roads

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KEYWORDS

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ABSTRACT

Municipal roads are the infrastructure of urban transportation and the main channels for people's travel. They not only connect various areas within the city but also link the city with the surrounding transportation network, playing a vital role in promoting urban economic and social development. Rutting is a major problem plaguing municipal roads, significantly impacting road lifespan, traffic safety, and driving comfort. Therefore, this paper studies the rutting stress resistance of asphalt concrete to optimize the pavement material mix and construction process, improve the pavement's load-bearing capacity and durability, and extend its service life.

INTRODUCTION

Rutting on municipal roads refers to the lateral and longitudinal deformation of the road surface under traffic load, mainly including two types: indentation and groove. Since the road surface material of municipal roads is a semi-rigid material, the force it is subjected to is mainly the repeated action of bicycle load, and because it has a high temperature sensitivity, rutting forms quickly, develops quickly, and is difficult to repair. In China, the problem of rutting on municipal roads is particularly serious. A systematic analysis of the current data on rutting on municipal roads in China will help provide a scientific basis and technical support for the prevention and control of rutting problems in China [1] .

1.Rutting mechanism and influencing factors

1.1.Rut Deformation Mechanism

Rutting refers to the uneven settlement of the pavement structure under vehicle load, resulting in lateral deformation. This deformation accumulates over time, causing irregular subsidence and bulging of the pavement. There are many reasons for rutting, including temperature factors, traffic factors, and the properties of asphalt mixtures [2] . Rutting is common in asphalt pavements in China and has obvious seasonality. Temperature factors mainly refer to the large deformation of the pavement caused by thermal expansion and contraction when the outside temperature rises. Traffic factors mainly refer to the vibrations that leave marks on the pavement when vehicles travel at high speeds. The properties of asphalt mixtures are also an important reason for rutting. When the asphalt content in the asphalt mixture is high, it is easy to cause poor bonding between the asphalt and aggregates, thus causing rutting.

1.2.Factors affecting wheel rutting

In pavement structures, rutting primarily refers to lateral deformation caused by repeated traffic loads, which is due to unevenness in the pavement structure. Rutting is divided into two types: permanent deformation caused by the surface layer under load, and permanent deformation caused by the base course and subgrade. While there is considerable research in my country on the formation mechanism and

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influencing factors of rutting, a unified understanding is still lacking. Much research focuses on low-temperature crack resistance and fatigue failure, both of which are related to factors such as aggregate gradation and asphalt content in asphalt mixtures.

2.Stress Analysis of Asphalt Concrete Against Rutting

2.1.Experimental Materials and Methods

In road design, my country mostly uses the Marshall test method, which adjusts the aggregate gradation to achieve the optimal porosity. However, in practical applications, the Marshall test method is not suitable for asphalt mixtures because it separates coarse and fine aggregates, and larger aggregate sizes result in higher porosity. Furthermore, the Marshall test at high temperatures causes the material to lose its homogeneity, leading to changes in specimen volume. Therefore, in designing asphalt mixtures for roads in my country, four gradations with better high-temperature stability are often used. Marshall tests on the four gradation types revealed that the maximum particle size of the asphalt mixture using the AC type is 13 mm, while the maximum particle size using the AH type is 6 mm. Considering all factors, this paper selects the AC type asphalt mixture for rutting stress research.

When proportioning asphalt concrete, the volume ratio of coarse aggregate in AC-13 type mixture is selected as 4:6, and the volume ratio of fine aggregate is selected as 3:7. The asphalt content is 2.36, 2.42, 2.50 and 2.51 kg/m3, respectively, and the mineral powder content of asphalt mixture is 3.36, 3.42, 3.47 and 4.17 kg/m3, respectively. The asphalt content in the mixture is all below 4%.

2.2.Overview of Basic Mechanical Properties of Asphalt Pavement

The basic mechanical properties of asphalt pavement include shear strength, tensile strength, and fatigue performance. Among these, the shear strength of asphalt pavement refers to its ability to resist shear stress. The shear strength of asphalt pavement is crucial for withstanding shear stress generated by factors such as vehicle loads and temperature changes.

The tensile strength of asphalt pavement refers to its ability to resist tensile stress. The tensile strength of asphalt pavement is affected by a variety of factors, such as the composition of the asphalt mixture, the mix proportion, the quality of the asphalt, and the pavement structure.

The fatigue performance of asphalt pavement refers to its ability to resist fatigue failure under long-term cyclic loading. Fatigue failure refers to the cracks and damage that occur in asphalt pavement under cyclic loading due to stress accumulation. Commonly used fatigue testing methods include beam fatigue testing and spoke fatigue testing. Beam fatigue testing involves preparing asphalt pavement samples into beam-shaped specimens , applying cyclic loading on a testing machine, and evaluating the fatigue performance of the asphalt pavement by measuring the fatigue life of the specimens. Spoke fatigue testing uses a device simulating the spokes of a vehicle tire to apply cyclic loading to the asphalt pavement, and evaluates the fatigue performance of the asphalt pavement by observing and recording cracks and damage during the test.

2.3.Vehicle Load Analysis

Traffic load on municipal roads refers to the pressure and load exerted on the road by vehicles during operation. Traffic load is a crucial factor affecting road structure and performance, depending on factors such as vehicle weight, vehicle type, speed, and traffic flow. Different types of vehicles, such as passenger cars, trucks, and buses, have significantly different weights. Heavy trucks and buses, with their greater weight, exert correspondingly higher loads on the road. For example, heavy trucks and buses, due to their large size and high axle load, exert greater pressure on the road. In contrast, passenger cars and motorcycles have relatively lower loads.

In addition, higher driving speeds will increase the impact and pressure of vehicles on the road, exacerbating road wear and damage. When the density of vehicles on the road is high and the traffic flow is large, the distance between vehicles is small, and the acceleration, deceleration and turning of vehicles are frequent, which will increase the load on the road accordingly [3] . The asphalt pavement design specification stipulates that the contact pressure of the tire design is 0.7 MPa, the asphalt is selected according to the model and specifications mentioned above, the thickness is selected as 20 cm, the middle layer is cement-stabilized crushed stone base course with a thickness of 35 cm, and the lower layer is cement-stabilized gravel base course with a thickness of 20 cm.

The mechanical parameters of the road surface are shown in the table below:

Structural layer	spring modulus	Poisson's ratio	Road surface depth
Asphalt concrete surface layer	1.2× 10³	0.35	0
Cement-stabilized crushed stone base	1.5× 10³	0.20	2
Cement-stabilized gravel subbase	1.4× 10³	0.23	4
subgrade	2.5× 10³	0.40	8
Asphalt concrete surface layer	1.2× 10³	0.33	10
Cement-stabilized crushed stone base	1.5× 10³	0.26	12
Cement-stabilized gravel subbase	1.4× 10³	0.21	14
subgrade	2.5× 10³	0.17	16

Assuming the three structural layers are in perfect contact, the maximum shear stress of the asphalt pavement is calculated as shown in the figure below:

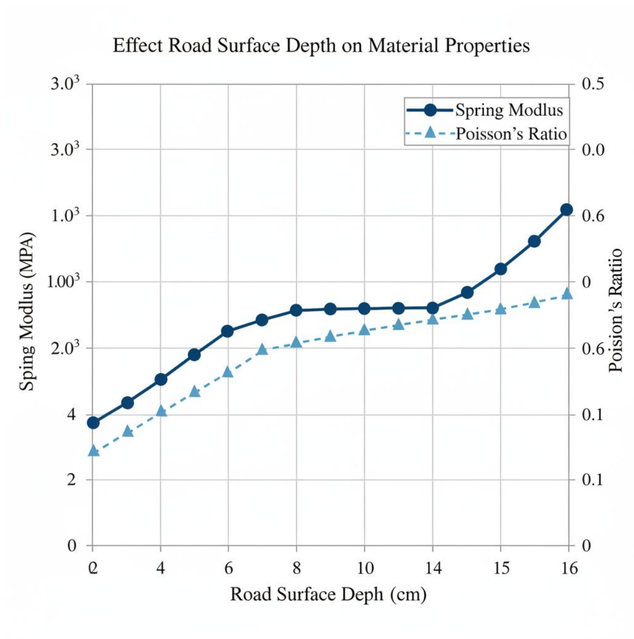

Fig.1. Maximum shear stress pavement depth variation diagram

As can be seen from the figure, the maximum shear stress is relatively large at a road surface depth of 4cm-10cm, indicating that the shear stress peak is in the asphalt concrete surface layer, which is prone to rutting [4] . As for the asphalt itself, the rutting usually occurs in the upper and middle layers. Therefore, it is recommended to optimize the asphalt structure ratio in the upper and middle layers of asphalt concrete and select a more suitable modified asphalt.

The following results were obtained after testing the pressure and asphalt bearing capacity:

Contact pressure (MPa)	Dynamic stability (cycles/mm)
0.5	3815
0.7	2984
0.8	2679
0.9	2503
1.0	2435
1.2	2232

Table.1. Table of Contact Pressure and Dynamic Stability Test Results

The data was plotted and fitted using Origin software, as shown below.

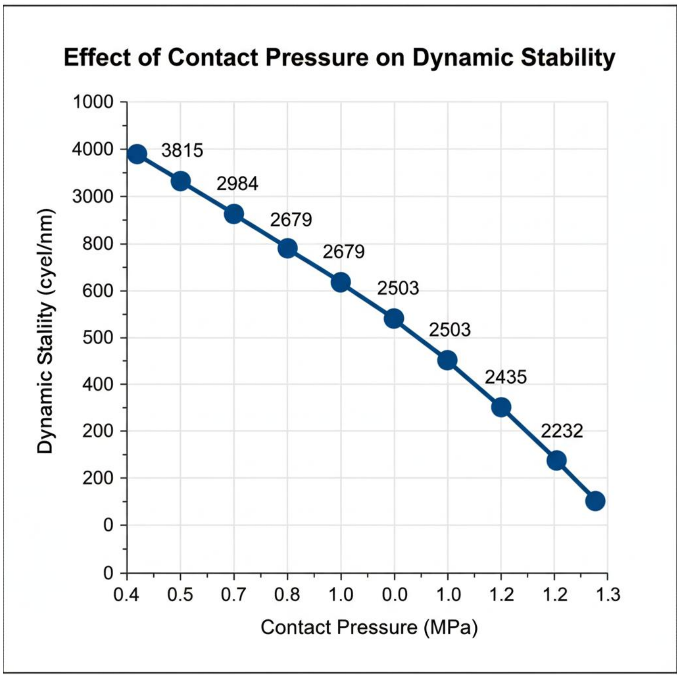

Fig.2. Relationship between contact pressure and dynamic stability

Using 0.7 as the standard limit, the trend line in the figure shows that the overall dynamic stability is good when the pressure is less than 0.7 MPa. However, if the pressure exceeds 0.7 MPa , the dynamic stability decreases significantly, which is detrimental to the service life of asphalt concrete pavement.

3.Prevention and control measures for wheel rut problems

3.1.Rational selection and proportioning of asphalt mixture

According to the traffic flow and design requirements of the road, select the appropriate asphalt grade. High-grade asphalt concrete (HMA) or modified asphalt concrete (SMA) usually have better rutting resistance [5] . After selecting the appropriate concrete, it is also necessary to calculate and control its content. Reasonable control of asphalt content can improve the flexibility and rutting resistance of asphalt concrete. Too high asphalt content will make the asphalt concrete too soft and easy to form ruts; too low asphalt content will make the asphalt concrete too hard and easy to crack. Determine the appropriate asphalt content according to the actual situation and test results. In addition, selecting the appropriate aggregate can improve the strength and stability of asphalt concrete [6] . The aggregate should have a good particle size distribution and a solid structure to increase the rutting resistance of asphalt concrete. Adding appropriate amount of additives and modifiers, such as polymer modifiers, asphalt tackifiers, etc. [7] to asphalt concrete can improve the adhesion and strength of asphalt concrete and improve its rutting resistance.

3.2.Strengthen construction process control

In terms of construction technology, the road's resistance to rutting stress can be further improved by focusing on construction temperature, construction thickness, compaction control, and construction quality testing [8] .

The surface temperature of asphalt concrete also has a certain influence on rutting stress, so the road surface should be cooled down in time during hot summer weather. Excessive construction temperature will cause asphalt concrete to be too soft and easily form rutting [9] ; excessive construction temperature will cause asphalt concrete to be too hard and easily crack. The construction temperature should be controlled within an appropriate range according to the properties of asphalt concrete and air temperature. In terms of thickness, reasonable control of the construction thickness of asphalt concrete can improve its density and strength and enhance its rutting resistance [10] . The appropriate construction thickness should be determined according to the traffic flow and design requirements of the road. The compaction control of asphalt concrete is also very important for its rutting resistance. Appropriate compaction machinery and compaction methods should be selected according to the properties and thickness of asphalt concrete, and the control of compaction quality should be strengthened.

In addition, during the construction of asphalt concrete, key parameters such as temperature, density, and thickness should be monitored and recorded to identify problems and make adjustments and corrections in a timely manner.

3.3.Strengthen road maintenance and upkeep

Road damage and cracks can affect the rutting resistance of asphalt concrete. Damage and cracks should be identified and repaired promptly to ensure the smoothness and density of the road surface. Furthermore, debris on the road surface, as well as drainage and road markings, can affect the road's rutting stress resistance. Effective traffic management and vehicle restrictions also have a certain impact on the service life of municipal roads .

Regarding road debris management: Regularly sweep away dust, mud, and weeds from road surfaces. Use sweepers, high-pressure water guns, and other equipment to ensure the road surface is smooth and clean. Regularly clean road drainage systems, including storm drains, pipes, and collection tanks, to ensure unobstructed drainage and prevent water accumulation from damaging the road surface. Clean debris and garbage from roadside ditches and curbs to prevent blockages and maintain their drainage function. Regularly clean road signs and markings to ensure they are clearly visible. Use cleaning agents and brushes to ensure drivers can clearly identify road signs and markings. Additionally, improve the placement and collection of roadside trash cans, and clean them regularly to maintain a clean environment around the road.

Implementing road vehicle restrictions requires consideration of various factors, such as road type, vehicle type, traffic flow, and traffic safety. Restriction signs should be placed at road entrances, clearly indicating the restricted vehicle types, times, and locations to remind drivers of the regulations. Traffic police or traffic controllers should be present during the restricted hours to check and advise restricted vehicles, ensuring compliant passage . Specific markings should be set up on restricted road sections to restrict vehicle types or times, reminding drivers of the regulations. It is important to note that the implementation of vehicle restriction measures must fully consider the actual road traffic conditions to avoid adverse impacts on traffic flow and traffic safety. Simultaneously, it is crucial to strengthen publicity and education regarding the restriction regulations to improve drivers' awareness and enforcement, ensuring the effectiveness of the restriction measures.

Conclusion

This paper analyzes the mechanical properties of asphalt concrete under high-temperature conditions, studies the influencing factors of rutting stress, and proposes corresponding prevention and control measures. The specific summary is as follows:

(1) In asphalt concrete pavement, the surface layer structure is mainly composed of semi-rigid base and flexible base. In semi-rigid base, due to its lower elastic modulus and higher deformation capacity, asphalt concrete pavement is prone to large rutting stress. Therefore, in actual engineering, measures such as overlaying asphalt concrete surface layer can be used to reduce rutting stress.

(2) In the construction of asphalt concrete pavement, attention should be paid to factors such as material ratio and construction process. In terms of material ratio, a higher asphalt content should be used as much as possible, and the aggregate gradation range of asphalt mixture should be broadened. In terms of construction process, attention should be paid to the control of compaction degree, smoothness and other aspects [5] .

(3) To address the rutting problem in actual engineering projects, measures such as overlay, asphalt surface treatment, asphalt pavement structure combination, asphalt surface layer structure combination and semi-rigid base course can be adopted to improve the rutting problem.

(4) In municipal roads, semi-rigid base courses and flexible base courses can be used in combination to effectively reduce rutting stress on the road surface. At the same time, asphalt pavement structure can also be combined and applied to rutting treatment to improve the service life of the road.

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