Study on mechanical properties testing of highway concrete pavement construction machinery materials

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Abstract: In order to solve the problems of large error and long time-consuming in the traditional mechanical property test methods, a new mechanical property test method for highway concrete pavement construction machinery materials is proposed. The relationship between the deformation component and the displacement component of the microstructure of the concrete pavement in the equilibrium coordinate system is obtained. The limit value of the critical thickness of the construction material of the highway concrete pavement is obtained by the second derivative function. Based on the analysis principle of AFM force curve, the relationship between mechanical materials and elastic modulus of highway concrete pavement construction is determined, and the performance analysis of highway concrete pavement construction mechanical materials is realised. The test results show that the error of mechanical properties analysis of highway concrete pavement construction machinery materials by the proposed method is only 0.3%, and the test time is short.

Keywords: concrete pavement; elastic mechanics; equilibrium differential equation; displacement component; permeability coefficient.

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1 Introduction

With the continuous development of China's economy, the quality requirements of the highway in the transportation are getting higher and higher. The choice of road surface materials directly affects the quality of road surface, thus affecting the development of China's traffic (Zhang et al., 2019). In recent years, in order to meet the requirements of traffic, the choice of road surface materials is becoming more and more diverse. Concrete

is a relatively common material in road surface construction, which cannot only absorb the noise generated by vehicles, but also has excellent water seepage performance, making it the best choice of materials in road construction (Xiong et al., 2019). Therefore, the research on the mechanical properties of highway concrete pavement construction machinery materials and the enhancement of highway quality has become a hot issue in the current research (Hengmao et al., 2018). Therefore, many researches have been carried out and some achievements have been made.

Song et al. (2019) put forward the research method of mechanical properties of polymer modified cement-based materials. This method analyses the toughness and endurance of highway concrete pavement materials in the process of rolling, analyses its shortcomings, selects a certain proportion of polymer to improve the cement mortar, and analyses the void and water permeability characteristics of the improved concrete. Through the actual test, it is found that the compressive performance of the mixed concrete material is higher, and the bending resistance is also improved. This method improves the chemical properties of concrete and improves the performance of materials, and the effect is good. However, the elastic mechanics of concrete is seldom considered, which leads to the poor application effect of concrete in practice. Sun and Zhou (2019) put forward the analysis method of mechanical properties of cement concrete pavement. This method firstly analyses the stress forms of cement concrete pavement, analyses the changes of pavement parameters under different loads, analyses the cracks at the corner, edge and actual corner of the pavement, analyses the stress of the laminate by using the finite element software ABAQUS, and completes the mechanical analysis of the cement pavement materials. This method is used to analyse the different mechanical properties of cement concrete pavement, and the analysis accuracy is high, but there is someone sidedness in the analysis, which is not suitable for practical application. Liu et al. (2020) put forward the demand analysis method for mechanical properties of prestressed concrete beam reinforcement materials based on crack resistance. This method mainly analyses the cross-sectional area of concrete bridge. On the basis of ensuring that the concrete can be bonded together, the tensile strength of reinforcement materials is enhanced. Through the finite element analysis model, the parameters of the reinforced layer of concrete bridge are analysed, so as to realise the analysis of crack resistance of concrete beam reinforcement. This method is aimed at the analysis of the mechanical performance requirements of concrete beam reinforcement materials, and has strong pertinence, but the analysis process is more complex and has certain limitations.

In order to improve the shortcomings of the above methods, this paper proposes a new test method for mechanical properties of highway concrete pavement construction machinery materials. The basic route of this method is as follows:

1 By analysing the microstructure characteristics of highway concrete pavement construction materials, the elastic mechanics of the material microstructure is determined. According to the mathematical balance differential equation, the relationship between the deformation component and displacement component of the material microstructure under the balance coordinate system is obtained.

2 The limit value of the critical thickness of highway concrete pavement construction materials is obtained by the second derivative function, and the permeability coefficient of concrete mixture pavement material is obtained to determine the mechanical performance index of highway concrete pavement construction material.

3 This paper analyses the analysis principle of AFM force curve, obtains the movement force of highway concrete pavement construction mechanical materials, analyses its reduced elastic modulus, determines the relationship between highway concrete pavement construction mechanical materials and elastic modulus, and realises the performance analysis of highway concrete pavement construction mechanical materials.

2 Structural analysis of construction machinery materials for highway concrete pavement

2.1 Analysis of microstructure characteristics

In the construction material structure of highway concrete pavement, analysing the microstructure of the material is the key step to analyse its mechanical properties (Zhu et al., 2019). The adhesion of construction materials of highway concrete pavement is an important guarantee for highway concrete pavement to exert compression and friction (Li et al., 2018). The strength of microstructure of highway concrete pavement construction material is one of its important properties. Its microstructure features are as follows:

1 Chemical bonding of materials. In highway concrete, the covalent bond interface formed by the chemical reaction between the matrix material and the material on the reinforced surface.

2 Adsorbability of concrete pavement materials. The safe operation of pavement mainly depends on the adsorbability of pavement paving materials. By enhancing the absorbability of adsorptive materials, the degree of infiltration of materials is enhanced, and the absorbability of concrete mixed materials is enhanced.

3 Weak interface of highway concrete pavement: the interface of low molecules generated by concrete composite materials and the environment under the joint action of the collection.

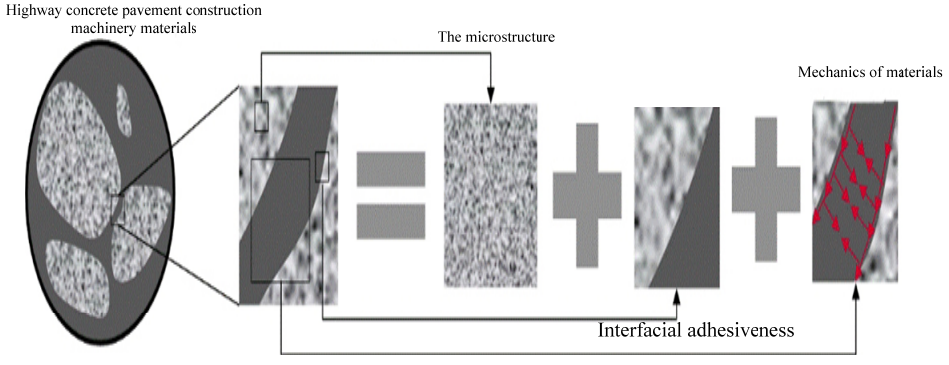
4 Material diffusivity: any material is in motion, and concrete pavement construction materials form cohesion through the movement of material molecules.

5 Mechanical action: The surface texture of the material strengthens the stability of the road surface through the mechanical bite force formed after filling.

The microstructure of highway concrete pavement construction materials is shown in Figure 1.

Under the common action of mixed materials and soil foundation, the microstructure of concrete pavement is affected by different loads. Deformation first occurs, and its deformation presents nonlinear characteristics, which changes with time. After the disappearance of load external force, part of its microstructure cannot be restored to the initial state. In order to ensure the stability of highway concrete pavement construction materials, mechanical problems of its microstructure need to be analysed (Jiang, 2018). The microstructure elasticity of concrete pavement is the key support of its structural stability. The elasticity of the microstructure of concrete pavement is analysed (Jiang et al., 2019). The mathematical model of elasticity mechanics is built to analyse the microstructure of concrete pavement.

Figure 1 Microstructure of construction material of highway concrete pavement (see online version for colours)



Suppose the elastic strain of the microstructure of concrete pavement $A = \{A_x, A_y, A_z, B_x, B_y, B_{xy}\}^T$, $\phi = \{\phi_x, \phi_y, \phi_z, \vartheta_x, \vartheta_y, \vartheta_{xy}\}^T$ its mathematical equilibrium differential equations are :

$$\begin{aligned} \frac{\partial \phi_x}{\partial x} + \frac{\partial \vartheta_x}{\partial y} + \frac{\partial \vartheta_y}{\partial z} = 0 \\ \frac{\partial A_x}{\partial x} + \frac{\partial B_x}{\partial y} + \frac{\partial B_y}{\partial z} = 0 \end{aligned} \tag{1}$$

According to the mathematical equilibrium differential equation, the relationship between the deformation component and the displacement component of the microstructure of concrete pavement under the equilibrium coordinate system can be obtained, that is:

$$\begin{aligned} A_x &= \frac{\partial \varepsilon}{\partial x} \\ A_y &= \frac{\partial v}{\partial y} \\ A_z &= \frac{\partial w}{\partial z} \end{aligned} \tag{2}$$

In the formula, ε, v and w represents the shape variables of microstructure in different coordinate systems.

In the plane strain, there is a certain relationship between the elastic deformation and stress in each direction of the microstructure of highway concrete pavement construction materials, that is:

$$\begin{aligned} \phi_x &= \frac{1}{\eta}\left[\phi_x - \varpi\left(\phi_y + \phi_z\right)\right] \\ \phi_y &= \frac{1}{\eta}\left[\phi_y - \varpi\left(\phi_x + \phi_z\right)\right] \\ \phi_z &= \frac{1}{\eta}\left[\phi_z - \varpi\left(\phi_x + \phi_y\right)\right] \end{aligned} \tag{3}$$

In the formula, η represents the elastic modulus of construction materials for highway concrete pavement, represents the elastic modulus of construction materials for highway concrete pavement, ϖ represent the material Poisson ratio.

By analysing the microstructure characteristics of highway concrete pavement construction materials, the elastic mechanics of material microstructure is determined. According to the mathematical equilibrium differential equation, the relationship between deformation component and displacement component of material microstructure of concrete pavement under equilibrium coordinate system can be obtained, which lays a foundation for mechanical analysis of construction materials of highway concrete pavement.

2.2 Determination of performance index

After analysing the microstructure characteristics of highway concrete pavement construction materials, it is necessary to analyse the critical thickness of highway concrete pavement construction materials. The interface thickness of highway concrete pavement construction materials affects the mechanical properties of construction machinery materials in the construction process. The critical thickness of the pavement interface refers to the reinforcement effect supported by the thickness of the interlayer of the highway concrete pavement construction material. Under the interaction of highway concrete pavement construction materials, the critical thickness reflects the tensile limit requirements of highway concrete pavement construction materials. In order to analyse the tensile limit requirements of the material, this paper uses the change of the tensile strength-sandwich thickness curve to determine its critical thickness. This article first obtains the upper and lower limits of the critical thickness of highway concrete pavement construction materials. This article uses the second-order derivative function to obtain, namely:

$$\begin{aligned} \xi_i &= e + fi_k + gi_k^2 + hi_k^3 \\ i_k^n &= \frac{-g}{4h} \end{aligned} \tag{4}$$

Among them, $e, f,\ g$ and h represents a cubic polynomial fitting coefficient, ξ_i represents the tensile strength of the material, i represents the limit value of the critical thickness of the material interface.

After obtaining the critical thickness limit value of highway concrete pavement construction materials, due to the concrete characteristics of highway concrete pavement construction materials, the material gap is large, which cannot only effectively reduce noise, but also have certain drainage performance. The permeability of concrete mixed pavement materials has an important impact on the research of its mechanical properties (Li et al., 2019).

It is assumed that the permeability coefficient of concrete pavement construction materials is χ, the value varies according to the change of particle, filling and so on. This coefficient is an important index of the influence of the mechanical properties of highway concrete pavement construction materials. The average velocity of penetration is proportional to the slope of the pavement, that is:

$$v = \chi \times p \tag{5}$$

In the formula, v represents the average velocity of penetration, p represents the slope value of highway concrete pavement.

When the road concrete pavement meets the rain and snow weather, the hydraulic slope changes due to the different angles. Under the influence of the general hydraulic slope, the seepage speed of the road concrete pavement material is as follows:

$$\frac{E}{t} = \kappa \times \left(\frac{\Delta h}{L} \right) \times M \tag{6}$$

In the formula, E is a certain amount of time, t represents the length of water penetration, Δh represents the hydraulic slope difference, M represents the cross-sectional area of highway concrete pavement.

If the hydraulic slope of highway concrete pavement changes abnormally, the length of highway concrete pavement does not change at this time. The seepage velocity of highway concrete pavement material is as follows:

$$lR = \chi \times (\frac{h}{D}) \times Mdt \tag{7}$$

In the formula, IR represents the water permeability when the hydraulic slope is abnormal, D represents the relationship between permeable distance and time.

Under the influence of the above different hydraulic slope, the permeability coefficient obtained by the water permeability change of highway concrete pavement material is obtained by integral form, that is:

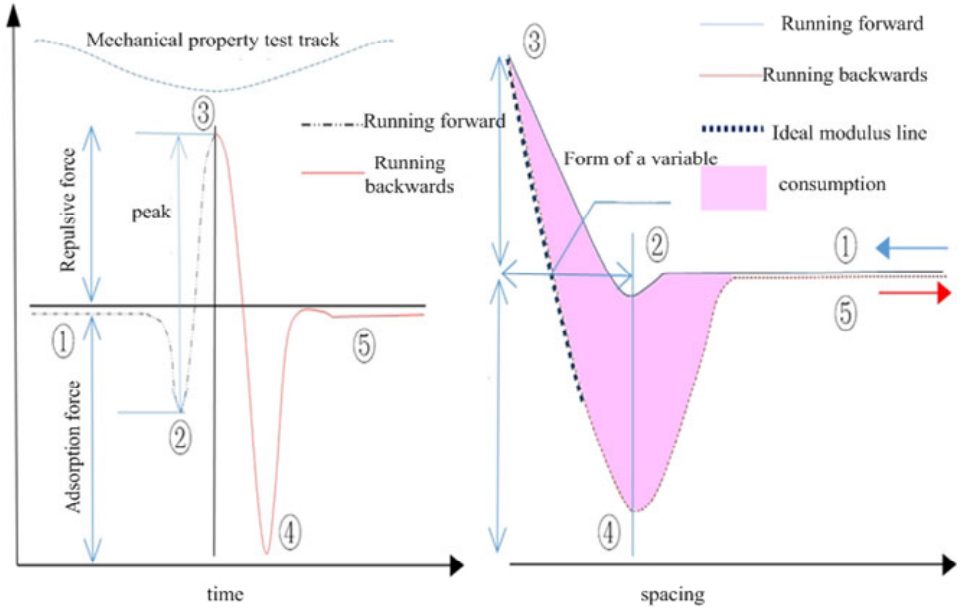
$$\chi = \frac{D \times i}{M(t_1 - t_0)} \ln \frac{h_0}{h_1} \tag{8}$$

The limit value of critical thickness of highway concrete pavement construction material is obtained by second order guide function, and the permeability of concrete mixed pavement material is obtained. The mechanical properties of highway concrete pavement construction materials are determined. It provides theoretical basis for the performance analysis of highway concrete pavement construction materials.

3 Analysis of mechanical properties of highway concrete pavement construction machinery based on AFM force curve

On the basis of the above performance indexes of highway concrete pavement construction machinery materials, the mechanical properties of highway concrete pavement construction machinery materials are analysed. In this paper, AFM force curve is adopted to analyse the mechanical properties of highway concrete pavement construction machinery materials (Sun et al., 2019). AFM force curve is widely used in material mechanics performance test, the mechanical properties of the material's elastic modulus, hardness and better adsorption ability test, linear displacement load curve of the improved material mechanics China's defects, guarantee the accuracy of the performance test, can be tiny features effectively test the performance of mechanics of materials, performance analysis of optimal (He et al., 2019). The working principle of AFM force curve is shown in Figure 2:

Figure 2 AFM working schematic diagram of the force curve (see online version for colours)



In Figure 2, when the surface of the sample reaches equilibrium, the material mechanics feedback the adsorption force of the sample. When the peak value reaches the maximum, the elastic motion trajectory of the material changes, and when the corresponding force leaves the material, the force feedback is 0.

On the basis of the above working principle analysis, in the analysis of mechanical properties of highway concrete pavement construction machinery, the motion force of the material is calculated, that is:

$$\psi - \psi_j = \frac{4}{3}\beta^* \sqrt{\tau (d - d_0)^3} \tag{9}$$

In the formula, Ψ represents the total force of motion of the material, Ψ_j indirect adhesion representing the movement of the material, β^* represents the elastic modulus produced under the contact surface of the material, d represents the final distance from which the moving force of the material operates, d_0 represents the initial distance from the movement of the material.

Among them, the elastic modulus produced under the contact surface of the material can reflect the shrinkage reduction of the mechanical material of highway concrete pavement construction (Xu, 2018). When the mechanical properties of the material are fixed, the change of the parameter is directly related to the change of the elastic modulus the material. It can be defined as:

$$\frac{1}{\beta^*} = \frac{1 - e_t^2}{\beta_t} + \frac{1 + e}{\beta_t} \tag{10}$$

In the formula, e represents Poisson's ratio of the elastic modulus of the material.

Using AFM force curve of highway concrete pavement construction machinery and material mechanics performance were analysed, and the analysis of AFM force curve in the process of analysis principle, on this basis, the acquisition of highway concrete pavement construction machinery materials movement force, analysis of the reduced modulus of elasticity, construction machinery of highway concrete pavement materials and the relation between modulus of elasticity, and realisation of highway concrete pavement construction machinery material performance analysis.

4 Experimental analysis

4.1 Testing environment

In order to verify the feasibility of this method, a simulation experiment is carried out. The experiment uses SPSS 13.0 software to collect and statistics the experimental data. The experimental operating platform is the MATLAB platform and the running computer system is the Window 10 system. The running memory is 8 GB, and the mechanical properties of the construction materials are tested.

4.2 Test parameter

In order to ensure the validity of the experimental results, it is necessary to define the experimental parameters strictly. The test parameters are shown in Table 1.

Table 1 Test parameters

Parameter	*The values*
Sample size/m^2	100
Sample material sieve %	5~10
Material moulding temperature/°C	150~200
Sample density g/cm^3	2.6~3.0
Testing time/min	200

4.3 Test scheme

To verify the effectiveness of the proposed method, the methods of comparing this paper, Song et al. (2019) and Sun and Zhou (2019) are used to analyse the error of the analysis of the mechanical properties of materials and the time-consuming of the analysis of the mechanical properties of materials. To verify the effectiveness of the proposed method.

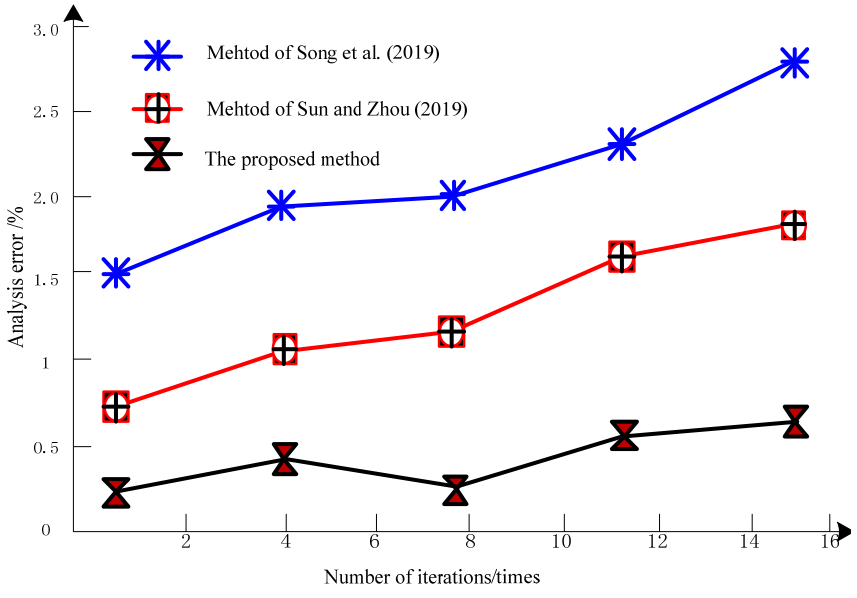
4.4 Test result

4.4.1 Error analysis of mechanical properties analysis of highway concrete pavement construction machinery materials

In order to ensure the effectiveness of the experiment, when comparing the error analysis of mechanical properties of materials with the method in this paper, the method in Song et al. (2019) and the method in Sun and Zhou (2019), iterative experiments were carried

out for many times, and the average value of the experimental results was taken. The experimental results are shown in Figure 3.

Figure 3 Error comparison of mechanical properties analysis of different methods (see online version for colours)



It can be seen from the analysis Figure 3 that in the same experimental environment, the error analysis of mechanical properties of materials was carried out by using the method in this paper, the method in Song et al. (2019) and the method in Sun and Zhou (2019), and there was a certain gap in the experimental results. Among them, the error of the proposed method is always lower than that of the other two traditional methods with a minimum of about 0.3%, while the error of the other two methods presents an upward trend and is always higher than that of the method presented in this paper. This is because the proposed method by second derivative function to obtain the limit value of the critical thickness of highway concrete pavement construction materials, and obtain the permeable performance coefficient of concrete pavement materials, determination of highway concrete pavement construction material mechanics performance, precise analysis target, verify the scientific effectiveness of the proposed method.

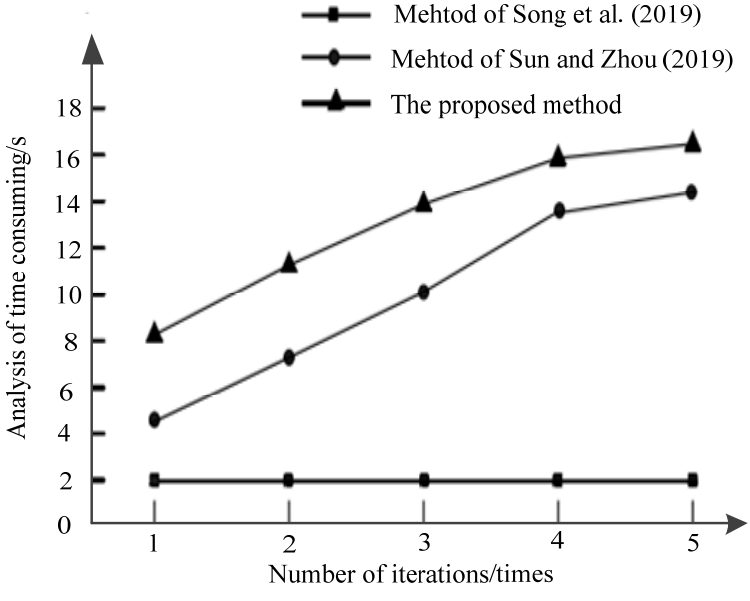
4.4.2 Time-consuming analysis of mechanical properties of highway concrete pavement construction machinery

On the basis of ensuring the accuracy of material mechanical properties analysis, the experiment compares the time consuming of this method, Song et al. (2019) method and Sun and Zhou (2019) method. The experimental results are shown in Figure 4.

As can be seen from the analysis Figure 4, with the change of iteration times, the time consumption of the three methods in material mechanical property analysis changes accordingly. Among them, the analysis time change of the proposed method is relatively stable, which always stays at about 2 s, while the other two methods always show a rising

trend, which is much higher than that of the proposed method. This is because the proposed method analyses the reduced elastic modulus, determines the relationship between mechanical materials for highway concrete pavement construction and the change of elastic modulus, realises the performance analysis of mechanical materials for highway concrete pavement construction, and thus shortens the analysis time of the proposed method.

Figure 4 Time-consuming comparison of mechanical properties of concrete pavement construction machinery



5 Conclusions

In this paper, highway concrete pavement construction machinery material mechanics performance test method, through analysing the characteristics of the highway concrete pavement construction material microstructure, determine the material microstructure of mechanics of elasticity, according to the mathematical balance differential equation, obtain microstructure of concrete pavement materials microstructure under balance coordinate system of the relationship between the deformation and displacement components; The limit value of the critical thickness of highway concrete pavement construction material is obtained through the second derivative function, and the permeability coefficient of concrete mixed pavement material is obtained to determine the mechanical performance index of highway concrete pavement construction material. The principle of AFM force curve is analysed to obtain the motion force of mechanical materials for highway concrete pavement construction, analyse its reduced elastic modulus, determine the relationship between mechanical materials for highway concrete pavement construction and elastic modulus change, and realise the performance analysis

of mechanical materials for highway concrete pavement construction. Compared with traditional methods, it has the following advantages:

1 The error of the proposed method in analysing the mechanical properties of highway concrete pavement construction machinery materials is only 0.3%, which has certain credibility.

2 Using the proposed method to analyse the mechanical properties of highway concrete pavement construction machinery materials takes the shortest time of 2 s, which is feasible to some extent.

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