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Analysis of Two Kinds of Rheological Properties Data of Asphalt

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Abstract. In order to study the rutting factor $G^*/\sin\delta$ and complex shear modulus G^*, two kinds of rheological performance data obtained under asphalt temperature scanning, this paper performs regression analysis on the relevant empirical formulas of these two kinds of data, using the determination coefficient R^2 and the comparison of the numerical magnitude of the fitted and true values of the regression against the error value Δ, and selects a reasonable formula for the next analysis and research, and uses a small number of known measurement point data of two different temperature spans for regression analysis, and compares the numerical magnitude of Δ, so as to discover and analyze the law.The results show that the fitted and true values of the commonly evaluated formula: $\lg\lg G^* = GTS_F \bullet \lg T + C_2$ for the complex shear modulus G^* have relative error values E of many data above 6.4%, which do not meet the specification requirements, but the Z as well as X of the formula $\lg(F) = A \bullet T + C$ (F can refer to $G^*/\sin\delta$ or G^*) under the regression of the same data are below 6.4%, which are more satisfying to use for research;At the same time, using Equation $\lg(F) = A \bullet T + C$ in the commonly used asphalt high temperature evaluation interval (50-80) for a deeper research analysis, it was found that a number of data in Δ obtained by regression analysis using three known measurement points with a temperature span of 15°C (50°C, 65°C, 80°C) were more than 6.4%, which did not meet the specification requirements; while using four measurement points with a temperature span of 10°C (50°C, 60°C, 70°C, 80°C) are all below 6.4%, which meet the specification requirements.

Keywords. Rutting factor $G^*/\sin\delta$; Complex shear modulus G^*; Determination coefficient R^2; Fit value; True value; Relative error value Δ; Measuring point

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1. Introduction

Dynamic shear rheometer is a common instrument for studying viscoelastic materials. The DSR test was first used to evaluate the high temperature and fatigue performance of asphalt in the SHRP study of asphalt binder performance.[1] The shear rheometer consists of a mainframe, cooling system and data processing software. The mainframe includes a stress-strain control device and two parallel oscillating plates, of which the upper plate is connected by a screw and can be lifted freely with the mainframe probe, thus applying a certain strain and frequency of force to the asphalt specimen, while the lower plate is screwed into the load plate and is fixed. In order to simulate the actual road conditions, the angular frequency of vibration is generally set to 10rad/s[2] .

Asphalt is a complex colloidal material that exhibits both viscosity and elasticity at room temperature.[3] . In order to quantify this viscoelastic property, the US SHRP program uses a dynamic shear rheometer to study the viscoelastic nature of asphalt. The temperature scan test is one of the tests used to evaluate the rheological properties of asphalt at high temperatures. In the test, the asphalt specimen is fixed between two parallel plates on the top and bottom, and the instrument simulates the loading conditions of cyclic loading by applying cyclic oscillations of dynamic stress to the asphalt sample at strain level. The test yields data such as energy storage modulus G' , loss modulus G'' , phase angle δ[4] The rheological indexes such as complex shear modulus $G*$ and rutting factor $G*/\sin\delta$ are used to evaluate the performance of asphalt at high temperatures.[5] The rheological indicators such as complex shear modulus and rutting factor are used to evaluate the performance of asphalt at high temperatures.[6]

Wang Zijun [7] et al. used Dynamic Shear Rheometer (DSR) temperature scanning to determine the temperature sensitivity of asphalt in the high and medium temperature region (>0°C), and showed that the $G*$ double logarithm of the complex modulus obtained from the DSR temperature scanning test and the temperature T logarithm have a linear relationship, and the slope in the linear equation obtained is called the complex modulus index GTS_F . The calculation equation is:

$$\lg \lg G* = GTS_F \bullet \lg T + C$$

Domestic Hongme Cai[8] et al. also used the complex modulus index GTS_F for the medium and high temperature evaluation of petroleum asphalt.

In China, Wen-Liang Wu[9] et al. then used the test results of temperature scan, the rutting factor $G*/\sin\delta$ was logarithmically fitted to the temperature T, and its slope can reflect the variation of rutting factor $G*/\sin\delta$ with temperature T, and the slope coefficient is called rutting factor index GTS_C, and the rutting factor index GTS_C was used to evaluate the high temperature performance of modified asphalt, and its calculation formula is[10]:

$$\lg(G*/\sin\delta) = GTS_C \bullet T + C$$

In China, Lin Jiangtao and Liang Hao [11] used time scan data for analysis and prediction, and the $G*/\sin\delta$ calculated by regression was basically the same as that determined by the AASHTO method, and the predicted determinations all met the JTG

E20-2011 "Highway Engineering Asphalt and Asphalt Mixture Test Procedure" on the allowable error of the repeatability of the original asphalt determination less than 6.4%. The requirements.

From the above findings, it can be seen that due to the different objects (complex shear modulus $G*$, rutting factor $G*/\sin\delta$), the formulas chosen are also different, one is the double logarithm of $G*$ and T log linear relationship type formula, formula type $\lg\lg G* = GTS_F \bullet \lg T + C$; another is the logarithm of $G*/\sin\delta$ and T linear relationship type formula, formula type: $\lg(G*/\sin\delta) = GTS_C \bullet T + C$, while domestic and foreign[12] For this reason, the author chose these different types of asphalt to obtain the dynamic mechanical properties of asphalt data: complex shear modulus $G*$ and rutting factor $G*/\sin\delta$ by temperature scanning test of dynamic shear rheometer (DSR), and carried out regression analysis by the formulae obtained from the above study to verify The regression analysis was performed to verify the fit of the regression trends of the two types of equations, and a small amount of known measured data was used to predict the data of unknown points in other temperature intervals, and the correlation coefficients obtained from these small amounts of measured data were used to evaluate the high temperature performance of asphalt.

2. Test Part

2.1. Raw Materials and Their Performance Indicators

Two types of 90# matrix asphalt were used in this test. APAO modifier has a milky white granular appearance, a viscosity of 18 Pa-s at 190°C, a density of 0.86 g/cm3, a needle penetration (25°C) of 25 mm, a softening point of 120°C, and a glass transition temperature of -38°C.

2.2. Preparation of Test Pieces

The dosage was 2% and 4%, respectively, to obtain APAO modified asphalt specimens. Firstly, put the 90# base asphalt in a common oven to preheat to 160°C, turn on the mixer, then add APAO according to the predetermined ratio, turn on the mixer at a rate of 1000 r/min for 5 min, then turn on the emulsification shear at a rate of 1 000 r/min for 20 min, and finally place the APAO modified asphalt in an oven at 120-130°C for constant temperature development 30 min, the APAO modified asphalt is produced.

2.3 Analysis and Testing

The conventional performance was tested according to the requirements of the Test Procedure for Asphalt and Asphalt Mixtures for Highway Engineering (JTG E 20-2011) for the three major conventional indicators of asphalt.

The temperature scan was performed with a dynamic shear rheometer (DSR), selecting a loading frequency of 10 rad/s, a test temperature of 45-85°C, and a 12% constant strain [13].

Figure 1. Dynamic shear rheometer (DSR)

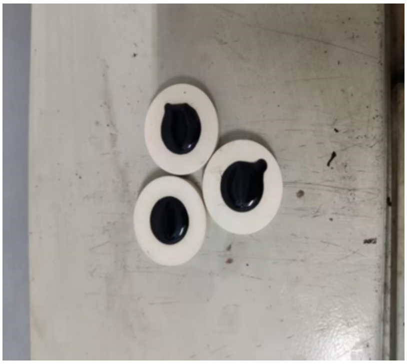

Figure 2. Modified asphalt sample

3. Analysis of Test Results

3.1 Research on Data Regularity of Rutting Factor $G^*/\sin\delta$

Based on the study of DSR temperature scan test data, this paper fitted regression according to the common formula (1) of $G^*/\sin\delta$ [14],, and the accuracy of this formula for predicting data was verified by $R^2_{(1)}$ and the results of comparing the size of the relative error value $\Delta_{G^*/\sin\delta(2)}$ between the fitted and true values of the regression. It is known from related papers that the temperature range for evaluating the high temperature performance of asphalt is mostly 52°C-76°C. Therefore, the data of rutting factor $G^*/\sin\delta$ in this temperature range is selected for regression fitting and the next law study is carried out in this paper.

$$\lg(G^*/\sin\delta) = GTS_C \bullet T + C_1 \tag{1}$$

Where: $G^*/\sin\delta$ is the rutting factor; GTS_C is the rutting factor index, T is the temperature, and C_1 is a constant.

The data temperature T of the test temperature interval (52-76) is brought into the equation in Table 1. and compared with the true value to compare the magnitude of $\Delta_{G^*/\sin\delta(2)}$. The magnitude of the $\Delta_{G^*/\sin\delta(2)}$ difference is calculated according to equation (2).

$$\Delta_{(G^*/\sin\delta)(2)} = \left| \frac{G^*/\sin\delta_{Fitting} - G^*/\sin\delta_{True}}{G^*/\sin\delta_{True}} \right| \tag{2}$$

In mathematical statistics, the significance of the coefficient of determination R^2 is an indicator of the degree of fit of the linear regression trend line, and its numerical magnitude reflects the degree of fit between the estimated value of the trend line and the corresponding actual data; the higher the degree of fit, the higher the reliability of the trend line [15].

According to Table 1, it can be seen that the values of the coefficient of determination R^2 regarding this type of formula (2) are above 0.999, infinitely close to 1, and the regression fit is very good, while it is obvious through Figure 3 that the relative error values $\Delta_{G^*/\sin\delta(2)}$ for both the $G^*/\sin\delta$ regression fit and the true value are below 6.4%, and the relative error values are very small. The prediction results meet the requirements of the specification and can be used for further experimental studies.

Table 1. Correlation regression fitting equations for $G^*/\sin\delta$ and T of different types of asphalt and $R^2_{(1)}$

$\lg\lg G^* - \lg T$	**Fitting formula**	R^2
APAO(2%)	$-0.7408\lg T + 1.9186$	0.9927
APAO(4%)	$-0.768\lg T + 1.9633$	0.9934
90#(1)	$-1.0534\lg T + 2.3850$	0.9949
90#(2)	$-0.9824\lg T + 2.2737$	0.9949

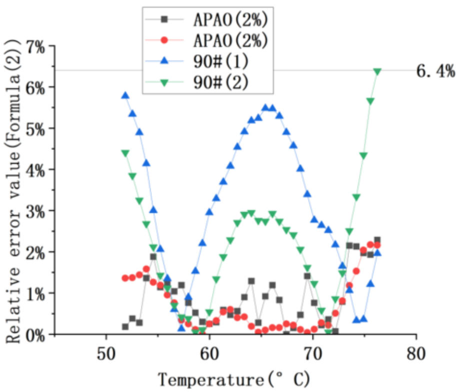

Figure 3. Relative error value $\Delta_{G^*/\sin\delta(2)}$ between regression fitting value and true value of $G^*/\sin\delta$ for different types of asphalt

The above study found that the R^2 value of the regression fit of formula: $\lg(G^*/\sin\delta) = GTS_C \bullet T + C_1$ is high and the size of the value of $\Delta_{G^*/\sin\delta}$ meets the specification, indicating that the degree of regression fit under this formula is good. This paper continues the study of this formula to study the laws of $G^*/\sin\delta$ under the temperature scan mode, if a small number of temperature intervals to predict the measured points in other temperature intervals data, saving test time and other costs at the same time, but also for the future test data to play a certain role in verification, has a very good practical value.

In this paper, we use the data from four temperature intervals of 50°C, 60°C, 70°C, 80°C, which are 10°C, and three temperature intervals of 50°C, 65°C, 80°C, which are 15°C, and use Equation (1) to fit the $G^*/\sin\delta$ values of these four points.

The values of T for the test temperature temperature interval (50-80) are brought into the regression fitting equation obtained above and compared with the true values, which are calculated by Equation (1) for $\Delta_{G^*/\sin\delta(1.3)}$.

$$\Delta_{(G^*/\sin\delta)(3)} = \left| \frac{G^*/\sin\delta_{Fitting} - G^*/\sin\delta_{True}}{G^*/\sin\delta_{True}} \right| \quad (3)$$

The smaller the difference between the fitted value of $G^*/\sin\delta$ and the true value of $\Delta_{G^*/\sin\delta}$, the closer the two are, the more the prediction meets the requirements, and the difference between the two sides should be less than 6.4% in accordance with the specification [16], which is in line with the ideal law prediction. The comparison of the data in Figure 4 and Figure 5 shows that using the data of $G^*/\sin\delta$ of the four temperature span 10°C measurement points of 50°C, 60°C, 70°C, and 80°C to predict the data of $G^*/\sin\delta$ in the temperature interval (50-80), the $\Delta_{G^*/\sin\delta(1.3)(four)}$ is below 6.5% and the maximum value of $\Delta_{G^*/\sin\delta}$ is below 6%; while using the data of $\Delta_{G^*/\sin\delta(3)(three)}$ of the three temperature span 15°C of 50°C, 65°C, and 80°C Some values of G from the °C measurement points exceeded the specification requirement of 6.4%, and some values even exceeded 9%, which did not meet the prediction requirements. Therefore, the data of the four measurement points with a temperature span of 10°C are more in line with the prediction requirements.

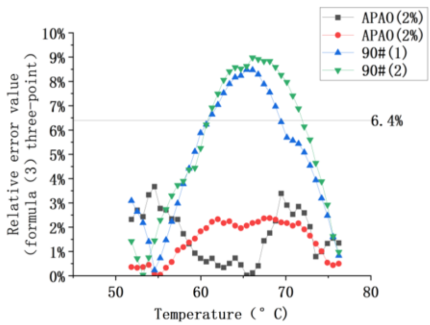

Figure 4. $\Delta_{G^*/\sin\delta(3)(three)}$ of $G^*/\sin\delta$ for different types of bitumen

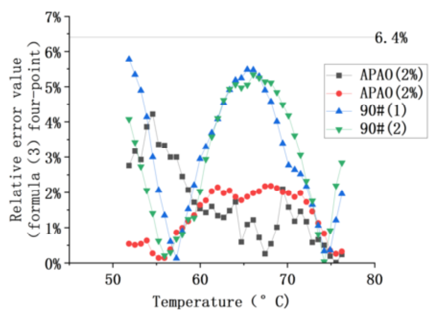

Figure 5. $\Delta_{G^*/\sin\delta(3)(four)}$ of $G^*/\sin\delta$ for different types of bitumen

Through the above test results can be seen, the use of 50 ° C, 60 ° C, 70 ° C, 80 ° C, the single four points of data derived from the $GTS_{C(four)}$ can be used as an evaluation of asphalt in the corresponding temperature range (50-80) of high-temperature performance indicators, but also the use of the four known points of data can predict the corresponding temperature range (50-80) in any unknown point $G^*/\sin\delta$ data.

3.2 Research on the Data Rule of Complex Shear Modulus G^*

Based on the above study of rutting factor $G^*/\sin\delta$, data within the same temperature interval (52-76) were selected and fitted regressions were performed using Equation (4). The accuracy of the prediction of Equation (4) was verified by $R^2_{(4)}$ and the comparison of the magnitude of the relative error value $\Delta_{G^*(5)}$ between the fitted and true values of the regression of the complex shear modulus G^*, while the next step of the law study was conducted.

$$\lg\lg G^* = GTS_F \bullet \lg T + C_2 \tag{4}$$

Where: G^* is the complex shear modulus; T is the temperature; GTS_F is the complex shear modulus index, and C_2 is a constant.

The value of the data temperature T for the test temperature interval (52-76) is brought into the equation in Table 2 and compared with the true value to compare the magnitude of $\Delta_{G^*(5)}$. The magnitude of $\Delta_{G^*(5)}$ is calculated according to equation (5).

$$\Delta_{G^*(5)} = \left| \frac{G^*_{Fitting} \text{-} G^*_{True}}{G^*_{True}} \right| \tag{5}$$

Table 2. Correlation regression fitting equations for G^* and T of different types of asphalt and $R^2_{(4)}$

$\lg\lg G^* - \lg T$	**Fitting formula**	R^2
APAO(2%)	$-0.7408\lg T + 1.9186$	0.9927
APAO(4%)	$-0.768\lg T + 1.9633$	0.9934
90#(1)	$-1.0534\lg T + 2.3850$	0.9949
90#(2)	$-0.9824\lg T + 2.2737$	0.9949

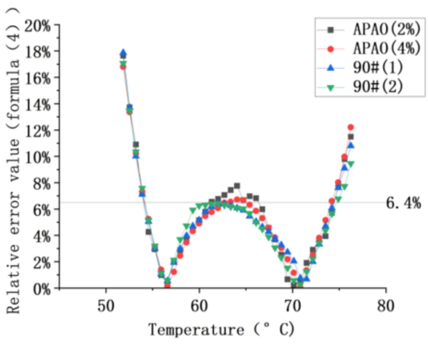

Figure 6. Relative error value $\Delta_{G^*(5)}$ between regression fitting value and true value of G^*

According to Table 2, it can be seen that the R^2 values of the regression fit formula (4) regarding the complex shear modulus $G*$ are all high and above 0.99, but the data in Figure 6 show that the values of the relative error value $\Delta_{G*(5)}$ between its regression fit and the true value are over 10% in some temperature intervals, and the values are large and the results are not satisfactory.

Through the above study, it was found that the $\Delta_{G*(5)}$ of the regression fit of $G*$ using equation (4): $\lg\lg G* = GTS_F \bullet \lg T + C_2$ is too large to meet the regression prediction requirements of the test results, while $R^2_{(1)}$ and $\Delta_{G*/\sin\delta(2)}$I of this type of equation (1): $\lg(G*/\sin\delta) = GTS_C \bullet T + C_1$ regarding the rutting factor $G*/\sin\delta$ meet the requirements.[17]

Therefore, in this paper, the complex shear modulus $G*$ is fitted to the regression using the same type of formula as the rutting factor $G*/\sin\delta$ (the relationship between the single logarithm of the object of study and the temperature T) and calculated using formula (7). The accuracy of this type of formula for predicting data is further verified by the size of the relative error value $\Delta_{G*(7)}$ between the fitted and true values of the $R^2_{(6)}$ as well as $G*$ regressions.

$$\lg G* = GTS_{F2} \bullet T + C_3 \tag{6}$$

$$\Delta_{G*(7)} = \left| \frac{G*_{Fitting} - G*_{True}}{G*_{True}} \right| \tag{7}$$

Where: $G*$ is the complex shear modulus; GTS_{F2} is the correlation coefficient about the complex shear modulus, T is the temperature, and C_3 is a constant.

Table 3. Correlation regression fitting equations for $G*$ and T of different types of asphalt and $R^2_{(6)}$

$\lg G* - T$	Fitting formula	R^2
APAO(2%)	$-0.0439T + 6.6467$	0.9999
APAO(4%)	$-0.0458T + 6.7309$	0.9999
90#(1)	$-0.0513T + 6.3238$	0.9992
90#(2)	$-0.0498T + 6.36$	0.9993

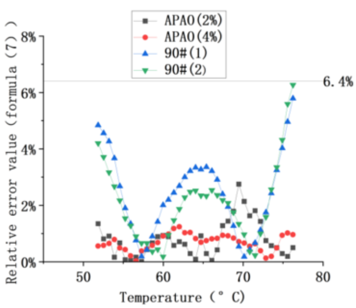

Figure 7. Relative error value $\Delta_{G*(7)}$ between regression fitting value and true value of $G*$ for different types of asphalt

According to the data in Table 3, it can be seen that the values of $R^2_{(6)}$ of $G*$ are above 0.999, and it can be seen through Figure 7 that the $\Delta_{G*(7)}$ of $G*$ are below 6.4% with a very small difference, which meets the requirements.

Through the results of the above study, it can be seen that both types of regression fitting formulas have a very good linear relationship, and both formulas can be used to evaluate the high-temperature performance of asphalt, but through the R^2 comparison of these two types of formulas, it is found that the linear fit of the commonly used formula (4) is not as good as that of formula (6). And through the comparison of the relative error value Δ_{G*} about $G*$, its formula(4) 's $\Delta_{G*(5)}$ is also relatively much larger than formula (6)'s $\Delta_{G*(7)}$ Comprehensive The results compare that formula (6) is more in line with the requirements of the study.

In summary, this type of formula: $\lg(F) = A \bullet T + C$ ((which can represent the rutting factor $G*/\sin\delta$ and the complex shear modulus $G*$) is therefore more suitable for use in these asphalt high-temperature evaluations and related experimental studies, and this type of formula is used for the next step of the law study.

Based on the study of rutting factor $G*/\sin\delta$, the study of complex shear modulus $G*$ was continued, and data from the same four measurement points of 50°C, 60°C, 70°C, and 80°C, as well as data from the three temperature span measurement points of 50°C, 65°C, and 80°C, were used to fit regressions to the values of these four points using equation (6).

The value of T for the temperature interval (50-80) is brought into the regression fitting equation obtained above and compared with the true value, and the relative error value C= is calculated by equation (8).

$$\Delta_{G*(8)} = \left| \frac{G*_{Fitting} \text{-} G*_{True}}{G*_{True}} \right| \tag{8}$$

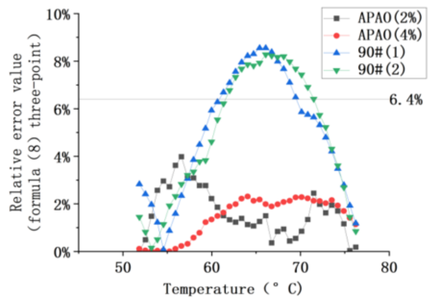

Figure 8. $\Delta_{G*(8)(three)}$ of $G*$ for different types of bitumen

It is obvious from the data in Figure 8 and Figure 9 that by comparing the fitted value of $G*$ with the true value of the relative error value $\Delta_{G*(8)}$, the value of $\Delta_{G*(8)(three)}$ is too large, so the relative error value of many data points predicted using the three measurement points with a temperature span of 15°C exceeds 6.4% and does not meet the specification requirements; while the value of $\Delta_{G*(8)(four)}$ is below the specification requirement of 6.4%, so the predicted data using the four measurement points with a temperature span of 10°C The data of the prediction only meets the requirements of the prediction. Therefore, G^* can also use the data of four known measurement points with a temperature span of 50°C, 60°C, 70°C, and 80°C to derive $GTS_{F(four)}$ as the evaluation of the high temperature performance of asphalt in the corresponding temperature range (50-80), and can also use the data of these four measurement points to predict the data of other unknown measurement points G^* in the corresponding temperature range (50-80). .

In summary, the above findings and predictions of rutting factor $G^*/\sin\delta$ and complex shear modulus G^* and are basically the same. Therefore, in future experimental studies related to $G^*/\sin\delta$ and G^*, the correlation coefficients ($G^*/\sin\delta$ or G^*) calculated and predicted from a small number of measurement points with a temperature span of about 10°C can be used to evaluate the high temperature performance of asphalt in the corresponding temperature range or to predict the data of any unknown point.

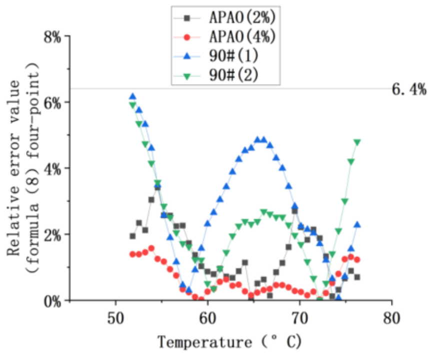

Figure 9. $\Delta_{G^*(8)(four)}$ of G^* for different types of bitumen

4. Conclusion

(1) The common evaluation formula of complex shear modulus G^* : R^2 of $\lg\lg G^* = GTS_F \bullet \lg T + C_2$ and the relative error values of fitted and true values Δ_{G^*} do not meet the prediction requirements, but this type of formula: R^2 of $\lg(F) = A \bullet T + C$ (F can refer to $G^*/\sin\delta$ or G^*) and the relative error values of fitted and true values meet the test requirements better and are therefore more suitable for use in the evaluation of asphalt high temperature performance and the prediction of data at unknown points.

(2) Relative to the data of three measurement points with a temperature span of 15°C (50°C, 65°C, 80°C), it is more accurate to predict the data of G^* and $G^*/\sin\delta$ at any temperature within 50-80°C using the data of four measurement points (50°C, 66°C, 70°C, 80°C) G^* and $G^*/\sin\delta$ with a temperature span of 10°C, and the size of the relative error value meets the specification of less than This regression prediction method is easier and more accurate than the traditional asphalt high-temperature performance testing methods in terms of sample preparation, data

collection and time spent, and This regression prediction method is simpler and more accurate than the traditional asphalt high-temperature performance testing methods in terms of sample preparation, data collection and time spent, and greatly reduces the test time and simplifies the asphalt high-temperature performance determination process.

(3) Due to the limited nature and limitations of the asphalt samples used in this paper, the extension of this method to other types of asphalt applications requires a large number of asphalt test samples for validation.

References

[1] Zhou Zhixiong. Study on the effect of filler on high and low temperature performance of asphalt mastic and prediction of asphalt mastic performance[D]. Hunan University, 2013.

[2] Yuan Zuguang. Study on the effect of wet, hot and light coupled environment on the performance of rubber modified asphalt and mixes in Guangxi[D]. Guangxi University, 2020. DOI:10.27034/d.cnki.ggxiu.2020.002356.

[3] Zhu B, Song H. Study on the dynamic mechanical properties of cement emulsified asphalt mortar under the action of water and temperature [J]. New Building Materials, 2022,49 (06): 6-11

[4] Lin Jiangtao, Fan Liang, Ma Shijie, Wang Wenxu. Dynamic mechanical behavior analysis of SBS modified asphalt under temperature scanning [J]. New Building Materials, 2012, 39 (08): 39-41

[5] Uwanuakwa Ikenna D.,Adamu Musa,Ali Shaban Ismael Albrka,Akpinar Pinar,Hasan Mohd Rosli Mohd,Shariff Khairul Anuar,Umar Ibrahim Khalil,Haruna S. I.. Effect of polymer molecular weight on the rheology of SBS polymer-modified asphalt binder[J]. Innovative Infrastructure Solutions,2023,8(3).

[6] Tembe Eugénio,Tamele Lucas,Buonocore Giovanna,Madivate Carvalho,Muiambo Herminio. Rheological and Thermo-Oxidative Aging Properties of Asphalt Modified with a Combination of Sasobit and Linear Low-Density Polyethylene[J]. Sustainability,2023,15(5).

[7] Wang ZJ, Zhang SHH, Li R, Long J. Study on the temperature sensitivity of domestic AH-90 heavy traffic road asphalt [J]. Petroleum Asphalt, 2002 (03): 6-9

[8] Hongmei Cai. Evaluation of the applicability of temperature sensitivity indicators for petroleum asphalt [J]. China Port Science and Technology, 2022,4 (01): 37-42

[9] Wu W-L, Dai S-L, S-L. Study on the rheological and temperature sensitive properties of regenerated asphalt from furfural extraction oil [J]. Journal of Zhengzhou University (Engineering Edition), 2022,43 (03): 52-58+66. DOI: 10.13705/j.issn.1671-6833.2022.03.005

[10] Meng YJ, Xi CC, QinYue, XuRuGuang, RongHongLiu. High temperature flow characteristics and temperature sensitivity of high viscosity modified asphalt [J]. New Building Materials, 2020, 47 (01): 145-149

[11] Lin Jiangtao, Liang Hao, Fan Liang. Experimental study on high and low temperature performance of asphalt based on time and frequency scanning [J]. Journal of Building Materials, 2018, 21 (03): 516-522

[12] Sinan HINISLIO Ğ LU. OPTIMIZATION OF THE TEMPERATURE SUSCEPTIBILITY OF BITUMEN MODIFIED WITH WASTE TIRE RUBBER BY TAGUCHI METHOD[J]. Erzincan Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 2014(1).

[13] Wang LJ, Liu KY. Rheological properties and microscopic distribution states of amorphous α-olefin copolymer/butadiene rubber composite modified asphalt[J]. Synthetic Rubber Industry, 2022,45 (01): 29-34. DOI: 10.19908/j.cnki. ISSN1000-1255.2022.01.0029."

[14] Guo Yongmei. Using DSR to evaluate the temperature sensitivity of modified asphalt in high-temperature areas [J]. Science and Technology and Engineering, 2012, 12 (36): 9890-9893

[15] Tang Youmian Research on Dynamic Mechanical Parameters of Asphalt Mixture for Xinjiang Highway Asphalt Pavement [D]. Xinjiang Agricultural University, 2017. DOI: 10.27431/d.cnki.gxnyu.2017.000301

[16] Shi Yuefeng Preparation and Performance Study of Modified Asphalt from Direct Coal Liquefaction Residue [D]. Beijing University of Architecture, 2017

[17] Amit Kumar,Kamal Kumar,Indu Shekhar,Manoj Thapliyal,Manoj Srivastava. Preparation of Petroleum Pitch and its Application in Making Bitumen with Improved Rheological Behaviour[J]. Indian Journal of Chemical Technology,2019,26(5).