Study on Evaluation Index of Anti-skid Performance of GAC-16 Asphalt Pavement Based on Temperature Correction

Qian Fan 1,2, *, Xinquan Xu 1, Chupeng Chen 1, Feng Liu 1
1 Guangdong Hualu Transportation Technology Co., Ltd., Guangzhou 510420, China
2 Guangdong Transportation Technology Testing Co., Ltd., Guangzhou 510550, China

*Corresponding author email: fanqian@scut.edu.cn

Abstract. Based on the study of temperature correction of british pendulum number (BPN) of GAC-16 asphalt mixture, the correlation between sideway force coefficient (SFC), british pendulum number (BPN) and mean texture depth (MTD) is studied. And the international friction index (IFI) calculated by different indexes is compared and analyzed. The result shows that the dry surface temperature is preferred for the temperature correction of the BPN of GAC-16 asphalt mixture. When conditions do not permit, such as rain weather, the temperature correction of the BPN may be considered by using the wet surface temperature. There is a good linear correlation between the SFC and the BPN. In the section where it is not convenient to test the SFC, the BPN can be used for the preliminary determination of the SFC. It is suggested to use the IFI calculated by the "MTD + BPN modified by the dry state surface temperature" to comprehensively evaluate the anti-skid performance.

Key words: road engineering; asphalt mixture; anti-skid performance; temperature correction; international friction index.

1. Introduction
At present, the main evaluation indexes of skid resistance of pavement in China are sideway force coefficient (SFC), british pendulum number (BPN) and mean texture depth (MTD), etc [1-3]. The SFC index is tested by a large-scale lateral force coefficient testing vehicle, which has a fast test speed, but can not be used to test the skid resistance of the indoor specimens. The british pendulum number tester is used to measure the BPN index, which represents the friction coefficient of the road under the condition of low speed (10km/h). It is suitable for indoor and real engineering, but the test speed is slow and the test process needs to be closed to traffic. The MTD index is tested by sand spreading method or laser texture tester, which is suitable for indoor and solid engineering [4-5].

According to the Specification for Design of Highway Asphalt Pavement (JTG D50-2017), when expressway and first-grade highway are handed over for acceptance, the main indexes of the pavement skid resistance performance are SFC and MTD [6]. In the standard of asphalt pavement maintenance quality stipulated in the Technical Specifications for Maintenance of Highway Asphalt Pavement (JTJ 073.2-2019), SFC and BPN are used as the main indexes for anti-skid performance, and SFC or BPN is used to divide the evaluation grade of anti-skid ability [7]. In recent years, most researchers choose 1 ~ 2 evaluation indexes to study the skid resistance of asphalt pavement. Xie Xiaoguang et al. [8] studied
the skid resistance of SMA asphalt mixture by using the BPN and MTD, and proposed the differential abrasion principle that can improve the skid resistance of SMA asphalt mixture. Meng Yongjun et al. [9] carried out a study on the relationship between BPN and pavement type, ice thickness, wheel load action times, and tire pressure, revealing the potential law of various factors and anti-skid performance of asphalt mixture. Zhao Xuetao [10] carried out the applicability, difference and correlation analysis of SFC and MTD. Zhi Yufeng et al. [11] carried out a study on the change law of the SFC of SMA asphalt pavement based on solid engineering, and put forward relevant measures to ensure the anti-skid performance of the handover inspection stage. It is obvious that the diversity of pavement anti-skid performance test methods and evaluation indicators causes the pavement's anti-skid performance to not be directly comparable.

In order to ensure the uniformity of the anti-skid evaluation index of asphalt pavement, PIARC of the World Road Association put forward the comprehensive evaluation index of anti-skid performance—International Friction Index, which has been recognized by some scholars. Zhang Xingpeng and Wang Duxing et al. [12-13] established the CTM-DFT model of the pavement coarse structure detection equipment through a comparative study with MTD-DFT model in PIARC test, which can be used for the conversion of international friction index. Jia Jinxiu et al. [14] preliminarily calculated the required value of China's cement concrete pavement with the international friction index as the standard value by using MTD and SFC. However, few researchers use SFC, BPN and MTD, which are widely used in China, to calculate and analyze the international friction index, and there is no correlation study on the international friction index calculated by different anti sliding evaluation indexes. Therefore, this paper takes GAC-16 asphalt mixture, which is widely used in Guangdong Province, as the research object. Based on the BPN temperature correction study, the correlation between SFC, BPN and MTD is studied, and the international friction index calculated by different indexes is compared. The results show the correlation of skid resistance evaluation index, which can provide reference for the selection of test method of skid resistance of asphalt mixture, evaluation and comparison of skid resistance of asphalt pavement.

2. Materials and mixing proportion

2.1. Materials

(1) The coarse aggregate adopts two kinds of diabase from a quarry in Guangdong province and a quarry in Hunan Province respectively, the fine aggregate adopts limestone and diabase manufactured sand respectively, and the filler adopts limestone ore powder. The main technical index requirements all meet the requirements of the current Technical Specification for Construction of Highway Asphalt Pavement.

| Test Indicators            | Diabase from Hunan Province | Diabase from Guangdong province | Technical Requirements |
|----------------------------|-----------------------------|---------------------------------|------------------------|
| Apparent relative density  | 2.854                       | 3.022                           | ≥2.60                  |
| Water absorption /%        | 0.47                        | 0.3                             | ≤2.0                   |
| Crushing value /%          | 12.6                        | 9.5                             | ≤26                    |
| Los Angeles abrasion loss /% | 10.6                       | 13.3                            | ≤28                    |
| Polishing value /%         | 45                          | 44                              | ≥42                    |

(2) Asphalt adopts SBS modified asphalt, and its main technical indicators meet the requirements of the current Technical Specifications for Construction of Highway Asphalt Pavements.

| Test Indicators               | Measured Values | Technical Requirements |
|-------------------------------|-----------------|------------------------|
| Penetration (25℃, 100g, 5s)/ 0.1mm | 53.0            | 40–60                  |
| Ductility (5℃, 5cm/min)/ cm    | 28.0            | >20                    |
| Softening Point / ℃            | 89.0            | ≥60                    |
2.2. Mixing Proportion

Three schemes are adopted to design the mixture ratio of GAC-16 asphalt mixture. Scheme 1: Use Hunan diabase as coarse aggregate and limestone as fine aggregate; Scheme 2: Use Guangdong diabase as coarse aggregate and diabase as fine aggregate; Scheme 3: Use Guangdong diabase as coarse aggregate and limestone as fine aggregate. The mixture grading curves of the three schemes are shown in Figure 1.

![Grading curve](image)

**Fig. 1** Grading curve

3. Test scheme

3.1. Laboratory test scheme

In order to study the influence of temperature on the BPN, the British pendulum number tester, temperature sensor and temperature gun were used to track and observe the BPN and test temperature of asphalt mixture specimens at different times. The main test schemes are as follows:

(1) GAC-16 asphalt mixture rut plate specimens were formed by three schemes. The middle strip contour was taken as the test part along the forming direction of the specimens and marked with marker pen.

(2) The rut plate specimens are placed on the cement floor in a row, the temperature sensor is installed on the bottom of the specimen, and the sensor is bonded firmly with high viscous asphalt. Cement mortar is used to fix all sides of the rut plate specimens. Temperature sensor is installed in the atmospheric environment beside the specimen, and no contact with other objects is ensured to ensure the accuracy of the temperature data.

(3) The slide block of the British pendulum number tester is aligned with the mark position, and the preliminary preparations such as leveling, zero adjustment and sliding length adjustment are carried out.

(4) Perform 6 consecutive BPN tests. The temperature gun is used to simultaneously test the surface temperature in dry state and wet state, and record the temperature readings at the testing time.

(5) Excluding the first test results, if the difference between the maximum value and the minimum value in the last five test results is not more than 3, the average value is taken as the BPN test result, otherwise, the reason should be found out and the test should be conducted again.

(6) Under different temperature conditions, the tracking test of BPN of the rut plate specimens is carried out; and based on the temperature and the test data of BPN, the temperature correction study of the BPN of GAC-16 asphalt mixture is carried out.

3.2. Field test scheme

In order to study the correlation among SFC, BPN and MTD, the SFC detector, British pendulum number tester and sand laying method were used to track and observe the test section. The main test schemes are as follows:
(1) Three schemes are adopted to pave the test section of GAC-16 asphalt pavement anti-skid surface on site, and the test section length of each scheme is about 60m.

(2) The SFC, BPN and MTD indexes of the slow lane and hard shoulder of the test section are tested by the sideway force coefficient testing vehicle, british pendulum number tester and sand laying method before, half a year and one year after the opening of the road; during the BPN test, the temperature gun is used to simultaneously detect the dry and wet road surface temperature of the test points.

(3) During the anti-skid performance test, the slow lane and hard shoulder were closed to ensure that the BPN and MTD test points are on the wheel track belt of the SFC test theory, and the test pile numbers can completely correspond.

(4) The test speed of SFC is 50km/h, one data is output every 10m, and the average value of two tests is taken as the final test result. During the BPN test, one spot is measured every 10m, and three measurement points are selected in parallel for each spot, and the average value of the three measurement points is taken as the final test result. During the MTD test, one data is output every 10m, and the average value of the two tests is taken as the final test result.

(5) The correlation among SFC, BPN and MTD indexes was analyzed to determine the feasibility of using laboratory mixed rutting board BPN and MTD to predict field SFC.

4. Analysis of test results

4.1. Temperature correction analysis of BPN
Based on the measured data, classify the BPN data per unit temperature change range, and establish the BPN and atmospheric temperature ($T_1$), dry surface temperature ($T_2$), and wet state of GAC-16 asphalt mixture formed by three schemes. The scatter plot of the surface temperature ($T_3$) and the bottom temperature of the specimen ($T_4$), and perform linear fitting. The linear fitting results are shown in Figure 2~Figure 4.

Fig. 2 Linear fitting results of BPN and temperature of GAC-16 (Scheme 1)

Fig. 3 Linear fitting results of BPN and temperature of GAC-16 (Scheme 2)
Fig. 4 Linear fitting results of BPN and temperature of GAC-16 (Scheme 3)

The linear fitting parameters of the BPN of GAC-16 asphalt mixture with air temperature ($T_1$), dry surface temperature ($T_2$), wet surface temperature ($T_3$) and bottom temperature ($T_4$) are summarized. The results are shown in Table 3.

Table 3. Linear fitting parameters of BPN and temperature of GAC-16 asphalt mixture

| Temperature          | Scheme 1                        | Scheme 2                        | Scheme 3                        |
|----------------------|---------------------------------|---------------------------------|---------------------------------|
| Air temperature $T_1$| $BPN=71.3-0.238T$ $R^2=0.73$    | $BPN=67.6-0.238T$ $R^2=0.64$    | $BPN=66.8-0.293T$ $R^2=0.72$    |
| Dry surface temperature $T_2$ | $BPN=73.2-0.274T$ $R^2=0.91$    | $BPN=67.4-0.180T$ $R^2=0.81$    | $BPN=70.3-0.356T$ $R^2=0.83$    |
| Wet surface temperature $T_3$ | $BPN=74.6-0.339T$ $R^2=0.80$    | $BPN=70.4-0.279T$ $R^2=0.76$    | $BPN=71.7-0.438T$ $R^2=0.81$    |
| Bottom temperature $T_4$ | $BPN=71.5-0.232T$ $R^2=0.54$    | $BPN=72.2-0.354T$ $R^2=0.76$    | $BPN=70.2-0.391T$ $R^2=0.79$    |

It can be seen from Figure 2–Figure 4 and Table 3:

(1) With the increase of test temperature, the BPN of GAC-16 asphalt mixture shows a downward trend. Based on this, the linear fitting relationship between BPN of GAC-16 asphalt mixture and temperature is established, as shown in Table 3.

(2) The BPN of GAC-16 asphalt mixture has the best linear correlation with dry surface temperature ($T_2$), the correlation coefficient can reach 0.8 ~ 0.9. The linear correlation with wet surface temperature ($T_3$) is second, the correlation coefficient can reach 0.7 ~ 0.8. The linear correlation with air temperature ($T_1$) and the bottom temperature ($T_4$) of the test piece is the worst, and the correlation coefficient can be more than 0.5. Considering the needs of field testing, it is recommended that the dry surface temperature be used for the temperature correction of the GAC-16 asphalt mixture; when conditions such as rain are not allowed, the wet surface temperature can be considered for the temperature correction of BPN.

(3) When the dry surface temperature increases by 1°C, the BPN of the three GAC-16 asphalt mixtures decreases by 0.274, 0.180, and 0.356. In order to facilitate further research, the average value of 0.270 is taken as the unit temperature correction value of the BPN of GAC-16 asphalt mixture.

(4) When the wet surface temperature increases by 1°C, the BPN of the three GAC-16 asphalt mixtures decreases by 0.339, and 0.279, 0.438. In order to facilitate further research, the average value of 0.352 is taken as the unit temperature correction value of the BPN of GAC-16 asphalt mixture.

4.2. Correlation analysis of anti-skid performance evaluation indexes

4.2.1. Correlation between SFC and BPN. Based on the BPN and SFC measured in the field and the corresponding dry and wet surface temperature data, the current Field Test Methods of Subgrade and Pavement for Highway Engineering (JTG E60-2008) [15] are adopted to modify the velocity and temperature of the field SFC test results. According to the regulations and the research results of this
paper, the test results of the field BPN were modified and converted into the value of the standard temperature of 20°C.

Based on the above calculation results, the SFC and modified BPN scatter plots of GAC-16 asphalt mixture were established respectively, and linear fitting was carried out. The fitting results were shown in Figure 5~Figure 7.

It can be seen from Figure 5~Figure 7:
(1) There is a good linear correlation between the SFC and the BPN, and the correlation coefficient can reach more than 0.75. It can be considered that in general, the greater the BPN, the greater the SFC.

(2) The correlation between the SFC and the BPN modified by the dry surface temperature is the best, with a correlation coefficient of 0.78; slightly better than the correlation between the BPN modified by the standard method, with a correlation coefficient of 0.76; also better than the correlation between the BPN modified by the wet surface temperature, with a correlation coefficient of 0.75.

(3) The relationship between the SFC and the BPN of GAC-16 asphalt pavement can be simply expressed as: \( \text{BPN} = 0.5 \times \text{SFC} + 34 \). For every 1 increase in the SFC of asphalt pavement, the BPN increases by about 0.5. When \( \text{BPN} < 68 \), \( \text{BPN} > \text{SFC} \); When \( \text{BPN} \geq 68 \), \( \text{BPN} \leq \text{SFC} \). In the section where it is not convenient to test the SFC, the BPN can be used for the preliminary determination of the SFC.

4.2.2. Correlation of MTD with SFC and BPN. Based on the test results of the anti-skid performance of the section in the field test, the MTD was taken as the horizontal coordinates, and the modified GAC-16 asphalt mixture BPN and SFC were taken as the vertical coordinates respectively to draw the scatter plot. The results are shown in Figure 8 and Figure 9.

![Fig. 8 Scatter diagram of MTD and BPN of temperature correction](image1)

![Fig. 9 Scatter diagram of MTD and SFC of temperature correction](image2)

It can be seen from Figure 8 and Figure 9 that there is no obvious correlation between the MTD and the BPN and the SFC. It may be mainly due to the difference in emphasis, that is, the BPN and SFC mainly reflect the fine pavement structure, while the MTD mainly reflects the coarse pavement structure.
4.2.3. Calculation and comparative analysis of international friction index. In order to fully reflect the fine and coarse pavement structure, the comprehensive indexes of "SFC + MTD" or "BPN + MTD" are considered to evaluate the anti-skid performance of asphalt pavement. The international friction index is an anti-skid performance evaluation index that comprehensively reflects the MTD and friction coefficient of the road surface. It is composed of friction number F60 and speed number SP [12-13]. This study uses MTD and BPN, MTD and SFC to calculate the international friction index value, and studies the correlation of the international friction index calculated by the two methods.

The calculation process of the international friction index [16]:

(1) Calculate the speed number based on the MTD of the road structure

\[ S_p = a + b \times \text{MTD} \]

Where, SP is the speed number, MTD is the construction depth, and a and b are the relevant parameters of the construction depth test equipment or method (clearly given in the PIARC report).

(2) The friction coefficient (SFC, BPN, etc.) is converted into the friction coefficient of the standard velocity (60km/h) \( \text{FR}_{60} = \text{FR}_S \times e^{\frac{(50-60)}{S}} \).

Where, \( \text{FR}_{60} \) is the friction coefficient converted into standard velocity, \( \text{FR}_S \) is the friction coefficient measured when the velocity is S, and S is the test velocity. If the test wheel of the friction coefficient testing equipment has a deflection angle, then \( S = V \times \sin \alpha \), where V is the vehicle driving speed and \( \alpha \) is the deflection angle of the test wheel.

(3) Calculate the friction index,

\[ \text{F}_{60} = A + B \times \text{FR}_{60} + C \times \text{MTD} \]

Where, \( \text{F}_{60} \) is the friction index, A, B and C are the relevant parameters of the friction coefficient test equipment or method (clearly given in the PIARC report), and if the test wheel is a smooth tire, then C=0.

The international friction indexes F1, F2, and F3 were calculated by using the MTD and BPN modified by regulations, the MTD and BPN modified by dry surface temperature, and the MTD and BPN modified by wet surface temperature, respectively. And F1, F2, and F3 were taken as the horizontal coordinates. The international friction index \( \text{F}_4 \) calculated by the MTD and the modified SFC was taken as the vertical coordinates. The scatter plot was established and the linear fitting was carried out, and the results were shown in Figure 10 – Figure 12. Where, the SFC in the calculation of international friction index adopts the value of SFC/100 measured by SCRIM test vehicle.
It can be seen from Figure 10~Figure 12:

(1) There is a good linear correlation between the international friction index $F_4$ calculated by using MTD and SFC and the international friction index $F_1$, $F_2$, $F_3$ calculated by using MTD and BPN.

(2) The correlation between the international friction index $F_2$ and $F_4$ is the best, with a correlation coefficient of 0.79; slightly better than the correlation between the international friction index $F_1$ and $F_4$, with a correlation coefficient of 0.78; also better than the correlation between the international friction index $F_3$ and $F_4$, with a correlation coefficient of 0.76. Therefore, when it is inconvenient to carry out SFC, it is recommended to use the international friction index calculated from the "MTD and BPN modified by dry surface temperature" for comprehensive evaluation of anti-skid performance.

(3) There is a significant difference between the international friction index $F_4$ calculated by MTD and SFC and the international friction indexes $F_1$, $F_2$ and $F_3$ calculated by MTD and BPN.

5. Conclusions

(1) Considering the accuracy of temperature correction and the convenience of field testing, it is suggested that the temperature correction of GAC-16 asphalt mixture BPN should be preferred by the dry surface temperature. In rainy days and other conditions do not allow, the wet surface temperature can be considered to modify the temperature of BPN. The BPN of GAC-16 asphalt mixture decreases by 0.270 and 0.352 for each increase of 1°C in dry and wet surface. This value can be used as the unit temperature correction value of the BPN of GAC-16 asphalt mixture.

(2) There is a good linear positive correlation between the SFC and the BPN, and the temperature correction with dry surface temperature has the best correlation with the SFC. For every 1 increase in the SFC of GAC-16 asphalt pavement, the BPN increases by about 0.5. In sections where the detection of the SFC is not convenient, the BPN is recommended for the initial judgment of the SFC.

(3) The international friction index calculated by the MTD and SFC has the best correlation with the international friction index calculated by the BPN modified by dry surface temperature and MTD. When it is inconvenient to carry out SFC, it is recommended to use the international friction index calculated from the "MTD and BPN modified by dry surface temperature" for comprehensive evaluation of anti-skid performance.

References

[1] Zhu Hongzhou, Liao Yiyuan. Present situations of research on anti-skid property of asphalt pavements[J]. Highway, 2018, 63(01): 35-46.

[2] Zhao Xiangmin. Research on Testing Method of Anti-skid Performance of Asphalt Pavement of Expressway [J]. East China Highway, 2019(01): 55-57.

[3] Sun Jiawei. [J]. Discussion on Anti-skid Index of Asphalt Concrete Pavement[J]. Highway, 2006(08): 278-280.

[4] Li Zhiqiang. Comparison of different evaluation indices and test methods for skid resistance of asphalt pavement[J]. Road Machinery & Construction Mechanization, 2018, 35(01): 111-115.
[5] Liu Mingwen, Ding Zuochang, Chen Guanhua, et al. Experimental study on skid resistance of asphalt pavement surface course[J]. Journal of China & Foreign Highway, 2011, 31(01): 62-65.

[6] Ministry of transport of the people's Republic of China. Specification for design of highway asphalt pavement: JTG D50-2017[S]. Beijing: China Communications Press, 2017.

[7] Ministry of transport of the people's Republic of China. Technical specifications for maintenance of highway asphalt pavement: JTG 5142-2019[S]. Beijing: China Communications Press, 2019.

[8] Xie Xiaoguang, Liu Dongxu, Chen He. Evaluation index of long-term skid resistance property of asphalt pavement[J]. Journal of Harbin Institute of technology, 2020(09): 1-6.

[9] Meng Yongjun, Lu Zubiao, Guo Heyuan, et al. Analysis of anti-sliding performance of iced asphalt pavement in north Guangxi area[J]. Highway, 2019, 64(12): 10-14.

[10] Zhao Xuetao. Research on detection and evaluation method of friction coefficient of highway pavement[J]. Transpoworld, 2019(23): 56-58.

[11] Zhi Yufeng, Su Kangxiang. Study on the change regular of SMA pavement coefficient of friction in rainy area of south China[J]. Highway Engineering, 2019, 44(03): 176-180.

[12] Zhang Xingpeng, Huo Jiantao, Zhang Ying. Experimental study on international friction index IFI[J]. Science & Technology Information, 2009(21): 436-437.

[13] Wang Duxing, Liu Honghui, Jia Jinxiu. Determination of international friction index by CTM and DFT[J]. Journal of China & Foreign Highway, 2009, 29(01): 53-57.

[14] Jia Jinxiu, Liu Honghui, Yang Hong. Establishment and application of international friction index[J]. Subgrade Engineering, 2009(04): 28-29.

[15] Ministry of transport of the people's Republic of China. Field test methods of subgrade and pavement for highway engineering: JTG E60-2019[S]. Beijing: China Communications Press, 2019.

[16] Liu Honghui. Study on the index and methods for the skid resistance performance of cement concrete pavement[D]. Xi'an, Chang'an University, 2009.