An Infrared Image Based Asphalt Temperature Separation Evaluation Model

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Abstract. This article points out the shortcomings of the NACT assessment index based on infrared images. In order to develop a new method for evaluating temperature separation, this article proposes two influencing factors, namely, a different temperature interval and a low temperature zone based on NACT temperature difference. For the temperature interval, three kinds of asphalt mixtures, AC-13, AC-16 and AC-20, are used to study the change of void ratio at different molding temperatures and obtain the temperature separation evaluation method based on the difference of void ratio in the internal test and obtain the TIC (Temperature Influence Coefficient) for different temperature intervals by conversion; for the low temperature zone, the influence coefficient δ for the low temperature zone is obtained by simulation analysis. By combining TIC and δ, TSSI (Temperature Separation Status Index) is obtained.

1. Introduction
The current temperature separation is mainly evaluated by the NCAT index [1], it is difficult to reconcile this evaluation criterion with the actual conditions of temperature splitting in construction. It was found that when the initial compaction temperature is controlled above a certain reasonable temperature value, there is still a significant temperature difference between different areas of the mixture, but the effect on the final compaction quality is minimal. When the initial pressure temperature is below a certain compaction temperature of the mixture, the compaction of the mixture is significantly lower regardless of the size of the temperature difference, it is difficult to meet the construction requirements. At the same time, the different regions of the low temperature zone also have different influence on the temperature separation [2]. Therefore, in this article, the influencing factors for the evaluation of temperature separation are divided into the following two points: (a) The temperature interval of asphalt mixture. (b) The size of the low temperature zone area of the mixture.

2. Influencing factors

2.1. Molding temperature

2.1.1 Void ratio difference and molding temperature. The molding temperature was set as the upper limit of the optimum compaction temperature of 150°C (T_70) and the lower limit of 90°C with an interval of 10°C. The void ratio of AC-13, AC-16 and AC-20 Marshall samples were measured. In this article, the void ratio at the optimum compaction temperature is used as the standard value, and the difference between the void ratios of different molding temperatures relative to the standard void ratio is calculated,
as shown in table 1.

**Table 1.** Void ratio and void ratio difference for different molding temperatures.

| Mixture Type | Temperature(℃) | T70 | T70-10 | T70-20 | T70-30 | T70-40 | T70-50 | T70-60 |
|--------------|----------------|-----|--------|--------|--------|--------|--------|--------|
| AC-13        | Void ratio (%) | 3.9 | 4.1    | 4.5    | 5.4    | 6.3    | 7.0    | 8.1    |
| AC-16        | Void ratio (%) | 3.9 | 4.1    | 4.7    | 5.8    | 6.9    | 7.4    | 8.4    |
| AC-20        | Void ratio (%) | 4.2 | 4.5    | 4.9    | 5.9    | 6.8    | 7.6    | 8.7    |
| AC-13        | Void ratio difference(%) | 0   | 0.2    | 0.6    | 1.5    | 2.4    | 3.1    | 4.2    |
| AC-16        | Void ratio difference(%) | 0   | 0.2    | 0.8    | 1.9    | 3.0    | 3.5    | 4.5    |
| AC-20        | Void ratio difference(%) | 0   | 0.3    | 0.7    | 1.7    | 2.6    | 3.4    | 4.5    |

The optimum compaction temperature 150℃ was set off from the molding temperature 150℃~90℃ to obtain the temperature difference range of 0℃~60℃, and the temperature difference range was used as the horizontal coordinate. The overall binomial fit of the three asphalt mixtures for the difference in void ratio resulted in a correlation coefficient of 0.9821, as shown in equation (1.1).

\[ y = 0.0007x^2 + 0.0323x \]  

(1.1)

2.1.2 Coefficient of the influence of the temperature zone. In contrast to the internal test method presented here, the change in void ratio of pavements at different construction temperatures has been studied by previous authors, as shown in figure 1[3]. The data on the change of void ratio at different construction temperatures are more discrete and random, and the difference of void ratio at similar temperatures can be up to 2%. This is because the variation of void ratio in actual pavement construction is influenced by various factors such as aggregate segregation, temperature separation, and construction quality [4].

![Figure 1](image-url)  

**Figure 1.** Variation of pavement void ratio at different initial pressure temperatures [3].
Table 2. Evaluation method of temperature separation based on the difference of void ratio of internal test.

| Degree of dissociation | No dissociation | Light dissociation | Medium dissociation | Severe dissociation |
|------------------------|-----------------|-------------------|--------------------|--------------------|
| Void ratio difference (%) | <0.8 | 0.8~1.5 | 1.5~2.2 | >2.2 |

In conjunction with equation (1.1), the effect of the different temperature zones of the mixture on temperature separation is divided, as shown in table 3. The temperature below Ti-18°C has a different effect on the temperature separation, so the temperature zone below Ti-18°C is referred to as the low temperature zone in this work.

The TIC (Temperature Influence Coefficient) is divided for the temperature zones with different influence levels. First, TIC is defined as 1 for the temperature zone with severe influence and TIC is defined as 0 for the temperature zone without influence. The TIC for the temperature zone with light and medium influence is combined with table 2 and equation (1.3).

\[
TIC = \frac{MSS - NS}{SS - NS} \quad (1.3)
\]

SS - the limit value of the void ratio difference of severe segregation, assumed 2.2%.
NS - the limit value of the void ratio difference of no dissociation, assumed 0.8%.
MSS - mean value of the void ratio difference of each segregation degree, 1.15% for light segregation and 1.85% for medium segregation.

Table 3. Temperature zone influence coefficients for different temperature zones.

| Degree of influence | No impact | Light impact | Medium impact | Severe Impact |
|---------------------|-----------|--------------|---------------|--------------|
| Temperature zone (°C) | >Ti-18 | Ti-29~Ti-18 | Ti-38~Ti-29 | <Ti-38 |
| Temperature zone influence coefficient (TIC) | 0 | 0.25 | 0.75 | 1 |

2.2. Low temperature zone

Previous studies have found that the elastic modulus of asphalt mixtures decreases rapidly as the void ratio increases [5][6]. In this article, with the help of finite element software (COMSOL), the force deformation conditions in the low temperature zone, i.e. the region with low elastic modulus, for different area sizes under the action of live loads are analyzed by simulation.

The deformations at the center of different low elastic modulus regions range from 0.24836mm to 0.28360mm, and the overall difference is not significant. All deformations are simultaneously subtracted from the deformation under the normal modulus of 0.24836 mm. The scatter plot of the area with low elastic modulus and the deformation increment is plotted on the area of 706.5cm², and the two curves can be well fitted with the correlation coefficients \( R^2 \) of 0.9875 and 0.998, respectively. The segmentation function DI (Deformation increment) of the relationship between different area sizes and deformation increments in the area with low elastic modulus is obtained as shown in equation (1.4).

\[
DI(s) = \begin{cases} 
0.0046\ln(s) - 0.0031 & s \leq 706.5 \\
0.0014\ln(s) + 0.0177 & s > 706.5
\end{cases} \quad (1.4)
\]

The low temperature zone factor is added to the model and combined with the actual infrared image to propose the low temperature zone influence factor \( \delta \), as shown in equation (1.5).

\[
\delta = \frac{DI(s)}{DI(s_0)} \quad (1.5)
\]
s - area of low temperature zone.
\( s_Ω \) - area of the road surface captured by the infrared image.

3. Temperature dissociation evaluation index model

3.1. Infrared image analysis

![Figure 2. Distribution of different temperature zones on the road surface.](image)

In figure 2 (a), the number of blocks containing slightly influenced temperature zones \( i \) is 63, and the number of blocks containing moderately influenced temperature zones \( i \) in figure 2 (b) is 17. In this article, the temperature zone and area size of each low temperature zone are analyzed, and the analysis results are used as the influence value of a single low temperature zone on temperature segregation. Then the influence value of each low temperature zone on temperature segregation is summed up, and finally the total influence of all low temperature zones on temperature segregation is obtained, so that an infrared thermography-based temperature segregation evaluation model can be constructed.

3.2. TSSI

TSSI is suggested by previous research on TIC and \( \delta \). As shown in equation (2.1).

\[
TSSI = \sum_{i=1}^{3} TIC_i \delta_{i1} \gamma_{i1} + \sum_{i=0}^{2} TIC_i \delta_{i2} \gamma_{i2} + \sum_{i=0}^{1} TIC_i \delta_{i3} \gamma_{i3} \quad (2.1)
\]

1, 2, 3 - denote the slightly influenced temperature zone, the moderately influenced temperature zone, and the severely influenced temperature zone, which are collectively referred to as \( \lambda \).

TIC\( \lambda \) - temperature zone influence coefficient for the \( \lambda \)-temperature zone, which takes the values given in table 3.

\( i_\lambda \) - number of blocks in the \( \lambda \)-temperature zone of the image.

\( \delta_{i\lambda} \) - the area influence coefficient of the low temperature zone of the \( i \)th \( \lambda \)-temperature zone, \( \delta_{0\lambda} = 0 \), which is obtained from equation (2.2).

\( \gamma_{i\lambda} \) - the ratio of the pavement area of the \( i \)th \( \lambda \)-temperature zone to the total pavement area, \( \gamma_{0\lambda} = 0 \), which is obtained from equation (2.3).

\[
\delta_{i\lambda} = \frac{DI(s_{i\lambda})}{DI(s_Ω)} \quad (2.2)
\]

DI(s) - increment of deformation in the low elastic modulus area, which is obtained from equation (1.4).

\( s_{i\lambda} \) - the area of the pavement corresponding to the \( i \)th \( \lambda \)-temperature zone.

\( s_Ω \) - the area of the pavement where the image was taken.
\( \gamma_{\lambda i} = \frac{s_{\lambda i}}{s_{\Omega}} = \frac{\theta_{\lambda i}}{\theta_{\Omega}} \)  \hspace{1cm} (2.3)

\( \theta_{\lambda i} \) - the area of the \( i \)th \( \lambda \)-temperature zone in the image.

\( \theta_{\Omega} \) - total image area.

4. Discussion
TSSI takes values in the range of \([0,1]\), where 0 represents completely segregation-free and 1 represents completely severe segregation. The TSSI value increases, the more serious the temperature separation is. It can be easily seen that the TSSI value is larger when the degree of influence of the temperature zone is higher, the area of the low temperature zone is larger, and the number of blocks of the low temperature zone is higher.

5. Conclusion
The main conclusions of this article are as follows.

(1) There is a good binomial agreement between the difference of void ratio and the molding temperature, and the correlation coefficient reaches 0.9821.

(2) Following the method for evaluating segregation based on void ratio in NCHRP-441 report, the method for evaluating temperature separation based on the void ratio difference in internal test was developed. The degree of influence of different temperature zones on temperature separation and the division of the influence coefficient of temperature zone TIC were determined by conversion.

(3) The incremental deformation DI(s) in the low temperature zone increases with the increase of the area s in the low temperature zone in the form of a segmented logarithmic function, and thus the influence coefficient \( \delta \) of the low temperature zone is obtained.

(4) The larger the value of TSSI is, the more serious the temperature separation is. The value of TSSI changes accordingly with the change of temperature zone, the area of low temperature zone and the number of blocks of low temperature zone.

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