A Circular Track Test Study on Permanent Deformation of Asphalt Pavement Structure

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ABSTRACT: The primary objective of this study was to determine the effect of asphalt structure patterns on permanent deformation. The secondary objective was to investigate contributions of pavement structural layers to permanent deformation of asphalt pavement. Three test segments were constructed at the Circular Track in Chongqing. The three segments had a similar HMA wearing course, binder course, and subgrade. However, the base course and subbase of the three segments were different, and total depth of asphalt layers was also different (400mm, 370mm, 280mm, respectively). Segments B and C had a Superpave base course, and segment A had an asphat treated base. Segment C had thicker cement stabilized aggregate subbase than segment A, while segment B had a granular aggregate subbase. All three segments were tested under the Accelerated Loading Facility to 500 thousand passes. The permanent deformation was evaluated using rutting measurements. The tests results showed that permanent deformation occurred mostly in top 200mm asphalt layers and maximum cumulative deformation rate occurred at about 120mm depth, which maybe indicated that binder course influenced permanent deformation of asphalt pavement significantly.

KEY WORDS: Circular track, asphalt pavement, permanent deformation, cumulative deformation rate

1 INTRODUCTION

Asphalt pavement with semirigid base/subbase has been applied very commonly in China. There are many advantages to use semirigid base/subbase such as high strength, easy construction and low initial investment. However, cracking of semirigid material is a serious problem, which can induce many other types of distress of asphalt layers and damages long time performance of asphalt pavement remarkably. Many measures were taken to improve long time pavement performance including using thicker asphalt layer and/or flexible base/subbase (granular material or asphalt treated material). A controversial problem is whether permanent deformation of unconventional asphalt pavement structures can be controlled effectively or not. Accelerated pavement testing (APT) enables pavement engineers to gain insight into this complex problem in a relatively short period of time (Hugo, F., 2004). Literature reviews show that some accelerated pavement testing investigated permanent deformation of unbound layers or subgrade (Zhang, W. et al, 2002; Bejarano, M.O. et al, 2004; Odermatt, N. et al, 2004), of which asphalt layers depth is mostly about 40mm~240mm. In this study, accelerated pavement testing was conducted to evaluate and compare permanent deformation of three asphalt pavement structures with thicker asphalt layers (more than 280mm) under high temperature. Contributions of pavement structural layers to permanent deformation of asphalt pavement were also investigated.

2 OBJECTIVES AND SCOPE

The primary objective of this study was to determine the effect of asphalt structure patterns on permanent deformation. The secondary objective was to investigate contributions of pavement structural layers to permanent deformation of asphalt pavement.

To achieve these objectives, three test segments were constructed at the Circular Track in Chongqing Communications Research & Design Institute (CCRDI). The three segments had a similar HMA wearing course, binder course, and subgrade. However, the base course and subbase of the three segments were different, and total depth of asphalt layers was also different. The physical properties of asphalt mixtures, base and subbase materials, and subgrade were determined. All three segments were tested under the Accelerated Loading Facility to 500 thousand times. The permanent deformation was evaluated using rutting measurements.

3 EXPERIMENTAL DESIGN

The experimental design consisted of four parts: pavement structure design of test segments, laboratory testing, circular track loading and permanent deformation measurements.

3.1 Structure of Test Segments

Table 1 presents structures of the three test segments. Segments B and C had a Superpave base course, and segment A had an asphat treated base. Segment C had thicker cement stabilized aggregate subbase than segment A, while segment B had a granular aggregate subbase.

Table 1: Pavement structures of three test segments

<table>
<tr><th>Segment A</th><th>Segment B</th><th>Segment C</th></tr>
<tr><td>40mm SMA13
(modified asphalt, basalt)</td><td>50mm SMA13
(modified asphalt, basalt)</td><td>40mm SMA13
(modified asphalt, basalt)</td></tr>
<tr><td>80mm Superpave19
(modified asphalt, limestone)</td><td rowspan="2">2×80mm Superpave19
(modified asphalt, limestone)</td><td>80mm Superpave19
(modified asphalt, limestone)</td></tr>
<tr><td>80mm Superpave25
(base asphalt, limestone)</td><td rowspan="2">2×75mm Superpave25
(base asphalt, limestone)</td></tr>
<tr><td rowspan="3">2×100mm ATB25
(base asphalt, limestone)</td><td rowspan="3">2×80mm Superpave25
(base asphalt, limestone)</td></tr>
<tr><td>10mm Slurry seal</td></tr>
<tr><td rowspan="2">360mm cement stabilized aggregate (5%)</td></tr>
<tr><td>200mm cement stabilized aggregate (5%)</td><td>220mm granular aggregate</td></tr>
<tr><td>840mm lime improved soil</td><td>850mm lime improved soil</td><td>800mm lime improved soil</td></tr>
<tr><td>600mm Sub-clay</td><td>600mm Sub-clay</td><td>600mm Sub-clay</td></tr>
</table>

3.2 Laboratory Material Testing

Performance grade of base asphalt and modified asphalt are PG 64-22 and PG 76-22, respectively. The Superpave mix design procedure was followed to design Superpave19 and Superpave 25, and the Marshall mix design procedure was followed to design SMA13 and ATB 25. Both cement stabilized aggregate and granular aggregate comply with the gradation specified by Technical Specificaitons for Construction of Highway Roadbases (JTJ 034—2000). The lower subgrade was sub-clay, and LL(%)=24.5, PI (%) = 18.5, W_{opt} (%) =4.2, r_{max}=2.191g/cm^3. The upper layer was lime improved sub-clay. Table 2 presents the other main material properties.

Table 2: Material properties

Sieve(mm)	Passing, %					
	SAM13	Sup19	Sup25	ATB25	Cement stabilized aggregate	Granular aggregate
31.5			100.0	100.0		100.0

Sieve(mm)	Passing, %					
	SAM13	Sup19	Sup25	ATB25	Cement stabilized aggregate	Granular aggregate
26.5		100.0	98.8	100.0	100.0	99.7
19	100.0	99.5	78.0	80.9	89.3	82.6
16	99.6	97.0	73.8	69.3	82.8	75.4
13.2	90.2	89.4	70.6	58.4	74.8	71.0
9.5	57.9	69.6	55.6	45.1	60.3	60.1
4.75	22.8	48.5	38.1	24.9	31.3	32.4
2.36	18.0	30.6	19.8	16.7	19.3	20.0
1.18	15.0	20.0	14.8	10.9	14.1	14.6
0.6	13.2	11.9	10.3	8.1	9.6	9.9
0.3	12.2	7.6	7.1	6.9	5.7	5.9
0.15	11.4	6.5	5.5	6.2	3.3	3.4
0.075	9.1	5.5	3.9	5.0	2.0	2.1
AC, %	5.7	4.3	3.9	3.7	r_{max}=2.33g/cm^3	r_{max}=2.13g/cm^3
Voids, %	3.7	4.0	4.0	5.3		
Stability，kN	10.0	12.2	9.4	12.4	W_{opt} (%) =3.3	W_{opt} (%) =3.3
Flow, mm	4.5	3.2	3.8	3.0		

3.3 Circular Track Testing

Figure 1: Circular track loading facility (CCRDI)

In this study, three test segments were constructed at the circular track in Chongqing Communications Research & Design Institute (CCRDI), Chongqing, China. Figure 1 shows a picture of the circular track. It is 3.5m wide and 2.0m deep, and was divided into three segments in this study, and each segment is 11m long. The loading facility is used to simulate dual tires of a single truck axle with 110 kN load, and travels at a speed of 35±5km/h for

500000 passes. Tyre pressure is 0.7MPa. To accelerate occurrence of permanent deformation, the temperature of surface course was controlled at 55±5℃ by utilizing temperature control system, which is close to the highest temperature of actual asphalt pavement surface in Chongqing.

3.4 Permanent Deformation Measurements

In this study, two methods were used to measure permanent deformation. Top displacement of subgrade, subbase and asphalt mix layers were measured using displacement meters, which can reflect absolute rutting depth of each layer. Surface permanent deformation of wearing course was measured using profile meter, which can show surface profile directly. Rutting measurement methods were illustrated in figure 2.

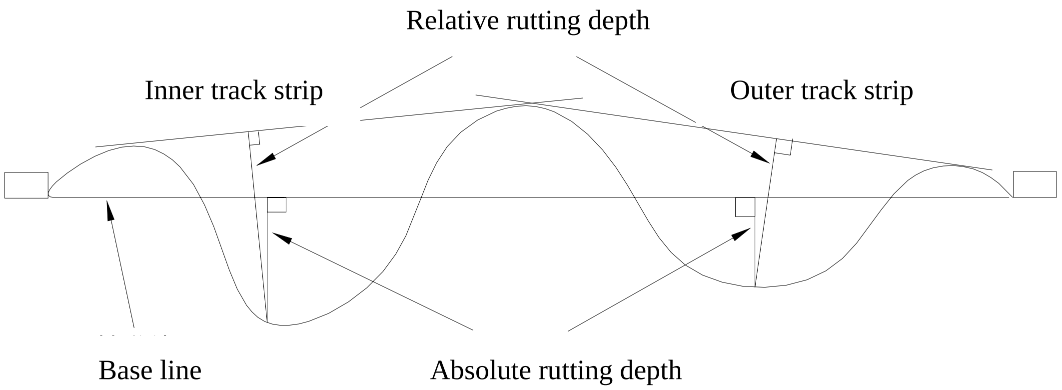


Figure 2: Sketch map of rutting measurements

4 DISCUSSION OF RESULTS

4.1 Rutting Measurements of Surface Course

Figure 3 depicts relative and absolute average rutting depth of surface course. It shows relative rutting depth of segment B is minimal maybe because three modified asphalt layers were used, and relative and absolute rutting depth of segment A is slightly deeper than segment C.

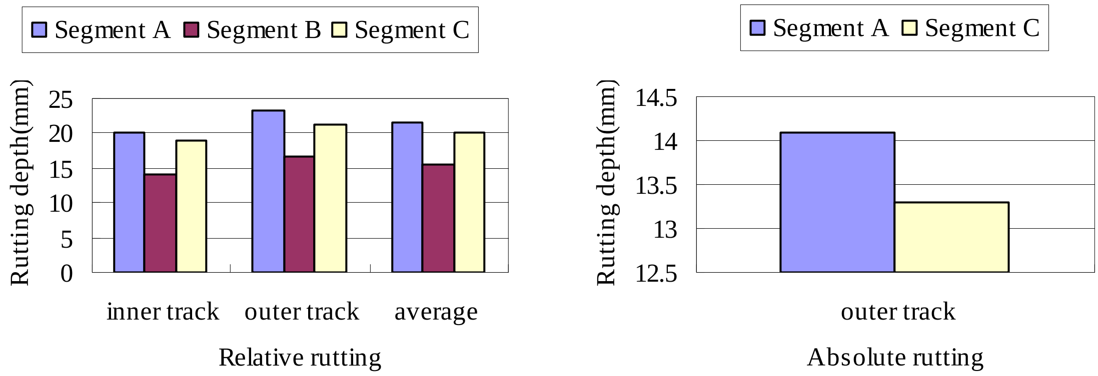
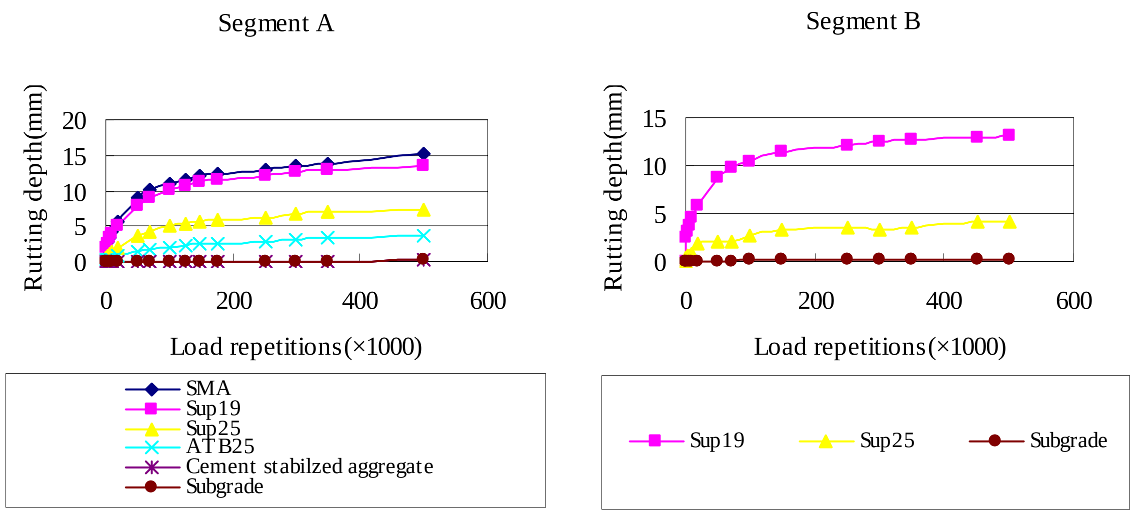


Figure 3: Relative and absolute average rutting depth of surface course

4.2 Displacement Measurements

Figure 4 depicts the top average displacement development with loading for all three tested segments. For all three segments, the top displacement of asphalt layers quickly increases at the initial stage, and then slowly grows with load repetitions increase. The top displacement of subgrade and subbase are very small.



Segment C

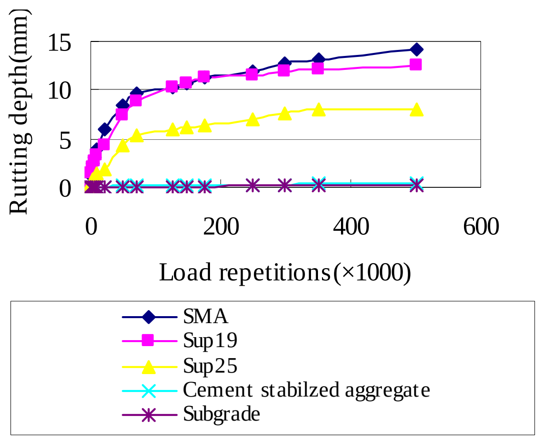


Figure 4: Top average displacement of each layer for segment A, segment B and segment C

4.3 Analysis of Permanent Deformation

Permanent deformation of each layer can be calculated based on displacement measurement results, as shown in table 3. The proportion of each layer to total permanent deformation is illustrated in figure 5.

Table 3: Permanent deformation of each layer

<table>
<tr><th colspan="2">Segment A</th><th colspan="2">Segment B</th><th colspan="2">Segment C</th></tr>
<tr><th>Layer</th><th>Permanent deformation, mm</th><th>Layer</th><th>Permanent deformation, mm</th><th>Layer</th><th>Permanent deformation, mm</th></tr>
<tr><td>SMA13</td><td>1.6</td><td>SMA13</td><td>1.6</td><td>SMA13</td><td>1.6</td></tr>
<tr><td>Sup19</td><td>6.0</td><td>Sup19</td><td>9.0</td><td>Sup19</td><td>4.5</td></tr>
<tr><td>Sup25</td><td>3.8</td><td>Sup25</td><td>3.9</td><td>Sup25</td><td>7.7</td></tr>
<tr><td>ATB25</td><td>3.4</td><td rowspan="2">Granular aggregate</td><td rowspan="2">0.0</td><td rowspan="2">Cement stabilized aggregate</td><td rowspan="2">0.2</td></tr>
<tr><td>Cement stabilized aggregate</td><td>0.0</td></tr>
<tr><td>Subgrade</td><td>0.2</td><td>Subgrade</td><td>0.3</td><td>Subgrade</td><td>0.2</td></tr>
<tr><td>Total</td><td>15.0</td><td>Total</td><td>14.8</td><td>Total</td><td>14.2</td></tr>
</table>

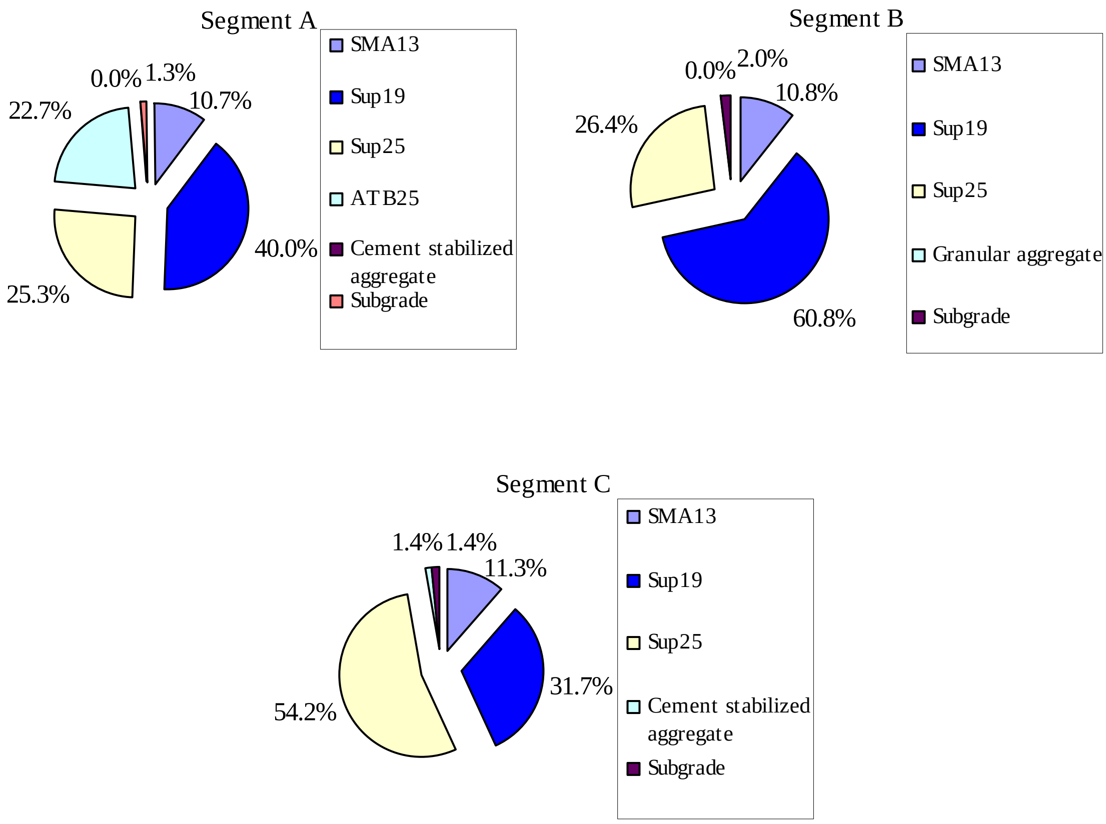


Figure 5: Proportion of each layer to total permanent deformation

It can be seen in figure 5 that permanent deformation mainly occurs in the asphalt layers for all three segments, and the proportion of top 200mm asphalt layers to total deformation is 76% for segment A, nearly 72% for segment B, and about 70% for segment C. Permanent deformation of binder course (Sup19) is dominant part of total deformation. Permanent deformation of subgrade and subbase are very small in this study.

4.4 Analysis of Cumulative Deformation Rate

Table 4 shows actual depth and corresponding cumulative deformation of asphalt layers. Relationship between cumulative deformation and actual depth can be fitted with equation (1).

Table 4: Actual depth and cumulative deformation

Segment	Asphalt layer	Actual depth，mm	Cumulative deformation，mm
A	SMA13	52.8	1.6

Segment	Asphalt layer	Actual depth，mm	Cumulative deformation，mm
	Sup19	128.8	7.6
	Sup25	190.8	11.4
	ATB25	398.8	14.8
B	SMA13	53.8	1.6
	Sup19	187.8	10.6
	Sup25	364.1	14.5
C	SMA13	42.8	1.6
	Sup19	114.0	6.1
	Sup25	299.7	13.8

$$y = -16.55259/\{1+\exp[(x-118.10645)/54.31719]\}+14.6389 \tag{1}$$

Where, y is cumulative deformation and x is actual depth.

Equation (2) can be derived from equation (1).

$$\frac{dy}{dx} = \frac{0.304739.\exp[(x-118.10645)/54.31719]}{\{1+\exp[(x-118.10645)/54.31719]\}^2} \tag{2}$$

Where, x is actual depth, and dy/dx is the cumulative deformation rate, which is illustrated in figure 6. Maximum deformation rate occurs at about 120mm depth in figure 6.

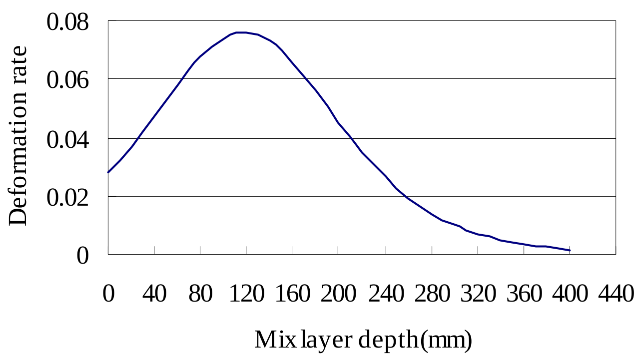


Figure 6: Relationship between cumulative deformation rate and actual depth

5 SUMMARY AND CONCLUSIONS

In this paper the effect of asphalt structure patterns on permanent deformation and contributions of pavement structural layers to permanent deformation were investigated. The following observations were made from the individual analysis of test results.

- Relative rutting depth of segment B is smallest of the three segments. Relative and absolute rutting depth of segment A is slightly deeper than segment C.
- Permanent deformation occurs in top 200mm asphalt layers mostly, and permanent deformation of subgrade and subbase are very small.
- Permanent deformation of binder course is dominant part of total deformation, and maximum cumulative deformation rate occurs at about 120mm depth. These results maybe indicate that binder course influences permanent deformation of asphalt pavement significantly.

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