STUDY OF THE RUTTING RESISTANCE OF ASPHALT SURFACING MIXTURES

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ABSTRACT

With the increase of traffic and heavy vehicles, bleeding and rutting of asphalt pavements are the most commonly observed forms of pavement distress on roads in China. There are many factors that can affect rutting. In this study, the influences of binder type, binder content, aggregate grading, temperature and loading are evaluated by means of a wheel tracking test. Three representative binders and asphalt mixtures, SMA13, AK-13A and Sup13, were selected. It was found that the modified binders have considerable advantages over the conventional asphalt binder in resisting rutting and stripping. A slightly higher modified binder content (< 0.5%) is not a hazard to the performance of asphalt mixtures. The circular track test results show that under high temperature and heavy load conditions, the SMA13 and Sup13 asphalt mixtures are superior to the AK-13A asphalt mixture in resisting rutting. The best performance was observed for the modified asphalt with high viscosity, paved immediately after plant mixing.

Keywords: SMA13, Sup13, AK-13A, modified binder, high-viscosity modified asphalt, wheel tracking test, circular track test

1. INTRODUCTION

With the increase of traffic and heavy vehicles, bleeding and rutting are the most commonly observed forms of pavement distress on roads. In recent years, rutting damage has appeared in many asphalt surfaces. This affects not only driving comfort, but also driving safety.

The asphalt at the surface is direct in contact with the surroundings and is the most critical layer in the whole pavement structure. In China, pavement designers prefer enhancing the subgrade layers and decreasing pavement depth. This puts a heavy burden on the surface layer. Recently, modified binders and asphalt mixtures, SMA13 and Sup13, have become popular asphalt wearing mixtures in China due to their good performance and functional properties, especially on heavily trafficked roads. However, there is currently little comparative information on these mixtures. In this research, the rutting resistances of the three mixtures were tested. The effects of binder type, binder content, aggregate grading, temperature and load on SMA13, AK-13A and Sup13 were analysed. The circular track test was used as the final step to evaluate the performance of the mixtures.

2. SELECTION OF MATERIAL

2.1 Selection of Mineral

According to construction practice in Jiangsu Province, China, basalt was chosen as the aggregate. For Sup13, limestone is used for sizes from 2.36 mm to 0.075 mm to improve compaction. The filler is made of limestone. All these materials meet the specifications of the Jiangsu Province Freeway Construction Headquarters.

2.2 Selection of Binder

Three types of binder were tested in this research. The first was a normal asphalt AH-70 and the second an SBS modified asphalt (SBSmB). Both these binders were obtained from the field. The third was a modified asphalt with high viscosity. Two types of high-viscosity modified asphalt were used. One was pre-produced in the factory (HVMB1) and the other (HVMB2) was made in the laboratory with 8% additive and Shell normal asphalt. The main properties of the binders are given in Table 1.

Table 1. Properties of the binders.

Technical details	AH-70	SBSmB	HVMB1	HVMB2
Penetration (25 ^{o}C, 100 g, 5 s) (0.1 mm)	75	70	63.5	50
Ductility (5 cm/min, 15 ^{o}C)(cm)	>100	>100	-	50 (10 ^{o}C)
Softening point (ring & ball)(^{o}C)	49.6	64	89	83.3
Density (15 ^{o}C)(g/cm^3)	1.035	1.030	1.030	-

2.3 Gradings

The composition and binder content of the three gradings researched are given in Table 2.

Table 2. Composition and binder content of three gradings.

Grading type	Percentage passing (sieve size , mm)(%)										Optimal proportion of binder to aggregate (%)	
	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075		
SMA13	100	90-100	50-75	22-32	16-27	14-24	12-20	10-16	9-13	8-12	SBS	6.2
	100	95	60.5	23	20	18	16	14	12	10		
AK-13 A	100	90-100	60-80	30-53	20-40	15-30	10-23	7-18	5-12	4-8	SBS	5.2
	100	95	70	41.5	30	22.5	16.5	12.5	8.5	6		
Sup 13	100	95	72	43	30	22	15	11	8	6	SBS	4.8

3. TEST METHODS

3.1 Modified Wheel Track Test

High temperature stability is one of the most important properties of asphalt mixtures. Nowadays, dynamic stability (DS) and cumulative deformation are used to evaluate rutting resistance at high temperatures. A loaded wheel was used to perform the test on standard samples of 30 x 30 x 5 cm. A 20-cm diameter, 5-cm wide rubber wheel transmitted 0.707 MPa pressure to samples at 60 ^{o}C in an air bath. The DS can be calculated by the following formula (Wang and He, 2000):

$$\text{Dynamic Stability: DS} = \frac{(t_2 - t_1) \times 42}{l_2 - l_1} \qquad (1)$$

Where: t_2 time, 60 min; t_1: time, 45 min

l_2 deformation at the 60th, mm

l_1 deformation at the 45th minute, mm.

From the definition of DS, a trend line is used to describe the mixture's resistance to rutting when the initial deformation is stable. However, the deformation is non-linear. Fifteen minutes may be too short to calculate the DS (Weimin, 2001), otherwise a small sensor error will be greatly magnified by the DS. We therefore modified our rutting test method and introduced the cumulative deformation to estimate high temperature stability. In all, 10 000 cycles were used to simulate heavy traffic. Cumulative deformation can be used to estimate the resistance to deformation, and the DS can be used to estimate the speed at which ruts develop.

3.2 Modified Air Void Test Method

A common practice is to cut cubic samples from a rutted slab to determine the air voids. However, the actual voids in a mixture can be classified into two types: one is open and the other is closed. When a cube is cut from a slab and smoothed, only the closed voids can be included. If the whole slab is tested, the air voids would be more compatible with field performance. In this research, all air voids were obtained by testing the slab.

3.3 Wheel Track Test in a Water Bath

The damage caused by water is serious, especially in southern China. Water ingress leads to disintegration and stripping, and other, related damage. An important reason is that the shear resistance of the mixture cannot support the load. Therefore the rutting resistance is relevant to the stripping sensitivity of the mixture. Currently, the water stability test is based on the Marshall sample, under the assumption that stripping occurs. In actual performance, under heavy loads and high water pressure, the adhesive strength between binder and aggregate becomes weak. When stripping occurs, cracks accumulate and propagate. The pavement rapidly loses its strength.

In order to take into account the influence of water, the rutting test in a water bath is used. This is a new method of evaluating the moisture stability, although there is no official standard for it in China. Based on the standard for the normal rutting test, a test specification is proposed. The slab is 300 mm × 300 mm × 500 mm, and it is placed in water at 60 ^{o}C for 4 hours. The pressure exerted by the tyre is 0.707 MPa and it is applied by a steel wheel wrapped with rubber. The width of the wheel is 5 cm. The loading frequency is 42 cycles per minute. In this research, a machine made in England was used.

3.4 Circular Track Test

The circular track test is a type of full-scale accelerated pavement test. It can simulate the rutting procedure in a pavement structure under a real load and correlates well with both laboratory tests and trial road tests. Compared with laboratory testing, the circular track test is better able to represent the rutting resistance of the actual pavement.

4. THE EFFECT OF BINDER PROPERTIES ON THE RUTTING RESISTANCE OF THE MIXTURE

In this research, the rutting resistance of asphalts with a normal AH-70#, SBS modified binder and pre-produced high-viscosity modified binder (HVMB1) were compared to evaluate the high-temperature stability and stripping resistance, using modified wheel track testing in both an air bath and a water bath. The test results are shown in Tables 3 and 4 and Figure 1.

Table 3. Results of modified rutting tests with different binders.

Mixture type	Binder type	Proportion of binder to aggregate (%)	Cumulated deformation under 10 000 cycles (mm)	DS (cycles/mm)
AK-13	SBSmB	5.2	2.159	7 268
	HVMB1		2.375	5 124
	AH-70#		17.403	1 120
Sup13	SBSmB	4.8	2.776	4 361
	HVMB1		2.485	4 138
SMA	SBSmB	6.2	2.674	3 941
	HVMB1		2.767	5 349

Table 4. Results of wheel track test in a water bath with different binders.

Mixture type	Binder type	Proportion of binder to aggregate (%)	Cumulated deformation under 4 676 cycles (mm)	DS (cycles/mm)
SMA13	SBSmB	6.2	2.98	2 359
Sup13	SBS	4.8	3.15	2 387
	AH-70	4.8	9.27	724
AK-13A	SBSmB	5.2	3.08	3 027
	AH-70	5.3	10.89	770

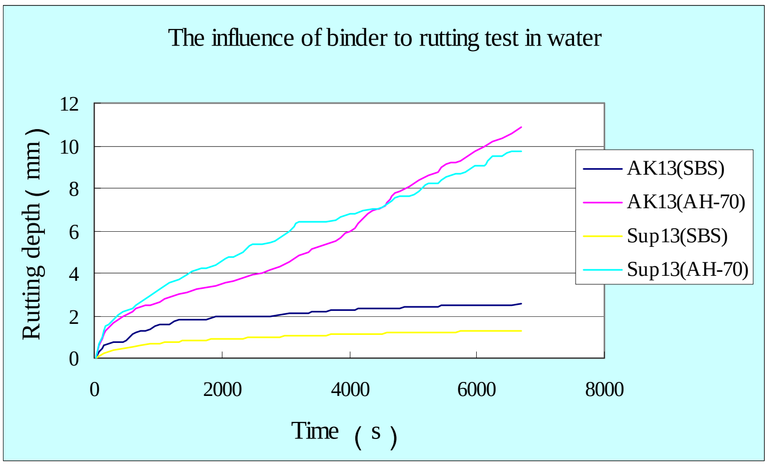

Figure 1. Effect of binder properties on rutting development in a water bath.

From the results of the modified rutting test, it was found that there are considerable differences in the rutting resistance of mixtures with normal asphalt and modified binder. When modified binder is used, the DS is generally over 4 000 cycles/mm, and the cumulative deformation at 10 000 cycles is less than 5 mm. For normal asphalt, the DS of AK-13A is only 1 000 cycles/mm and the cumulative deformation is higher than 17 mm.

The influence of binder properties on rutting resistance is clearly shown in the rutting test in water. Figure 3 shows that there are two stages when modified binder is used in AK-13A and Sup13. In the first stage, the mixture samples are further compacted. This can simulate the first days when a new road is opened to traffic. The deformation in this stage increases quickly. In the second stage, the deformation becomes stable and the slopes are flat, but for normal asphalt, the curves slope upwards. The deformations develop fast. Therefore the modified asphalt provides a considerable improvement in rutting resistance and stripping stability. High-viscosity modified binder does not show better properties as expected. This may be explained by its long storage period and deposition.

5. THE INFLUENCE OF BINDER CONTENT ON RUTTING RESISTANCE OF THE MIXTURE

Much research has been done on the effect of normal asphalt content on the rutting resistance of the mixture. However, there are significant differences between normal asphalt and modified binder. In this research, modified binder was used in the three types of gradings. Three to five binder contents were tested for each aggregate grading. The air voids were obtained from slab samples. The test results are shown in Tables 5, 6 and 7.

Table 5. Rutting test result of sma13 with different binder contents.

Mixture type	Proportion of binder to aggregate (%)	Air voids (%)	Cumulative deformation under 10 000 cycles (mm)	DS (cycles/mm)
SMA13	5.9	6.1	2.731	5 073
SMA13*	6.2	5.2	2.674	3 941
SMA13	6.5	4.7	3.067	5 353

*Optimal binder content

Table 6. Rutting test result of ak-13a with different binder contents.

Mixture type	Proportion of binder to aggregate (%)	Air voids (%)	Cumulative deformation under 10 000 cycles(mm)	DS (cycles/mm)
AK13A	4.7	7.72	2.103	5 503
AK13A*	5.2	6.22	2.128	7 268
AK13A	5.7	5.67	2.621	4 770

*Optimal binder content

Table 7. Rutting test results of sup13 with different binder contents.

Mixture type	Proportion of binder to aggregate (%)	Air voids (%)	Cumulative deformation under 10 000 cycles (mm)	DS (cycles/mm)
Sup13	3.8	8.1	1.719	9 856
Sup13	4.3	6.6	1.709	7 765
Sup13*	4.8	5.9	2.776	4 361
Sup13	5.3	4.1	2.543	7 591
Sup13	5.8	2.8	2.492	4154

*Optimal binder content

The following results were obtained from the above test: In the wheel track test, AK-13A (optimal binder content, proportion of binder to aggregate 5.2%) has a similar DS to that of Sup13 (rich binder content, proportion of asphalt to aggregate 5.3%). They all reached a level of 7 500 cycles/mm, and are superior to Sup13 with optimal asphalt content (proportion of binder to aggregate 4.8%). The results of the cumulative deformation are at the same level. When modified binder is used, the rich binder content does not threaten the rutting resistance. The rutting resistance of the mixture is due to the aggregate friction and the binder's adhesive strength. Although the rich binder content will reduce the friction and increase the free binder in the mixture, the adhesive strength will increase relatively because its high viscosity changes slightly at the test temperature. If the binder content increases, the free binder will decrease the rutting resistance.

6. INFLUENCE OF GRADING ON THE RUTTING RESISTANCE OF THE MIXTURE

With the optimal asphalt content, the DS of AK-13A is on a high level, Sup13 is on the middle level, and SMA is low. This can be explained in the following ways:

- There are some differences in the design method. The volumetric method was used for all the gradings. The volumetric parameters of SMA 13 were obtained from Marshall samples made with a 50-blows compaction, but this is not enough for pavements under heavy traffic. The design of Sup13 is based on practical performance. It incorporates the concept of effective volume and uses gyratory compaction so, under optimal air void conditions of 4%, the asphalt content of Sup13 is lower than that of AK-13A. In order to get higher compaction, the 2.36 mm - 0.075 mm grade in Sup13 was limestone instead of basalt. Limestone is superior to basalt in compaction, but inferior to basalt in abrasion. This can explain why the optimal asphalt content and dynamic stability of Sup13 is low. Despite the high filler and fibre contents, the asphalt content of SMA 13 is still greater than that of Sup13 and AK-13A. The strengthening mechanism is different. The stability and durability of SMA13 are based on the stone-to-stone contact of the coarse mineral aggregates and the glueing of the particles by mortar with a high amount of binder. Sup13 and AK-13A have almost the same grading – they fall between a suspended dense structure and a dense framework structure. They have not only the stone skeleton but also the cohesive strength of densely graded concrete. SMA is a critical mixture. In heavy traffic conditions, if 4% is taken as the design air voids, the SMA may be filled and overfilled due to compaction and re-orientation. It is the opposite of SMA 13.
- There are differences between the moulded samples. Higher-quality controls are required with SMA13. The poorly proportioned distribution of fibre and compaction of the mixture cause a decrease in strength. It is difficult to compact SMA 13 to the optimal level. This is reflected in the deformation-time curve. The deformation of SMA 13 within the first several minutes is higher than that of Sup13 and AK-13A. It also explains why the DS and the cumulative deformation of SMA are worse.

7. EFFECTS OF HIGH TEMPERATURE AND OVERLOADING ON THE RUTTING RESISTANCE OF MIXTURES IN THE CIRCULAR TRACK TEST

7.1 Test Load and Temperature

In this test, the full-scale APT at Southeast University was used. The dual wheel load is 120 kN and the tyre pressure is 0.75 MPa. The wheel speed is 25 ± 5 km/h. The temperature range at a depth of 4 cm is controlled between 55 and 60 ^{o}C. The sections of pavement are shown in Table 8.

Table 8. Sections of the pavement.

Mixture: type of surface	Structure number	Measured interface
AK-13A (SBSmB)	1	1, 2, 3
AK-13A (SBSmB)	2	13, 14
SMA-13 (SBSmB)	3	7, 8, 9
Sup-13 (SBSmB)	4	10, 11, 12
AK-13A (SBSmB)	5	15, 16
AK-13A (HVMB2)	6	4, 5, 6

All the data measured can be used to obtain the “absolute” and “relative” depths of rutting. The “absolute” depth is the reduced depth from the original height. The “relative” depth is the distance between the bottom of the rutting track and the peaks of two adjacent rutting tracks (Figure 2).

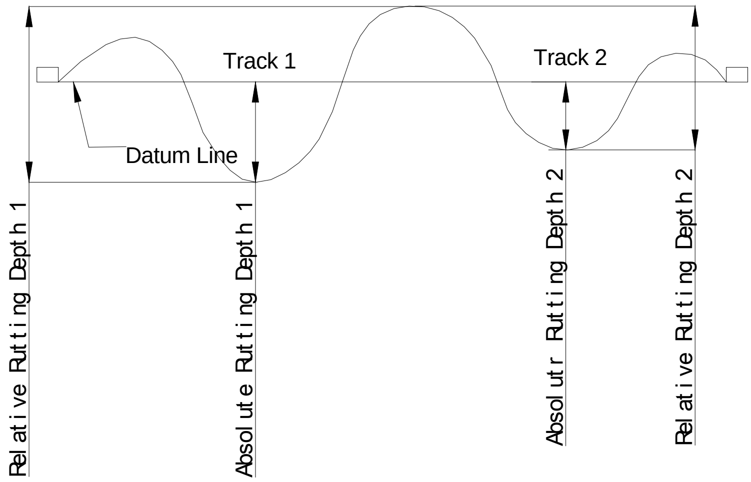

Figure 2. Measurement of rutting depth.

In actual traffic, the loads of vehicles are distributed over a portion of the road through wander. If the APT is used, the wheel track of which is located in a specific ring, and the simulation will be more critical than it is in practice. The absolute and relative depths of rutting under different cycles for each structure are shown in Figures 3 and 4. The unit in the figures is 0.01 mm.

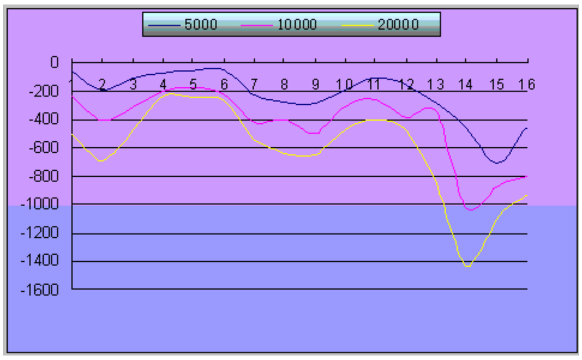

Figure 3. “Absolute” rutting depths of different interfaces under different load cycles.

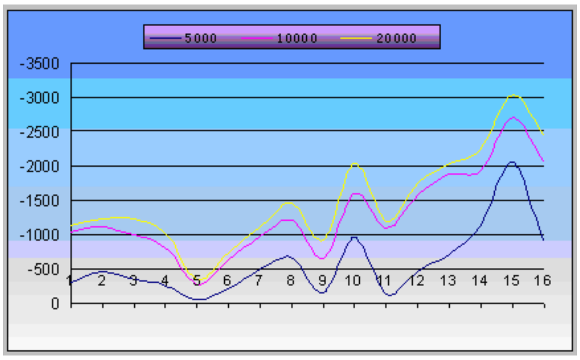

Figure 4. “Relative” rutting depths of different interfaces under different load cycles.

7.2 Discussion and Analysis of Circular Test Track Results

In this test, the temperature 4 cm below the surface is controlled. Because of the different heating between circular track and real road, the surface temperatures may reach 70 ^{O}C. A load heavier than that in the specification is taken into account. This test simulates the pavement condition under high temperature and overloading.

This test showed that:

- Under high temperature and overloading, rutting occurs and develops quickly even if modified binder is used.
- The properties of the binder have a significant effect on rutting resistance. In the structures of AK-13A, the asphalt with high-viscosity modified binder (HVMB2) is superior to the rest of the mixtures with SBS modified binders.
- Different mixtures show different performances in rutting resistance. When the same binder is used, SMA13 and Sup13 have similar performances and are both superior to AK-13A.

8. CONCLUSIONS

In this research, various types of tests, including the modified rutting test, a rutting test in a water bath and the circular test track, were carried out. The effects of binder type, binder content and grading on the rutting resistance were compared.

It can be concluded that:

- There is a significant difference between normal and modified binder. The difference is also reflected in rutting resistance in water. When modified binder is used, all these properties are improved considerably.
- For modified binder, rich modified binder content ($<$ 0.5%) does not threaten the performance of the mixture.
- Because of the difference in design methods, the mixtures show different properties. In general, SMA13 and Sup13 are superior to AK-13A.
- More attention should be paid to high-viscosity modified binder. The binder made in the mixing plant has the best performance.

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