Performance Evaluation of Polymer-modified Asphalt Binder in High-modulus Asphalt Mixture

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ABSTRACT: High-modulus asphalt mixture (HMAC) has been used and developed for nearly 20 years because of the nice high temperature stability and the good anti-fatigue performance. The hard asphalt additives play an important part in developing the rut-resisting performance of asphalt mixture pavement. In this text, the comparisons of performance test have been done for four types of additives which were designed in EME mixtures. In the tests, mix design has been employed according to the LCPC specifications, and contrasting research has been done both in France and China sieving system. The richness modulus in EME2 has been applied in the selecting gradation and asphalt binder content. The rutting test, dynamic elastic modulus test and four-point fatigue test were proposed to estimate the high temperature performance, dynamic modulus and anti-fatigue performance of asphalt mixture mixed with different kinds and amount of additives.

KEY WORDS: HMAC，PR plast module，abundance coefficient， performance test

1. INTRODUCTION

Hard asphalts have mainly been used in base and binder courses with a surfacing which ensures a certain thermal stability. They have been developed to provide technical solutions to the problem of mitigation of rutting of surface layers and to increase the rigidity of the base courses of asphalt pavements. The Laboratory Central des Ponts et Chaussées in French（LCPC）requirements for high modulus mixtures are contained in the specification NF P 98-140 “Les Enrobés á Module Elevés”. There are two types of high modulus mixtures, EME-Class 1 and EME-Class 2. The difference between them is the percentage of asphalt binder. (J-F and Brosseaud 1994) EME-2 mixtures require a higher percent of asphalt binder (defined by a modulus of richness) and therefore have a lower air void content. The higher asphalt content mix has higher fatigue resistance.

The purpose of this study was to evaluate the effect of different polymer additives on the stiffness of EME. The intent of this study was not to perform a complete mix design according to NF P 98-140 but rather to evaluate alternate methods of asphalt binder modification. (Smith T, 1994, Smith T, 1997) The study is to evaluate polymer-modified asphalt binder with deferent additives in high-modulus asphalt mixture and EME2 formulation studies using Chinese materials.

2 EME MIX DESIGN METHOD OF LCPC

There are four levels of mix design. The level 4 is the highest grade of EME mix design with tests listed in Table 1.

- Design air voids using the gyratory compactor (PCG)
- Moisture damage test (Duriez)
- Rut resistance (LCPC rut tester)
- Modulus, either by direct tension or sinusoidal compression
- Fatigue testing

Table 1 Specification properties of high modulus mixture

Property	Specification Limit	Test Method	Property	Specification Limit	Test Method
Min Thickness	7 cm	NF P 98-140	Complex Modulus	>14,000 MPa	NF P 98 260-2
Maximum Thickness	12 cm	NF P 98-140	Direct Tension Modulus	>14,000 MPa	NF P 98-260-1
Asphalt Binder Content	5.7	NF P 98-140	Fatigue	>130 x 10-6	NF P 98-261-1
Duriez (TSR)	>75%	NF P 98-251-1	Design Gyrations	100	NF P 98-252
Rutting	<8 mm at 30,000 passes	NF P 98-253-1	Design Air Voids	3 – 6%	NF P 98-140

Workability is evaluated by compacting specimens in the LCPC gyratory compactor. For a 0/14 mixture the design number of gyrations is 100. At 100 gyrations, the mixture must have between 3 and 6% air voids.

Rutting is measured on a French wheel-tracking machine. A slab, 100-mm thick, is compacted and subjected to a loaded pneumatic tire at 60°C. For normal hot mix asphalt the requirement is no more than 10% of the thickness (10 mm) rut depth after 10,000 passes. For the EME mix, the requirement is no more than 8 mm rut depth after 30,000 passes.

Direct tension modulus is measured using a specimen that is four times taller than the diameter. A creep load is applied in tension at different temperatures and a master stiffness curve is developed. At the end of the test， a constant rate of elongation is applied and the stiffness curve is evaluated to determine the point of non-linearity.

Complex modulus is measured by applying a sinusoidal compressive load at 10 Hz and measuring the resulting deformation. Testing is done at 15°C. (Sanders P J, 2005)

Fatigue is measured using a trapezoidal specimen subjected to a sinusoidal strain at 25 Hz. The test is performed at 10°C. Specimens are run at different strain levels and a plot of strain versus failure (based on stiffness reduction) is created. The strain at which one million load cycles causes failure is determined.

3. HMAC MIX DESIGN

Hard asphalts are defined here like having a penetration less than 25 mm/10 at 25°C. There are three grades: the penetration grade (PG) 15/25, 10/20, and 5/10. The hard asphalts thus should have a higher temperature resistance and a lower capacity of healing than the softer 35/50 asphalt. The EME asphalt binders with PG 35/50 are normally modified by the hard asphalt additions to increase the softening points and viscosities and retain good low temperature performance. In this test, Chinese PG 50 asphalt binder and four hard asphalt modifiers are applied as follows Tab 2. In the table, except PR Plast by France, the other three are all China-made additive products with almost the same price.

Table 2 Additive content of high-modulus mixture

Additive	Dosage of additives	
	Manufacturers recommend	Supplement dosage
France PR	0.5％（Accounted for mineral aggregate quality）	0.6％（Accounted fort mineral aggregate quality）
A	0.5%（Accounted for mixture quality）	0.6％（Accounted for mixture quality）
B	0.4％（Accounted for mixture quality）	0.5％（Accounted for mixture quality）
C	8％（Accounted for base asphalt quality）	10％（Accounted for base asphalt quality）

Note:(A、B、C refer to Chinese three different additives as the same below)

For EME mixture has no strict gradation limitation, the gradation of the test get a little adjustment in fine aggregates for the purpose of appropriate air void in fields as shown in Table 3.

Table 3 The Gradation by Chinese sieving

Sieve Size, mm	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Test gradation	100	95.5	73.6	42.7	22.5	16.7	11.9	9.0	7.5	6.3
LCPC's recommendation	100	95	76	52	37	25	17	12	9.8	7.6

Richness modulus can be explained as equivalent thickness of asphalt which wrapping the aggregate surface. Richness modulus is defined by specific surface area of aggregate and density of aggregate. By the selection gradation, the calculated asphalt aggregate ratio is no less than 5.7% (Tab.4)

Table 4 Control index of asphalt content

Technical index	Technical requirement
Porosity（%）	≤6
richness modulus	≥3.4
The smallest asphalt aggregate ratio（%）	≥5.7

4. PERFORMANCE TESTING OF THE HMAC

4.1 Mixture Compaction, Curing and Coring:

The LCPC gyratory compactor has a smaller angle than the Superpave gyratory compactor. In this test, our tests set Superpave gyratory compactor into LCPC's with the angle 0.8°, the compression 0.6 MPa and 100 gyrations.

4.2 Dynamic Stability DS Test Results

Rutting is measured by dynamic stability DS which is the total passes for every 1mm rutting with 0.7MPa and temperature 60℃. Asphalt mixture specimens mixed with PR Plast module, A, B and C, four kinds of additives are compared respectively, under the same conditions (Tab 5).

Table 5 dynamic stability DS test results of trial blends

Additives		Asphalt aggregate ratio(%)	Rut dynamic stability（passes/mm）				Coefficient of variation（%）
			1	2	3	Average	
PR Plast	0.5%	5.7	3500	3500	3316	3439	3.1
	0.6 %		4500	4500	3938	4313	7.5
A	0.5%		5250	5727	5727	5568	4.9
	0.6 %		7875	7000	7000	7292	6.9
B	0.4%		4500	4500	3706	4235	10.8
	0.5 %		3938	4846	4200	4328	10.8

C	8%		4200	5250	5250	4900	12.4
	10%		5727	5250	4846	5274	8.4

As shown, rutting test result showed that 0.5% addition of product A has the highest DS , and its anti-rutting performance has been significantly increased with the addition of 0.1%. In all, three kinds of additives A, B and C can achieve similar or higher rut-resisting performance of PR product.

4.3 Complex Modulus Test Results

Samples were tested for complex modulus using the Superpave Performance Tester. Testing was done at 15°C and 20°C. Stiffness and phase angle was measured at the following frequencies 25, 20, 10, 5, 2, 1, 0.5, 0.2, 0.1, 0.05, 0.02 and 0.01 Hz. The stiffness and phase angle at 10 Hz is summarized in Table 6.

Tab 6 Complex modulus test results of trial blends

Additives and dosage		Temperature（℃）	Dynamic stability（MPa）					Coefficient of variation（%）
			1	2	3	4	Average	
PR Plast module	0.50%	15	9685	13457	11758	9608	11127	16.6
		20	6824	10048	8460	7484	8204	17.1
	0.60%	15	11658	11802	12700	13036	12299	5.5
		20	8931	8658	10040	9686	9329	6.9
A	0.50%	15	13736	12301	12598	12055	12673	5.9
		20	9284	10364	10479	9882	10002	5.4
	0.60%	15	12805	12634	15452	13089	13495	9.8
		20	10557	9303	12327	11085	10818	11.6
B	0.40%	15	9139	10000	12430	10107	10419	13.5
		20	6969	7913	9026	7458	7842	11.2
	0.50%	15	10385	9546	11221	11872	10756	9.4
		20	8036	7741	8832	8901	8378	6.9
C	8%	15	10801	12766	10989	10501	11264	9.1
		20	8831	10323	9166	8331	9163	9.2
	10%	15	14126	14306	12512	13837	13695	5.9
		20	10707	11399	10197	11029	10833	4.7

As shown in Table 6, in 15℃ and 0.5% addition, A and C show a higher modulus performance when compared with PR; in 20℃ and 0.5% addition, A, B and C maintain their advantages relative to PR. Thus, A/5%, A/6%, C/10% are all available to get the effect of PR/6% in high-modulus performance. However, it should be noticed that most dynamic modulus of testing EME2 mixture are not get the specified value 14000MPa.

4.4 Fatigue Test Results

The fatigue tests used a four-point bending beam test machine manufactured by Cooper testers. Testing was done at 10 Hz because of machine limitations. (Luis 2006)(Sanders 2007)The results of fatigue tests are shown in Tab 7. For the EME-2 mixture design Specification NF P 98-140 requires fatigue testing to be done with a two-point bending test performed at 25 Hz and 10°C. The four-point bending beam test done in this asphalt binder formulation study is sufficient to evaluate candidate modification techniques, but can not be used for the actual mix design.

For an EME mix design, the fatigue test is performed at different levels of strain. The failure criterion at each strain level is defined as a 50% reduction in stiffness. A strain level was run at 400 με (+/- 200 με) and the final strain was closer to 50%.

Table 7 Fatigue test results of trial blends

Additives and dosage		Frequency	Result				Coefficient of variation （%）
			1	2	3	Average	
PR Plast module	0.50%	Fatigue frequency	95853	67230	61933	75005	24.3
	0.60%	Fatigue frequency	99753	64912	72265	78977	23.3
A	0.50%	Fatigue frequency	99392	69752	89613	86252	17.5
	0.60%	Fatigue frequency	73492	71173	76693	73786	3.8
B	0.40%	Fatigue frequency	81664	62273	76692	73543	13.7
	0.50%	Fatigue frequency	61873	72313	71913	68700	8.6
C	8%	Fatigue frequency	106372	118732	85813	103639	16.0
	10%	Fatigue frequency	93913	111693	98027	101211	9.2

As shown in Table 7, C with 8% and 10% had obvious advantage in fatigue test results higer than the other produts. The anti-fatigue property of 0.5% addtion of A is better than PR. In the contrast with PR/0.6%, A /0.6%, B/0.5%, A /10%, if the result of PR/0.6% is seen as a level, additive C is higher than the level and the other products is a little lower than the level.

5. CONCLUSIONS

To sum up, the additives A, B, and C show the similar or even higher anti-rutting performance, dynamic modulus and anti-fatigue performance than PR. The EME mix design according to LCPC specification was employed to performance evaluation of the same mixture with deferent additives. The rutting test, dynamic elastic modulus test and four-point fatigue test were proposed to estimate the high temperature performance, dynamic modulus and anti-fatigue performance of asphalt mixture mixed with different kinds and amount of additives. In addition, other researches are expected to be done for the evaluation of hard asphalt and aggregate gradation in HMAC.

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