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Feasibility Study Using New High Modulus Additives in High Modulus Base Mix in Algerian East-West Expressway Project

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Abstract: This paper reports a study comparing four additives used to produce high modulus pavements of which one is an accepted product normally used in France. The other three additives are newly developed products that have been used in China pavement practice, however, without following the French specification. This research evaluated the feasibility of using the new additives to produce acceptable high modulus mixtures. Mixtures were produced with different additive contents, and their performances were evaluated and compared using the wheel track test in accordance with the Chinese method T 0719, and the modulus and fatigue tests in accordance with NF EN 12697-26 and NF EN 12697-24, respectively. The test results showed that mixtures produced with the new additives had similar performances as the accepted French product. In fact, some new mixtures even displayed properties superior to those produced with the French product. Therefore, some of the new additives evaluated in this study could be accepted for use as an optional choice in high modulus mix design.

***Key words**: Additives; Feasibility; High modulus; Performance.*

Introduction

This paper reports an evaluation of several additives for the production of high modulus asphalt concrete in order to choose the proper additives to be used in the Algeria East-West Expressway project. The study was necessary to evaluate the feasibility of producing high modulus asphalt concrete using the newly developed additives and provide the necessary information for decision-making. The pavement project in question is a bidirectional four-lane expressway about 360*km* in length. Its structural design follows the standard French specification. It is constructed of high modulus asphalt concrete (EME) having a thickness of 20*cm*. This mixture acts as the flexible base layer. The additive from Europe is expensive; therefore, if alternative and less expensive additives with equivalent performance could be found, there could be considerable economic benefits due to the large quantity of EME needed for this project.

There are well-developed additives for manufacturing high modulus asphalt concrete that have been used for many years in France. In recent years, several new additives with similar functions have been developed. Although these newly developed additives have been used in China, their application did not follow the French specifications. Therefore, whether or not these products could be alternatives to provide mixes meeting the requirements of the French standard and provide economical applications is uncertain. This study is important to answer questions regarding the feasibility, in terms of quality and cost, of using these potential additives in the Algeria East-West Expressway project.

So far, there is no laboratory in China that can complete the formulation of a job following the French methods exactly. The work described in this paper applies the test methods as close as possible to the French methods. In order to determine the feasibility of the proposed application, a well established French product (additive) was selected to serve as a base reference to compare the performance of three newly developed additives and to determine if the new products showed performance meeting the requirements of French high modulus asphalt concrete.

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Materials

Asphalt

The penetration grade of the bitumen used for high modulus asphalt concrete in France is normally less than 50 (0.1*mm*). In China, bitumen of this grade has not yet been widely used. In this study, 40/60-grade bitumen was chosen; properties of the bitumen are summarized in Table 1.

Aggregates

The aggregates and the filler used in this study were those normally used in China.

Table 1. Physical Properties of the Bitumen.

	Penetration at 25°C	Durability at 10°C	Softening Point (R&B)*	Dynamic Viscosity at 60°C
Unit	0.1*mm*	*cm*	°C	Pa·s
Result	58	19	48.5	286
Method	T0604 – 2000 [1]	T0605 – 1993 [2]	T0606 – 2000 [3]	T0625 – 2000 [4]

*R&B: a softening point test method, Ring & Ball method.

Table 2. Gradation of Mix.

Sieve (*mm*)	14	12.5	10.0	8.0	6.3	4.0	2.0	1.0	0.315	0.25	0.08
Passing (%)	98.1	93.2	76.0	64.0	55.0	37.0	21.0	16.0	9.8	9.0	7.2

Table 3. Methods and Proportion of Additives to Produce Mixes.

Product	A	B	C	D
Description	Mature Product	New-Developed Product		
Calculation Method	Weight Ratio by Mix	Weight Ratio by Mix	Weight Ratio by Mix	Weight Ratio by Bitumen
Proportion 1, %	0.6	0.5	0.4	8
Production 2, %	0.5	0.6	0.5	10

Additives

Four additives were used in this study. One was an acceptable additive used frequently in France. The other three were additives that have been newly developed by different enterprises.

Mix Design

Gradation

The gradation of the aggregates used met the requirements for producing the French high modulus asphalt concrete according to EME 0/14. The gradation used to develop the gradation curve is shown in Table 2.

Asphalt Content

The French mix design method controls the minimum asphalt content for each mix type and different class by an empirical richness factor known as the *K* factor. Different product specifications require different *K* values. The minimum binder content is calculated by Eq. (1) according to French specification NF P98-149 [5]:

$$TL = k \times \alpha \sqrt[5]{\Sigma} \qquad (1)$$

where,
K: richness factor;
TL: binder content (ratio by weight of asphalt to aggregate), %;
α: 2.654/Gse;
Gse: effective specific gravity of aggregate;
∑: conventional surface area of total aggregate skeleton;

$$100\Sigma = 0.25G+2.3S+12s+135f$$

where,
G: percentage by weight of aggregate larger than 6.3*mm*,
S: percentage by weight of aggregate between 6.3 and 0.315*mm*,
s: percentage by weight of aggregate between 0.315 and 0.08*mm*,
f: percentage by weight of aggregate smaller than 0.08*mm*.

For the French mix type EME class 2, the French product specification NF P 98-140 [6] requires the binder content to have a *K* value no less than 3.4. This gives a minimum binder content of 5.4% with the given gradation. The work reported in this paper uses a binder content of 5.7% to evaluate the performance of the four additives; therefore, this gives a *K* value of 3.6 by recalculation of Eq. (1), which meets the requirement of NF P98-140.

Concentrations (Proportions) of Additives

Table 3 shows the calculation methods and concentrations (proportions) of the different additives used to produce the mixes. The preparation of the mixes with some of the additives was a little different. For products A, B, and C, it was necessary to pre-mix the additives with the aggregate for a few minutes before adding the bitumen. Product D was first mixed with the bitumen to produce modified bitumen, which was then mixed with the aggregate. For product D, the No. 2 concentration of 10% of the additive by weight of the bitumen is equivalent to a concentration of 0.5% of additive by weight of total mix. In the discussion that follows, this will be used to compare with concentrations 0.5% of the other additives.

The mixes described in this paper were prepared using the aggregate gradation described in Table 2. The binder content used was of 5.7%. These mixes were used to compare the performance of the different additives at the concentrations listed in Table 3.

Mix Testing

The French mix design method used five test methods to characterize the mixes used in the study of EME; they are the gyratory compaction test, the sensitivity to water test, the wheel tracking test, the modulus test, and the fatigue test. In this study, all of these tests were used except the sensitivity to water test. The gyratory compaction procedure used in this study followed that of the French test method NF EN 12697-31 [7]; the wheel tracking test followed the method of China T0719 [8], and the modulus and fatigue tests followed the methods NF EN 12697-26 [9] and NF EN 12697-24 [10], respectively.

Gyratory Compaction Test

For the gyratory compaction test, the French method is different from the Superpave method. The latter requires the internal and external angles to be 1.16° ± 0.02° and 1.25° ± 0.02°, respectively, but the French method requires 0.82° ± 0.02°and 1.00° ± 0.02°for internal and external angles, respectively. The present study follows the French method. The French specification, NF P 98-140, uses different compaction cycles for each nominal aggregate size. It requires 100 gyratory compaction cycles for EME 0/14, and the design void content, $V_n = 100$, should be no more than 6%. With the

Table 4. Void Results of Gyratory Compaction Test for Different Additive Proportions.

Additive	A		B		C		D	
Proportion, %	0.5	0.6	0.5	0.6	0.4	0.5	8	10
Void %	3.1	3.2	3.4	3.2	3.5	3.2	3.4	3.2

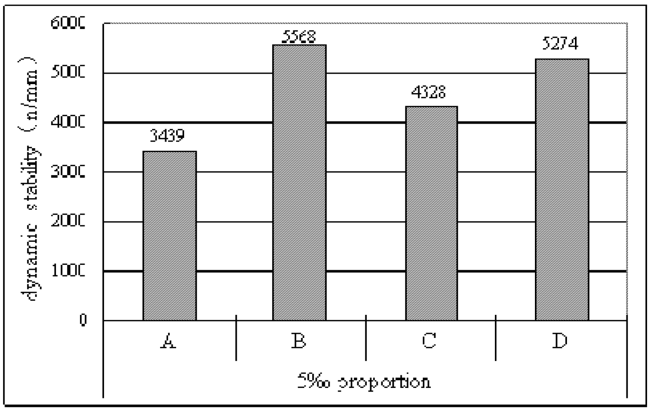

Fig. 1. Anti-Rutting Performance at Same Additive Proportion.

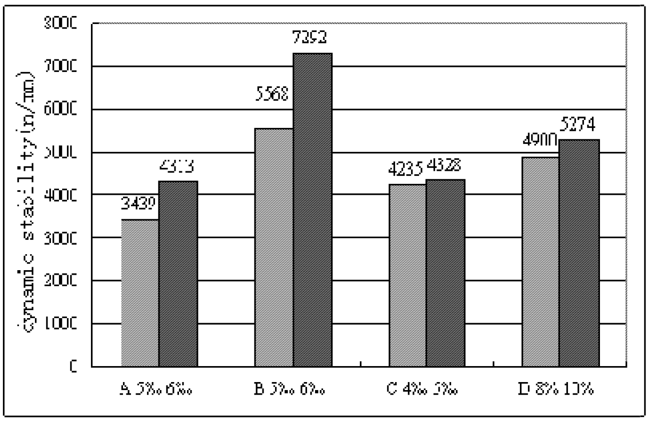

Fig. 2. Anti-Rutting Performance of Different Solutions.

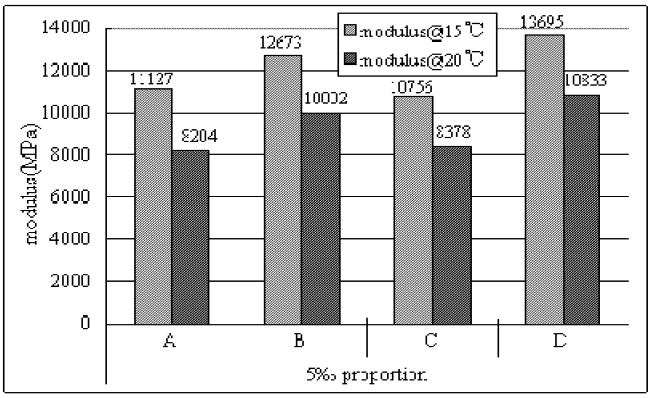

Fig. 3. Modulus of Different Additive at Same Proportion.

given gradation and binder content of 5.7%, which is a conventional value in France, the data in Table 4 provide the gyratory compaction voids for asphalt mixtures with different proportions of additive. The void content of each mix varies between 3.1 and 3.5%, which meets the required standard.

Wheel Tracking Test

The Influence of Additive Type

Data in Fig. 1 show the influence of the four additives, all at 0.5% by weight of total mix, on wheel tracking test results. Because the only variable is the additive type, the results present the relative effectiveness of the additives. From Fig. 1, it can be seen that products B and D show better performance under the wheel tracking test. Product C also shows an advantage; however, product A shows a lower performance level in its ability to resist the effects of the wheel loading. Thus, Fig. 1 shows that products B, C, and D give better performance than product A.

Comparison of Anti-Rutting Performance of Different Additives

The main objective of this work was to make sure that products B, C, or D would be acceptable to replace the well-established product A. Considering that 0.6% is the normal amount of additive A that is used in France, in the following discussions, the 0.6% for additive A will be considered as the base reference criterion to determine whether or not the other additives can meet the necessary performance requirements.

Fig. 2 shows the wheel tracking test results on mixtures containing different additives at two different concentrations. The results indicate that product B showed the best resistance to permanent deformation. Product D showed an advantage over product A at 0.6% concentration. Product C had an equivalent performance to product A at 0.6% concentration.

From the wheel tracking test, based on the use of 0.6% concentration of additive A for comparison, all of the other products had an acceptable performance level, of which B and D gave better results.

Modulus Test

Two different modulus test methods were used: the uniaxial direct tensile test, NF P98-260-1 [11] and the complex modulus test, NF P98-260-2 [12]. The first method gives the modulus at 0.02s through the use of the master curve of "modulus vs. time" at a reference temperature of 15°C. The second method gives the modulus at 10*Hz* using the "modulus vs. frequency" curve at the same temperature. The specification requires that the results should be no less than 14,000*MPa* for both methods. The two methods are considered equivalent, and so are the results for each method. These two methods have been incorporated into specification EN 12697-26, which is known in France as specification NF EN 12697-26. The corresponding methods are described in its Appendix E and A. Besides these two methods, NF EN 12697-26 provides other alternative methods. The "direct tension-compression test on cylindrical specimens" was chosen for use in the work reported in this paper and is described in Annex D of NF EN 12697-26. In the present study, a test temperature of 15°C was used, and 20°C was

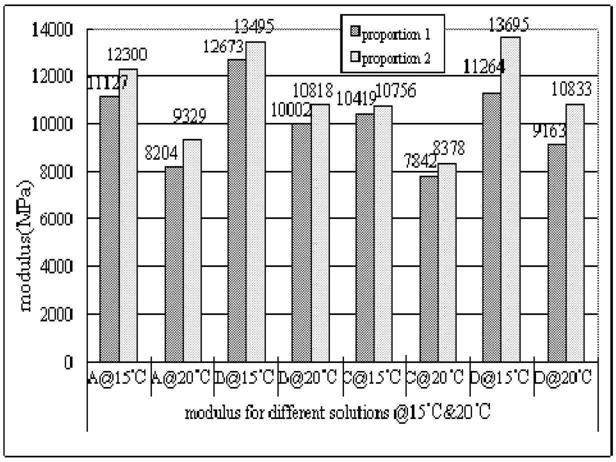

Fig. 4. Modulus Results for Different Product Solutions.

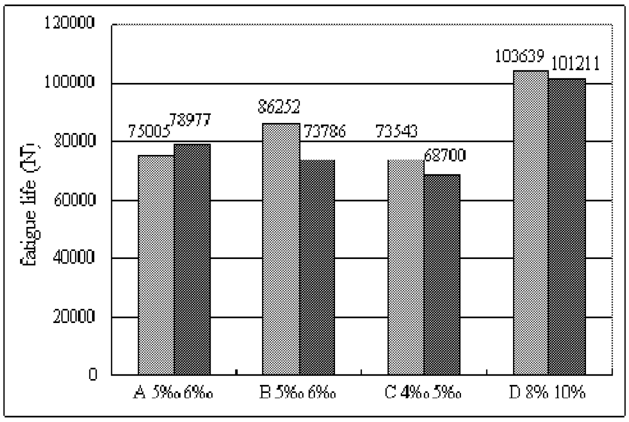

Fig. 5. Fatigue Results of Different Solutions.

used for further comparison.

Influence of Additive Type

Fig. 3 shows the moduli at two different temperatures for asphalt mixtures containing 0.5% additive by weight of total mixture. Using the same additive concentration of 0.5%, the data in Fig. 3 show that, at 15°C, mixtures D and B have higher moduli than the other mixtures. The modulus of mixture C is slightly lower than that of mixture A; however, they are quite similar. The results at 20°C show that mixtures D and B still have superiority over product A; the modulus of mixtures C and A are still very similar. The modulus results show that products B and D are significantly better than product A at the same additive levels.

Modulus Comparison of Mixes with Different Additives

The established additive, A at 0.6% concentration is used as the base criterion for evaluation of the other additives to determine the possibility of their adoption for use in high modulus asphalt concrete. Fig. 4 shows the modulus results for the mixes with different additives at two different temperatures. The additive concentration (proportion) 1 is recommended, and considering that additives B, C, and D have not been used in practice in conjunction with the French specification, the concentration (proportion) 2 is adopted as an optional concentration in case of failure of the recommended one. From Fig. 4, it is shown that three combinations of additives and concentrations could give the performance level equivalent to or better than that of additive A at 0.6% concentration based on the data at 15°C. The three combinations are 0.5% for B, 0.6% for B, and 10% for D. If the results of 20°C are considered, the same three combinations also qualify. Also, additive D at a concentration of 8% is very similar to A at 0.6%.

It should be noted here that the penetration for a high modulus asphalt mix in France is normally less than 50 (0.1*mm*), but this penetration grade of asphalt is not commonly used in China; therefore, a 58 (0.1*mm*) penetration grade asphalt was used in this study. Also, the method used is different from the French method. So, it is probably because of these two reasons that the modulus is lower than 14,000*MPa*, which is the requirement for an EME class 2 mixture. But based on the modulus determined for the French product with its normal concentration serving as reference and comparing results using the other product concentrations with the French reference, it is possible to judge whether or not the other additives can provide satisfactory solutions. This is the main objective of this paper.

From the modulus testing, it was determined that additive B at 0.5 and 0.6% concentration, and Additive D at 10% concentration could achieve the performance level of additive A at 0.6% concentration at both 15 or 20°C.

Fatigue Test

Fatigue testing in France follows the French method, NF P 98-261-1 [13]. It uses a trapezoidal sample loaded at two points. The test is carried out at three strain levels. For each strain level, six effective fatigue cycle results should be obtained. From data at the strain levels and the cycles stated, the strain value corresponding to 10^6 cycles, designated as ε6, can be calculated by regression analysis. The test method used in this study was the four-point bending test method. This method has been incorporated in EN 12697-24 and is described in its Appendix D. Method NF P 98-261-1 is described in Appendix A of EN 12697-24, which is designated in France as NF EN 12697-24.

In this test, the strain level is controlled at 400μ to compare the fatigue life of each mixture. The additive's function is to enhance the modulus of the mix; however, the additive does not improve its fatigue life. Normally a higher fatigue life is achieved by increasing the bitumen content. The analysis here compares only the fatigue behavior of the different mixtures.

From Fig. 5, considering 0.6% for A as the base criterion, it can be seen that the D mixture at the two different concentrations both qualify as alternative acceptable mixtures. Also, the mixture with 0.5% of additive B could also give equivalent performance.

Therefore, from the fatigue comparisons, three combinations of new additives at different concentrations could produce mixtures that qualify as acceptable. They are additive D at 8% concentration, additive D at 10% concentration, and additive B at 0.5% concentration.

Conclusions

From the analyses of the wheel tracking test, mixtures containing additives B, C, and D can give equivalent or better performance properties than mixes using the base criterion of additive A at 0.6% concentration.

From the analyses of the modulus test, mixtures containing additive B at 0.5% concentration, B at 0.6%, and D at 10% gave equivalent performance properties to the base mixture, A, at 0.6% concentration.

From the analyses of the fatigue test, mixtures using additive B at 0.5% concentration, D at 8%, and D at 10% gave equivalent performance behavior to mixtures using additive A at 0.6%.

In summary, based on the total analyses, acceptable, new mixtures using additives B and D that achieved the performance level of additive A at 0.6% were found. These results show promise for new optional solutions for producing high modulus asphalt concrete.

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