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STUDY ON THE PERFORMANCE OF HIGH-MODULUS ASPHALT CONCRETE PAVEMENT IN EXTREME CURVES OR STEEP SLOPES OF TRUNK HIGHWAY

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ABSTRACT

With the purpose of the project, we determined the performance of high modulus asphalt concrete (HMAC) pavement in sharp curves or steep slopes of the trunk highway. We selected bending of road surface, bending and stretching strain at the bottom of surface layer, vertical compressive strain at the bottom of surface layer as research parameter index. By using the three-dimensional model analysis function of the finite element software ANSYS, the mechanical models of asphalt pavement with three different structures under the action of steep slope and heavy traffic are established. Firstly, the conventional asphalt pavement consists of 4cmAC-13 bituminous pavement (the top layer) and 6cmAC-20 bituminous pavement (the bottom layer). Then, the HMAC pavement 1 consists of 4cmAC-13 bituminous pavement (the top layer) and 6cmAC-EME14 bituminous pavement (the bottom layer).The HMAC pavement 2 consists of 6cmAC-EME14 bituminous pavement (the top layer) and 4cmAC-13 bituminous pavement (the bottom layer). Then we tried it out that for the deflection value, the HMAC pavement 1 was 5.34 percentage point reduced than the conventional asphalt pavement. At the same time, the HMAC pavement 2 was 6.95 percentage point reduced than the conventional asphalt pavement. So, it can significantly reduce the bending strain at the bottom of the surface layer by using HMAC as asphalt pavement structure. For the resistance to shear strain and vertical compressive strain at the bottom of the surface layer, the HMAC pavement 1 is the best. Then the HMAC pavement 2 follows and then the conventional asphalt pavement. The results show that the HMAC can significantly improve the overall stiffness of the pavement and reduce the bending, shearing and vertical strain. Meanwhile, it can also reduce the occurrence of wheel rut, upheaval, fatigue crack and other common diseases.

KEYWORDS

Asphalt pavement, Pavement performance, Mechanical model, High modulus asphalt concrete, Sharp curves or steep slopes

INTRODUCTION

High modulus asphalt concrete (HMAC) is a kind of pavement material with high modulus and good anti-fatigue performance. So it can effectively reduce the road thickness and save resources [1]. The concept of HMAC was first proposed by France. For the sake of solving the problem of insufficient rutting resistance of asphalt pavement and insufficient base course stiffness, the concept of HMAC was first proposed by France [2-3]. According to the French "LPC Bituminous Mixtures Design Guide", only the asphalt mixture that meet requirements of modulus（15℃, 10Hz, 0.02s）⩾14000Mpa, richness modulus>3.4% and rut depth（30000cycles）<7.5% can be called the "durability high-modulus asphalt mixture"[4].

In recent years more and more attention has been paid to the research of HMAC in China. But the asphalt used is mainly low-mark asphalt, modified asphalt, etc. Some organizations such as South China University of Technology, Chang'an University, Jiangsu Transportation Institute, Liaoning Transportation Research Institute Co.,ltd experimental studied its high temperature performance, low temperature performance, moisture susceptibility and fatigue resistance. The problem is that the durability of the mixture is neglected in the pursuit of the increase of modulus.

BACKGROUND

The dependent subject is supported by transportation science and technology fund in Guizhou China. Trunk highway has a large volume of traffic and a high proportion of heavy vehicles in China. The consequence is that rutting, shifting, cracking and other diseases appear on the road too early. This has had a serious impact on the regional economy. The results show that the HMAC can be used to reduce the thickness of the surface structure and improve the durability [5]. So it is suitable for heavy load, steep slope, hot summer and cold winter [6].

We selected G326 in Zunyi as the test section. The width of the pavement is 12m, and the original pavement structure is: 25cm lime flying-ash+6cm bituminous concrete surface course of AC-16. Before construction, the asphalt pavement mainly exist ruts, pits, cracks, loose, peeling and other diseases. In order to ensure the calculation accuracy and reduce the computational workload, software ANSYS was used for modeling and analysis [7].

PREPARATION OF HIGH MODULUS ASPHALT MIXTURE

Aggregate

The pavement in extreme curves or steep slopes of trunk highway requires strong shear strain resistance.

The internal friction angle is positively correlated with the internal friction resistance between aggregates. It can be concluded that to improve the shear strain resistance of asphalt mixture, the internal cohesion and internal friction angle of the mixture should be improved. So we chose the aggregate with the characteristics of hard texture, rough appearance, embedded extruding force, and strong adhesive with asphalt. The aggregate should meet the requirements of form2D, angularity index, etc.

Form2d

Form2D is divided into four grades from 0 to 20. The smaller the value, the closer the two-dimensional shape is to the circle.

$$Form\ 2D = \sum_{\theta=0}^{\theta=360-\Delta\theta}\left[\frac{R_{\theta+\Delta\theta}-R_{\theta}}{R_{\theta}}\right] \quad (1)$$

In the formula: R_θ——The radius of the particle at the Angle θ

Δ_θ——Angular micro-increment

Form 2D test results of fine aggregate is just as Figure 1. The abscissa is form2D, and the ordinate is the cumulative of particles.

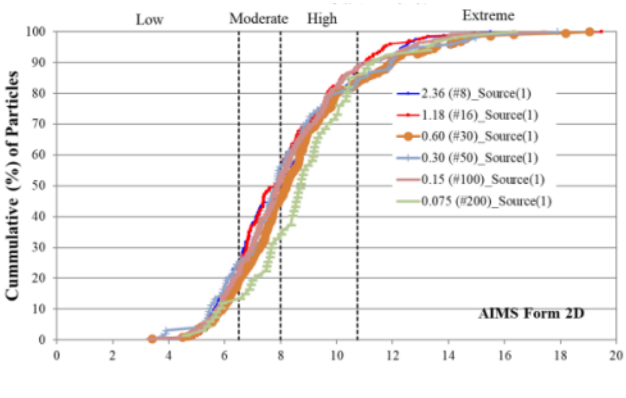


Fig.1 - Different particle size form2D test results

Angularity index

The angularity index is usually used to describe the concave and convex state of aggregate. Aggregate image measurement system (AIMS) was used to scan the shape profile of aggregate particles to identify the edges and corners. Then we can calculate the angularity index of each aggregate as the formula below.

$$GA = \frac{1}{n/3-1}\sum_{i=1}^{n-3}\left|\theta_i - \theta_{i+3}\right| \quad (2)$$

In the formula: GA——angularity index

θ——The angle direction of aggregate’s vertex

n ——Number of edges and vertices

i ——edges and vertices of i

The test results of angularity index are shown in Figure 2.

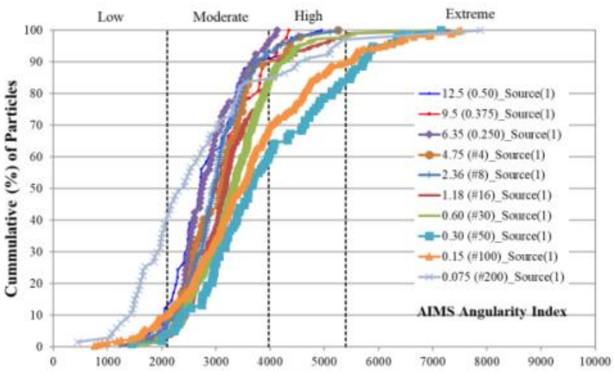


Fig.2 - Test results of angularity index

Hard asphalt

Hard asphalt is the key material of high modulus asphalt mixture. In this project, the hard asphalt produced in Luoyang is configured with 70# asphalt in a certain proportion. However, it is necessary to admixture or premix in advance before the construction. The testing results of various index of hard asphalt are as follows.

Tab.1 - Performance index of hard asphalt

Index	Unit	Results	Test method
penetration（25℃，5s，100g）	0.1mm	14	T0604-2011
Softening point（$R\&B$）	℃	64.0	T0606-2011
Flash point	℃	321	T0611-2011
density（15℃）	g/cm^3	1.038	T0603-2011

High modulus asphalt mixture

According to the recommended grading range of French high modulus asphalt mixture EME2, the high modulus asphalt mixture suitable in extreme curves or steep slopes of trunk highway is designed with reference to the aggregate gradation and asphalt aggregate ratio (AAR) of previous engineering applications to determine the compaction characteristics of the mixture. The asphalt aggregate ratio is 5.6%. The aggregate gradation after sieving analysis test is just as Table 2.

Tab.2 - Aggregate gradation after sieving analysis test（The sieve hole，mm）

Aggregate gradation	The percentage of passing through the sieve hole（%）									
	0.075	0.15	0.3	0.6	1.18	2.36	4.75	9.5	13.2	16.0
EME14	6.9	9.2	12.1	17.6	24.5	35.3	49.4	75.0	98.0	100.0

PAVEMENT MECHANICAL MODEL IN EXTREME CURVES OR STEEP SLOPES

Effect of slope on mechanical properties of pavement

Loading mode: single side dual tires.

Model size: lateral 6.0m, driving direction 10.0m, depth direction 5.0m, represented by x axis, y axis and z axis.

Longitudinal slope: 6%.

Automotive braking force: Φ=0.5.

Load distribution method: bzz-100 standard axial load was adopted in stress analysis, which was simplified as rectangular local load. The width of single track was 18.6cm, the length was 19.2cm, the net distance between two tracks was 12.8cm, and the pressure of single tire was 0.7MPa[8].

The influence of longitudinal slope on the pavement deflection is not obvious. The pavement deflection increases slowly with the increase of slope, from 0.14248mm at 0% to 0.14326mm at 6%, increasing by 0.55%.The result is shown in Figure 3.

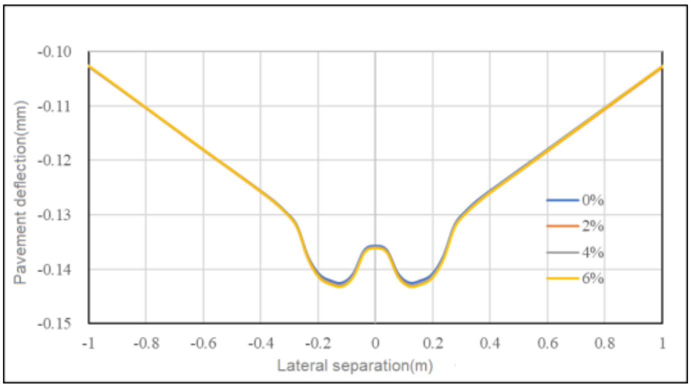


Fig.3 - The pavement deflection along the transverse direction of different slopes

With the increase of slope, the longitudinal shear strain at the bottom of the surface layer has small fluctuations, as shown in Figure 4.

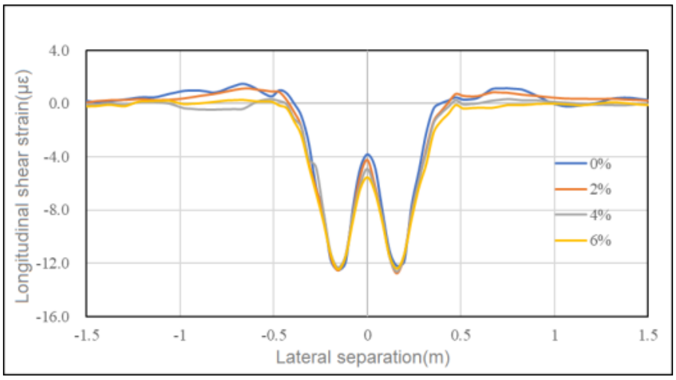


Fig.4 - The longitudinal shear strain along the transverse direction of different slopes

The vertical compressive strain fluctuates along the transverse direction. As the slope increases, the strain value increases, and the strain peak increases from 34.811με of slope 0% to 36.561με of slope 6%, with a small increase of 5.03%, as shown in Figure 5.

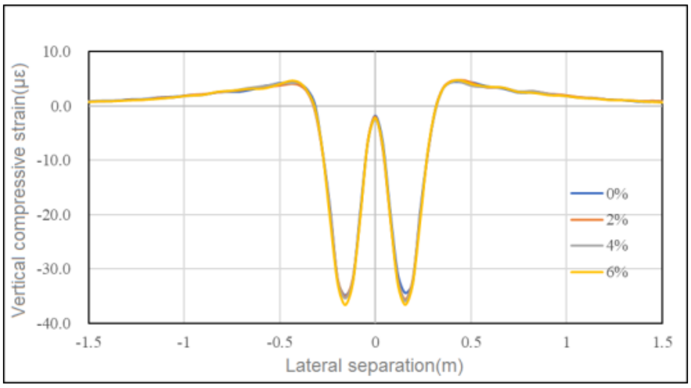


Fig.5 - The vertical compressive strain along the transverse direction of different slopes

The model of finite element

By using the three-dimensional model analysis function of the finite element software ANSYS, the mechanical model of asphalt pavement with three different structures under the extreme curve or steep slope is established and the corresponding conditions of asphalt pavement with three different structures are analyzed. The input parameters are in chapter effect of slope on mechanical properties of pavement. Figure 6 is the schematic diagram of the longitudinal section of extreme curve and steep slope, and Figure 7 is the finite element model.

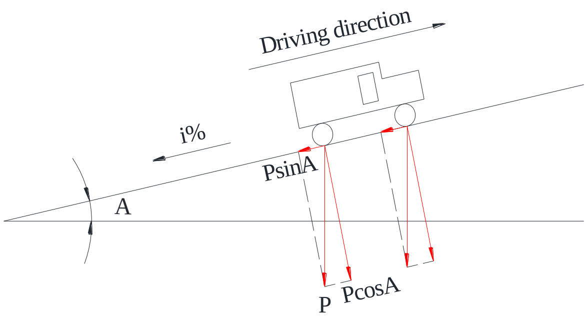
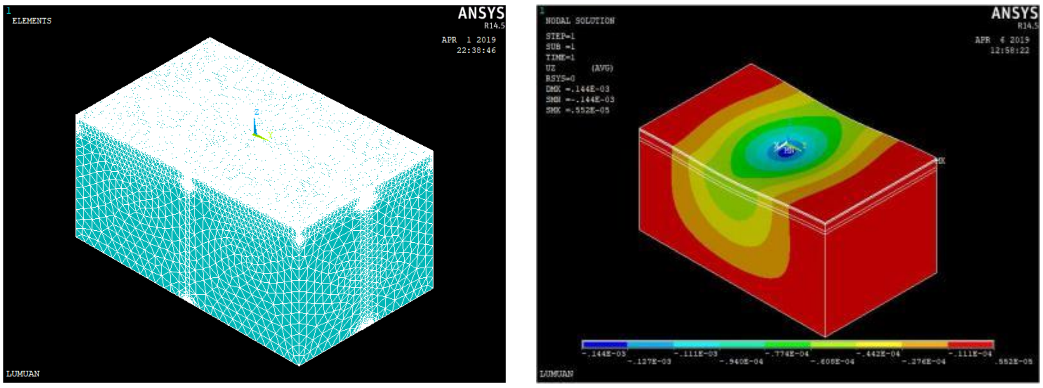


Fig.6 - Schematic diagram of vertical section of extreme curve and steep slope



(a) *(b)*

Fig.7 - Finite element model and unit division

Pavement structure parameter

Table 3 ~ Table 5 show the structure composition and material parameters of conventional asphalt pavement and high-modulus asphalt pavement of trunk highway. The dynamic compression modulus under the condition of 20℃ and 10Hz is adopted for the asphalt surface layer, the elastic modulus is adopted for the cement stabilized gravel base, the wet-adjusted rebound modulus is adopted for the graded gravel subbase, and the equivalent rebound modulus of the top surface is adopted for the soil subgrade. The mechanical effect of freezing-thawing cycle in the dry and wet state is fully considered.

Tab.3 - Materials and properties of the conventional asphalt pavement

Structural layer	Thickness(cm)	Elastic modulus（MPa）	Poisson ratio
Top layer:AC-13	4	8000	0.25
Following layer:AC-20	6	9000	0.25
Base：cement stabilized macadam	45	15000	0.25
Soil subgrade	-	50	0.4

Tab.4 - Materials and properties of the HMAC pavement 1

Structural layer	Thickness(cm)	Elastic modulus（MPa）	Poisson ratio
Top layer:AC-13	4	8000	0.25
Following layer:AC-20	6	16000	0.25
Base：cement stabilized macadam	45	15000	0.25
Soil subgrade	-	50	0.4

Tab.5 - Materials and properties of the HMAC pavement 2

Structural layer	Thickness(cm)	Elastic modulus（MPa）	Poisson ratio
Top layer:AC-13	6	16000	0.25
Following layer:AC-20	4	9000	0.25
Base：cement stabilized macadam	45	15000	0.25
Soil subgrade	-	50	0.4

Finite element analysis of asphalt pavement in extreme curve and steep slope

The pavement deflection

The peak value of surface deflection was 0.14326mm for the conventional asphalt pavement, and 0.13561mm of surface deflection of the HMAC pavement1, 5.34% lower than that of conventional asphalt pavement. The peak value of surface deflection of the HMAC pavement 2 is 0.1333mm, which is 6.95% lower than that of conventional asphalt pavement. Therefore, the adoption of HMAC as the asphalt pavement structure can improve the overall stiffness and deformation resistance.

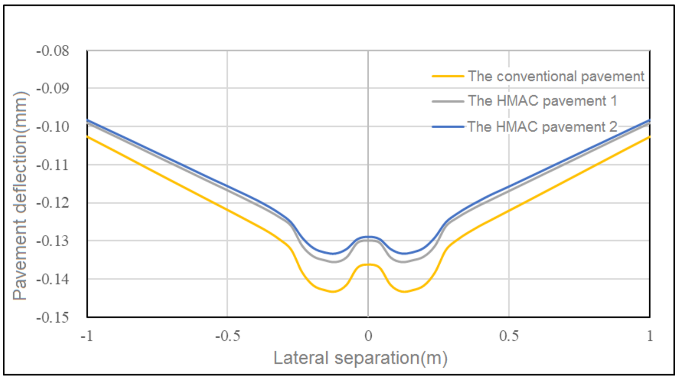


Fig.8 - The pavement deflection along the transverse direction of different pavement

Shear strain

It can be concluded that using HMAC as the asphalt pavement can significantly reduce the longitudinal shear strain of the pavement bottom surface, reduce the probability of bond failure between the surface layer and the base layer, and reduce the rutting, cladding, crack and other early failure phenomena of the asphalt pavement.

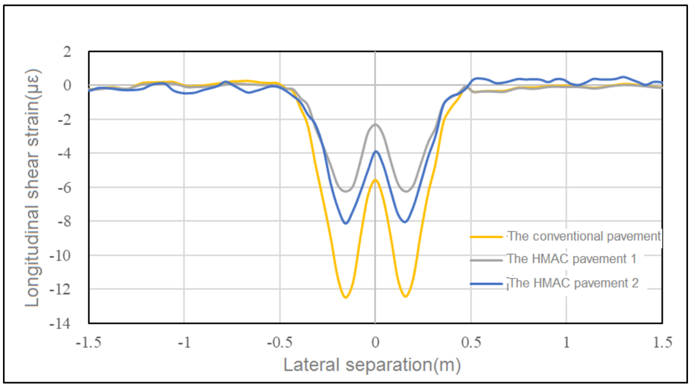


Fig.9 - The longitudinal shear strain along the transverse direction of different pavement

Vertical compressive strain of the bottom of the surface layer

Figure 10 shows that the vertical compressive strain at the bottom of HMAC pavement 1 is significantly reduced compared with the other two types of pavement, and its peak is 28.87% lower than conventional pavement and 23.18% lower than HMAC pavement 2. HMAC pavement 1 has better resistance to permanent deformation of the structure.

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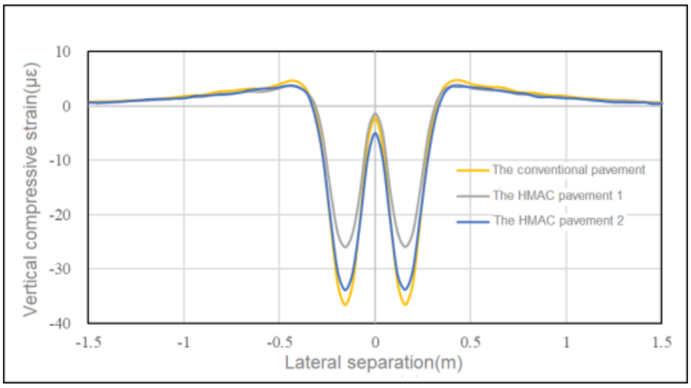

Fig.10 - The vertical compressive strain along the transverse direction of different pavement

THE ENGINEERING APPLICATION OF HMAC IN EXTREME CURVES OR STEEP SLOPES

Asphalt pavement construction

According to the characteristics of the road diseases, in order to improve the durability, rutting resistance, and considering test section cannot interrupt the traffic for a long time, we make a thorough treatment of these diseases at first and then adopted the overall plan of laying 6cm HMAC. So, there is not necessary to mill and resurface as a whole.

Production mix proportion

According to the available data, the final production mix proportion was determined after several tests, as shown in Table 6.

Tab.6 - Design of mix proportion

Materials & Quantity	Aggregate gradation after sieving analysis test（the sieve hole,mm）(%)									
	0.075	0.15	0.3	0.6	1.18	2.36	4.75	9.5	13.2	16
4#silo（30）	1.5	1.8	2.0	2.2	2.2	2.2	2.4	26.0	88.0	100.0
3#silo（20）	1.9	2.2	2.4	2.4	2.4	2.6	5.6	99.0	99.9	100.0
2#silo（15）	3.1	3.4	3.6	3.7	3.8	8.2	80.8	99.9	100.0	100.0
1#silo（33）	11.3	18.4	24.8	38.0	57.1	86.6	98.4	100.0	100.0	100.0
Mineral powder（2）	95.0	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Aggregate gradation	7.0	9.5	11.8	16.3	22.6	33.0	48.4	77.6	96.4	100.0

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(a) (b)

Fig.11 - HMAC pavement after construction

Field test of test section

The content of field test includes: core sample thickness and compaction, and the test results are shown in Table 7.

(a) (b)

Fig.12 - Drilling core sample and the core sample

Tab.7 - Core sample thickness and compaction

No.	Stake mark	Core sample thickness(cm)	Measured relative density	Theoretical relative density	Compaction (%)
1	K388+955	5.5	2.372		96.0
2	K389+055	6.8	2.419	2.470	97.9
Average		6.2	2.396		97.0

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From the core sample, the distribution of coarse and fine aggregate is uniform and the gradation is reasonable. From the core sample compactness test results, the compactness all meets the requirements of interior design.

Tracking

Our research group kept track of the test section for a whole year. After a hot season and heavy traffic, there are no ruts and pits and other diseases. At the same time, after a low temperature season and heavy traffic, no spalling, loose, shrinkage, fatigue cracks and other diseases appeared. Road performance is satisfactory.

CONCLUSION

(a) The comparative analysis of the mechanical models of different asphalt pavement structures under the condition of extreme curves or steep slopes shows that adopting the HMAC as asphalt pavement can significantly reduce the longitudinal or transverse positive strain, and prevent fatigue cracking of asphalt concrete. At the same time, the resistance of pavement to fatigue cracking is improved, and the rutting, enveloping and cracking of pavement are reduced.

(b) Through the experimental research in the test section, the field compaction degree, uniformity, compaction performance and other indicators meet the design expectations. After one year of operation, under the action of high temperature and heavy vehicle, ruts and pits and other diseases did not appear, while under the action of low temperature and heavy vehicle, low-temperature cracks and loose diseases did not appear, showing good road performance. We could conclude that HMAC pavement has a good road performance.

(c) Through mixing ratio, model analysis, and evaluation after paving the test section, EME14 structure scheme can effectively improve the anti-cracking and anti-deformation capacity of asphalt pavement, meanwhile it improves road performance and improve driving comfort and safety. So EME14 structure scheme meets the use requirements in extreme curves or steep slopes.

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