Development of a Hi-Soft Asphalt Pavement for Cold Regions

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ABSTRACT: Through structural evaluation and performance prediction, a new type of asphalt pavement was developed, based on 3 years of laboratory and in-situ tests. It is named a Hi-soft Asphalt Pavement, HIHSA in short due to its characteristics of being more flexible, and more adaptable to deformation and bearing capacity defects of the roads, etc. As the recent research findings from a research project financed by the Ministry of Communications, P.R. CHINA, HIHSA is more suitable for low volume roads in cold regions. During the development, the researchers highlights the use of local materials such as the naturally crushed stone accumulated in mountain slope, the river gravels and others, to the largest extent for wearing course, base-course and subgrade. And due to no need to heat at high temperatures for both aggregates and binders comparing with hot–mix asphalt, less low temperature cracking, easy recycling and maintenance, HIHSA is also very cost-effective. 11 different kinds of pavement materials and structures were chosen for the test road, which is located in the northern-most China's Daxing-anling Region. According to in-situ observations and experiments on bearing capacity, frost heave, cracks and other defects, and others, in connection with lab tests and structural calculation and analysis, Specifications for HIHSA Pavements' Design, Construction and Quality Control were worked out for further wide application in other northern and western provinces and areas.

KEY WORDS: Asphalt, pavement, cold, crack, bearing.

1 INTRODUCTION

With the rapid development of trunk highway's construction in Heilongjiang province and even in the country, construction of highways connecting counties, towns and villages (rural highways in short) is also emerging in large scale, to make full use of the trunk highways. In Heilongjiang province according to the official plan, 83860 kilometers of rural highways will be constructed. These rural highways are mainly characterized of low-volume. In fact A.D.T. of some trunk highways in western and remote provinces are also in the category of low-volume.

Regional climatic and hydrogeologic conditions and local materials differ obviously in the country with large territory. Especially in the cold regions, the moisture failures of asphalt pavements, widely existed in the country, plus low temperature deteriorate low temperature cracking and other frost affected failures.

In western, northern and some other remote provinces, economic development lags behind, toll collection is in difficulty as less vehicles from other provinces pass over. Furthermore, construction funds have already been in shortage for trunk highways, nothing to say for rural highways.

Due to the above considerations, this research program has been conducted by Heilongjiang Institute of Highways and Transport Research (HIH) since 2002, which was entrusted and funded by the Ministry of Communications, P.R. China. It aims at developing a new construction technology for low-volume highways, which is of low cost, capable of largely making use of local materials and mitigating low temperature cracking and other frost affected failures. Part of the research work and findings are outlined in the paper.

2 PRINCIPLE OF HIHSA PAVEMENT PERFORMANCE

2.1 HIHSA Pavement

For HIHSA Pavement, HIHSA, a kind of material similar to asphalt mix is used as wearing course paved on a base-course. HIHSA material is composed of binder with low viscosity, crushed stone or crushed gravel, and adhesive to enhance the adhesion between binder and aggregates. It is with larger voids' content, lower strength, but of better fluidity at normal and minus temperatures, more adaptable to deformation, and more resistant to low temperature cracking. It allows itself certain amount of water to pass through the structural layers, by which it possesses what we call certain water permeability. Due to largely differing from traditional asphalt pavement in terms of materials, structure, production and construction, and especially working principle of performance, comprehensively it is a new pavement technology, suitable to construction of low volume highways in cold regions. For convenience, HIHSA may denote either HIHSA mix or HIHSA pavement, when this term separately appeared in the paper.

HIHSA development is based on the concept and approach of Finnish soft asphalt or oil gravel, which originated from Sweden, developed in Finland, widely applied in

Finland and other Scandinavian countries; its application can also be found in USA since mid 1990's.

2.2 Principle of Pavement Performance

Based on analysis to related application in the international society and especially by the experimental studies that last for three years up to now, the working principle of HIHSA pavement is summarized and put forward as followed.

●The binder is of low viscosity, and of certain fluidity at low temperatures even below zero.

●Subject to wheel loading, aggregates adapt to wheel movements; wearing course materials is in a certain moving state.

●The mix is of plastic deformability; it gets to be dense with wheel loading. The strength is obtained gradually as light oil evaporates. It is of better adaptability to deformation.

●Due to its materials and structure and others, there exists less cracks of pavements at low temperature. Furthermore these cracks can heal as the binder moves with aggregates' moving, when subject to repeated wheel loading at higher temperatures.

●The pavement structure is of permeability and capable of draining of water. The wearing course water permeated down to base course can be drained off rapidly. Moisture stability is ensured by the use of unbound granular materials.

Behind the development of HIHSA, a few kinds of cognition were obtained, some of which are new or were not quite understood previously, such as cognition to road performance between cold and hot mix, to permeable and impermeable pavements, to consideration of strength or deformation priority in design of low volume roads, and to unification of materials and structure. They will be expressed late in another paper. They are not only helpful for the application of HIHSA, but also can be employed to guide the developments of other kinds of pavements and even the development of the research field.

3 BINDER, GRADING OF AGREGGATES AND MIX DESIGN PRINCIPLE OF HIHSA PAVEMENT PERFORMANCE

3.1 Adhesion of Binder

Studies show that the binder's adhesion is the most important factor affecting the performance of HIHSA pavement. Because of the existence of light oil in the binder, the binder's adhesion is lower than that of ordinary asphalt. The binder is much closer to Newton fluid. Following Newton's law of inner friction, viscosity formula of HIHSA is expressed as the following equation.

$$\eta = \frac{\tau}{\dot{\gamma}} \qquad (1)$$

where η is coefficient of dynamic viscosity, viscosity in short, Pa•s; τ denotes shear stress, Pa; and $\dot{\gamma}$ is rate of shear strain.

3.2 Base asphalt and Binder for HIHSA

The test result of base asphalt is shown in Table 1. The reason for selecting this Base asphalt is that it is a commonly used asphalt, available and easily to be processed to HIHSA binder.

Table 1: Test result of base asphalt.

Category			1	2	3	Average
Penetration (Pene.) (0.1mm)		25℃	101.7	101.3	101.6	101.5
		15℃	31.2	31.5	31.3	31.6
		5℃	12.2	12.1	12.4	12.2
Ductility (cm)		25℃	126.3	128.1	132.4	＞100
		15℃	-	-	-	-
		5℃	29.9	32.7	32.9	31.8
Softening point (S.P)(℃)			43.0	43.5		43.3
Wax content (%)			1.75			
Kinematic viscosity (135℃)			274.83 mm^2/s			
R.T.F.O. (163℃, 75mm)	Mass loss (%)		-0.24	-0.28	-	-0.26
	Pene. (25℃)		69.8	69.6	70.1	69.8
	Pene. Ratio (%)		69			
	Ductility (cm)	25℃	123.7	136.4	132.5	＞100
		15℃	102.3	103.5	106.9	＞100
		10℃	80.9	80.7	81.0	80.8
	S.P.(℃)		53.2	53.0	-	53.1

Note: R.T.F.O. denotes rotary thin film oven test. All tests adopt testing methods stipulated in the national specifications in use.

By mixing the base binder with certain amount of additives, through a series of selective tests, we can obtain the required HIHSA binder. The test result of one kind of HIHSA binders that we use for test roads is listed in Table 2. For different traffic volumes, in terms of average daily traffic (ADT), the technical specifications are different; the significant difference lies in kinematic viscosity. Specifically the larger the design ADT, the larger the binder viscosity is. This is because we need larger strength for a pavement to bear traffic loads when the design ADT is larger. Two types of binders were adopted for the test roads.

Table 2: Test results of one kind of HIHSA binders.

Category	Condition	Result
Penetration	15℃，1/10mm	230.7
Kinematic viscosity	60℃, mm^2/s	6500
R.T.F.O. mass loss	60℃，±,%	1.0
Asphaltine	%	6.99
Saturation component	%	25.61
Aromatic component	%	25.48
Resin	%	34.14
Wax content	%	2.2

Note: The binder is composed of base asphalt and 15% of additives.

3.3 Grading of Aggregates

For HIHSA mix, aggregates can be either crushed stone or crushed gravel. According to site investigations in Heilongjiang province, resources of river gravel are fairly abundant and widely and evenly dispersed, which is also more inexpensive to obtain compared with crushed stone. The river gravel deposits are also immense in western provinces of China. As a comparison, both the local river gravel and stone are used as aggregates for the test road. Table 3 shows one grading of gravel aggregates.

Table 3: Grading of river gravel aggregates.

Sieve (mm)	1~2cm	0.5~ 1cm	Stone chips	<.5cm	Sand	Mineral powder	Upper limit	Lower limit	Mid value	Result
19	97.1	100	100	100	100	100	100	100	100	99.71
16	62.5	100	100	100	100	100	100	90	95	96.25
13.2	26.3	99.9	100	100	100	100	95	80	87.5	92.60
9.5	0.9	56.3	100	100	100	100	85	66	75.5	76.98
4.75	0	0.2	100	90.8	98.98	100	68	45	51.5	58.58
2.36	0	0	86.7	2.5	93.79	100	48	32	40	40.76
1.18	0	0	46.2	0.7	83.37	100	38	20	29	27.30
0.6	0	0	35.7	0	74.07	100	28	13	20.5	23.12
0.3	0	0	18	0	47.53	99.55	18	7	12.5	15.13
0.15	0	0	6.2	0	12.3	93.6	13	5	9	7.77
0.075	0	0	1.9	0	2	75.35	7	3	5	4.54
Mix（%）	20	30	0	20	25	5				100

In addition to grading, there are a few other technical requirements for aggregates as traditional asphalt mix. Tables 4 and 5 give results of adhesion and strength test for aggregates respectively.

Table4: Adhesion test of aggregates.

Type of binder	For crushed gravel (grade)	For crushed stone (grade)
Base asphalt	2	3
6‰ Additives	4	4

Table5: Strength test of aggregates.

Type of aggregates	Los Angeles abrasion（%）	Crushing value（%）
Crushed stone	11.9	15.2
Crushed gravel	9.8	14.4

3.4 Mix Design

There are quite a lot differences between HIHSA pavement and common asphalt pavement. Major difference lies in their deterioration principles. For the deterioration of asphalt pavement, rut, wave and other phenomena appear when shear strength is not large enough or plastic deformation is over large at high temperature, and too much cracks appear due to insufficient tensile strength or weak deformability at low temperature. HIHSA pavement is mainly applied to low volume roads in cold regions. The materials of the pavement need to be of certain fluidity to adapt to loading action and base course deformation. When fluidity of the mix is not enough cracking happens if the applied loads exceed cracking limit; Under unfavorable hydrologic conditions, effected by surface water and/or underground water, deterioration of the pavement accelerates if water stability of the mix is not good enough. Hence design target of the mix is to design such a mix that is capable to resist low temperature cracking, is of moisture and thermal stability, and is of good abrasion resistance and durability.

Usually there are two test methods to evaluate moisture stability. One is water-soaking stability applicable to binder with viscosity more than 4000 mm^2/s, which is similar to water-soaking Marshall stability test but the temperature in water and oven is 40 degrees centigrade due to the viscosity is low. The other much simple method is water-soaking mass loss for binder with lower viscosity.

To evaluate its cracking resistance at low temperature, it is not suitable to use tensile stiffness at low temperature. The reason is that HIHSA materials itself is low in strength, it relies on larger deformation of the binder to resist cracking. The tensile stiffness is not high, for small force may cause certain deformation. Experiences in cracking resistance have been integrated in selection of binder and grading design.

Cracking performance is quite often evaluated with site survey or investigation. Freeze-thaw indirect tensile test may be employed for the purpose.

Selection of the mix types and determination of binder content is generally empirical. Mix type is divided by different particle range; different particle range corresponds to suitable binder type and binder content. And each type of mix corresponds to certain range of ADT. It is convenient for engineering practice, rational and cost-effective as well. The binder content is in the category of 3.0-4.5%. The void content (VC) is 7-14%.

4 IN-SITU EXPERIMENTS AND PERFORMANCE EVALUATION

The test road for the research program is in S207 Jiagedaqi – Mohe highway, 20km north of Tahe county, Daxing-anling region, the north most and the coldest part of China. It is 9.135km long with station number K45+000 – K48+860.4 and K0+000 – K5+275. Construction standard adopts Class 3 highway with asphalt pavement, 6m wide with design ADT of 1000. Prior to the construction, it is a gravel road for forestry transportation. Flood ice, ice lake of the local saying, and isolated permanent frozen ground exist frequently along the road. It was constructed with the blend of many kinds of easily available local materials. Both climatic and hydrologic conditions are unfavorable (see Table 6 for detail).

Table 6: Climatic and hydrogeologic characteristics in Daxing-anling region.

Geographical characteristic	High latitude
Climate	Frigid temperate zone
Vegetation	Principally forestry zone
Annual mean air temperature	-2～-7℃
Average air temperature in January	-18～-31℃
Average air temperature in July	16～22℃
Annual lowest air temperature	-33～-60℃
Annual highest air temperature	32～37℃
Annual mean air temperature deviation	46～53.5℃
Annual precipitation	400～600mm
Annual evaporation	1000mm or so
Snow accumulation	10～50cm
Average ground temperature	0～2.5℃
Sectional structure of permanent ground	Principally disconnected frozen ground
Seasonal freeze-thaw process	Frost penetration＞3m，thawing fast
Physical geological phenomenon	Marshland, flood ice etc. common

4.1 Structural Design of the Pavement

The base course and subbase course are made of unbound granular materials; the resilient moduli of the two courses are not less than 140Mpa and 90Mpa respectively. Their gradings should meet the requirements. For the test road we use local river gravel and naturally crushed stone accumulated on mountain slope. Different thickness and combination are considered in order to find the right criteria for design. Besides we make the following variations of materials and structures for the test road, as shown in Table 7.

Table 7: Variations of Materials and Structures.

No.	Station Number	Binder	Aggregates (crushed)	Binder Content%	Description of grading and structure
1	K5+275～K4+430	H	Stone	4.2	Normal grading except Item5
2	K4+430～K4+360	H	Gravel	4.2	Normal
3	K4+360～K4+060	S	Gravel	3.6	Normal
4	K4+060～K3+780	S	Stone	3.6	Normal
5	K4+755～K4+840*	H	Gravel	4.2	Quasi-yard grading
6	K3+780～K2+780	H/S	Stone	4.3or3.7	Quasi-asphalt mix grading
7	K1+528～K47+495	H	Gravel/ stone/blend	4.3	Crack-resistant grading
8	K2+260～K1+528*	H	Gravel	4.3	Skid-resistant grading
9	K45+000～K45+847	H	Gravel	4.3	Grading with higher content of uncrushed gravel
10	K1+528～K0+193	H	Blend	4.3	Grading with higher sand content
11	K44+000～K44+050	H	Blend	4.3	Normal grading, paved on cement concrete base-course

Note: Items with * denotes left lane in station increasing direction. H and S imply relatively harder and softer binder respectively, with the viscosity ranging from 2000 to 8000 mm^2/s.

Based on miscellaneous analysis and evaluation, for instance, to in-situ experiments and observations of test road, theoretical structural calculations with the designing program of multilayer elastic system (Ministry of Communications, P.R.China, 1997), and related experiences abroad, a typical structure is proposed for HIHSA pavement in cold regions. It is around 4cm HIHSA surface course (wearing course) plus 15 – 25cm of unbound base course (graded gravel or stone) plus 20 to 25cm of unbound subbase course (graded gravel or stone) plus subgrade. A filter course above subgrade is also required, which is frost-proof layer in cold regions. It should be noted that situations with ADT larger than 2500 and less than 400 are not considered, and necessary to be at least calculated separately.

Extensive site observations and experiments were conducted on frost heave, periodical moisture content, surface water and ground water, wearing course sampling, bearing capacity, deflection, evenness, rut, skid-resistance and others. Data from quality examination shows that skid-resistance and evenness can meet the specifications in use very well. Both mixture production and road performance show that materials No.6 in Table 7 is difficult to manage and hence not suggested for application so far.

4.2 Observation of Crack Resistance

Crack resistance has been observed continuously，see Table 8 for part of the data from site observations. As is known to all, it is very important to cold regions' research. Cracking and crack-induced issues of asphalt pavement with semi-rigid base course which is typical and common in China, have long aroused pubic concerns, improvements and new solutions are being strived for.

In the study area, transverse cracks of common asphalt pavement generally happen at about every 10m in longitudinal direction. For the entire HIHSA test road, it cracks averagely at every 54m. From Tables 7 and 8, in the section using normal grading plus H binder, No. 1 and 2 in Table 7, it cracks averagely at every 24m. In the section using normal grading plus S binder, No. 3 and 4 in Table 7, it cracks averagely at every 48.3m. In the section using crack-resistant grading, No. 7 in Table 7, it cracks at an interval of 87.7m. It can be seen that HIHSA pavement is of high crack resistance, and the crack resistance varies with the binders and gradings of aggregates adopted. Some of the research findings will be described in a separate paper. The cracks heal back fairly well in summer time.

Table 8: Listing of Crack Observations.

Station	Length,m	Width,mm	Station	Length,m	Width,mm
K47+700	5	5	K0+300	6	5
K47+750	6	10	K0+590	3	3
K47+980	6	10	K0+670	6	10
K48+140	6	8	K0+865	6	5
K48+165	5	8	K0+945	6	5
K48+190	6	8	K0+970	6	5
K48+200	6	10	K0+990	6	5
K48+235	6	8	K1+040	6	15
K48+350	6	20	K1+120	6	15
K48+450	6	10	K1+200	6	20
K48+510	6	10	K1+270	6	5
K48+625	6	10	K1+325	6	5
K48+790	6	5	K1+410	6	5
K48+835	6	8	K1+480	6	15
K0+020	6	15	K1+520	6	10
K0+290	6	15	K3+800	6	5

Table 8: Listing of Crack Observations (Continued).

Station	Length,m	Width,mm	Station	Length,m	Width,mm
K3+855	6	10	K4+655	6	5
K3+930	6	5	K4+675	6	10
K4+015	6	20	K4+715	6	5
K4+030	5	5	K4+750	6	10
K4+060	4	8	K4+805	6	10
K4+075	3	5	K4+835	6	5
K4+160	6	15	K4+845	6	5
K4+185	5	10	K4+850	6	5
K4+235	6	5	K4+860	6	3
K4+270	6	3	K4+875	6	3
K4+300	3	3	K4+890	6	3
K4+360	5	3	K4+980	6	5
K4+370	6	5	K4+990	6	3
K4+390	6	8	K5+000	6	5
K4+405	6	3	K5+040	6	3
K4+415	6	3	K5+070	6	3
K4+440	6	5	K5+080	5	3
K4+455	6	8	K5+105	6	5
K4+490	6	8	K5+125	6	3
K4+525	6	5	K5+175	6	5
K4+540	6	5	K5+200	4	3
K4+570	6	20	K5+220	6	8
K4+585	6	5	K5+245	6	5
K4+600	6	5	K5+265	6	5
K4+620	6	8			

Note: In the Table is listed the location in terms of station number, how long and how wide of each crack. The observing date is January 8, 2004.

4.3 Frost Stability

Site experiments show that frost heave ratio varies generally between 1% and 3%, in the category of weak frost heave. According to the authors' previous studies on highway flooding ice, for the kind of materials used for the base and subbase, frost heave would not happen and flooding ice would do instead. 1% - 3% is yielded due to subgrade, and does not cause any relevant failure.

4.4 Moisture Stability

Water permeates and drains off easily due to the void content (7-14%) in HIHSA mix, the type of base and subbase course adopted, the slope larger than 3%, and the special arrangement of road shoulder, etc. Water stability is well guaranteed. Table 9 shows the result of a permeability test.

Table 9: Water permeability tests of the pavement.

Station number	Permeability coefficient （ml/min）	Description
K25+500	3333	After 2 days paved
K26+000	3000	4 days
K26+500	1000	7 days
K27+000	888	8 days
K27+200	66.6	15 days
K28+000	59	60 days
K28+600	50	6 months and more
K29+300	30	6 months and more
K29+800	35	6 months and more

It can be noted from Table 9 that with time after open to traffic, water permeates via wearing course less and less. It also tells the wearing course mix gets dense in the same tendency.

5 CONCLUSIONS

Systematic lab and in-situ experimental studies upon HIHSA development were conducted for about three years, in view of the cold climatic condition and with consideration of making use of the locally abundant gravel and other materials. The studies involve materials, pavement structure and design, production and construction technology, quality control and others. Partial research findings and concluding remarks are as followed.

- ■Principles for HIHSA pavement performance is put forward.
- ■HIHSA pavement is suitable for construction of low volume highways in cold regions.
- ■Successful development and application for HIHSA is realized under rigid cold condition. In January of 2003, the average air temperature reached as low as -32℃, which broke the local record.
- ■Typical structure for HIHSA pavement in cold region is proposed.
- ■HIHSA pavement is of excellent crack resistance, water stability, frost stability and deformation adaptability.
- ■HIHSA pavement is cost effective, and is capable of decreasing construction cost by about 20% and more comparing identically with common asphalt pavements.

■Specifications for HIHSA Pavement Design, Construction and Quality Control in Cold Regions were worked out for further wide application in other northern and western provinces and areas.

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