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Study on low temperature performance of Gussasphalt on steel decks with hard bitumen

Yang Jun

(College of Transportation, Southeast University, Nanjing 210096, China)

Abstract: Using a Hamburg wheel-track test device, the resistance to rutting of Gussasphalt is tested and compared. Gussasphalt with hard bitumen has good resistance to rutting. The related resistance abilities to cracking at low temperature of Gussasphalt are tested and compared through flexural experiments and the composite structure fatigue test with temperature dropping. Gussasphalt with high performance polymer modified bitumen has a longer fatigue life and a lower breaking temperature; they can be used in the future surfaces for steel bridge decks in Germany.

Key words: Gussasphalt; surfaces for steel decks; hard bitumen; high performance polymer modified bitumen; low temperature performance

Because of good flexibility and fatigue resistance characteristics of Gussasphalt, double-decked Gussasphalt structures are used throughout Germany. The design life of Gussasphalt is 15 to 20 years, the various problems of surfaces appeared after 1 or 2 of use years[1,2]. Rutting is one of the most frequent damages even though the European climate is moderate. To reduce the rutting, it has been suggested to apply harder and polymer-modified bitumen.

1 The Origin of the Problem

In Germany, "Additional technical contract conditions and guidelines for the production of bridge surfaces on steel"(ZTV-BEL-ST 92)[3] is for the protection and surface layer with asphalt on steel bridges. It stipulated the use of PmB45 as a binder for bridges. Not polymer modified bitumen are no longer permitted prevent the cracks from appearing frequently at early deep temperature over the lengthways stiffness.

On the other hand, road construction administrations and building companies also desire to reduce rutting and get more stable surfaces with PmB25 instead of PmB45. However, the improvement of stability would mean a deterioration of low temperature performance of surfaces.

It is the purpose of this study to find out whether it is possible for Gussasphalt with PmB25 to improve the stability as desired and not to deteriorate low temperature performance through laboratory examination (wheel tracking test and fatigue exam). Thus in the future stable surfaces can be built with a longer life.

2 Methodical Procedure

5 different binders are predefined by the BASt to produce Gussasphalt. They are normal bitumen B30/45, two polymer modified bitumen PmB45 and PmB25, two high performance modified bitumen Sealoflex 5-50 (SFB5-50) and Olexobit NV25(PmB25 + Sasobit). The examinations of basic materials (bitumen, aggregate, and filler), mix design and the wheel-tracking test with the Hamburg Wheel Tracking Device are carried out.

When the temperature drops, asphalt becomes hard and loses good flexibility. The flexural strain of Gussasphalt prisms (4 cm × 4 cm × 16 cm) with different bitumens are tested and compared at low temperatures, such as 5, 0, −5 and −10 ℃.

The low temperature performance of Gussasphalt are decided by the composite structure fatigue exam at different temperatures down to the failure of beams, which are produced with steel plate, adhesive layer and Gussasphalt, as the actual surfacings on steel decks. The examining temperatures are carried out 3 K decreased per step from the fixed start temperature by the pre-test. The exam beam is subjected to load alternation after reaching the examining temperature step with 10^5 cycles, respectively, subjected to a predefined load and predefined frequency (2 Hz in accordance with the TP-BEL-ST[4]) in the fatigue test.

3 Binder Related Indices and Mixture Gradation

The related indices of binders are in Tab.1. The

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Biography: Yang Jun (1968—), female, doctor, associate professor, yangjun@seu.edu.cn.

Tab.1 Binder related indices

Binder	Needle penetration/mm	Softening point/℃	Fraaβ breaking point/℃	Elastic recover percent/%	Density/(g·cm^{-3})
B30/45	3.6	57	-9.3	—	1.038 7
PmB45	4.7	60	-17.0	69.0	1.030 9
PmB25	3.3	69	-12.0	65.5	1.030 8
NV25	3.0	72	-23.0	*	1.035 7
SFB5-50	5.8	101	-14.5	87.0	1.018 4

Note: * The sample wasn't pulled to demand length, it broke; — It hasn't been tested, because it is a normal binder, the others are polymer-modified binders.

limestone filler and basalt aggregate are used in the test. The mixture gradation and the gradation in ZTV Asphalt-StB 2001[5] are in Tab.2.

Tab.2 Mixture gradation for GA 0/11S

Sieve size/mm	Passing percent/mm		
	Composite gradation	Upper limit of ZTV Asphalt-StB 2001	Low limit of ZTV Asphalt-StB 2001
11	94.8	90	100
8	75.4	70	85
5	61.2	58	70
2	48.9	45	55
0.71	38.9	32	48
0.25	32.3	24	40
0.09	25.9	20	30

4 Gussasphalt with Hard Bitumen Wheel Track Tests

Through the Gussasphalt penetrations test at 40 ℃, the optimal binder contents of each Gussasphalt are determined and the high temperature performances aretested with the Hamburg wheel-tracking device under the same condition, which are at 50 ℃, with rubber wheel and in an air bath. The test results are in Tab.3. Gussasphalt with hard bitumen has higher resistance to rutting.

Tab.3 Test results of Gussasphalt with Hamburg Wheel-Tracking Device

Binder	Content/%	Plates parameters			Deformation at 2×10^4 cycles/mm			
		Density/(g·cm^{-3})	Air void/%	Thickness/cm	Fixed point value		Section average value	
					Test	Average	Test	Average
B30/45	7.1	2.567	1.8	4.0	6.5	5.8	7.4	6.6
B30/45	7.1	2.558	2.1	4.2	5.0		5.7	
PmB45	7.2	2.551	1.0	4.0	3.3	3.9	3.9	4.6
PmB45	7.2	2.55	1.1	4.1	4.5		5.3	
PmB25	7.5	2.562	0.9	4.1	2.5	2.4	2.8	2.8
PmB25	7.5	2.582	0.1	4.1	2.2		2.7	
NV25	7.4	2.567	1.8	4.1	2.8	2.8	3.2	3.1
NV25	7.4	2.564	1.9	4.0	2.7		3.0	
SFB5-50	6.9	2.558	1.8	4.1	1.8	2.5	2.3	2.9
SFB5-50	6.9	2.557	1.9	4.1	3.2		3.5	

5 Gussasphalt Flexural Strain Tests

Form rutting plates and cut plates to prisms. The size of prisms are 4 cm × 4 cm × 16 cm. The test temperatures are 5, 0, -5 and -10 ℃. Use cooling box to make the samples reach the test temperature. The load speed is 50 mm/min without an environmental temperature control box. The test results are in Tab.4.

When the temperature drops, the breaking strength and flexural limit strain of Gussasphalt prisms with polymer modified bitumen become smaller or remain at a similar lower level, and the breaking stiffness modulus becomes bigger or remains at a similar higher level. The test results are similar to other research accomplishments[6,7]. They are reliable. During the test temperature period, it is a little difficult to find the obvious difference between different Gussasphalts. Further fatigue tests are necessary.

Tab.4 Gussasphalt flexural strain test results

Gussasphalt	Temperature/℃	Breaking strength/MPa	Breaking strain/10^{-3}	Breaking stiffness modulus/GPa
SFB5-50	5	18.1	14.82	1.286
SFB5-50	0	13.3	11.64	1.232
SFB5-50	-5	11.8	6.69	1.811
SFB5-50	-10	11.5	6.63	1.803
PmB25	5	14.7	8.77	1.696
PmB25	0	13.8	10.23	1.370
PmB25	-5	10.4	6.22	1.697
PmB25	-10	10.6	6.20	1.761

6 Fatigue Specimens Fabrication[3,4,8] and Apparatus

The size of the steel plates is 700 mm × 200 mm × 12 mm.

The surface preparation of steel plates is carried out in accordance with TP-BEL-ST, it is to clean the rust off the steel plate and make its surface condition meet the demands of Reinheitsgrad SA 2 1/2.

The adhesive layer is a kind of three-layered structure, which includes two epoxy asphalt layers (Icosit HM Primer, Icosit Haftmasse) attached to a rubber modified asphalt layer (Esha buffer layer). The fabrication is carried out in accordance with the corresponding handbooks and specifications, subject to professional advice. The total thickness of the adhesive layer is 10 mm or so. The laboratory of Institut für Straβenwesen at RWTH AACHEN carries out the fabrications of adhesive layers and Gussasphlat layers of fatigue beams. The same optimal bitumen percents with the wheel-tracking test are adopted for Gussasphalt layers of each bitumen. The protection and surface layer is 35 mm of thickness respectively and 150 mm of width at the middle of the steel plate. The mix temperature of Guβasphlat is 250 ℃ with 60 r/min for 1 min and the retaining time is 1 h with 10 r/min.

The air void percent ages of asphalt exert significant impact on their fatigue life[7,9,10]], they must be controlled at the same level. Broken specimens were used to check the air voids of Gussasphalt. The related test results are in Fig.1. The air void percentages of Gussasphalt are controlled not to exceed 2%. The fabrication and control methods of the fatigue beams are suitable. The fatigue test results of specimens are reliable and comparable.

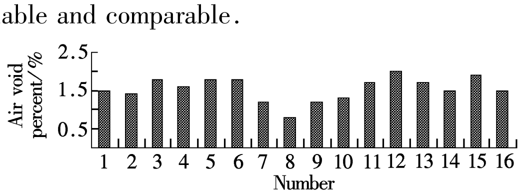

Fig.1 Air void percentages of Gussasphat of fatigue specimens

The laboratory of the Institut für Eisenhüttenkunde at RWTH AACHEN carries out the fatigue tests. The lowest temperature of cooling room is about − 20 ℃. The static and dynamic deflections are measured and recorded through the displacement sensors and computer. The load function corresponds to a sine function, which swings with constant load amplitude between the bottom load F_o and waiter load F_g. The requirements for the bottom load are based on the experimental conditions and mechanical influences, with which the lifting movement and touching down of the load device during experimental execution should be avoided.

7 Fatigue Experimental Model

After a lot of pretests, the test model is decided, 1 field model with the span $L = 350$ mm is adopted. The 350 mm of sample is stored on the two steel rollers with 50 mm of diameter (See Fig.2). The load is bought in 1 steel roller with 50 mm of diameter above the steel plate into the sample. The load roller is at the middle to support steel rollers.

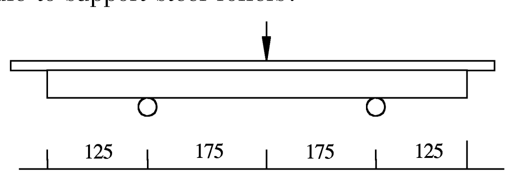

Fig.2 Field model (unit: mm)

In order to decide the suitable load for the next fatigue tests, related tests are carried out. Based on the controlled requirements of steel plate, the maximum deflection of steel plate without Gussasphalt is 0.95 mm, and the corresponding dynamic load of 6.4 kN was found at 20 ℃. At − 3 ℃, with 7 kN of waiter load and 0.5 kN of bottom load, for specimens with B30/45, 10^5 cycles were carried out. Cracks couldn't be found because of the smaller deflection. Based on the deflection measure values for steel bridges, the maximum deflection of steel deck is 0.5 mm at 15 to 25 ℃[2]. For the specimen with NV 25 at 20 ℃, the corresponding static load is only 4.8 kN (See Fig.3).

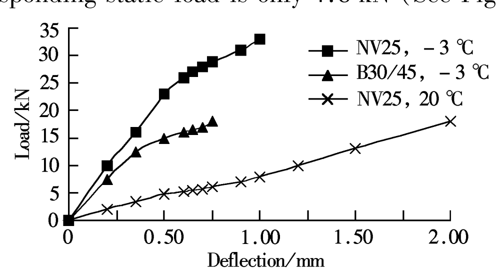

Fig.3 Load vs. deflection at different temperatures

Breaking tests with static load way were carried out (See Fig.3). The asphalt deflection developments are different at room temperature (20 ℃) and low temperature (− 3 ℃). At room temperature, when the deflection is 2.00 mm, the asphalt with NV 25 doesn't break and the corresponding load is 18 kN; but at low temperature, when the deflection is only 0.65 mm, the asphalt starts to crack and the corresponding load is 27 kN. When the temperature drops, asphalt becomes harder and less flexible. The strength and limit deformation of asphalt with normal bitumen B30/45 are smaller than asphalt with NV25 at the same temperature (−3 ℃).

Based on Fig.3, for asphalt with NV25 at −3 ℃, the yield load is 20 kN. The suitable load should be less than 20 kN. For asphalt with B30/45 at −3 ℃, the breaking load is less than 18 kN. Compared with other research results, the suitable load would be between 13 kN and 16 kN.

Analyzing the test data in Tab.5, some rules are found. As the load cycles increase, the deflections increase (asphalt develops creep) at the same temperature. Asphalt becomes hard and deflection should decrease as the temperature drops, but asphalt remains the load history; the deflection of next step at the beginning is less than the deflection of last step at the end and is bigger than the deflection of last step at the beginning for the same specimen. Load pause is applied to change the temperatures which makes asphalt relax stress and recover deformation. The same experimental condition is very important. The composite structure fatigue test checks the comprehensive ability of Gussasphalt at low temperature, which includes resistance to fatigue, deformation recovery and so on.

Tab.5 Suitable load decision

Bitumen	Specimen	Waiter load/kN	Temperature/℃	Dynamic deflection/mm				Test results
				Beginning	Crack	10^5 cycles	Increment	
B30/45	9	13	−3	0.082		0.082	0	No crack
B30/45	9	16	−3	0.108	0.159−0.181		0.051−0.073	Crack at 51 × 10^3
NV25	5	16	−3	0.206		0.224	0.018	No crack
NV25	5	16	−6	0.207	1.213		1.006	Crack at 36 × 10^3
NV25	5	13	−3	0.181		0.184	0.003	No crack
NV25	7	13	−6	0.123		0.137	0.014	No crack
NV25	7	13	−9	0.077		0.085	0.006	No crack
SFB5−50	1	16	−3	0.140		0.172	0.032	No crack
SFB5−50	1	16	−6	0.151	0.195−0.933		0.044−0.782	Crack at 20 × 10^3
SFB5−50	2	15	−3	0.093		0.082	−0.011	No crack
SFB5−50	2	15	−6	0.100		0.133	0.033	No crack
SFB5−50	2	15	−9	0.821				Crack at the beginning

8 Fatigue Test Results and Discussion

Based on the previous test results (See Tab.5), to get a clear breaking temperature list for different bitumens, the upper limit load (waiter load) 15 kN has been determined to be the suitable load. Further test results under the same condition, the same start temperature and constant load controlled way are in Tab.6. Based on the test results in Tab.6, the softer asphalt (PmB45) is cracked earlier than the harder asphalt (PmB25). This is the opposite conclusion of traditional wisdom.

Tab.6 Fatigue test results at low temperature

Bitumen	Specimen	Waiter load/kN	Temperature/℃	Dynamic deflection/mm				Test results
				Beginning	Crack	10^5 cycles	Increment	
PmB45	2	15	−3	0.113		0.114	0.001	Microcrack at the beginning, but can't find it
PmB45	2	15	−6	0.648				Obvious crack
PmB25	2	15	−3	0.116		0.329	0.213	No crack
PmB25	2	15	−6	0.788			1.006	Crack at the beginning
PmB45	1	15	−3	0.146		0.110	−0.036	Microcrack at the beginning, but can't find it
PmB45	1	15	−6	0.172		1.375	1.203	Think it has broken, but can't find crack
PmB45	1	15	−9	0.767		0.770	0.006	Obvious crack

The different ways of cracking result from different types of asphalt at different temperatures. At −6 ℃ and 16 kN, NV25 and SFB5−50 broke in a brittle way. The cracks of PmB45 develop gradually, see Figs.4, 5and 6, especially for PmB45, at −3 ℃ and 15 kN, the load becomes smaller during the test, that is microcracks occurred. It is hard to find a microcrack. It means the asphalt hasn't yet become hard, but it hasn't enough strength to support a heavy load.

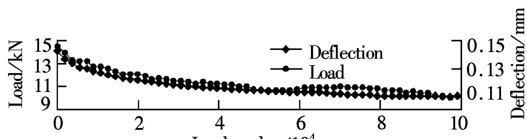

Fig.4 Load and deflection develop during the test (PmB45−1, 15 kN, −3 ℃)

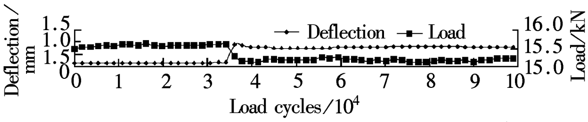

Fig.5 Deflection and load develop during the test (NV25 - 5, 16 kN, - 6 ℃)

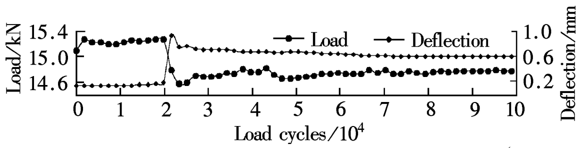

Fig.**6** Load and deflection develop during the test (SFB5 - 50 - 1, 16 kN, - 6 ℃)

9 Conclusions and Suggestions

Gussasphalt with hard bituminous materials in the project has a higher resistance to rutting.

During the test temperature period (5 - 10 ℃), the breaking strength and limit strain of Gussasphalt with polymer modified bitumen in this project becomes smaller or remains at similar lower level, and the breaking stiffness modulus become bigger or remains at similar higher level. It is hard to decide which is better bitumen. Further fatigue tests are necessary.

Based on the test results in Tabs.5 and 6, at low temperatures Gussasphalt with NV25 and SFB5 - 50 have a longer fatigue life than other Gussasphalt of B30/45, PmB45 and PmB25, which might be applied to Gussasphalt for surfaces on steel decks in the future.

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钢桥面硬沥青浇注式沥青混合料低温性能研究

杨 军

(东南大学交通学院,南京 210096)

摘 要 通过汉堡轮辙试验,考察了浇注式沥青混合料的抗车辙能力,硬沥青浇注式沥青混合料具有良好的抗车辙能力.通过低温弯曲试验和逐步降温的钢桥面铺装复合结构疲劳试验,测试与比较了使用硬沥青的浇注式混合料低温抗裂性能.高性能聚合物改性沥青浇注式混合料具有较长的疲劳寿命和较低的断裂温度,可用于钢桥面浇注式沥青铺装.

关键词 浇注式沥青混合料; 钢桥面铺装; 硬沥青; 高性能聚合物改性沥青; 低温性能

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