Comparative Performance of Pavement Mixes Containing Conventional and Engineered Asphalts

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Results of a comprehensive laboratory evaluation of asphalt and pavement mixes containing conventional and engineered paving binders are presented. Model pavement structures were constructed and tested under full-scale dynamic loads and high temperatures simulating field conditions for rutting evaluation. Pavement rutting was monitored over hundreds of thousands of load cycles simulating long-term performance. Comparative results on pavement temperature susceptibility and low-temperature behavior of various conventional and engineered asphalt mixes are presented. Pavement temperature susceptibility is evaluated by determination of resilient moduli (M_R) at various test temperatures. Low-temperature performance is evaluated by determination of pavement stiffness values derived from direct tension tests carried out at very slow speeds. Conventional physical properties and the Strategic Highway Research Program's performance characteristics on test asphalts are presented and discussed in relation to actual measured performance. Analysis of test results identified three asphalt characteristics of particular importance for good performance; all are measured on the aged thin-film oven test residue including asphalt viscosity at 60°C, low-temperature penetration at 4°C, and asphalt temperature susceptibility.

Rutting of asphalt pavements is a problem that many roadway authorities face North America. Pavement rutting can be affected by many factors, including the quality of materials used in terms of aggregates, quality of asphalt cement, and the resultant properties of the selected mix. The mix performance will be affected by the volume of commercial traffic, axle weights and configuration, tire type, tire pressures, and climatic conditions, particularly warm summer temperatures (*1, 2*).

During the past decade, not only has the number of commercial transports and buses increased significantly, but also axle loads and the use of higher tire pressures, and radial and super-single tires by truckers have resulted in widely observed pavement-rutting problems on many highways and arterial roads. Rehabilitation of premature rutting damage not only depletes available maintenance dollars but also inconveniences travelers.

In recent years, highway engineers and researchers have developed alternative mixes to be used in situations of severe loading or when conventional paving materials perform inadequately. Such asphalt mixes may contain large stones, higher percentages of coarse aggregate, or higher percentages of crushed particles—up to 100 percent of the total aggregate mixture. Ontario Ministry of Transportation (MTO), for example, developed new dense-graded asphalt concrete pavement mixes, such as heavy duty binder and heavy duty surface course mixes. Specifications for these heavy duty mixes require the use of 100 percent crushed quarry materials, both in the coarse and the fine aggregates. Use of large stone mixes (*3*) and stone mastic (*4,5*) are other examples of heavy duty pavement mixtures that are expected to attain a higher degree of aggregate interlock, improved load-carrying properties, and enhanced resistance to pavement rutting.

The use of such heavy duty, high stone content, high stability mixes, however, poses performance questions, particularly about long-term durability. Field observations indicate that compaction of such mixes is difficult, and attainment of a 95 percent minimum compaction level, required in dense-graded mixes for good durability, is difficult or, in some cases impractical to achieve.

Other materials have received considerable attention from various highway and road authorities, such as asphalt modifiers (*6,7*), premium grade asphalts (*8,9*), and polymer modified materials (*10,11*). The presence of asphalt cement in the mix can significantly affect pavement performance (*12, 13*). Physical properties and temperature susceptibility characteristics of the asphalt binder influence pavement stiffness, both at high and low field-operating temperatures, and thereby can dramatically affect final performance of the mix. Such modified or engineered asphalts have been used with conventional and with high-stability heavy duty mixes to control rutting, improve low-temperature behavior, and enhance overall pavement durability.

PAVEMENT TEST PROGRAM

The purpose of this investigation was to conduct a comparative test program on pavement mixes containing conventional and engineered asphalts and assess the effects of asphalt properties on pavement performance. Asphalt characteristics were evaluated both by conventional testing and according to the Strategic Highway Research Program SHRP asphalt-binder specifications.

Four commercial asphalt binders were included in the test program: two engineered asphalts and two conventional binders. The two conventional materials were 85–100 pen and 150–200 pen grades. The two engineered asphalts were both 85–100 pen and included an SBS polymer modified asphalt (Styrelf) as well as an asphalt produced by a modified refining process without use of polymer, "premium asphalt." These two engineered asphalts are well-known materials that have been used in many paving projects in various parts of Canada and the United States The premium and the conventional asphalts were obtained from Petro-Canada Lake Ontario Refinery, Mississauga, Ontario. The Styrelf polymer modified material was obtained from Polymac Engineered Asphalts Inc. of Oshawa, Ontario.

The aggregate mixture used conformed to the MTO's requirements for HL3 mix. The HL3 mix is a dense-graded asphalt con-

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crete mix with a 13-mm (0.5-in.) top aggregate size, and typically is used in Ontario for surface course paving on highways carrying up to 5,000 AADT per lane. In all comparisons, the mix design employed was kept the same, the asphalt cement type being the test variable.

Pavement evaluations carried out included determinations of pavement resistance to rutting, low-temperature cracking, and pavement temperature susceptibility. Rutting resistance evaluations were performed at Petro-Canada Asphalt Research Lab in Sheridan Park, Ontario, on full-scale pavement structure models tested under full-scale heavy dynamic loading. Hundreds of thousands of load cycles were applied at high temperatures to simulate long-term permanent deformation response.

Low-temperature stiffness evaluations were carried out on pavement samples using a direct tension test performed at very slow speeds. Pavement temperature susceptibility was determined by measurements of pavement resilient moduli (M_R) on standard pavement briquettes at various temperatures, using dynamic, indirect tension testing.

CHARACTERISTICS OF TEST ASPHALTS AND MIXES

Physical Characterization of Test Asphalt

Physical characteristics of the four test asphalts were determined and are presented in Table 1. Physical properties of the conventional asphalts are typical of high quality 85–100 pen and 150–200 pen asphalt cements used in eastern Canada and the northeastern United States. These materials meet all ASTM and AASHTO specifications for penetration-graded asphalts as well as the requirements for Group A asphalt cement specified by the Canadian General Standards Board (CGSB) as well as all MTO asphalt specifications.

As compared with the 85–100 pen conventional product, both the premium and the Styrelf asphalts provided significantly higher viscosity values, both at 60°C and 135°C, higher low-temperature (4°C) penetration, and superior temperature susceptibility parameters in terms of the penetration-viscosity number (PVN) and the penetration index (PI). The test results on the residue from the thin-film

TABLE 1 Physical Characteristics of Test Asphalts

	ASTM Reference Test	Conventional Asphalts		Engineered Asphalts	
		85-100 Pen	150-200 Pen	Premium	Polymer Modified
Viscosity, poise, 60°C (140°F)	D2171	1453	584	3092	4372
Viscosity, cSt, 120°C (248°F)	D2170	760		1165	1918
Viscosity, cSt, 135°C (275°F)	D2170	350	230	612	835
Pen, 25°C (77°F), 100 g, 5 s	D5	91	168	91	88
Pen, 4°C (39°F), 200 g, 60 s	D5	27	47	38	34
Pen, 4°C (39°F), 100 g, 5 s	D5	7	12	12	10
Ductility, 4°C, cm	D113	60	>150	12	49
Flash Point, C O C, °C (°F)	D92	306 (583)	308 (586)	274 (525)	318 (604)
Pen-Vis No. (PVN), 25-60		-0.5	-0.4	+0.3	+0.6
Pen-Vis No. (PVN), 25-135		-0.5	-0.5	+0.3	+0.7
Penetration Index (PI), 25-4		-1.8	-1.95	-0.3	-0.8
Thin Film Oven Test (TFOT)	D1754				
Mass, % Loss		0.047	0.02	0.14	0.16
Pen, 25°C, 100 g, 5 s	D5	56	100	54	55
% of Original Pen		62	60	59	63
Pen, 4°C, 200 g, 60 s	D5	20	35	30	26
Pen, 4°C, 100 g, 5 s	D5	6	10	9	8
Viscosity, poise, 60°C (140°F)	D2171	2,999	1,215	13,124	11,133
Viscosity, cSt, 135°C (275°F)	D2170	460	325	1,117	1,240
PVN (25-60)		-0.5	-0.6	+0.9	+0.7
PVN (25-135)		-0.6	-0.5	+0.5	+0.7
PI (25-4)		-0.9	-1.1	+0.5	0.0
Solubility in $ClCHCCl_2$	D2042	99.9	99.9	99.9	99.9

oven test (TFOT) also confirm these improved qualities of the engineered asphalt products. Asphalt viscosity at 60°C (high pavement operating temperatures) increased several times over, suggesting that these engineered asphalts should significantly improve rutting resistance more than conventional 85–100 pen grade material.

Again, a significant increase in low-temperature asphalt penetrations measured at 4°C, 200 g, 60s on the TFOT residues is obtained with the engineered products. With improved temperature susceptibility for these asphalts, they should yield superior low-temperature pavement performance. The 150–200 pen asphalt was also evaluated for its low-temperature pavement performance.

By comparing the low-temperature penetrations (4°C, 200 g, 60s) of the engineered and conventional asphalts, it would appear that these engineered asphalts should provide low-temperature pavement performance equivalent to an asphalt grade between 85–100 and 150–200 pen materials. But, because of the improved temperature susceptibility of the engineered asphalts, one may expect their low-temperature performance to approach that of the softer grade 150–200 pen materials at temperatures below 4°C.

In summary, analysis of the physical test data suggests that both engineered asphalts included in this test program should improve pavement rutting, as well as improve low-temperature pavement performance relative to the conventional 85–100 pen control materials.

SHRP Binder Tests and Analysis

A summary of the results on SHRP asphalt binder tests is given in Table 2. These test data were developed through a testing program carried out at Pennsylvania State University. The SHRP test data were obtained on three of the four test asphalts as illustrated in Table 2. A detailed description of the SHRP performance specifications is given in a work by Anderson and Kennedy (*13*).

By comparing the engineered asphalt with the 85–100 pen and 150–200 pen conventional materials, the SHRP test results indicated the following:

TABLE 2 Summary of SHRP Binder Test Results

SHRP Test	**Conventional Asphalts**		**Engineered Asphalt Premium**	**SHRP Binder Specifications**
	(AC-5) 150-200 Pen	**(AC-15) 85-100 Pen**		
	Tests on Original Binder			
Flash Point, °C	308	306	274	230 min.
Viscosity, Pa.s @ 135°C	0.212	0.338	0.560	3 Pa.s max.
Dynamic Shear, SHRP B-003				
Temp. at which $G^*/\sin\delta = 1.0$ kPa	56.9	63.5	68.4	52 to 70+ depending on grade
Physical Hardening Index, h	1.71	1.61	1.45	Report
	Tests on Rolling Thin Film Oven Test Residue			
Mass Loss, %	0.007	0.056	0.119	1.0 max.
Dynamic Shear, SHRP B-003				
Temp. at which $G^*/\sin\delta = 2.2$ kPa	56.4	64.5	70.9	52 to 70+ depending on grade
	Tests on Pressure Aging Vessel Residue, SHRP B-005			
PAV Aging Temperature, °C	100	100	100	90 to 110 depending on grade
Dynamic Shear, SHRP B-003				
Temp at which $G^*\sin\delta = 5.0$ MPa	13.6	20.3	13.5	7 to 34 depending on grade
Creep Stiffness, SHRP B-002				
Temp. at $S(t) = 300$ MPa	-22.0	-19.5	-24.8	0 to -36 depending on grade
Temp at which $m = 0.3$	-23.3	-18.0	-20.0	
Direct Tension, SHRP B-006				
Temp. at which Failure Strain = 1.0%	-16.2	-11.6	-14.5	0 to -36 depending on grade
SHRP Binder Classification	PG 52-28	PG 58-22	PG 64-28	

1. Engineered asphalt should provide a higher rutting resistance performance, as indicated by the B-003 test on RTFOT residue. The temperature at which $G^*/\sin\delta$ reaches 2.2 kPa is about 7°C (12°F) higher for the engineered product than for the conventional 85–100 pen asphalt.
2. Engineered asphalt also should provide superior cold-temperature performance as indicated by the creep stiffness, SHRP B-002, and the direct tension SHRP B-006 test results. SHRP tests rated the engineered asphalt cold-temperature performance between the two conventional asphalts. The limiting temperature at which the *m* value is equal to 0.3 for the 85–100 pen conventional asphalt is −18.0°C (0°F) compared with −20.0°C (−4°F) for the engineered asphalt and −23.3°C (−10°F) for the conventional 150–200 pen materials. The limiting temperature at which the binder stiffnesses are equal to 300 MPa is −24.8°C (−12°F) for the engineered asphalt versus −19.5°C (−2°F) for the 85–100 pen and −22.0°C (−8°F) for the 150–200 pen conventional asphalts.
3. SHRP test results indicate superior fatigue performance for the engineered asphalt. The temperature at which $G^*/\sin\delta$ is equal to 5.0 MPa is 7°C (12°F) lower for the engineered product if compared with that of the control 85–100 pen conventional product. Note that the limiting temperature for fatigue performance of the engineered asphalt is equivalent to that displayed by the softer 150–200 pen (AC-5) conventional product.
4. For design purposes, the SHRP test results rated the engineered product in the same low temperature classification as the 150–200 pen (AC-5) materials, [i.e., a minimum pavement design temperature of −28°C (−18°F)], and in a classification higher than the 85–100 pen (AC-15) conventional product for high temperature performance, [i.e., an average 7-day maximum pavement temperature of 64°C (147°F) versus 58°C (136°F) for the conventional material].
5. In the final analysis, according to the SHRP test results, the engineered asphalt is a superior asphalt that has higher resistance to rutting and tenderness; has superior fatigue, low-temperature, and physical hardening characteristics; and meets requirements for ten SHRP performance grades versus only four grades for each of the conventional materials 85–100 pen and 150–200 pen consecutively, as shown in Table 3. According to the SHRP classification, the engineered asphalt has a useful temperature span of 92°C; whereas each of the conventional asphalts tested has a 80°C span.

Characteristics of Asphalt Test Mixtures

Marshall design characteristics for the HL3 test mixes were determined and are presented given in Table 4. The HL3 mix contained 40 percent coarse aggregate, 60 percent fine aggregate, and 5.4 percent asphalt cement. The coarse aggregate is a crushed quarry limestone material, and the fine aggregate is a 2:1 blend of sand and washed screenings. All the three test mixes provided excellent stability and overall Marshall properties exceeding the HL3 requirements in the MTO specifications (Table 2).

Note that the HL3 test mix used is a high-quality mix; it contains large amounts of crushed quarry materials for good interlock, and high-stability properties to optimize the effects of the aggregate on final performance. No significant differences in Marshall properties are noted between conventional and engineered asphalts.

TABLE 3 Comparative Compliance to SHRP PG-Grades for Asphalts Tested

Grade	Conventional Asphalts		Engineered Premium Asphalt
	85-100 Pen (AC-15)	150-200 Pen (AC-5)	
PG 52-10	YES	YES	YES
PG 52-16	YES	YES	YES
PG 52-22	No	YES	YES
PG 52-28	No	YES	YES
PG 52-34	No	No	No
PG 52-40	No	No	No
PG 52-46	No	No	No
PG 58-16	YES	No	YES
PG 58-22	YES	No	YES
PG 58-28	No	No	YES
PG 58-34	No	No	No
PG 58-40	No	No	No
PG 64-16	No	No	YES
PG 64-22	No	No	YES
PG 64-28	No	No	YES
PG 64-34	No	No	No
PG 64-40	No	No	No
PG 70-10	No	No	No
PG 70-16	No	No	No
PG 70-22	No	No	No
PG 70-28	No	No	No

TABLE 4 Marshall Characteristics for Various HL3 Test Mixes

	Conventional Asphalt 85-100 Pen	Engineered Asphalts		Ontario MTO, HL3 Specifications
		Premium	Polymer Modified	
Voids, %	3.1	3.3	3.6	3-5
Stability, N	13,967	13,580	14,975	8,900 min.
(lb)	(3,140)	(3,055)	(3,366)	(2,000 min.)
Flow, 0.25 mm	11	11.3	12.5	8 min.
VMA, %	15.0	15.7	15.4	15.0 min.

PAVEMENT PERFORMANCE EVALUATIONS

Various test mixes were evaluated for pavement rutting resistance, low-temperature stiffness, and pavement resilient modulus.

Pavement Rutting Resistance

Test pavements were constructed in the Petro-Canada Research and Development pavement performance simulation test pit and then tested under full-scale repeated loadings simulating heavy trucks. The pavement structure was built in layers from the subgrade and under controlled conditions to attain required thickness, moisture, and density. The total structure was tested with a 40 kN (9 kips) dynamic load at 9 cps frequency and at a loading pressure of 552 kPa (80 psi), simulating a fully loaded truck axle traveling at 50 km/hr (30 mph). The pavement structure consisted of 600 mm (24.0 in.) of sand subgrade, 225 mm (9.0 in.) of granular base, and 75.0 mm (3.0 in.) of asphaltic concrete mix. A detailed description of the test is given elsewhere (*12*).

Pavement permanent deformation is monitored continuously with various load cycles. The test is run for 1,000,000 load cycles at the desired test temperature. At the end of the test, the pavement surface profile is recorded and pavement rutting under the centerline of the load is measured.

Three test pavements were evaluated using the two engineered asphalts and the conventional 85–100 pen material as a control. Rutting resistance evaluation testing was carried out at 50°C (122°F) using a specially designed environmental chamber placed on top of the pavement in the test pit.

Test results for the three HL3 pavements are plotted in Figure 1. In terms of performance, both the premium and the polymer modified asphalts provided superior rutting resistance when compared with the pavement with conventional asphalt. At the start of the test, the rutting performance was excellent for each of the three test pavements. Differences in performance began to be observed after passes of 10,000 to 20,000 load cycles, when the conventional pavement section started to show deterioration at an accelerated rate. As more loads were applied, the superior performance of the premium and the polymer modified asphalts became clear. These quality pavements performed equally well throughout the test.

After 100,000 load cycles, pavement permanent deformation in the HL3 mix with conventional asphalt amounted to 19.8 mm (0.8 in.) versus 10.8 mm (0.4 in.) and 11.9 mm (0.5 in.) for the premium and polymer modified asphalt pavements, respectively. These values represent a 45 percent reduction in pavement rutting with premium asphalt and a 40 percent reduction with the polymer modified materials.

Because excessive rutting occurred in the pavement test section with the conventional asphalt, the test was terminated after 300,000 load cycles. Tests for the other two pavement sections continued to 900,000 load cycles (Figure 1).

Comparing the number of 40 kN (9.0 kips) load cycles needed to cause 26.0 mm (1.0 in.) deformation in each of the three pavement test sections, it is clear that the premium and the polymer modified asphalt pavements provided a significant increase in load-carrying capacity. As illustrated in Figure 1, the number of accumulated heavy load cycles carried out by these pavements is more than 300 percent of that carried out by the pavement with conventional asphalt.

Figure 2 shows a schematic diagram for pavement surface profiles taken before and after the test for the conventional and premium asphalt sections. The total pavement rutting in the mix with conventional asphalt amounted to 37.7 mm (1.5 in.) versus 18.4 mm (0.7 in.) for the mix with premium asphalt. This represents a 51 percent reduction in the total pavement rutting. Note that lateral displacement of the mix under the combined effects of repeated heavy loadings and high test temperature is substantial in the conventional asphalt pavement section. Lateral displacement of the paving material is significantly reduced with use of the premium asphalt, substantially reducing total pavement rutting as indicated in Figure 2.

In summary, the results of the rutting resistance evaluations demonstrated clearly that the quality of the asphalt cement in the mix greatly influences the final rutting performance. Pavement permanent deformation reduction of up to 50 percent was obtained with the use of the engineered asphalts tested.

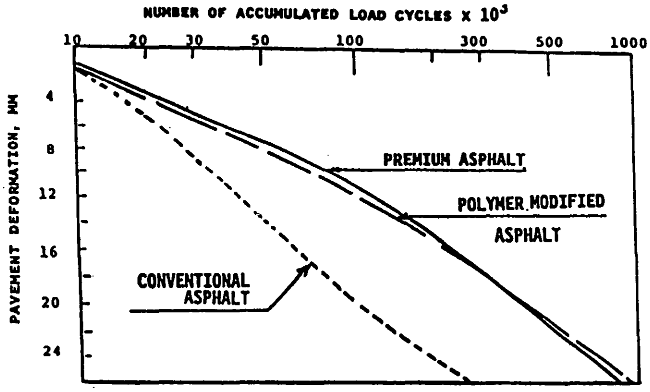

FIGURE 1 Pavement permanent deformation versus load cycles for various HL3 test mixes, 50°C (122°F).

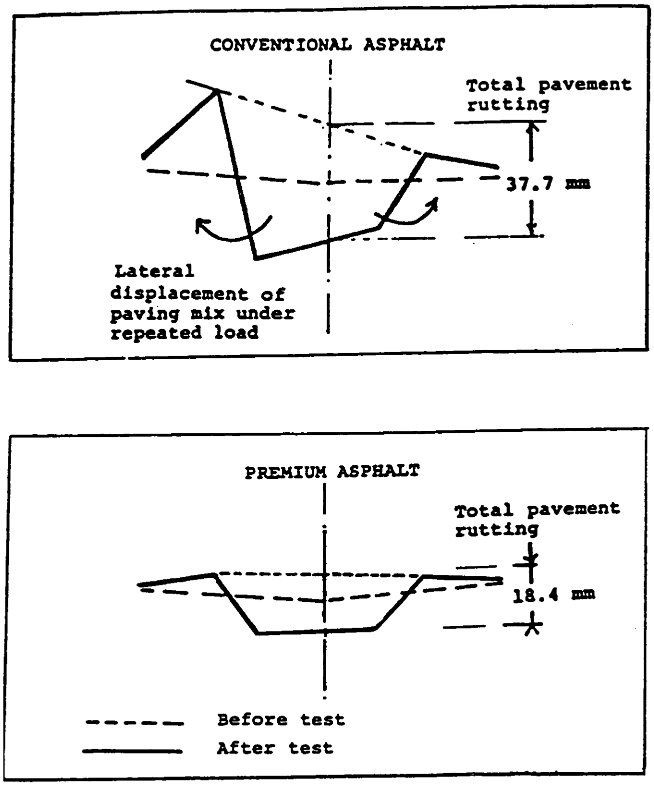

FIGURE 2 Pavement surface profiles before and after 100,000 load cycles, 50°C (122°F).

Pavement Low-Temperature Stiffness

Low-temperature pavement stiffness evaluations using a direct tension testing were carried out on samples cut from standard pavement briquettes. The pavement briquettes were tested at the University of Waterloo cold temperature facility (*14*) using a constant rate of extension, 0.004 mm/min (0.00016 in./min), at a temperature of −18°C (0°F).

The testing included conventional, premium, and polymer modified asphalts. For comparison, a sample of the same HL3 mix with the 150–200 pen conventional asphalt cement was also included in the study, as shown in Table 5. The test results shown represent an average for a minimum of five test samples.

The effects of asphalt cement on low-temperature stiffness is significant and is well demonstrated in these tests. On comparing mix stiffness for premium and conventional asphalts, it is clear that the mixes with engineered asphalts provide substantial reductions in low-temperature pavement stiffness, 42 and 45 percent at −18°C (0°F). The reductions observed with premium asphalt appear to approach the levels experienced with the control mix containing the 150–200 pen asphalt. These results suggest that pavements constructed with such engineered asphalts will not only provide substantial reductions in pavement permanent deformation but also significantly improve low-temperature pavement performance.

Pavement Temperature Susceptibility Evaluations

Pavement resilient modulus determinations were carried out on standard pavement briquettes at three test temperatures (5°C, 25°C, and 40°C) using indirect tension testing, ASTM D4123 (*15*). The test results on HL3 mixes for both conventional and premium asphalts are shown in Table 6. Test results confirm the superior temperature susceptibility properties of the pavement mixtures with premium asphalt. Improved resilient modulus was obtained at both low and high temperatures with the engineered asphalt. Pavement mix moduli at 5°C were 15 percent lower and at 40°C were 25 percent higher with the engineered asphalt as compared with the same mix with conventional asphalt. These results confirm the superior pavement rutting performance and the improved low-temperature behavior observed with premium asphalt pavements.

Temperature susceptibility performance of the various test mixes is directly related to temperature susceptibility of the asphalt in the mix. Note that both test asphalts exhibit the same 85–100 pen consistency at 25°C; however, the superior temperature susceptibility of premium asphalt as indicated by the PVN and PI parameters (Table 1) is directly responsible for the superior performance of the mixes containing this material. To attain good pavement performance under a wider range of field operating conditions, the asphalt binder must have superior temperature susceptibility properties.

INFLUENCE OF ASPHALT PHYSICAL PROPERTIES ON PAVEMENT PERFORMANCE

Although all three test asphalts used in the pavement rutting evaluation were of the same grade (i.e., 85–100 pen) their relative performance was quite different. The superior pavement rutting per-

TABLE 5 Summary of Low-Temperature Pavement Stiffness

Test Speed 0.004 mm/minute
Test Temperature -18°C (0°F)
Test Samples measured 40 mm x 40 mm x 75 mm

	Conventional Asphalts		Engineered Asphalts	
	85-100 Pen	150-200 Pen	Premium	Polymer Modified
Mean Failure Stress, KPa (psi)	4461(647)	4026(584)	3585(520)	4716(684)
Mean Stiffness Modulus, MPa(psi x 10^3)	6.1(884)	2.77(401)	3.38(490)	3.52(510)
Stiffness as a % of Conventional Mix	100	45	55	58
% Stiffness Reduction at -18°C	-	55	45	42

TABLE 6 Pavement Resilient Moduli Test Results

	Conventional Asphalt 85-100 Pen	Engineered Asphalt Premium
Modulus of Elasticity (M_R)		
5°C, MPa (psi x 10^3)	4.72 (684)	4.13 (598)
25°C, MPa (psi x 10^3)	1.86 (270)	1.78 (258)
40°C, MPa (psi x 10^3)	0.61 (88)	0.75 (108)

formance of the pavements made with the engineered asphalts can be attributed to the rheology of these materials. Both the Styrelf and premium asphalts have significantly higher viscosity values at 60°C than the conventional 85–100 pen asphalt, and their deformation resistance corresponds with such properties.

Absolute viscosity at 60°C (140°F) is particularly important because it represents the asphalt consistency at a high operating temperature range in which pavement mix is generally softer and weaker. The higher the absolute viscosity of the binder at 60°C, the stiffer and the more resistant the pavement mix to permanent deformation.

But, because different asphalt materials, depending upon chemical composition and other factors, would age during mixing at the hot mix plant at different rates, the viscosity of the virgin asphalt may not be the best indicator of long-term performance. One must examine the characteristics of the residue from the TFOT or RTFOT, which simulate the aged asphalt after mixing at the hot mix plant. This is quite apparent from the data on physical characteristics presented in Table 7. Comparing the TFOT viscosity at 60°C (140°F) for the three asphalts tested in the rutting evaluations, both the premium and the polymer modified products show consistencies in the range of 11,000 to 13,000 poise in comparison to 3,000 poise for the conventional asphalt. The three- to fourfold increase in asphalt viscosity at 60°C produced the significant reductions noted in pavement rutting for the mixes tested with these materials.

SHRP performance testing predicted the improved rutting resistance of the engineered product tested, premium asphalt. The temperature at which the dynamic shear measurement of $G^* / \sin \delta$ on the RTFOT residue reached 2.2 kPa was 7°C to 8°C higher in the case of the engineered product, as compared with the control asphalt. Improved rutting performance of the engineered product is also consistent with the higher moduli values obtained on the pavement samples containing this material.

The low-temperature pavement stiffness behavior of the various test mixes is affected primarily by the asphalt binder in the mix. Mixes with the engineered asphalts provided substantial reductions in low-temperature pavement stiffness. The asphalt physical property that may best describe asphalt consistency at low temperature is the low-temperature penetration (4°C, 200 g, 60s) measured on the aged TFOT residue as shown in Table 7. The higher the value of the low-temperature penetration, the more flexible and less stiff is the pavement mix, and the better the pavement performance at low temperature. Note that the Pen Ratio (4°C/25°C), Table 7, fails to differentiate between the low-temperature performances of the

TABLE 7 Asphalt Physical Characteristics Influencing Rutting, Low-Temperature Stiffness, and Pavement Temperature Susceptibility

Pavement Performance Concern	Asphalt Properties	Conventional Asphalts		Engineered Asphalts	
		85-100 Pen	150-200 Pen	Premium	Polymer Modified
Rutting Resistance	Absolute Viscosity @ 60°C, P				
	Original	1453	584	3092	4372
	TFOT Residue	2999	1215	13,124	11,133
Low Temperature Thermal Cracking	TFOT Residue				
	Pen @ 25°C, 100 g, 5 s	56	100	54	55
	Pen @ 4°C, 100 g, 5 s	6	10	9	8
	Pen @ 4°C, 200 g, 60 s	20	35	30	26
	Pen Ratio (4°C/25°C)	36	35	56	47
Temperature Susceptibility	TFOT Residue				
	PVN (25-60)	-0.5	-0.6	+0.9	+0.7
	PVN (25-135)	-0.6	-0.5	+0.5	+0.7
	PI (25-4)	-0.9	-1.1	+0.5	+0.0

two conventional asphalts. The parameter essentially measures asphalt temperature dependence instead of low-temperature behavior.

The engineered asphalts provided approximately a 50 percent increase in low-temperature penetration (4°C, 200 g, 60s) over that of conventional asphalt; this improved property, coupled with improved temperature susceptibility of the asphalt, produced the significant reductions noted in pavement low-temperature stiffness for the test mixes incorporating these materials.

SHRP performance tests on thermal cracking performed on the aged residue from the pressure aging vessel predicted improved low-temperature performance of the engineered asphalt and rated it closer to the performance of the 150–200 pen asphalt. These results were confirmed by low-temperature pavement stiffness tests carried out on the pavement samples containing these asphalts.

Asphalt temperature susceptibility, as indicated by PVN, PI, and pen ratio measurements, is another critical parameter; it influences pavement temperature susceptibility, pavement stiffness, and pavement performance over the entire range of field-operating temperatures. To attain good pavement performance for heavy loading conditions at extremely warm and cold temperatures, the asphalt cement must have good temperature-susceptibility properties. The requirement now has been recognized in the CGSB asphalt specifications (i.e., grouping A, B, C asphalts according to their temperature susceptibility). New SHRP performance-based asphalt specifications also recognize the importance of this property and classify various asphalts according to their temperature susceptibility. The engineered asphalts evaluated provided superior temperature susceptibility parameters, with positive PVN and PI values and pen ratios around 50 percent—significantly higher parameters than were established for the conventional asphalts.

Other asphalt physical characteristics such as kinematic viscosity at 135°C and flash point will affect handling of asphalt at the hot mix plant as well as mixing temperatures and final field compaction of the product.

SUMMARY AND CONCLUSIONS

A comprehensive asphalt test program on pavement mixes containing conventional and engineered asphalts evaluated pavement performance in terms of pavement rutting, low-temperature stiffness, and pavement temperature susceptibility.

Pavement samples were tested under full-scale dynamic, heavy loadings to hundreds of thousands of load repetitions to simulate the long-term pavement permanent deformation response. Low-temperature pavement stiffness evaluations were carried out on pavement samples using a direct tension testing at very slow speeds. Pavement temperature susceptibility tests were conducted by determining test pavement resilient modulus for a temperature range, 5°C to 40°C, using dynamic indirect tension tests on standard pavement briquettes.

It is well established that substantial improvements in pavement rutting performance can be achieved by using asphalt mixtures containing maximum amounts of crushed aggregates, which provide good interlocking properties and higher load-carrying characteristics. Results of this investigation show that the use of high-quality asphalt cement in the mix may be equally important. The use of premium and polymer modified asphalts provided rutting reductions of up to 50 percent and an increase in pavement load-carrying capacity of more than 300 percent. Mixes with these engineered asphalts also exhibited superior low-temperature behavior and reduced low-temperature pavement stiffness by as much as 45 percent. Mixes containing premium asphalt exhibited superior temperature-susceptibility characteristics and provided improved pavement moduli values at both the highest and lowest test temperatures, further confirming the improved rutting and low-temperature performance results.

The authors identified three important asphalt physical characteristics affecting pavement performance: absolute viscosity at 60°C, low-temperature penetration at 4°C, and asphalt temperature susceptibility, all measured on aged TFOT residue. Substantial improvement in pavement rutting, low-temperature stiffness, and temperature susceptibility performance resulted when test pavements incorporated asphalts that were characterized by high viscosity, high low-temperature penetration, and low-temperature susceptibility.

When the test asphalts were characterized according to SHRP binder specifications, the engineered premium asphalt showed significant performance improvements at high, intermediate, and low temperatures in contrast with unmodified control asphalts. SHRP test results rated the engineered premium asphalt in an improved class for both rutting and low-temperature cracking. The engineered asphalt also showed significant improvement in the limiting temperature for fatigue performance. It satisfied requirements for 10 SHRP asphalt grades whereas the conventional asphalt product met requirements for only four. The final SHRP classification suggests that the engineered asphalt has a useful service temperature span of 92°C as compared with a span of 80°C for conventional asphalt.

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