Evaluation of Effects of Deicing Additives on Properties of Asphalt Mixtures

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This paper summarizes the results of an experimental study to evaluate the effects of two deicing additives, Verglimit and PlusRide, on the properties of asphalt mixtures in terms of their resistance to rutting, low-temperature cracking, and moisture damage. Verglimit consists mainly of calcium chloride and a small amount of sodium hydroxide. PlusRide is derived from granulating whole tires and tire buffings. These deicers, which are added to the mixture, are currently being used, but their effects on mixture properties are not well established. Mixtures were cured for different periods of time, and the following tests were performed: static and repeated-load indirect tension tests and incremental static-dynamic creep tests. In addition, the VESYS computer program was used to predict the performance of pavements with deicing additives. On the basis of the findings of this study, it appears that Verglimit improves the temperature susceptibility of asphalt concrete and increases its susceptibility to moisture damage because the particles absorb moisture, but that it decreases visual stripping. PlusRide reduced the stiffness of the mixture, thereby increasing its resistance to low-temperature cracking but decreasing its resistance to rutting. The VESYS analysis also predicted that pavements with PlusRide could have a rutting problem. Finally, it was observed that PlusRide reduced the amount of visual stripping by resisting swelling.

Roadway surface ice deposits are a major problem in some parts of the United States. Currently, highway agencies try to maintain ice-free pavements through sand application or by using deicing salts. Evidence has gathered over the years that the use of deicing salts is adversely affecting the ground water, damaging roadside vegetation, and corroding steel structures and vehicles. The use of sand on ice increases the stopping distance of vehicles. One technique to improve ice control and to alleviate the use of salt and sand on pavements is to add certain deicing additives to bituminous mixtures. In the late 1960s and the 1970s two deicing additives, Verglimit and PlusRide, were developed in Europe. Applications of these additives in several European countries demonstrated that these two deicers have the ability to reduce icing problems and related accidents. Encouraged by the success of these deicing additives in Europe, researchers have conducted considerable experimental work and field trials using Verglimit and PlusRide in the United States (*1–3*). Effects of deicing additives on mixture properties are not well established, however, because they are generally not measured.

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OBJECTIVES

The objectives of this study were

1. To investigate the effects of adding Verglimit or PlusRide rubber on the performance of asphaltic pavements in terms of resistance to rutting, low-temperature cracking and moisture damage, and service life by measuring their resilient modulus, tensile strength, creep compliance, and permanent deformation properties; and
2. To predict the performance of pavements with deicing additives using the VESYS computer program, when loaded by the Accelerated Loading Facility (ALF) located at the Federal Highway Administration (FHWA) Pavement Testing Facility (PTF), Turner-Fairbank Highway Research Center (TFHRC), McLean, Virginia.

MATERIALS AND SAMPLE PREPARATION

To evaluate the effects of Verglimit and PlusRide on properties of asphalt concrete mixtures, four different mixtures were prepared: two control mixtures, asphalt-rubber concrete mixture, and asphalt mixture with Verglimit.

Asphalt Cement

The asphalt cement used in this study was an AC-20 grade. This asphalt was obtained from the same company that constructed the PTF sites. The properties of the asphalt were examined at the TFHRC laboratory according to AASHTO designations (*4*). It was observed that they all satisfy the requirements of AASHTO M226.

Aggregates

The aggregate gradation and physical properties are presented in Table 1. The total percent passing conforms to Virginia State S-5 gradation for surface design. The PlusRide modified asphalt mixture requires a high coarse aggregate content (i.e., a gap gradation) to provide space for the rubber granules in the compacted mixture and to form a durable and stable mixture. The specifications and physical properties of the aggregates and PlusRide are presented in Table 2.

TABLE 1 PERCENT PASSING AND PHYSICAL PROPERTIES OF PTF WEARING COURSE AGGREGATES

Gradation	Aggregates Components				
Sieve Size	7/16 Trap Rock	Concrete Sand	#10 Trap Rock Screening	Total	VA Spec S-5
1/2	100.0	100.0	100.0	100.0	100.0
3/8	92.9	100.0	100.0	96.5	_
#4	36.1	97.5	97.4	66.8	53-67
#8	10.1	90.5	78.8	46.8	_
#16	5.5	75.4	55.8	34.6	_
#30	4.1	46.5	39.0	23.1	19-27
#50	3.5	15.7	26.9	13.0	_
#100	3.2	3.7	18.6	7.9	_
#200	2.5	1.0	12.6	5.3	4-8
% Blend	50.0	20.0	30.0	100.0	
Bulk Sp. Gr.	2.829	2.599	2.708	2.744	
Bulk SSD Sp. Gr.	2.886	2.625	2.783	2.790	
Apparent Sp. Gr.	2.938	2.670	2.929	2.877	
Absorption	1.310	1.030	2.800	1.700	

Verglimit

Verglimit is a deicing additive that can be introduced into bituminous concrete when it is being mixed for surface placement to act as a continuous presence against ice formation on highway pavements. It is composed of particles ranging from 0.1 mm to 5 mm. The particles consist mainly of calcium chloride and a small amount of sodium hydroxide. The particles are coated with a water-resistant layer of either linseed oil or polyvinyl acetate and are an integral part of the wearing course. Encapsulation keeps the material inactive until the pavement surface wears under traffic action and the pellets are exposed and crushed so the additive can mix with ambient moisture to form a mild salt solution (*1*). Because the Verglimit is blended throughout, it is supposed to continue to work through the life of the wearing course.

PlusRide

PlusRide is derived from granulating whole tires and tire buffings. It was supplied by a manufacturer in two different rubber particle sizes: coarse particle designated as WTP-1/4 and fine particle designated as GR-20. The WTP-1/4 consists of wheel tire chopped particles that all pass the 1/4-in. sieve, and the GR-20 indicates that the granular rubber particles all pass the no. 20 sieve. The rubber used was a mixture of 80 percent coarse and 20 percent fine granulated rubber to meet the manufacturer's specifications.

Mixture Preparation

The Marshall method was used to determine the optimum asphalt content (OAC). The Verglimit was added at a level of 5.5 percent in terms of total weight of the mix (aggregates + asphalt cement + Verglimit). The Verglimit partially replaced the aggregates passing the no. 4 sieve. In the experiments it was found that the addition of Verglimit about 30 sec before the end of mixing is most suitable for ensuring a visually homogenous distribution in the mixture and satisfactory coating. Because Verglimit is water-soluble, the vacuum saturation of the Rice method was performed using a volumetric flask to measure the maximum theoretical gravity of asphalt mixture with Verglimit. In addition, the weight of the sample in the water was measured after the sample was immersed in a water bath for 1 min instead of 3 to 5 min to measure the density of Verglimit samples.

PlusRide was added at a level of 3 percent by the total weight of the mixture including the PlusRide, and specimens were prepared according to the supplier's recommendations. The unheated rubber particles were first dry-mixed with the

TABLE 2 PERCENT PASSING AND PHYSICAL PROPERTIES OF AGGREGATES AND PLUSRIDE MATERIALS USED IN PREPARING MIXTURES WITH PLUSRIDE

Sieve Size	Percent Aggregates Passing		Manufacturer Spec	PlusRide Percent Passing	PlusRide Manufacturer Spec
	Control Mix	PlusRide Mix			
3/4	100.0	100.0	100.0	_	_
1/2	75.0	73.9	_	_	_
3/8	59.2	57.4	50-62	_	_
1/4	41.4	39.0	30-44	100.0	100.0
# 4	38.0	35.6	_	97.6	76-100
# 10	26.5	26.3	20-32	36.2	28-42
# 16	22.3	21.2	-	-	-
# 20	20.5	19.8	_	22.4	16-24
# 30	19.0	18.1	12-23	20.4	_
# 50	13.9	13.9	-	-	-
# 100	10.7	11.0	-	-	-
# 200	8.3	8.7	7-11	0.2	_
Bulk Sp. Gr.	2.791	2.686		1.19	
Bulk SSD Sp. Gr.	2.833	2.720			
Apparent Sp. Gr.	2.912	2.788			
Absorption	1.5	1.4			

hot aggregates, and then the asphalt was added. The mixture was then oven-cured at 320°F for 1 hr. To prevent expansion and cracking of the specimens, weights were placed on the compacted specimens in the molds for 24 hr. Weights of 10 and 30 lb were used for Marshall and 4-in. by 8-in. cylindrical specimens, respectively. The criterion to determine the OAC of the PlusRide mixture is to achieve the void content in the range of 2 to 4 percent in the compacted mix. It may be noted that the Marshall flow and stability criteria are not valid for the PlusRide mixtures.

TESTS AND PROCEDURES

Tensile Strength

This test was used to evaluate the mixture's resistance to moisture damage and to low-temperature cracking. The tensile strength test involves loading a Marshall specimen with compressive loads that act parallel to and along the vertical diametral plane (*5*). In this study Marshall apparatus was used to apply load. To distribute the load uniformly and to maintain a constant loading area, the compressive load was applied through a 1/2-in.-wide steel loading strip that is curved at the interface with the specimen and has a radius of curvature equal to 2 in. The load was applied diametrically at a constant vertical strain rate of 2 in./min until it reached the maximum load that causes the specimen to fail by splitting. Subsequent testing was conducted at −30°F, −15°F, 0°F, 10°F, 32°F, 41°F, 65°F, 77°F, and 90°F at a deformation rate of 0.1 in./min using a compression machine to provide an indication of the low-temperature cracking of the mixtures (*6*).

Diametral Resilient Modulus

This test was performed to measure stiffness, resistance to low-temperature cracking, and resistance to moisture damage. The resilient modulus of mixtures was determined using the method developed by Schmidt of the Chevron Research Company (*7*). A loading device capable of applying repeated load across the vertical diameter of a Marshall specimen was used. In our procedure, a 0.1-sec duration was used and the horizontal deformation was measured using two sensitive strain

gages mounted directly on the specimen. After the deformations of two pulse loads were measured, the pulsating load was stopped and the specimen was rotated 90 degrees; then the pulse load was applied again, and the horizontal deformation was measured. Testing was performed at three temperatures: 41°F, 77°F, and 104°F. In performing this test a control deformation level in the range of 30–80 microinches was used because, after numerous trials, it was found that the relation between load and deformation remains linear within that range. Also, testing was conducted at −30°F, −15°F, 0°F, 10°F, 32°F, 41°F, 65°F, 77°F, and 90°F to investigate the susceptibility to low-temperature cracking.

Moisture Damage Tests

To examine the effects of deicing additives on the resistance to moisture damage, indirect tensile strength tests and resilient modulus tests were conducted on wet and dry specimens (*8, 9*). The wet specimens were partially saturated with distilled water at room temperature using a vacuum saturation of 20 in. Hg. A maximum saturation between 55 and 80 percent is believed to be sufficient. If the degree of saturation was not within that range, a slightly higher vacuum was used. After the wet specimens reached the specified range, they were moisture- conditioned by being soaked in distilled water at 140 ± 1.8°F for 24 hr, and then soaked in distilled water at 77°F to adjust the temperature. The moisture damage was presented as the ratio of the tensile strength of wet specimens to the tensile strength of the dry specimens, TSR. Also, the moisture damage was presented as the ratio of the resilient modulus of the wet specimens to that of the dry specimens, RMR (*8*). In addition, a visual stripping was performed; a criterion for acceptability in visual evaluation is 10 percent (*10*).

Incremental Static-Dynamic Creep Tests

The resistance to rutting was evaluated by determining the permanent deformation characteristics following the FHWA incremental static-dynamic procedure, which defines the VESYS parameters ALPHA and GNU, and the stiffness in terms of its creep compliance and dynamic modulus (*11*). In this test, 4-in. (102-mm) by 8-in. (204-mm) cylinders were tested. The equipment used was the MTS hydraulic system. Measurements of vertical strain were made by two LVDTs on opposite sides of the cylinder. The vertical load was applied by a 4-in.-diameter steel disk through a ball-bearing interface. Six cylinders were prepared from each mixture and were tested at 65°F, 77°F, and 104°F. For conditioning, haversine load pulses were applied once per second (with a loading duration of 0.1 sec) 20 times. A 10-lb preload was used throughout all tests to keep the loading disk and the specimen in contact; then a load of 1,130 lb was applied, and the magnitude of the creep deformation as a function of time was measured during incremental loading. When the load was released, total permanent deformation was measured as a function of time. Then a repeated haversine loading was applied to the specimen; each load application has a load duration of 0.1 sec and a 0.4-sec rest period. The accumulated deformation after a certain number of load repetitions was recorded for the analysis.

TEST RESULTS AND ANALYSIS

Effect of Aging on Mixture Properties

To determine the effect of aging on the behavior of asphalt mixtures, 50 Marshall specimens from each mixture were fabricated and divided into 5 sets. Each set consisted of 10 samples and was cured at 77°F for different periods of time: 2, 7, 14, 28, and 90 days. After each curing period two properties were evaluated: resilient modulus and resistance to moisture damage.

Resilient Modulus

Test results of resilient modulus using the Schmidt apparatus are presented in Tables 3 and 4 as a function of curing time and testing temperature. It was observed that there was no consistent trend or significant effect due to the curing time.

Statistical analysis indicated that Verglimit causes a significant decrease in stiffness at low temperature (41°F), a significant increase in stiffness at high temperature (104°F), and

TABLE 3 RESILIENT MODULUS RESULTS OF VERGLIMIT MIXTURES, ksi

Curing time (days)	Verglimit Percent	Temperature, °F		
		41	77	104
2	0.0	1540	152	39
	5.5	1041	169	50
7	0.0	1678	205	37
	5.5	1214	171	41
14	0.0	1399	230	42
	5.5	1221	190	57
28	0.0	1430	197	39
	5.5	1121	180	54

TABLE 4 RESILIENT MODULUS RESULTS OF PLUSRIDE MIXTURES, ksi

Curing time (days)	Percent PlusRide	Temperature, °F 41	77	104
2	0	2138	248	40
	3	904	222	41
7	0	2101	283	44
	3	909	165	36
14	0	1969	239	43
	3	1106	212	30
28	0	2110	255	58
	3	1164	177	46
90	0	2130	301	54
	3	1032	125	18

no significant effect on stiffness at 77°F. Therefore, Verglimit is expected to improve the temperature susceptibility of asphalt concrete mixtures.

It was also observed that PlusRide causes a slight decrease in stiffness at 41°F, 77°F, and 104°F. Therefore, PlusRide is expected to improve resistance to low-temperature cracking and to have no effect on resistance to permanent deformation.

Moisture Damage

Table 5 presents the TSR and RMR of the mixtures investigated in this study. It was observed that absolute values of TSR and RMR were different. However, the increased potential for moisture damage, percent of control, is almost identical for the TSR and RMR of the Verglimit mixture. In addition, there is a very good correlation between TSR and RMR in percent of control. For the PlusRide mixture, TSR shows little increased potential for moisture damage, whereas RMR shows some increased potential. It may be noted that there is a fair correlation between them.

Overall, the precision of RMR is very poor compared with TSR. Therefore the values of RMR were not used for the analysis. Visual stripping was not observed in both mixtures with and without PlusRide and Verglimit.

Resistance to Rutting

For most cylinders, a 1,000-sec incremental creep test was performed to calculate the creep compliance $D(t)$ at the loading times of 0.01, 0.1, 0.3, 1, 3, 10, 30, 100, and 1,000 sec. The creep compliance of some cylinders was measured only up to 30 or 100 sec because the deformation was out of the range of the LVDT, especially at a testing temperature of 104°F. Creep compliance data are tabulated in Tables 6 to 9. A statistical comparison of the creep compliance data from the control mixture and from the Verglimit mixture, at a level of significance of $\alpha = 0.05$ using a t-test, reveals no significant difference between the two mixtures at different temperatures. This generally indicates a similar susceptibility to fracture at low temperature and resistance to high-temperature deformation. Also, a statistical comparison of the creep compliance of the control mixture and of the PlusRide mixture, at a level of significance of $\alpha = 0.05$ using a t-test, showed that the PlusRide mixture had a significantly higher creep compliance than the control mixture at all temperatures. Because the PlusRide mixture had a higher creep compliance at all temperatures, it appears that the addition of PlusRide softens the asphalt mixture.

The dynamic modulus for the mixtures was calculated at the 200th load cycle when performing the static-dynamic incremental creep test using the following formula:

$$E = \sigma/\varepsilon$$

where

E = dynamic modulus (psi),
σ = applied repeated stress (psi), and
ε = average cumulative permanent strain of the two LVDTs at the 200th cycle.

The dynamic moduli are presented in Figures 1 and 2. These results show that the addition of Verglimit caused a reduction

TABLE 5 TSR AND RMR RESULTS FOR DIFFERENT MIXTURES INVESTIGATED

Time	Verglimit Control		Verglimit Mixture		PlusRide Control		PlusRide Mixture	
(days)	TSR	RMR	TSR	RMR	TSR	RMR	TSR	RMR
2	0.90	0.87	0.49	0.35	1.00	0.93	0.92	0.69
7	0.96	0.78	0.39	0.23	0.91	0.60	0.92	0.44
14	0.76	0.56	0.43	0.30	0.83	0.73	0.75	0.49
28	0.97	0.78	0.60	0.71	0.94	0.80	0.85	0.59
90	–	–	–	–	0.98	0.98	0.92	0.78
S	0.095	0.134	0.092	0.216	0.066	0.154	0.074	0.142
X	0.896	0.747	0.477	0.397	0.932	0.807	0.872	0.597
% of Control			53.2%	53.0%			93.6%	74.0%

Note: After 90 days curing, Verglimit samples swelled and cracked due to the continued absorption of moisture, therefore, tests were not performed on Verglimit mixture after 90 days.

TABLE 6 CREEP COMPLIANCES FOR CONTROL MIXTURE TO EVALUATE VERGLIMIT (10^{-6}/psi)

Creep Time	Temperature, ^{0}F		
(sec)	65	77	104
0.01	0.735	1.427	5.805
0.10	1.970	3.943	16.103
0.30	3.664	6.830	20.470
1.00	6.920	11.318	22.675
3.00	12.845	13.879	22.075
10.00	15.220	16.680	23.391
30.00	18.761	20.746	-
100.00	21.691	23.640	-
1000.00	26.007	31.595	-

TABLE 7 CREEP COMPLIANCES FOR VERGLIMIT MIXTURES (10^{-6}/psi)

Creep Time (sec)	Temperature, ^{0}F 65	77	104
0.01	0.933	1.193	5.427
0.10	2.132	4.110	14.154
0.30	4.151	7.561	18.552
1.00	7.639	13.149	19.323
3.00	12.507	18.099	20.746
10.00	18.832	18.132	20.746
30.00	22.547	20.120	21.208
100.00	24.813	22.197	-
1000.00	-	-	-

TABLE 8 CREEP COMPLIANCES FOR CONTROL MIXTURE TO EVALUATE PLUSRIDE (10^{-6}/psi)

Creep Time (sec)	Temperature, ^{0}F 65	77	104
0.01	0.387	1.127	5.568
0.10	1.498	3.372	15.015
0.30	2.532	5.954	19.607
1.00	4.920	10.314	21.953
3.00	8.646	15.060	21.000
10.00	14.214	19.743	22.197
30.00	18.761	21.881	-
100.00	22.497	23.752	-
1000.00	29.069	27.2479	-

TABLE 9 CREEP COMPLIANCES FOR PLUSRIDE MIXTURE (10^{-6}/psi)

Creep Time (sec)	Temperature, °F 65	77	104
0.01	1.091	2.491	13.812
0.10	3.501	9.955	38.461
0.30	6.740	19.083	70.422
1.00	13.755	35.523	111.110
3.00	27.739	49.019	142.857
10.00	53.330	50.000	140.850
30.00	71.680	—	—

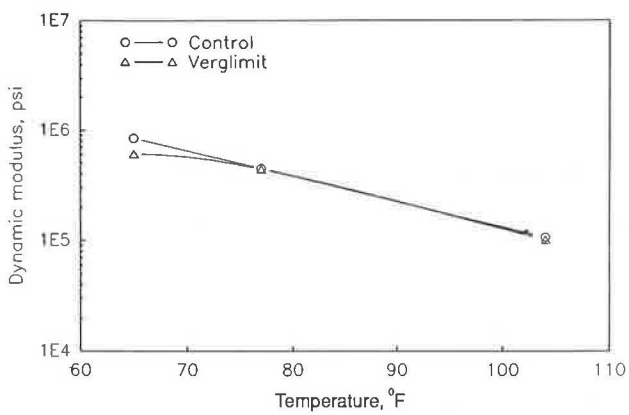

FIGURE 1 Dynamic modulus versus temperature.

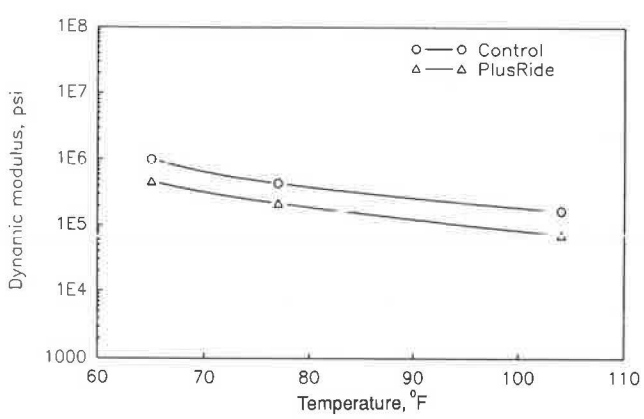

FIGURE 2 Dynamic modulus versus temperature.

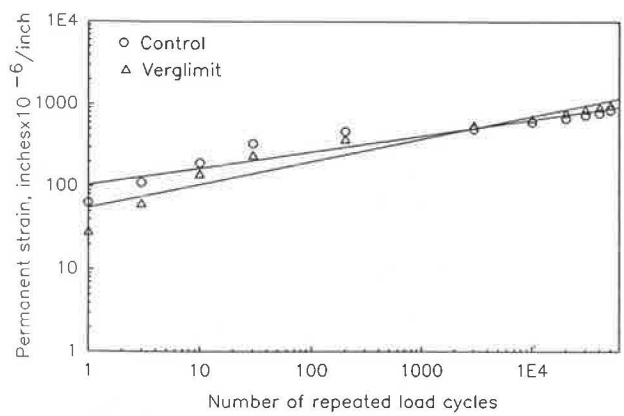

FIGURE 3 Permanent strain load repetitions at 65°F.

in stiffness at low temperature. It is believed that this reduction indicates an improvement in the resistance to low-temperature cracking. The PlusRide mixture had a lower dynamic modulus than the control mixture at all testing temperatures. Statistically, there was no significant difference between the dynamic modulus of the control mixtures and those of the mixtures with the deicing additive.

Permanent deformation properties were obtained by conducting the repeated compression loading procedure of the static-dynamic incremental creep test. Figures 3 through 8 present the permanent strain data for all mixtures versus the number of load applications at 65°F, 77°F, and 104°F, respectively. GNU and ALPHA for all mixtures involved in this study are presented in Table 10. The following observations were made through an analysis of test results:

1. The mixture containing Verglimit exhibited lower deformation at high temperature. Therefore, it would be expected

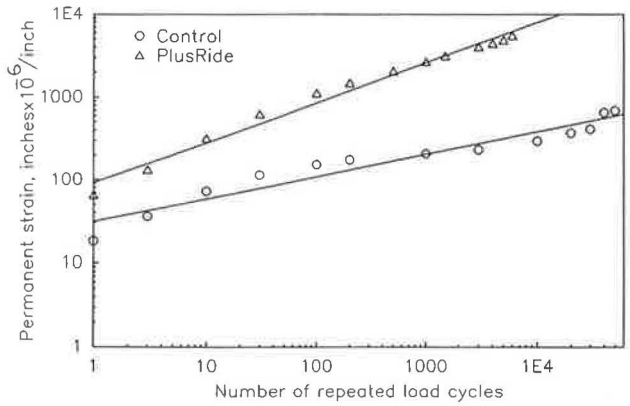

FIGURE 4 Permanent strain versus load repetitions at 65°F.

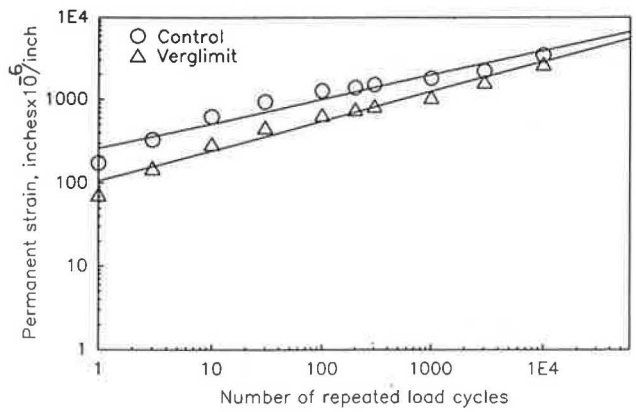

FIGURE 5 Permanent strain versus load cycles at 77°F.

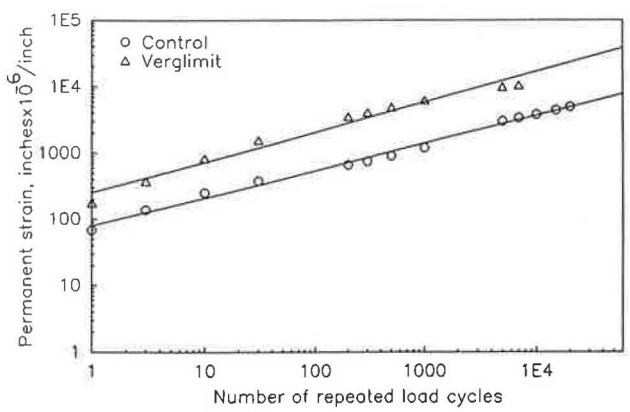

FIGURE 6 Permanent strain versus load repetitions at 77°F.

that mixtures with Verglimit would have less permanent deformation than would control mixtures at high temperatures.

2. The susceptibility to permanent deformation appeared to be significantly decreased by the addition of Verglimit, because there was a significant decrease in intercept values between the control and the Verglimit mixtures.

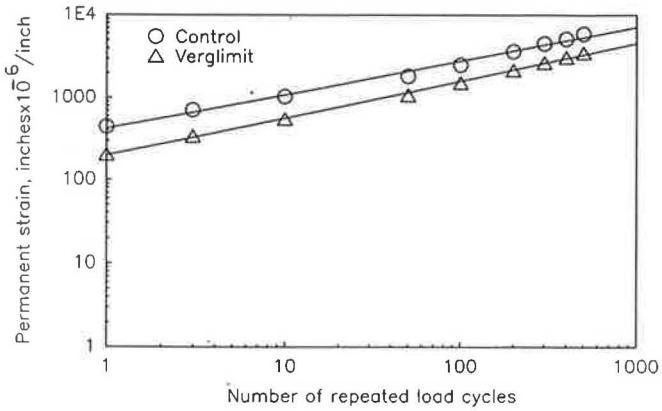

FIGURE 7 Permanent strain versus load repetitions for Verglimit mixture at 104°F.

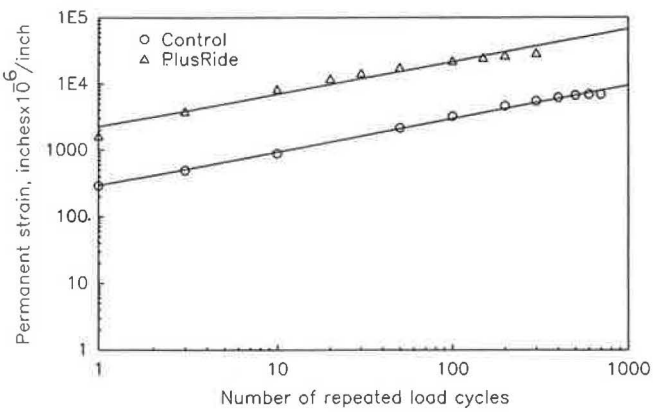

FIGURE 8 Permanent strain versus load repetitions for PlusRide mixture at 104°F.

3. PlusRide increased the permanent deformation at all temperatures.

Resistance to Low-Temperature Cracking

To measure the resistance to low-temperature cracking, 18 Marshall specimens were prepared and tested for resilient modulus and tensile strength at −30°, −15°, 0°, 10°, 32°, 41°, 65°, 77°, and 90°F, using two specimens at each temperature. The procedure for a relative comparison of low-temperature performance involved plotting the $\log_{10}$ (modulus or tensile strength) versus the temperature of each mixture and determining the temperature difference or "shift" between the plots. In this study, a reference tensile strength of 300 psi and a reference modulus of 3,000 ksi were used to determine where the shift should be measured because these values were in the middle of the brittle-ductile transition zone for the control mixtures.

Figure 9 shows that the resilient modulus test produced a shift of −3°F for the Verglimit mixture relative to the control, because of a slight decrease in temperature susceptibility; and that the tensile strength test produced virtually equal data for the Verglimit and control mixtures and no shift was found.

TABLE 10 VESYS PERMANENT DEFORMATION PARAMETERS DETERMINED FROM COMPRESSION REPEATED LOAD TEST

Type of Mix	Temperature °F	ex10^{-6} in/in	S	I	GNU	ALPHA
Control	65	106.8	0.198	2.0183	0.190	0.8900
	77	204.4	0.207	2.6643	0.470	0.7927
	104	846.8	0.408	2.6373	0.209	0.5915
Verglimit	65	146.3	0.176	2.1443	0.168	0.8238
	77	205.5	0.256	2.2900	0.243	0.7439
	104	1217.8	0.455	2.2922	0.073	0.5449
Control	65	92.0	0.270	1.4920	0.090	0.7300
	77	208.0	0.420	1.9020	0.160	0.5800
	104	542.0	0.500	2.4660	0.270	0.5000
PlusRide	65	184.0	0.480	1.9670	0.240	0.5200
	77	399.0	0.450	2.4060	0.290	0.5500
	104	1221.0	0.490	3.3500	0.900	0.5100

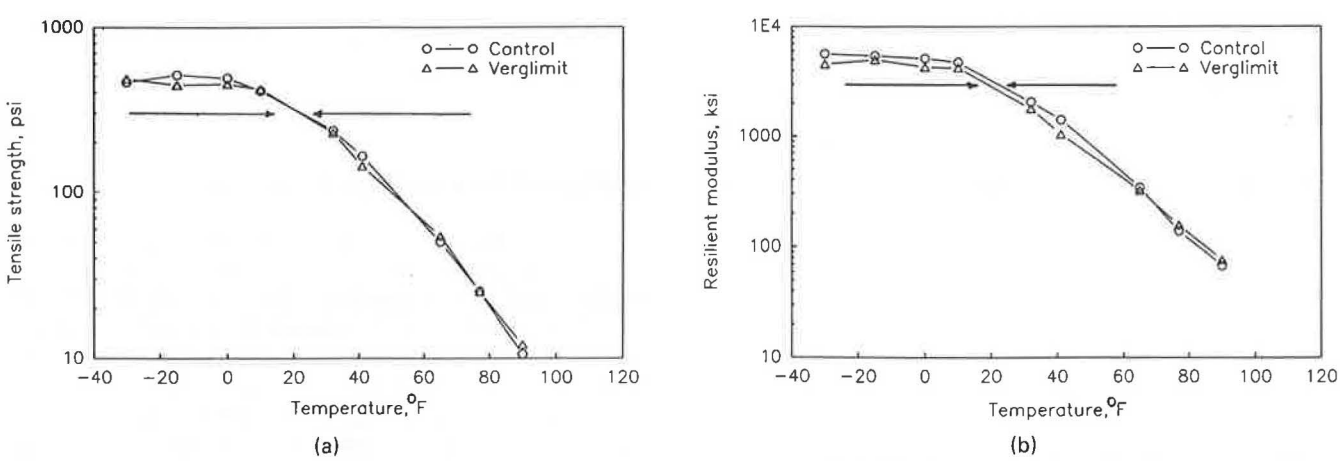

FIGURE 9 (a) Tensile strength versus temperature for Verglimit mixture. (b) Resilient modulus versus temperature for Verglimit mixture.

Figure 10 shows that the resilient modulus test produced a shift of −17°F for the PlusRide mixture compared with the control, whereas the tensile strength test produced a shift of −14°F. The PlusRide mixture produced lower moduli and tensile strengths at all temperatures; thus, it is more resistant to low-temperature cracking.

STRUCTURAL EVALUATION USING VESYS-3AM

The VESYS-3AM computer program was used to predict the structural performance of the mixtures with deicing additives. The VESYS model requires the following inputs to predict

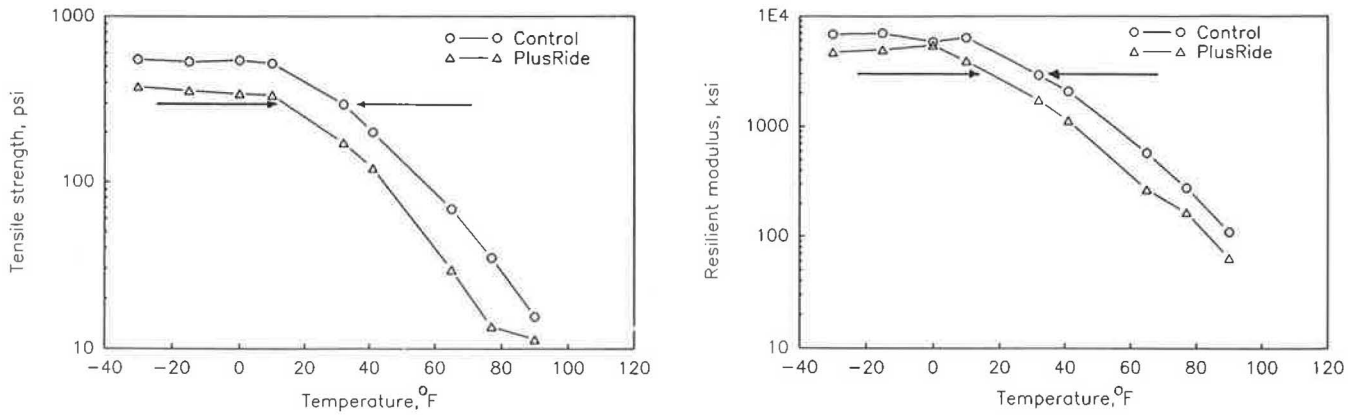

FIGURE 10 (a) Tensile strength versus temperature for PlusRide mixture. (b) Resilient modulus versus temperature for PlusRide mixture.

the pavement responses to a defined wheel load: traffic, system geometry, climate, and physical properties of the material layers. The pavement selected for evaluation using the VESYS-3AM was Test Section 2 of Lane 2 (L2S2) at the PTF.

Traffic

A tire pressure of 140 psi and a load of 19,000 lb were applied on L2S2. The average number of passes applied by the ALF on L2S2 is presented in Table 11.

System Geometry

The L2S2 cross section was selected for the VESYS-3AM analysis. This section consisted of a 2-in. surface, a 5-in. binder, a 12-in. base, and a subgrade.

Climate

The temperature history of L2S2 is presented in Table 11. These temperatures were supplied to the FHWA by the National Oceanic and Atmospheric Administration (NOAA) weather station at Dulles International Airport.

System Performance

The initial serviceability index (PSI) for L2S2 was 4.08. Hence, for the VESYS-3AM analysis, an initial PSI of 4.08 was chosen. The minimum acceptable PSI was set at 2.5.

Material Characteristics

The material characteristics used in the VESYS-3AM program are the dynamic modulus, GNU, and ALPHA at every season for each layer and the fatigue parameters k_1 and k_2 for the binder layer. Because Verglimit and PlusRide are deicing additives that are added to the surface layer only, it is expected that cracking of pavements with and without deicing additives will be the same. Therefore, a typical K_1 and K_2 were assumed; these values were 0.3×10^{-11} and 5, respectively. No rutting was observed in the subgrade and binder layers of L2S2; thus their GNU and ALPHA were assumed to have values that produce no rutting.

Results of the VESYS Analysis

Results of the VESYS-3AM analysis for the four mixtures investigated in this study are shown in Figures 11 through 13. The following observations were made through the VESYS analysis:

1. The PlusRide mixture showed a higher potential for rutting than the other mixtures. There was no significant difference in rutting performance between control and Verglimit mixes.
2. There were no significant difference in the predicted fatigue cracking between control and Verglimit mixes at differing numbers of passes. It was predicted that the PlusRide mixture has a higher cracking susceptibility than the control mixtures. This coincided with the laboratory test results; that is, the addition of PlusRide rubber caused a significant decrease in the stiffness of the asphalt concrete mixture.
3. On the basis of PSI prediction results, the mixtures are rated from best to worst as follows: (a) Verglimit mixture, (b) control mixture for Verglimit study, (c) control mixture for PlusRide study, and (d) PlusRide mixture.

FIELD EVALUATION

In addition to the laboratory and VESYS evaluation of mixtures with PlusRide and Verglimit, a field survey was performed on pavements constructed using two deicing additives in Rhode Island. The field survey essentially consisted of measurements of the rut depth, cracking, bleeding, and raveling. It was noted that pavement sections with deicing additives have experienced rutting slightly higher than that observed in the control sections. Also, raveling was observed in the Verglimit section and bleeding in the PlusRide section.

TABLE 11 TRAFFIC AND TEMPERATURE DATA OF L2S2 AT PTF

Interval Number	No. of Days	Estimated Pavement Temp, °F	ALF Avg. No. of Passes Per day	Cumulative Extended No. of Days	Extended No. of Passes
1	4	85	3660	16.6	882
2	1	81	1260	33.2	76
3	2	94	1251	49.8	151
4	3	91	4662	66.4	843
5	2	80	1148	83.0	138
6	1	91	2612	99.6	157
7	1	96	1549	116.2	93
8	4	87	3856	132.8	929
9	5	91	3648	149.4	1099
10	13	76	5817	166.0	4555
11	5	80	7437	182.6	2240
12	27	79	6417	199.2	10437
13	5	70	4569	215.8	1376
14	7	65	7049	232.4	2972
15	4	58	5032	249.0	1213
16	1	55	258	265.6	16
17	6	57	4908	282.2	1774
18	5	46	6229	298.8	1876
19	2	46	7393	315.4	891
20	2	43	6071	332.0	731
21	5	50	6207	348.6	1870
22	2	48	4208	365.2	507

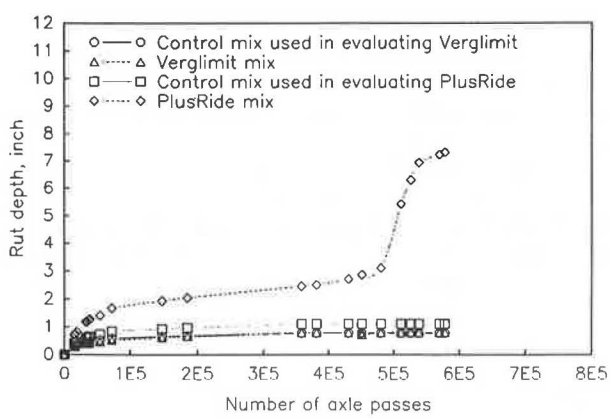

FIGURE 11 Predicted rut depth using VESYS-3AM.

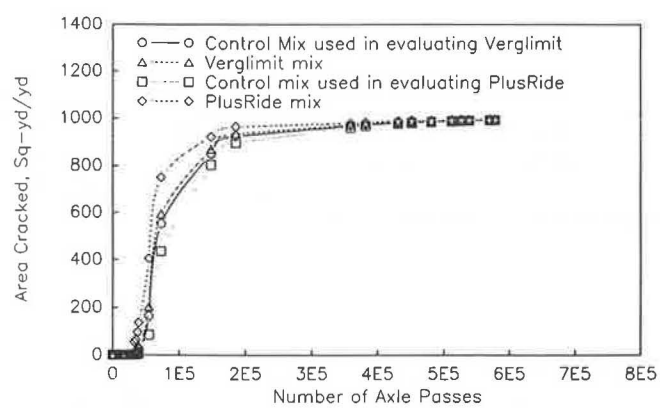

FIGURE 12 Predicted area cracking using VESYS-3AM.

CONCLUSIONS

The study presented was designed to evaluate the effect of two deicing additives on asphalt concrete stiffness, resistance to moisture damage, resistance to low-temperature cracking, and resistance to permanent deformation. Also, the performance of pavements with these two additives was predicted using the computer program VESYS-3AM. On the basis of the results of this study and a review of the available literature, the following conclusions are suggested as valid:

1. The resilient modulus test results of the aging study indicate that the addition of Verglimit reduced stiffness at low temperatures and increased stiffness at high temperatures.

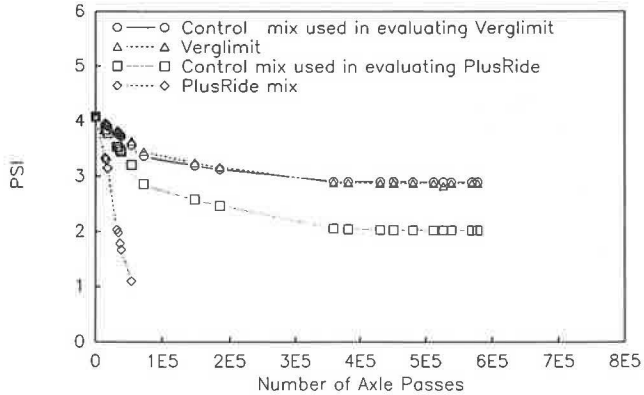

FIGURE 13 Predicted Present Serviceability Index (PSI).

Therefore, Verglimit appears to improve slightly the temperature susceptibility of the asphalt mixture. The addition of PlusRide resulted in lower stiffness only at low temperatures. Consequently, it is expected that PlusRide would improve resistance to low-temperature cracking.

2. It was observed that absolute values of TSR and RMR are different. However, the increased potential for moisture damage, percent control, is almost identical for TSR and RMR of Verglimit mixtures. For PlusRide mixture, TSR shows little increased potential for moisture damage, whereas RMR shows some increased potential. Overall, the precision of RMR is very poor compared with that of TSR. Therefore, the values of RMR were not used for analysis.

3. In evaluating the effect of additives on the resistance to permanent deformation, it was observed that the addition of PlusRide decreased stiffness in some specimens at high temperatures. Therefore, it is expected that the PlusRide rubber would cause a greater rutting problem than would the control mixture in the field at high temperatures. The Verglimit mixture had a lower permanent deformation at high temperatures than did the control mixture.

4. The test results at various temperatures again indicated that the PlusRide mixture improved resistance to low-temperature cracking. However, there was no significant difference in resistance to low-temperature cracking between the control and Verglimit mixtures.

5. During curing of the Verglimit samples, moisture absorption kept occurring that caused the samples to swell and crack. Therefore, it is expected that pavements with Verglimit could have cracking problems in the field.

6. The VESYS-3AM analysis showed that pavement with PlusRide would have a rutting problem, which coincides with Conclusion 3. However, the analysis did not predict more fatigue cracking in the Verglimit pavement. This may be due to the fact that the VESYS model for cracking cannot include moisture absorption.

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