since the same six AC-20 asphalt cements and the same mix composition were used on the Elk County research project, which has been evaluated periodically since September 1976. Two of the six test sections developed low-temperature-associated shrinkage cracking during the first winter. It should be realized, however, that the 0.84-mm/s (2-in/min) rate of loading that was used is much higher than the rate of loading at which such cracking actually takes place.

3. Within the temperature range used in this study, both temperature and recovered asphalt penetration showed excellent correlation with mix tensile strength. Mix tensile strength increased as temperature or penetration decreased.

4. Both temperature and asphalt penetration correlated very well with mix stiffness modulus. Mix stiffness modulus increased as temperature or penetration decreased.

5. The asphaltic concrete stiffness moduli computed by the two indirect methods (the Heukelom and McLeod modifications of the van der Poel method) compare reasonably well with the measured values in the temperature range from 4°C to 25°C (39.2°F to 77°F).

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Implementation of Stripping Test for Asphaltic Concrete

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Laboratory data were gathered by using a stripping test that is being developed and evaluated under NCHRP Project 4-8(3)/1 and is expected to be adopted for use in the state of Virginia. The testing program included a determination of the significant influences of different brands of asphalt cement and antistripping additives on the susceptibility to stripping of asphaltic concrete. Aggregates from eight sources, three asphalt cements, and two antistripping additives were used in various combinations. The results indicate that the new test method measured no significant differences in the stripping susceptibility of mixes with different asphalts. In one of the three mixes in which the effect of the type of additive was determined, a significant difference was found. Results of supplementary tests with a modified version of the test method indicate a good correlation with those obtained by use of the original method. It is concluded that the new method can probably be simplified to allow the use of equipment now available in district materials laboratories in Virginia.

A means of accurately predicting the stripping susceptibility of an asphaltic concrete has been sought for many years. The many test methods used to determine the tendency to strip have proved deficient when they are used to predict stripping under today's environmental and traffic conditions. However, a test recently developed under NCHRP Project 4-8(3)/1 appears promising (1).

For the field evaluation phase of the NCHRP project, the Virginia Department of Highways and Transportation was one of seven state agencies selected to install test sections with stripping-susceptible aggregates and to monitor their performance. A 290-m (950-ft) test section was installed in the coastal plains of Virginia in May 1976. The asphaltic concrete mix contained a stripping-susceptible aggregate and no antistripping additive. The stripping test performed on the mix at the time of construction revealed low strength values, and a significant amount of asphalt was observed to be separated from the aggregate surfaces. Quantitatively, the test predicted that significant stripping would occur over a long period of time. Observation and testing of cores performed two years after construction have indicated that stripping damage is occurring and apparently in the manner predicted.

On the basis of preliminary results from the field evaluation, the test method was investigated further to obtain answers to two questions:

1. Does the type of asphalt cement used affect the stripping susceptibility of a mix to such an extent that the test would have to be repeated each time a different asphalt cement was used with a particular aggregate?
2. Does the type of antistripping additive affect stripping susceptibility to such an extent that a mix that requires an additive would have to be retested each time a different additive was used?

PURPOSE AND SCOPE OF THE RESEARCH

The purpose of the investigation was to determine the effect of the type of asphalt cement and antistripping additive on the stripping of several asphaltic concretes as that effect is measured by the newly developed stripping test. It was also desirable to become familiar with the test in preparation for its adoption by the Virginia Department of Highways and Transportation. The test was performed on mixes that were believed to be susceptible to stripping. Three brands of asphalt cement and two brands of antistripping additives were used in various combinations with aggregates from eight sources.

PROCEDURE

Mixes and Materials

The aggregates and mix designs were obtained from each Virginia highway district where the mixes had been used in a pavement installation. All mixes were type S-5 except mix 7, which was a type I-2 mix (2) (1 mm = 0.039 in):

Sieve Size (mm)	Percentage Passing S-5 Mix	Percentage Passing I-2 Mix
25.4		100
12.8	100	
9.5		63-77
4.75	53-67	43-57
2.36		
0.6	19-27	
0.3		6-14
0.075	4-8	2-6
	5.0-8.5	4.5-8.0

The percentage asphalt content in the two types of mixes was as follows: 5.0-8.5 percent in the S-5 mix and 4.5-8.0 percent in the I-2 mix. The aggregates from the eight different sources, all of which were thought to be susceptible to stripping, were granite, gravel, quartzite, and diabase.

The properties of AC-20 asphalt cements obtained from the Exxon, Shell, and Chevron companies are given below [1 cm^2/s = 100 centistokes; 1 Pa•s = 10 poises; t°C = (t°F - 32)/1.8; 1 mm = 0.039 in]:

Asphalt Source	Viscosity At 135°C (cm^2/s)	Viscosity At 60°C (Pa·s)	Penetration at 25°C, 0.1 mm
Exxon	4.25	215.9	78
Shell	3.90	191.7	63
Chevron	4.08	185.4	75

The antistripping additives used were 0.5 percent No-strip ACRA-500 and 1.0 percent Kling Beta LV by weight of asphalt cement (amounts recommended by the Virginia Department of Highways and Transportation).

The mixes tested are given in Table 1. In test phase 1, eight mixes with Exxon asphalt cement and no additive were tested. Mixes 3, 4, and 7, which yielded the high, medium, and low ratios of tensile strength, respectively, were selected for testing in phase 2 with Shell and Chevron asphalt cements. In phase 3, the antistripping additives were combined with the asphalt cement that produced the lowest tensile-strength ratio in phases 1 and 2.

The procedure suggested by Lottman in the field evaluation phase of NCHRP Project 4-8(3)/1 (3) was used in preparing, preconditioning, and testing the specimens.

Preparation of Specimens

The aggregates were combined according to mix design gradations obtained from district materials engineers. The aggregate was heated in an oven to 149°C (300°F); the asphalt cement was heated to 135°C (275°F) and then mixed with the aggregate in a laboratory mixer for approximately 2 min. The mixture was cooled at room temperature for 2.5 h and then placed in a forced-air oven at 60°C (140°F) for 15 h. The mixture was removed from the forced-air oven and placed in a 121°C (250°F) oven for 2 h before compaction.

Compaction was performed according to section 3.5 of ASTM D1559-76—Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus. The compactive effort was 50 blows on each side except for mixes 2, 5, and 8, which required only 30, 30, and 25 blows, respectively, to yield a void content representative of in-service pavements.

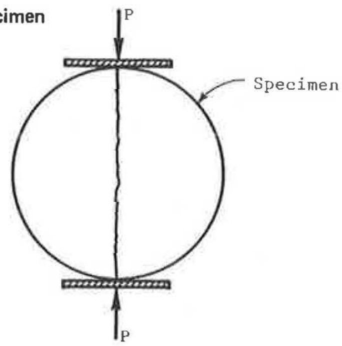
It has been verified by Lottman that voids have a significant influence on the degree of stripping in a mix; it was therefore important for the laboratory mixes to contain void contents similar to those produced in field mixes. One of the mixes known to have a stripping history was initially compacted at a low void content, and the test results indicated no stripping. Specimens were recompacted at a higher void content, and the tests indicated a significant amount of stripping.

Permeable voids (voids saturated with water under vacuum) were determined by the procedure given by Lottman (3). This required weighing the desiccated specimen in air and in water, the surface-dry specimen in air, and the vacuum-saturated specimen in air and in water.

Table 1. Asphalt cements and antistripping additives contained in mixes.

Mix	Aggregate	Test Phase 1	2	3
1	Crushed gravel	Exxon asphalt		
2	Quartzite	Exxon asphalt		
3	Crushed gravel	Exxon asphalt	Shell and Chevron asphalts	Shell asphalt, Kling Beta LV and ACRA 500 additives
4	Granite	Exxon asphalt	Shell and Chevron asphalts	Chevron asphalt, Kling Beta LV and ACRA 500 additives
5	Granite	Exxon asphalt		
6	Diabase	Exxon asphalt		
7	Granite	Exxon asphalt	Shell and Chevron asphalts	Shell asphalt, Kling Beta LV and ACRA 500 additives
8	Granite	Exxon asphalt		

Figure 1. Loading of specimen in indirect tensile test.



Preconditioning

Preconditioning is designed to simulate damage that occurs when the pavement is subjected to the environment and to traffic. The two types of preconditioning were (a) vacuum saturation and (b) vacuum saturation plus freezing at -18°C (0°F) for 15 h and thawing in a 60°C (140°F) water bath for 24 h (referred to as freeze-thaw).

Vacuum saturation is achieved by applying a vacuum of about 100 mm (4 in) of mercury for 30 min to the submerged specimens and then allowing them to remain submerged for an additional 30 min. This type of preconditioning simulates short-term damage, whereas freeze-thaw preconditioning simulates long-term damage that may occur over several years.

Testing

The specimens to be tested dry were wrapped in aluminum foil and coated with wax to ensure watertightness and were placed in a 12°C (54°F) water bath 3 h before testing. The preconditioned specimens were placed unwrapped in the water bath 3 h before testing. The direct tensile test was performed by loading the specimen in a diametral direction at a vertical deformation rate of 1.6 mm/min (0.065 in/min) with a hydraulic, closed-loop test system (see Figure 1). The indirect tensile strength S_t (in pascals) was computed as follows:

$$S_t = (S/1.75 \times 10^6)(P/t) \quad (1)$$

where

P = maximum compressive load on specimen (N);
t = thickness of sample (m); and
S = maximum tensile stress (Pa) produced in a 102-mm (4-in) diameter solid cylinder by a load of P = 1733 N per millimeter of thickness (10 000 lb per inch of thickness) (S is dependent on flattening of the specimen edge and may be determined by formula or graphic solution).

After testing, the specimens were split apart and examined visually for stripping damage.

Resilient modulus tests were performed on each specimen at 22°C (72°F) and 12°C (54°F) although the results were not used to determine susceptibility to stripping. The specimens were initially placed in a 22°C water bath for 2 h as described above. The resilient modulus test was performed, and then the specimens were placed in the 12°C water bath for 3 h, after which the resilient modulus tests were repeated. After the resilient modulus tests at 12°C, the specimens were treated immediately in indirect tension as previously described.

RESULTS

Phase 1

The stripping test was performed on eight mixes with the same asphalt cement (Exxon AC-20). The tensile strength ratio (TSR)—a ratio of preconditioned strength to dry strength—is used to predict stripping. A TSR of 1.0 indicates no stripping potential, and a TSR of less than 1.0 indicates that there is stripping potential. From experience, a TSR of less than 0.7 was considered unsatisfactory. None of the mixes showed significant damage as a result of preconditioning by vacuum saturation (see Table 2). Six of the eight mixes yielded a TSR of less than 0.7 under freeze-thaw preconditioning; thus, significant stripping over the long term is predicted.

Three mixes were selected for further investigation in phases 2 and 3. The mixes selected as having a high, medium, and low TSR were mixes 3, 4, and 7, respectively. It was impossible to test more than three mixes in phases 2 and 3 because of the excessive number of specimens and tests that would have been required.

Phase 2

Phase 2 involved testing mixes 3, 4, and 7 with two additional asphalt cements to determine if the brand of asphalt cement affected the TSR. The test results are given in Table 3.

The TSR showed no damage to the specimens preconditioned by vacuum saturation. The magnitudes of the TSR values for the mixes with different asphalt cements were similar for the specimens preconditioned by freeze-thaw.

An analysis of variance indicated that the asphalt cement did not have a significant effect on the TSR of the freeze-thaw specimens at a 95 percent level of confidence. The significance of this result is that, after a mix has been tested, it will not have to be retested each time a different asphalt cement is used.

Table 2. Results of phase 1 of indirect tensile test.

Mix	Voids in Total Mix (%)	Average Indirect Tensile Strength (MPa)			Average TSR	
		Dry	Vacuum Saturation	Freeze-Thaw	Vacuum Saturation to Dry	Freeze-Thaw to Dry
1	6.3	0.63	0.64	0.29	1.01	0.46
2	5.4	0.39	0.39	0.20	1.02	0.52
3	3.4	0.62	0.69	0.72	1.11	1.17
4	4.7	0.61	0.62	0.32	1.02	0.52
5	6.1	0.36	0.34	0.28	0.94	0.77
6	8.0	0.42	0.43	0.23	1.02	0.56
7[a]	6.8	0.41	0.42		1.02	
	6.8	0.53		0.23		0.44
8	7.0	0.44	0.46	0.28	1.03	0.62

Note: 1 MPa = 145 lbf/in².

[a] Two sets of specimens were required because of testing malfunction.

Table 3. Results of phase 2 of indirect tensile test.

Mix	Asphalt	Voids in Total Mix (%)	Average Indirect Tensile Strength (MPa)			Average TSR	
			Dry	Vacuum Saturation	Freeze-Thaw	Vacuum Saturation to Dry	Freeze-Thaw to Dry
3	Exxon[a]	3.4	0.62	0.69	0.72	1.11	1.17
	Shell	3.4	0.75	0.77	0.61	1.03	0.81
	Chevron	3.9	0.65	0.70	0.65	1.09	1.00
4	Exxon[a]	4.7	0.61	0.62	0.32	1.02	0.52
	Shell	6.0	0.79	0.79	0.37	0.99	0.47
	Chevron	5.3	0.65	0.68	0.27	1.05	0.41
7	Exxon[a]	6.8	0.41	0.42		1.02	
		6.8	0.53		0.23		0.44
	Shell	7.4	0.70	0.71	0.19	1.01	0.26
	Chevron	6.9	0.61	0.61	0.21	0.99	0.35

Note: 1 MPa = 145 lbf/in².

[a] Test results from phase 1.

Table 4. Results of phase 3 of indirect tensile test.

Mix	Asphalt	Additive	Voids in Total Mix (%)	Average Indirect Tensile Strength (MPa)			Average TSR	
				Dry	Vacuum Saturation	Freeze-Thaw	Vacuum Saturation to Dry	Freeze-Thaw to Dry
3	Shell	ACRA 500	4.5	0.77	0.77	0.74	1.00	0.96
		Kling Beta LV	4.5	0.78	0.79	0.75	1.02	0.96
		None	3.4	0.75	0.77	0.61	1.03	0.81
4	Chevron	ACRA 500	7.0	0.63	0.67	0.59	1.05	0.92
		Kling Beta LV	7.0	0.63	0.64	0.56	1.01	0.88
		None	5.3	0.65	0.68	0.27	1.05	0.41
7	Shell	ACRA 500	6.7	0.68	0.69	0.45	1.02	0.66
		Kling Beta LV	6.7	0.74	0.74	0.65	1.02	0.90
		None	7.4	0.71	0.71	0.19	1.01	0.26

Note: 1 MPa = 145 lbf/in².

Table 5. Tensile strength ratios determined by two test methods.

Mix	1.6 mm/min at 12°C		51 mm/min at 25°C	
	Voids in Total Mix (%)	TSR	Voids in Total Mix (%)	TSR
1	6.3	0.46	6.9	0.52
2	5.4	0.52	5.4	0.45
3	3.4	1.17	4.7	1.12
4	4.7	0.52	5.5	0.51
5	6.1	0.77	6.6	0.72
6	8.0	0.56	7.3	0.52
7	6.9	0.44	6.6	0.41
8	7.0	0.62	7.5	0.52

Note: 1 mm = 0.039 in.

Phase 3

In phase 3, mixes 3, 4, and 7 were tested in combination with two antistripping agents. The results are given in Table 4.

The TSR measurements showed no damage to the specimens preconditioned by vacuum saturation. Both of the antistripping additives caused an increase in TSR over the TSR of the mixes with no additive, and an analysis of variance indicated that the increase was significant. There was also a significant difference between the performances of the two antistripping additives. Therefore, if an aggregate or a mix is tested and found to require an additive, it will probably have to be retested each time a different additive is used. Particular additives may have to be required for particular aggregates.

Modification of Test Method

Materials laboratories in Virginia that would normally be performing the stripping test do not have the equipment to test at a deformation rate of 1.6 mm/min (0.065 in/min) and a temperature of 12°C (54°F). Thus, it would be easier to implement the test method if existing equipment could be used.

To investigate this possibility, the mixes tested in phase 1 were retested at a deformation rate of 51 mm/min (2 in/min) and a test temperature of 25°C (77°F). The Marshall device for testing stability and the 25°C

(77°F) water bath used in the test of asphalt cement penetration, devices that are usually available in materials laboratories, were used in performing the test.

The results of both test methods are given in Table 5. A correlation between the two test methods was obtained in the following form:

$$Y = 0.927X + 0.008 \quad R = 0.976 \qquad (2)$$

where Y = TSR at 51-mm/min (2-in/min) deformation rate and 25°C (77°F) test temperature and X = TSR at 1.6-mm/min (0.065-in/min) deformation rate and 12°C (54°F) test temperature.

The t-test indicated that there was no significant difference in the test methods at a 95 percent level of confidence. The methods were equivalent in their ability to predict stripping.

The test conditions selected in NCHRP Project 4-8(3)/1 were developed by using asphalt and aggregate sources representative of the United States; therefore, these test conditions may yield the best overall predictions. However, the modified test results are encouraging and appear to yield comparable predictions of TSR values for Virginia asphalts and aggregates.

Visual Examination of Split Specimens

After the indirect tensile tests were performed, the specimens were split apart and examined visually for stripping damage. Generally, the amount of stripping that was visible was indicative of the relative TSR, especially for the same mix with different properties (such as density) or with and without additives.

CONCLUSIONS

1. None of the mixes showed significant stripping damage after only preconditioning by vacuum saturation; therefore, either pavement damage would not occur in a short period of time or preconditioning by vacuum saturation does not predict the short-term performance of Virginia mixes. This conclusion is supported by observed stripping failures in Virginia.
2. Six of the eight mixes showed significant stripping damage after freeze-thaw preconditioning; therefore, pavements that incorporate these mixes would probably show evidence of stripping over a long period of time.
3. On the basis of results with the three asphalt cements used, asphalt cement does not significantly affect the tensile-strength ratio.
4. There was a significant difference between the performances of antistripping additives for one mix.
5. A modified test method that uses equipment now available in most materials laboratories in Virginia can be used in place of the test method that calls for a 1.6-mm/min (0.065-in/min) deformation rate and a 12°C (54°F) test temperature.
6. The relative magnitude of stripping can be detected by a visual examination of specimens.

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Abridgment

Engineering Characteristics of Dryer-Drum Asphalt Mixtures

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In recent years, there has been a substantial increase in the use of dryer-drum mixers. Although several investigators have studied some of the properties of the asphalt concrete mixtures produced by using these mixers, tensile strengths, resilient or elastic properties, and fatigue properties for these kinds of mixtures are not readily available. Thus, the Texas State Department of Highways and Public Transportation (TSDHPT) requested that a limited investigation be conducted to determine the characteristics of asphalt mixtures produced by using a dryer drum and to determine whether these mixtures are satisfactory.

EXPERIMENTAL PROGRAM

The objectives of the study summarized in this paper were

1. To evaluate the fatigue and elastic properties of