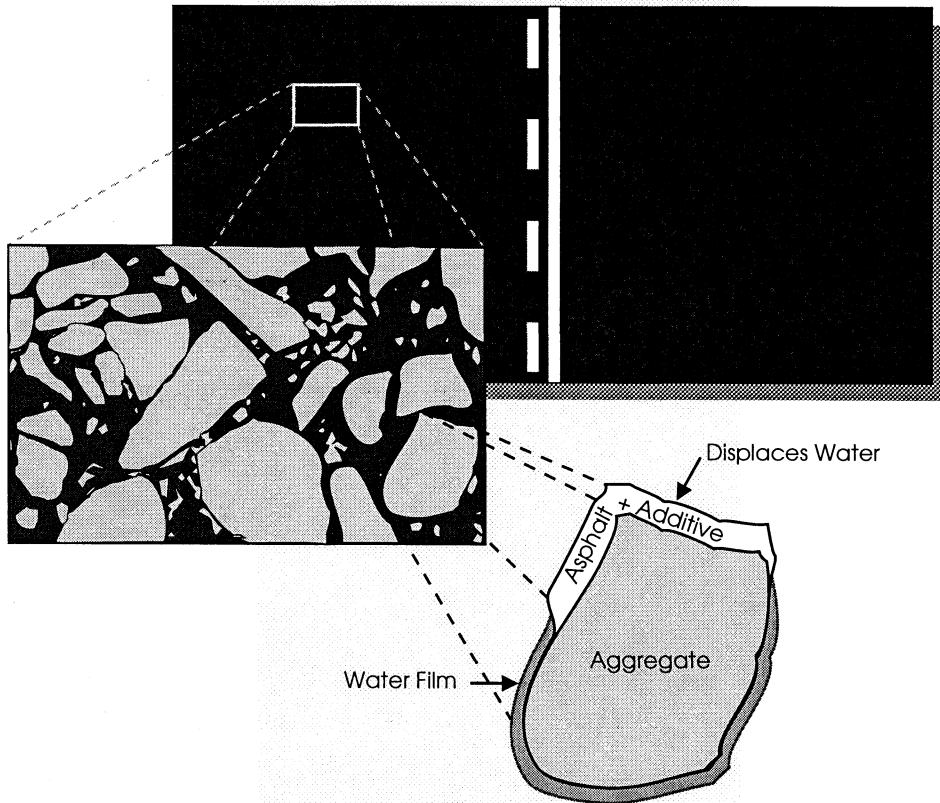


FINAL REPORT

EFFECTIVENESS OF ANTISTRIPPING ADDITIVES IN THE FIELD



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<p>Abstract</p> <p>Stripping has long been recognized as a cause of asphalt pavement damage. Water may get between the asphalt film and the aggregate surface, causing an adhesive failure, or water may combine with the asphalt to affect the cohesive strength of the material. Various types of antistripping additives have been used in the attempt to alleviate or eliminate stripping. The Virginia Department of Transportation has used antistripping additives in some of its asphalt mixes since the 1960's. In the 1980's hydrated lime was found to outperform several chemical additives. VDOT began to require asphalt contractors to use chemical additives that produced test results equal or superior to hydrated lime. Presumably, chemical additives were then improved to compete with hydrated lime. This study was undertaken to find if the new generation of additives prevented stripping in Virginia's hot mix asphalt.</p> <p>Twelve test sections were established, 9 using chemical additives and 3 containing hydrated lime. After 3 to 4 years, eight of the sections containing chemical additive demonstrated considerable visual stripping in cores. The sections containing hydrated lime showed much less stripping. The TSR test used on mix sampled during construction did not accurately predict the stripping that occurred. A follow-up survey of existing pavements should be conducted to verify the possible inadequacy of some chemical additives. Also, the TSR test should be examined and possibly modified to more closely duplicate Virginia's environmental conditions.</p>				

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agency.)

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ABSTRACT

Stripping has long been recognized as a cause of asphalt pavement damage. Water may get between the asphalt film and the aggregate surface, causing an adhesive failure, or water may combine with the asphalt to affect the cohesive strength of the material. Various types of antistripping additives have been used in an attempt to alleviate or eliminate stripping.

The Virginia Department of Transportation has used antistripping additives in some of its asphalt mixes since the 1960's. In the 1980's hydrated lime was found to outperform several chemical additives. VDOT began to require asphalt contractors to use chemical additives that produced test results equal or superior to hydrated lime. Presumably, chemical additives were then improved to compete with the hydrated lime. This study was undertaken to find if the new generation of additives prevented stripping in Virginia's hot mix asphalt.

Twelve test sections were established, 9 using chemical additives and 3 containing hydrated lime. After 3 to 4 years, eight of the sections containing chemical additive demonstrated considerable visual stripping in cores. The sections containing hydrated lime showed much less stripping. The TSR test used on mix sampled during construction did not accurately predict the stripping that occurred.

A follow-up survey of existing pavements should be conducted to verify the possible inadequacy of some chemical additives. Also, the TSR test should be examined and possibly modified to more closely duplicate Virginia's environmental conditions.

EFFECTIVENESS OF ANTISTRIPPING ADDITIVES IN THE FIELD

G. W. Maupin, Jr., Principal Research Scientist

INTRODUCTION

Stripping of asphalt concrete has been defined as "the weakening or eventual loss of the adhesive bond usually in the presence of moisture between the aggregate surface and the asphalt cement in an HMA pavement or mixture."¹ It has long been recognized as a cause of pavement damage. Technical papers dealing with stripping were written a half-century ago, and concentrated research efforts started to multiply approximately 25 years ago.

Thorough literature surveys already exist;^{2,3} it is unnecessary to duplicate them here. By way of introduction, the basics of stripping and work dealing with antistripping additives will be briefly considered.

Stripping can involve two mechanisms, adhesion and cohesion, which contribute to strength loss. Water may get between the asphalt film and the aggregate surface, causing an adhesive failure. Also, water may combine with the asphalt to affect the cohesion and result in reduced stiffness. Either mechanism will cause strength reduction in the material, but only the adhesive failure will be visible upon examination of the interior surfaces of the asphalt concrete. Most studies have dealt primarily with adhesive type mechanisms, possibly because of its tangible nature.

Several theories attempt to explain the adhesion of asphalt cement to aggregate: surface energy, chemical reaction (chemical bonding), molecular orientation, and mechanical factors.³ The bonding of asphalt cement to aggregate is probably a combination of all these mechanisms.

In the surface energy theory, the unbalanced forces of the liquid surface molecules cause the molecules to be attracted inwardly, resulting in surface tension. If two liquids are equal in all other respects, but one has lower surface energy (surface tension), it will wet a solid more readily. Water is apparently better than asphalt cement at wetting an aggregate surface at room temperature. When the temperature of asphalt is raised, the surface energy is decreased. Asphalt can be made to wet aggregate better by raising the temperature considerably. Not only must the surface tension be considered when comparing the ability of liquids to coat a solid, but the internal energy (cohesion) must also be considered.² For instance, asphalt has high cohesive energy at room temperature and is very difficult, if not impossible, to coat and bond to aggregate.

Chemical bonding theory states that chemical reactions occur between the asphalt cement and aggregate. The strength of the chemical bonds affects adhesion. Many studies have dealt with the acidic or basic nature of aggregates. Asphalt is considered to be slightly acidic. Materials with unlike properties would supposedly be more likely to bond. PH has been used to

determine whether an aggregate may form good bonds, along with a measurement of aggregate surface charge called zeta potential.

Molecular orientation theory states that molecules in the asphalt tend to orient themselves to satisfy the energy demands of the aggregate surface.³ Since asphalt molecules are nonpolar and water molecules are dipolar, the water may have a greater affinity than asphalt for aggregate surfaces (mostly negatively charged).

The mechanical bond may be influenced by aggregate surface texture, porosity, dust coatings, and surface area.³ Surface texture and porosity involve a mechanical interlock between the asphalt film and the aggregate surface. Dust coatings prevent the aggregate surface from being coated by the asphalt cement. Also, aggregate surface area affects the thickness of the asphalt film and its susceptibility to penetration by water.

During the construction process there are several ways to try to deter or prevent stripping. One method is to control the aggregates used. Using aggregates with the proper porosity and surface texture should help. Washing the aggregate will remove any dust coating detrimental to the adhesion of the asphalt cement. Also, additives can help promote a strong bond. The two primary types of antistripping additives are chemical liquid agents and hydrated lime.

Chemical additives act as wetting agents which decrease the surface tension of the asphalt. They can also help form a chemical bond with the asphalt and silica component of the aggregate.³ The most common chemical additives are fatty amines added directly to the asphalt cement before it is mixed with the aggregate. Hydrated lime is added directly to the surface of the aggregate before it is coated with asphalt. It may be added to damp aggregate or as a slurry to gain the most benefit. It has been postulated that hydrated lime reacts strongly with carboxylic acids of asphalt; fewer acids are adsorbed by the aggregate surfaces, resulting in a strong asphalt-aggregate bond.⁴

In the early 1980's, pavement failures caused by stripping were noticed in pavements containing chemical antistripping additives. In a Federal Highway Administration study, some state agencies found stripping in mixes containing chemical additives.⁵ A Washington state study identified stripping in mixes containing chemical additives but could not verify whether the correct amounts had been incorporated into the mixes.⁶ Because the effectiveness of chemical additives was a concern in Virginia, test sections of asphalt concrete containing hydrated lime were constructed and compared to adjacent sections of asphalt concrete containing chemical additives. The good early performance of the sections with hydrated lime prompted VDOT to begin requiring the use of hydrated lime or a chemical additive that could achieve comparable test results. The tensile strength test, known as the Root-Tunnicliff test,^{7, 8} was used to determine compliance.

Chemical additive companies began to improve their additives to meet the new requirements. Even though the specifications required that the chemical additive produce a test result comparable to that of the mix containing hydrated lime, there was no certainty that the new generation of chemical additives would produce mixes that would not strip. This study was initiated to gather field performance data on asphalt concrete containing the new generation of antistripping additives.

PURPOSE AND SCOPE

The purpose of this study was to determine the effectiveness of the antistripping additives used during 1990 and 1991, when test sections were established. Test sections were placed in the field and evaluated to assess the magnitude of stripping associated with various antistripping additives. Major emphasis was placed on the evaluation of chemical antistripping additives; however, three of the twelve test sections were constructed with asphalt concrete that contained hydrated lime as the antistripping additive.

METHODOLOGY

General

There is always some doubt about whether stripping tests accurately predict field performance. Even though the additives may pass the approval-acceptance TSR test it is wise to occasionally verify field performance by observing test pavements with known additives. The intent was to determine general statewide performance. Most of the sections were subjected to fairly heavy traffic levels, and located in different parts of the state to include a wide range of weather conditions and aggregate types (Figure 1).



Figure 1. Location of test sections.

Mix was sampled as the overlays were being placed and transported back to the research lab for testing. Also, samples were cut from the pavement and the void level determined. After the sections were exposed to traffic for three to four years cores were taken and examined visually for stripping. Visual stripping was used to determine the effectiveness of the additives.

Tests

TSR Test (Indirect Tensile Test)

Virginia test method VTM-62⁹ was one of the tests used to determine the predicted stripping susceptibility of the mixes placed. Though based on the Root-Tunnicliff method, it is more specific. The Root-Tunnicliff method allows several variations throughout the procedure.

Two sets of 64 mm by 100 mm diameter specimens were compacted to 7.5 (± 1) percent voids. One set was tested in a dry condition at 25^oC using the TSR test at a 51 mm/min deformation rate. The second set was subjected to a partial vacuum under water until 55 to 80 percent of the internal voids were filled. It was then tested in indirect tension. The ratio of tensile strength of the wet set to the tensile strength of the dry set, TSR, was used to predict the potential for moisture damage. At the time these tests were performed the TSR was required to be equal to or greater than that for a mix containing hydrated lime and at least 0.75.

Boiling Test

The field testing procedure in Virginia Test Method (VTM-13)⁹ was used to evaluate the mixes that were sampled and transported back to the research lab. The test procedure basically consisted of boiling approximately 400 g of sample under water for 10 minutes and comparing it visually to an unboiled sample. If the boiled sample appeared to have any stripping it failed the test. Three tests were performed for each test section.

Air Voids

The percent air voids in eight samples, taken from the pavement immediately after construction and at the time of evaluation, was determined according to the ASTM *Standard Test Method for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures*, ASTM D 3203. The voids were computed from the specimen bulk specific gravity and theoretical maximum specific gravity by the following formula.

$$VTM = 100 \left(1 - \frac{\text{bulk specific gravity}}{\text{theoretical maximum specific gravity}} \right)$$

where:

VTM = Percent air voids

Bulk specific gravity = bulk specific gravity of the specimen

Theoretical maximum specific gravity = theoretical maximum specific gravity of the specimen mixture.

Visual Evaluation of Cores

Three cores 100 mm in diameter were removed from the pavement, both in and between wheelpaths. They were wrapped in plastic and sealed to prevent the evaporation of moisture and possible healing of any stripping that might have occurred, taken to the laboratory, and broken apart so the interior could be examined. The rating system was zero to five, zero being no stripping and five being essentially 100 percent stripped. Stripping of the coarse aggregate (plus 4.75 mm) was estimated separately from stripping of the fine aggregate (minus 4.75 mm).

Test Sections

Samples were collected during paving on 12 overlay paving projects in 1990 and 1991 (Table 1). The locations where the samples were taken were identified so stripping evaluations could be done after exposure to traffic. Nine of the projects were on interstate or primary highways. Another highway (Route 663), located in an urban area, received a high volume of automobile traffic although no official traffic count was available.

Ten of the mixes were type SM-2C (Table 2), designed with a 75-blow Marshall test containing an AC-30 asphalt cement. The two SM-3A mixes, coarser than the SM-2C mixes and designed with a 50-blow compactive effort, contained AC-20 asphalt cement. Three of the mixes contained hydrated lime and nine of the mixes contained one of five brands of chemical antistripping additives. The coarse aggregates included granite, metarhyolite, aplite, diabase, and siltstone. The fine aggregates were usually the same rock type, but sometimes were from a different source.

Table 1. Test Sections

Route	Traffic, 18 Kip ESAL's x 10 ³	Mix	Post - Construction Voids, percent	Additive	Aggregates	
					Coarse Aggregate (+ 4.75 mm)	Fine Aggregate (- 4.75 mm)
58	137	SM-2C	12.2	Hyd. Lime (L)	Granite	Nat. Sand
I-64H	877	SM-2C	10.3	Adhere HP Plus (C1)	Metarhyolite	Quartz Sand
29	982	SM-2C	10.1	AS Special (C2)	Aplite	Aplite and Quartz Sand
01	513	SM-2C	13.3	Adhere HP Plus (C1)	Granite	Granite and Natural Sand
28	250	SM-2C	15.0	ACRA-2000 (C3)	Diabase	Different Diabase
I-64NK	1066	SM-2C	13.2	Adhere HP Plus (C1)	Metarhyolite	Natural Sand
I-66	1176	SM-2C	11.9	Kling Beta 2600 (C4)	Siltstone	Siltstone and Natural Sand
I-77	2160	SM-2C	11.1	Hydr. Lime (L)	Granite	Granite and Natural Sand
I-81	2931	SM-2C	11.0	Hyd. Lime (L)	Diabase	Diabase and Natural Sand
663	NA	SM-2C	7.3	Kling Beta 2600 (C4)	Diabase	Diabase and Natural Sand
622	NA	SM-3A	NA	Kling Beta 2600 (C4)	Siltstone	Siltstone and Natural Sand
690	NA	SM-3A	NA	101-25-B Exxon (C5)	Diabase	Diabase and Natural Sand

Table 2. Mix Design Range

Sieve, mm	Percent Passing	
	SM-2C	SM-3A
25.0		100
19.0	100	97 - 100
12.5	97 - 100	72 - 86
9.5	82 - 94	
4.75	48 - 62	40 - 58
0.6	18 - 24	14 - 24
0.075	4 - 7	3 - 6

RESULTS

Table 3 shows the test results for pavement voids at the time of the stripping evaluation, stripping tests, and the field stripping evaluation.

Boiling Test

All of the mixes passed the boiling test; therefore, no stripping was expected in the pavements.

TSR Test

All TSR results were above 0.9 except the mix placed on Route 1. This mix, which also served as a control mix on an asphalt rubber field project, had a very low TSR of 0.71. The minimum acceptable value cited previously was 0.75.

Pavement Voids

Pavement voids ranged from 3.1 percent to 7.7 percent for all pavement sections measured. These void levels were approximately 50 percent of the original void levels.

Table 3. Results

Route	Mix	Final Voids, Percent	TSR	Boil Test	Additive	Aggregates		Field Stripping Eval. *	
						Coarse (+4.75 mm)	Fine (-4.75 mm)	C. A.	F. A.
58	SM-2C	7.2	0.94	Pass	Hyd. Lime (L)	Granite	Nat. Sand	1	1
I-64H	SM-2C	5.5	0.91	Pass	Adhere HP Plus (C1)	Metarhyolite	Quartz Sand	4	4
29	SM-2C	4.6	0.99	Pass	AS Special (C2)	Aplite	Aplite and quartz sand	3	0
1	SM-2C	7.6	0.71	Pass	Adhere HP Plus (C1)	Granite	Granite and natural sand	4	4
28	SM-2C	7.7	0.94	Pass	ACRA-2000 (C3)	Diabase	Another diabase	1	0
I-64 NK	SM-2C	7.2	0.96	Pass	Adhere HP Plus (C1)	Metarhyolite	Natural Sand	3	3
I-66	SM-2C	5.5	0.91	Pass	Kling Beta 2600 (C4)	Siltstone	Siltstone and Natural Sand	4	4
I-77	SM-2C	5.6	0.91	Pass	Hyd. Lime (L)	Granite	Granite and Natural Sand	0	1
I-81	SM-2C	6.6	0.93	Pass	Hyd. Lime (L)	Diabase	Diabase and Natural Sand	2	2
663	SM-2C	3.1	0.93	Pass	Kling Beta 2600 (C4)	Diabase	Diabase and Natural Sand	3	3
622	SM-3A	NA	0.93	Pass	Kling Beta 2600 (C4)	Siltstone	Siltstone and Natural Sand	4	4
690	SM-3A	NA	0.93	Pass	101-25-B Exxon (C5)	Diabase	Diabase and Natural Sand	4	0

* Scale: 0 = no stripping
5 = 100 percent stripped

Visual Evaluation of Cores

Visual stripping ranged from very slight to moderately severe for both the coarse and fine aggregate.

DISCUSSION

Figure 2 shows the stripping observed in cores removed from the pavement after three to four years of traffic. In 10 of the 12 sections the stripping was the same or nearly the same for the coarse and fine aggregates. This observation is probably logical since many of the mixes contained fine aggregate from the same source as the coarse aggregate. Interestingly, two of the secondary routes with low traffic, Routes 622 and 690, displayed considerable stripping. This suggests that high traffic volumes are not always necessary to induce stripping.

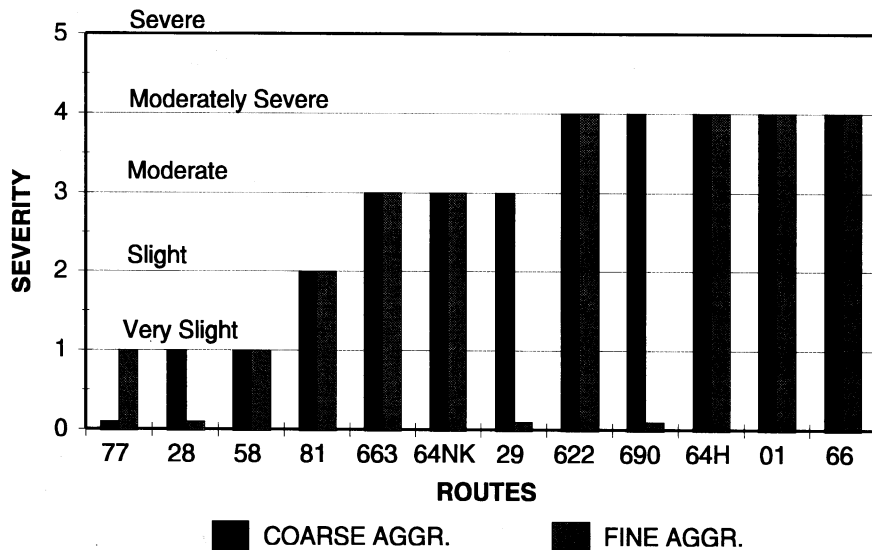


Figure 2. Stripping after 3 to 4 years of traffic.

Figure 3 illustrates the severity level of stripping of coarse aggregate for the mixes containing hydrated lime and for the mixes containing various chemical additives. The mixes containing hydrated lime were below the moderate severity level of three, but only one mix containing chemical additive was below that level.

Figure 4 illustrates the severity of stripping of fine aggregate for the mixes containing hydrated lime and for mixes containing the chemical additives. None of the mixes containing hydrated lime had a severity level above two. However, six of the 12 projects containing

chemical additives had at least a severity level of three. Some mixes did not contain the same coarse and fine aggregate; possibly the additive effectiveness differed between coarse and fine aggregate.

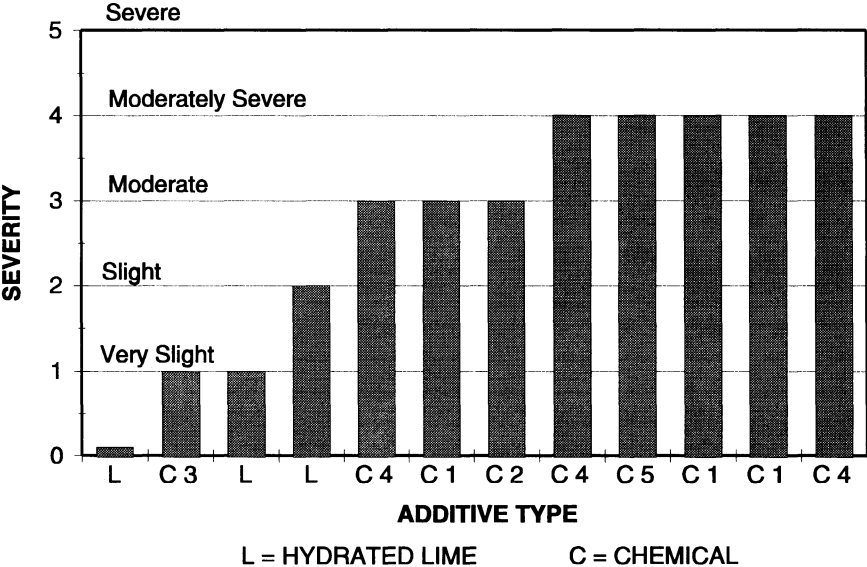


Figure 3. Severity of stripping of coarse aggregate.

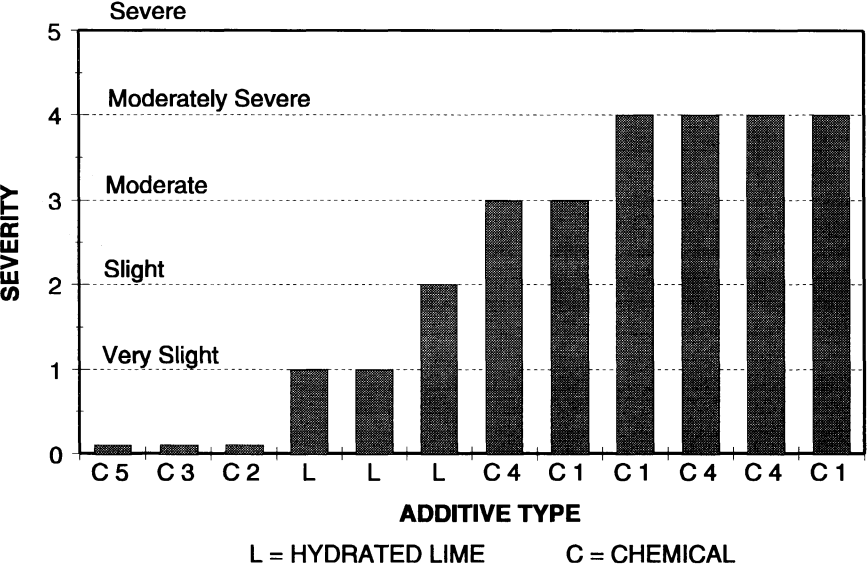


Figure 4. Severity of stripping of fine aggregate.

If visual stripping indicates potential performance, the present chemical additives are not as effective as was hoped. The pavements did not strip to the point of total disintegration, but the loss of adhesion observed by the visible stripping should result in decreased fatigue life and durability. Conclusions could not be reached concerning particular brands of additives since not enough projects containing single brands could be included in this study.

Neither the TSR test nor the boiling test showed satisfactorily which mixes would strip. None of the mixes failed the boiling test and only one mix that stripped had an unacceptable TSR. Possibly additives may be effective over the short term for the duration of the test but not over the long term in pavement service. The extremely poor correlation of field observation with prediction of stripping by the TSR test was disappointing.

Aschenbrener¹⁰ compared several variations of the TSR test to field performance of mixes in Colorado. Variations of the procedure that changed the degree of severity included the aging of the mix before compaction, degree of saturation, and inclusion of a freeze cycle. None of the variations predicted performance perfectly. The variation closely resembling VDOT's TSR test identified those mixes that performed well and those that disintegrated but did not identify those mixes that required high levels of maintenance. A more severe test variation including a higher level of saturation and a freeze cycle did identify mixes needing high levels of maintenance. It was suggested in the report that Colorado adopt two levels of severity for their testing to match the variety of environmental and traffic conditions in the state.

Although Virginia does not have the same environmental conditions as Colorado, it is possible that a more severe test procedure is necessary. Consideration should be given to increasing the severity of the test method and further verifying the effectiveness of chemical additives over the long term.

CONCLUSIONS

1. Eight of nine projects containing chemical antistripping additives showed considerable visual stripping after three to four years of service.
2. All of the three projects containing hydrated lime showed less stripping than the projects containing chemical additives.
3. The TSR test did not accurately predict the visual stripping observed in the mixes after three to four years.

RECOMMENDATIONS

There is still a question about the long term effectiveness of antistripping additives, particularly chemical additives. Future work on long term effectiveness would be beneficial. A laboratory study and a general field survey of existing pavements would be helpful. The laboratory study would attempt to determine the short term effectiveness of additives as measured by the stripping test. The long term effectiveness of the same mixes would be determined after an extended period of exposure (one year). The samples could be subjected to a combination of outdoor exposure and accelerated laboratory conditioning such as freeze-thaw cycles. It is important to introduce long exposure periods, since the time element is not considered in the current test methods.

Because considerable stripping was observed in most of the projects containing chemical additives in this study, a more general survey should be conducted. A larger number of projects located throughout the state should be sampled and examined for stripping. Projects constructed between 1990 and 1993 using a variety of chemical additives should be selected. Projects containing hydrated lime should be included to verify the good performance of the lime projects sampled in this study.

The severity of VDOT's stripping test should also be reconsidered, to make sure that the test does not approve unsatisfactory additives. It may be necessary to change the test method to include a higher level of saturation or a freeze cycle.

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