Evaluation of New Generation of Antistripping Additives

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A laboratory evaluation of antistripping additives is presented. The three additives included one lime additive added to the aggregates and two liquid additives mixed with the asphalt cements. Each additive was evaluated at various levels of concentration. Control mixtures with no additives were also evaluated. The laboratory evaluation program consisted of measuring the unconditioned resilient modulus at various temperatures and the moisture-conditioned resilient modulus and tensile strength. The ratios of the unconditioned to the conditioned values were also used in the evaluation. On the basis of the results of the laboratory evaluation program, lime reduces the stripping potential of asphalt concrete mixtures. The liquid additives did not provide any significant improvement in the measured strength parameters (resilient modulus and tensile strength) of asphalt concrete mixtures. Therefore, the liquid additives have not proven to be effective antistripping additives.

Premature pavement failures in the forms of raveling, rutting, and cracking have been a common occurrence in the western United States for the past several years. This type of damage, which requires millions of dollars in repairs, can most often be attributed to the loss of adhesion between the asphalt cement and the aggregate surface. Also referred to as stripping, the loss of adhesion is the result of moisture infiltrating the asphalt concrete layer. Partial or complete stripping leads to a strength loss on the order of 70 to 95 percent (*1*).

Several methods may reduce the moisture sensitivity of asphalt concrete mixture. Lime added to the aggregate or liquid antistripping chemicals added to the asphalt cement are commonly used throughout the United States as antistripping agents. It is believed that the lime changes the surface chemistry and polarity of the aggregate surface, producing a stronger adhesion with the asphalt cement (*1*). Liquid antistripping additives act as surfactants and allow the asphalt to coat the aggregate particles more easily and, at the same time, to displace adsorbed water on or near the surface of the aggregate particles (*2*).

BACKGROUND

Stripping in asphalt concrete pavements has been a nagging problem for many state agencies and materials engineers for the past several decades. It causes millions of dollars in pavement damage. Research efforts have been expanded to minimize or reduce the problem by the use of antistripping additives. The first use of such additives can be dated back to the early 1930s, when stripping was recognized as an adhesion problem (*2*).

The principal objective of any antistripping agent is to strengthen the bond between the asphalt cement and the aggregate surface. Chemical antistripping additives are readily soluble in asphalt cement and are designed to decrease the surface tension between the asphalt and aggregate surface, thereby allowing the aggregate to be more easily wetted by the asphalt (*3*). These types of chemicals are known as surface active agents, or surfactants. Common examples are the soaps and detergents used to impart wetting characteristics to all types of aqueous solutions.

Materials such as hydrated lime have proven to be effective in reducing the stripping potential of asphalt concrete mixtures. Hydrated lime functions in part like mineral filler and can also help to alter the chemistry of an aggregate surface. Several theories have been recognized as to why lime is so effective. First, lime improves the bonding of calcium with silicates in aggregate. Second, there is a possible interaction with the acidic portions of the asphalt. Third, aggregates with clay coatings have ion exchange and pozzolonic reactions between the calcium in lime and the silica in clay (*1*). Previous research studies have shown that the effect of lime on the moisture sensitivity of asphalt-aggregate mixtures depends on other variables: types of lime, methods of applying lime to the mixtures, changes in aggregate sources, and air voids present in the pavement.

RESEARCH PROGRAM

The objectives of this research program were to conduct a laboratory experiment to evaluate the effectiveness of (*a*) the various antistripping agents in reducing or eliminating the stripping potential of asphalt concrete mixtures and (*b*) the two liquid antistripping chemicals against the Type N hydrated lime.

DESIGN OF LABORATORY EXPERIMENT

The design of the research program consisted of selection of the materials (i.e., additives, asphalt, and aggregates), design of mixtures, and selection of laboratory tests.

Table 1 gives a summary of the experimental design. Each asphalt concrete mixture (i.e., aggregate source) was tested

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TABLE 1 TEST MATRIX

		Anti Strip Agent							
		Lime		Liquid I			Liquid II		
		1	2	0.5	1	2	0.5	1	2
Helms	L	L	L	L	ML	ML	L	ML	ML
Doyle	L	L	L	L	ML	ML	L	ML	ML

0.5, 1, and 2 = Represent the percent of antistrip agent.

L = Test sequence L, Temperature and Moisture sensitivity.
M = Test sequence M, Limited mix design

with no additive (control), and with all four additives at various percentages. This setup allowed for several multiple comparisons, which will be discussed in the data analysis section.

MATERIALS

One lime product representing a normally hydrated Type N lime was tested in this program. Two new generations of antistripping chemicals were used as additives to the asphalt cement. Liquid Additive I is a new generation additive produced by Exxon Chemical, and Liquid Additive II is a product of Unichem International. An AR- 4000 asphalt cement grade was used to prepare all the mixtures. It was supplied by Witco's Golden Bear refinery located in Oildale, California. Aggregates were obtained from two sources located in northern California and northern Nevada. The northern Nevada aggregate (Helms aggregate), which has a history of stripping potential, was obtained from a river deposit in Sparks, Nevada. The total gradation consists of crushed coarse aggregates and a blend of crushed and natural sand. The California aggregate was obtained from a limestone quarry in Doyle, California (Doyle aggregate). The aggregate gradation shown in Figure 1 was selected to provide a gradation that would meet three standard specifications: Nevada Department of Transportation Type II, Caltrans ¾-in. maximum size, and ASTM dense mixture ½-in. maximum size.

MIXTURE DESIGNS—TESTING SEQUENCE

The basic Hveem mix design presented in the Asphalt Institute's Manual Series No. 2 (*4*) was followed with two exceptions. First, samples were extruded from the molds and allowed to cool to 77°F, then the resilient modulus and the bulk specific gravity were determined. The resilient modulus was determined for a loading frequency of 0.33 Hz, with a load duration of 0.1 sec and a rest period of 2.9 sec. Second, the samples were reheated to 140°F for 2.5 hr (±0.5 hr) before determining their Hveem stability. Once the stability was determined, samples were once again cooled to 77°F, and the indirect tensile strength was determined. All testing was performed according to the applicable ASTM standards.

Because the gradation was fixed, and therefore not adjusted to achieve the minimum of 35 stability, the selection of the optimum asphalt cement content was based solely on the binder content required to achieve 4 percent air voids. However, for all selected optimum asphalt contents, the minimum stability value of 35 was achieved.

LABORATORY TESTS

As discussed earlier, the major cause of asphalt concrete stripping is the infiltration of water through the pavement surface. The strength of asphalt concrete is drawn from the bonding

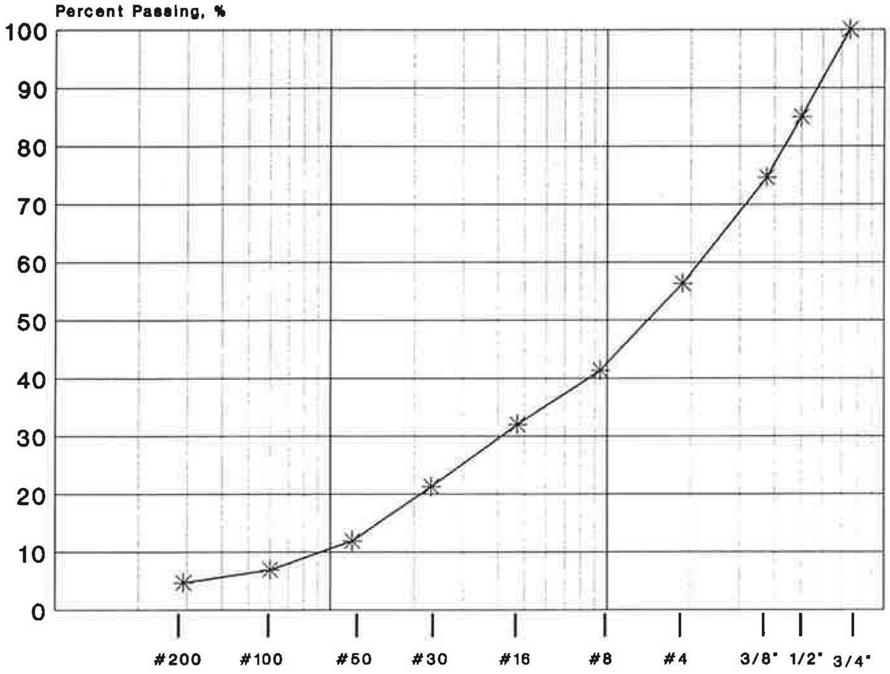


FIGURE 1 Gradation used in research project.

between the asphalt cement and the aggregates. The existence of moisture in asphaltic concrete causes major damage to the asphalt cement–aggregate bonding and therefore reduces the overall strength of the mixtures. Therefore, any laboratory experiment conducted to evaluate the effectiveness of antistripping agents must investigate the effects of the agents on the overall strength of the mixtures under severe water infiltration conditions. For the laboratory experiment conducted in this research, the resilient modulus and indirect tensile strength were identified as representative values of the overall strength of asphalt concrete mixtures. The resilient modulus and tensile strength of the original mixtures and mixtures with antistripping agents are evaluated under various levels of temperature and moisture conditioning.

The moisture-conditioning sequence used in this program is a modification of the Lottman moisture-conditioning procedure (5). It consisted of subjecting the test specimens to a vacuum saturation of 24 in. Hg for approximately 10 min to achieve at least 90 percent saturation. The samples were then wrapped in plastic and placed in a 0°F freezer for 15 hr followed by a thawing period of 24 hr in a 140°F water bath. After the thawing period the samples were brought down to testing temperature by placing them in a 77°F bath for 2.5 hr (±0.5hr). The resilient modulus and indirect tensile strength tests were then performed on the conditioned samples. The temperature conditioning testing sequence consisted of determining the resilient modulus of each set of three specimens at 34°F, 77°F, and 104°F.

The method of adding the antistripping agents to the asphalt concrete mixture differs from one agent to another. In the case of lime, the specified percentages of lime were mixed with the prewetted aggregates (5 percent water by dry weight of aggregate). Finally, the aggregate- lime mixtures were heated before mixing with the binder. When either liquid additive is used, the desired amount (0.5, 1, or 2 percent) was added directly to the asphalt cement at the required mixing temperature and stirred continuously for 2 to 4 min. The asphalt–liquid additive mixture is then used in the preparation of the asphalt concrete mixtures.

DATA ANALYSIS

As discussed earlier, the laboratory testing program consisted of evaluating the resilient modulus of the various mixtures under different temperatures and evaluating the resilient modulus and indirect tensile strength of the various mixtures before and after moisture conditioning. The overall objective of this research was to evaluate the effectiveness of the various antistripping additives. Therefore, the influence of the various agents on the physical properties of the mixtures had to be evaluated. The following data analyses were conducted:

1. Repeatability analysis of the individual laboratory tests,
2. Evaluation of the effects that antistripping agents have on the resilient modulus of mixtures at various temperatures,
3. Evaluation of the effects that antistripping agents have on the values of unconditioned and conditioned resilient modulus and the corresponding ratios, and
4. Evaluation of the effects that antistripping agents have on the values of unconditioned and conditioned indirect tensile strengths and the corresponding ratios.

Repeatability Analysis

The repeatability analysis consisted of evaluating the mean, standard deviation, and coefficient of variation (CV) of each set of three replicate measurements. The CV is the ratio of the standard deviation to the mean times 100. Most CV values varied between 5 and 15 percent except for the modulus at 34°F. This range of CV values is acceptable for laboratory testing data and will be considered in the next part of the data analysis (i.e., evaluation of antistripping additives).

Temperature Susceptibility of Resilient Modulus Values

The test results for this portion of the research program are given in Tables 2 through 4. Evaluation of the test results was based on comparisons made with the control mixtures. It can be seen from Table 2 that, in the two cases (Helms and Doyle), increasing the percentages of lime resulted in a slight increase in stiffness at all temperatures.

Table 3 gives the test results for both aggregates using the Liquid I additive. At ½ percent a slight increase at 77°F and 104°F was noticed along with a decrease of value at 34°F for both aggregates. A general slight increase at all temperatures was seen for both aggregates at the 1 percent concentration level. At 2 percent, the results varied between the Helms and Doyle aggregate sources. Combining this data with the repeatability analysis results, it can be concluded that there was roughly no appreciable increase of stiffness for either aggregate source.

In analyzing Liquid II, individual variability between the aggregate sources is noticed (Table 4). There was no increase of resilient modulus values for either aggregate at ½ and 2 percent. At 1 percent concentration, a slight increase of modulus values was noticed at 34°F and 77°F for both aggregate types.

Moisture Sensitivity and Resilient Modulus Values

Figures 2 and 3 show that the resilient modulus after moisture conditioning is significantly improved with the addition of lime

TABLE 2 TEST RESULTS FOR EVALUATION OF TEMPERATURE SUSCEPTIBILITY (LIME, AVERAGE OF THREE REPLICATES)

Aggregate Source Additive	Air Voids	Resilient Modulus, Ksi at Temperature, (°F)		
		34°F	77°F	104°F
Helms No Additive (Control)	9.9	3322	272	31
Lime - 1%	9.0	3580	295	31
Lime - 2%	9.4	4238	329	33
Doyle No Additive (Control)	8.4	3816	264	33
Lime - 1%	7.6	5372	321	38
Lime - 2%	7.9	6132	360	50

TABLE 3 TEST RESULTS FOR EVALUATION OF TEMPERATURE SUSCEPTIBILITY (LIQUID I, AVERAGE OF THREE REPLICATES)

Aggregate Source Additive	Air Voids	Resilient Modulus at Temperature, (°F)		
		34°F	77°F	104°F
Helms No Additive (Control)	9.9	3322	272	31
Liquid I - 0.5%	10.1	2145	289	32
Liquid I - 1.0%	7.9	5491	435	37
Liquid I - 2.0%	7.8	4781	276	31
Doyle No Additive (Control)	8.4	3816	264	33
Liquid I - 0.5%	8.5	3550	311	35
Liquid I - 1.0%	9.0	4048	412	40
Liquid I - 2.0%	8.4	3964	258	30

TABLE 4 TEST RESULTS FOR EVALUATION OF TEMPERATURE SUSCEPTIBILITY (LIQUID II, AVERAGE OF THREE REPLICATES)

Aggregate Source Additive	Air Voids	Resilient Modulus, Ksi at Temperature, (°F)		
		34°F	77°F	104°F
Helms No Additive (Control)	9.9	3322	272	31
Liquid II - 0.5%	9.6	1979	249	23
Liquid II - 1.0%	8.4	4492	280	26
Liquid II - 2.0%	8.8	3445	219	21
Doyle No Additive (Control)	8.4	3816	264	33
Liquid II - 0.5%	9.4	3949	255	25
Liquid II - 1.0%	9.4	4153	277	26
Liquid II - 2.0%	8.9	3177	237	26

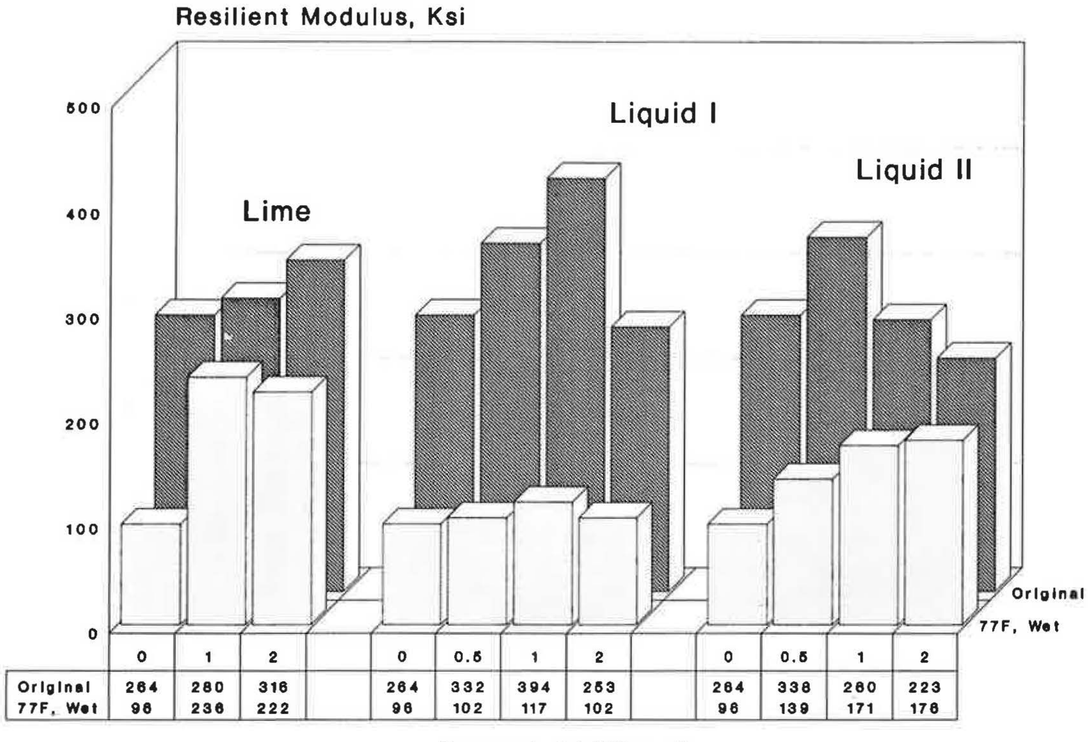


FIGURE 2 Comparison of resilient modulus before and after moisture conditioning for Helms aggregate.

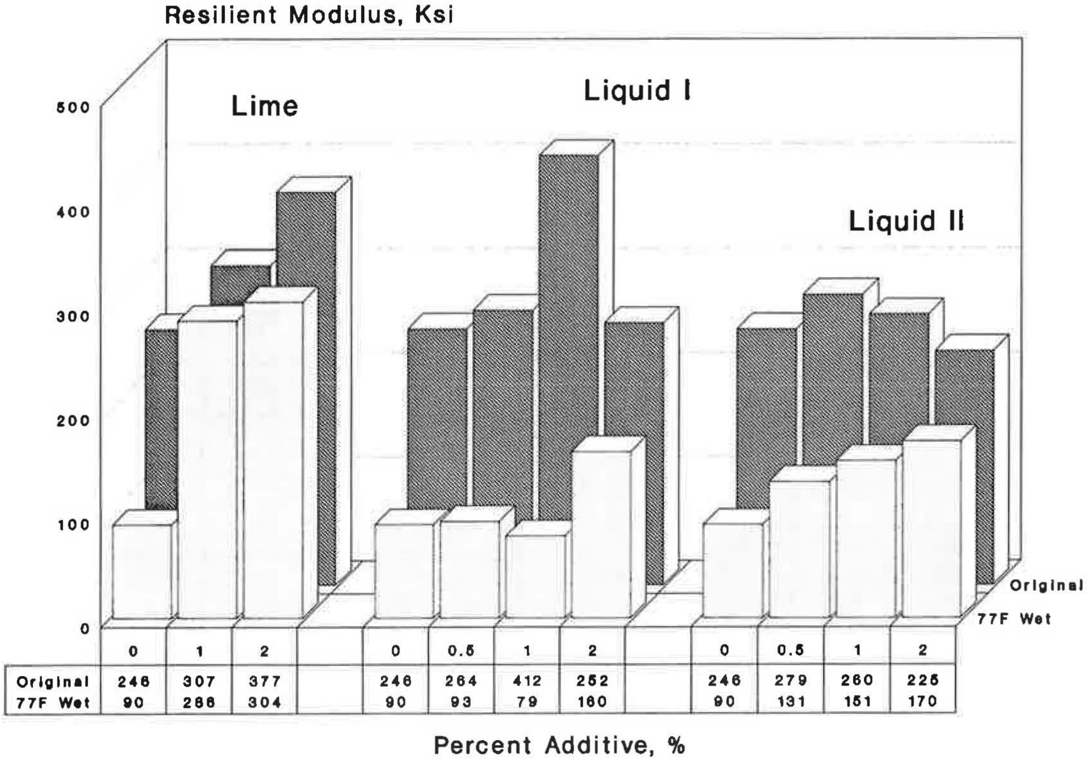


FIGURE 3 Comparison of resilient modulus before and after moisture conditioning for Doyle aggregate.

in any amount for both aggregate sources. It can also be seen that the modulus for lime mixtures for each aggregate is still increasing for the unconditioned specimens and has not leveled off. This indicates that the addition of more lime may be advantageous. For both aggregate sources, the ratios of conditioned to unconditioned resilient modulus values are at least 70 percent for all percentages of lime products (Figures 4 and 5).

In the case of the Liquid I antistripping agent, Figures 2 and 3 show that the 1 percent concentration level has significantly increased the unconditioned modulus of the mixtures with both types of aggregates. However, after conditioning there is a retention of only 30 and 20 percent for the Helms and Doyle mixtures, respectively. Figures 4 and 5 indicate that Liquid I does not generally decrease the moisture sensitivity of the mixture for either aggregate at any concentration level. Although at 2 percent some increase of the ratios is noticeable, the additive does not prove as effective as both lime products. Liquid II indicates some potential to be an effective antistripping agent. Although at most concentration levels the mixtures are not as stiff as those of the limes (Figures 2 and 3), their retention values improve with higher percentages of the additive (Figures 4 and 5). The Helms mixture has a high ratio of 80 percent, whereas the Doyle mixture has a high value of 76 percent. An observation unique to the Liquid II data is that the highest retention ratios occurred at concentration levels different from those that produce the highest unconditioned modulus values.

Moisture Sensitivity and Tensile Strength Values

The test results are shown in Figure 6 through 9 (tensile strength values and tensile strength ratios). Figures 6 and 7 show that the tensile strength after moisture conditioning is significantly improved with the addition of limes in any amount for both aggregates. The tensile strengths for lime mixtures steadily increases with increasing percentages of lime for both aggregates. A tensile strength ratio of 104 is achieved with the Doyle mix when using 2 percent lime, whereas with the Helms mixture the 1 and 2 percent concentration levels have very close ratios (Figures 8 and 9). Both ratios are above 80 percent and are considered highly acceptable. A ratio of more than 100 means that the mixture has no moisture sensitivity at all, a good indication of an optimal mix.

In the case of Liquid I, the tensile strength data are similar to the resilient modulus results. Liquid I at first shows some promising unconditioned results with strengths of 115 and 116 psi at 2 percent for the Helms and Doyle mixtures, respectively. However, after conditioning, relatively poor retained strengths are again achieved with this additive. At 1 percent for the Helms mixture, the retained strength is 70 percent, but one must consider its low unconditioned value of 72 psi compared with the lime products.

The Liquid II additive produced initial tensile strengths as high as those of the lime products, with the Helms mixture maximizing at ½ percent and the Doyle at 1 percent concentrations. The Helms mixture has increasing ratios (Figure 8);

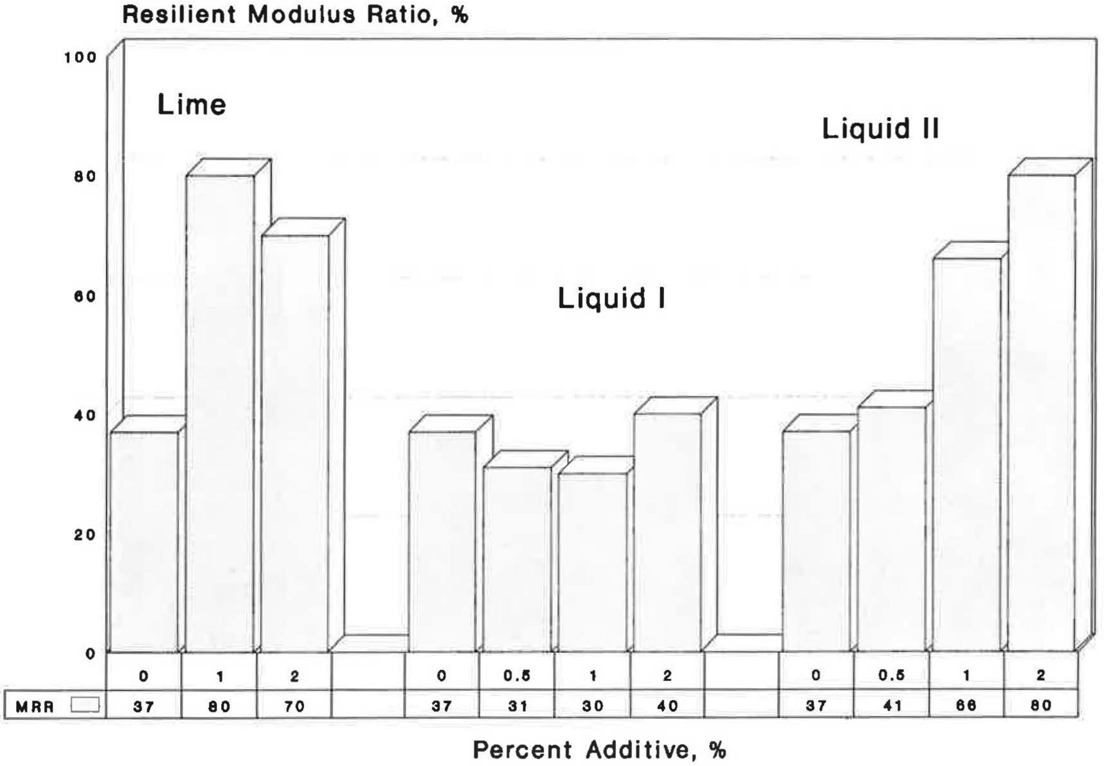


FIGURE 4 Comparison of resilient modulus ratios for Helms aggregate.

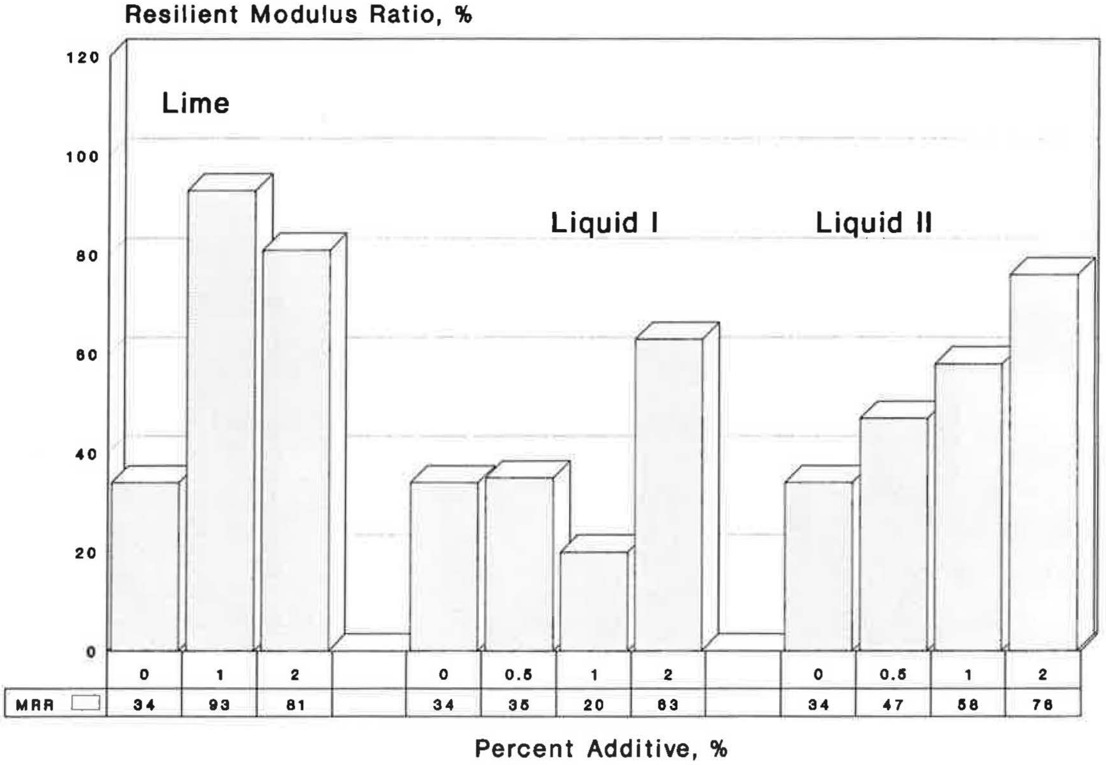
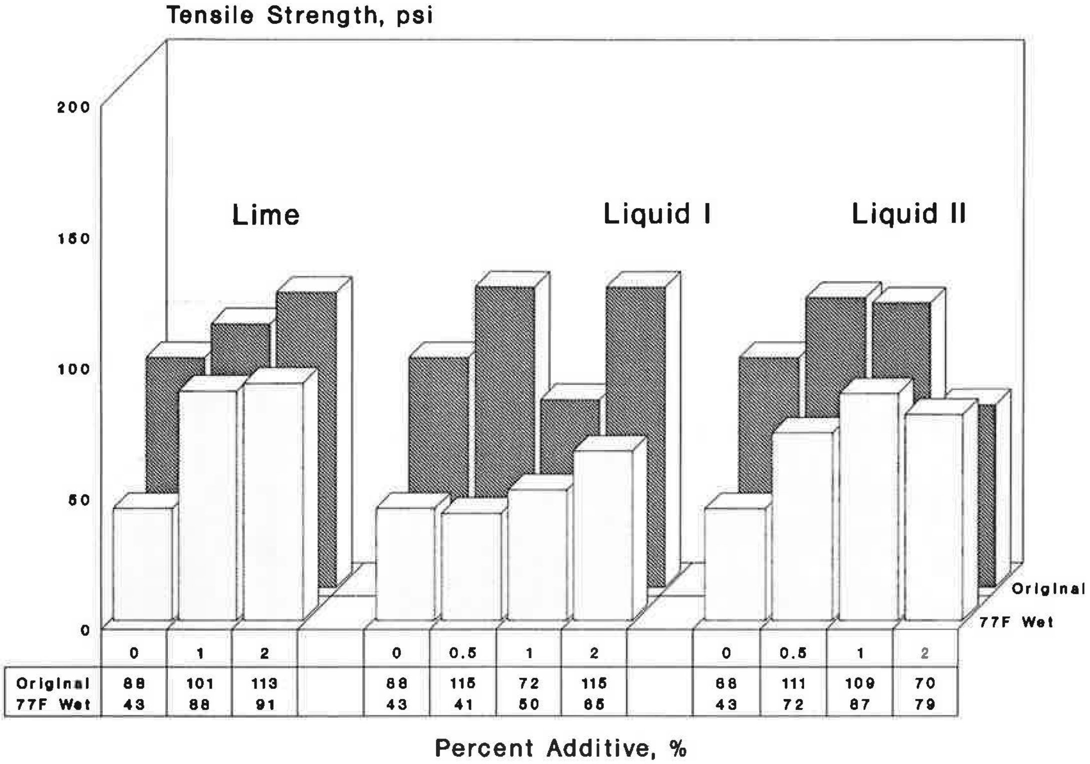
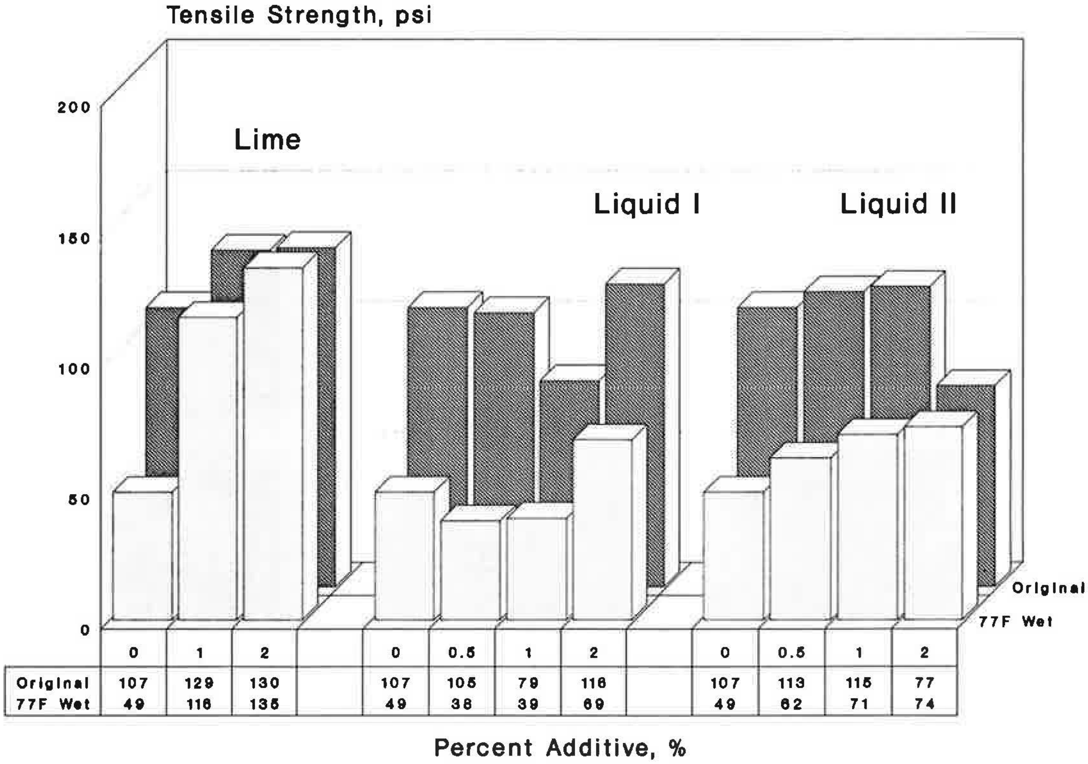


FIGURE 5 Comparison of resilient modulus ratios for Doyle aggregate.



	0	1	2		0	0.5	1	2		0	0.5	1	2
Original	88	101	113		88	115	72	115		88	111	109	70
77F Wet	43	88	91		43	41	50	65		43	72	87	79

FIGURE 6 Comparison of tensile strength before and after moisture conditioning for Helms aggregate.



	0	1	2		0	0.5	1	2		0	0.5	1	2
Original	107	129	130		107	105	79	116		107	113	115	77
77F Wet	49	116	135		49	38	39	69		49	62	71	74

FIGURE 7 Comparison of tensile strength before and after moisture conditioning for Doyle aggregate.

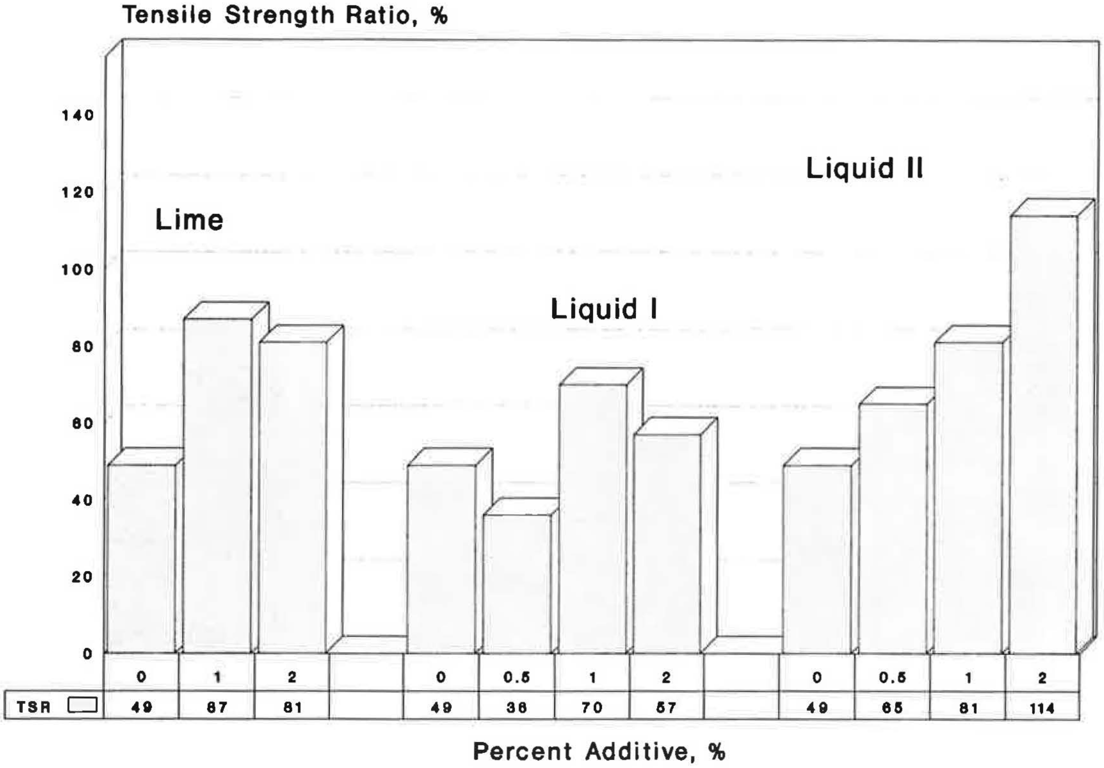


FIGURE 8 Comparison of tensile strength ratios for Helms aggregate.

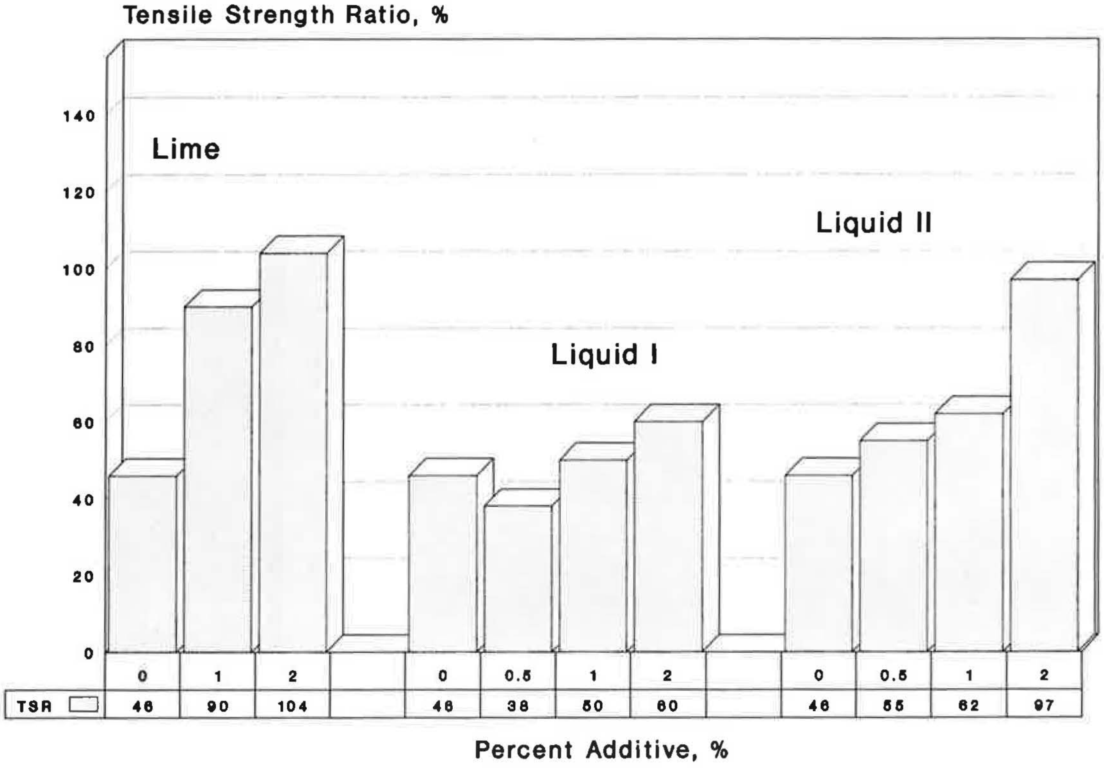


FIGURE 9 Comparison of tensile strength ratios for Doyle aggregate.

however, a large drop of unconditioned strength occurs at 2 percent with an original value of 70 psi. This high ratio coupled with the low unconditioned tensile strength is not considered highly effective. The same concept holds true for the Doyle mixture with a retained strength of 97 percent (Figure 9).

SUMMARY AND CONCLUSIONS

Three different types of antistripping additives were evaluated in this laboratory testing program. The evaluation consisted of measuring the effect of additives on the resilient modulus at various temperatures and the moisture-conditioned and unconditioned resilient modulus and tensile strength values. On the basis of the analysis of the laboratory data, the following conclusions can be drawn:

1. Lime additive indicates a consistent increase in the resilient modulus at all tested temperature levels for both types of aggregates (Helms and Doyle).
2. The effect of the Liquid I additive on the resilient modulus at various temperatures was inconsistent. In general, the 1 percent concentration was the most effective in increasing the resilient modulus at the various temperatures.
3. The effect of the Liquid II additive on the resilient modulus at various temperatures indicates a weak trend. The modulus values increased as a function of concentration level up to a level of 1 percent. After 1 percent the modulus values decreased (at 2 percent).
4. Lime indicates similar effects on the conditioned and unconditioned resilient modulus and tensile strength values of the mixtures made with both aggregate types. In general, both Lime I and II proved to be effective antistripping agents.
5. Liquid I additive showed a significant increase in the unconditioned modulus. However, it showed little retention in the modulus values after moisture conditioning. In the case of tensile strength some increase was obtained depending on the aggregate type. On the basis of its laboratory performance, the Liquid I additive did not prove to be an effective antistripping agent.
6. The Liquid II additive showed a consistent improvement in the unconditioned modulus and tensile strength values. High ratios of conditioned to unconditioned values were obtained; however, these high ratios did not coincide with the unconditioned values. Although the Liquid II additive showed some increase in the modulus, tensile strength, and ratios, its effectiveness as an antistripping additive is highly questionable.

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