CHEMICAL ADDITIVE USAGE ON UNPAVED ROADS IN THE MOUNTAIN PLAINS STATES

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Disclaimer

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ABSTRACT

Research identified that some North Dakota counties are facing a shortage in quality gravel. Other counties may experience a shortage in the near future. The use of chemical additives, such as soil stabilizers and dust suppressants, may help to reduce the need and demand for gravel. Many products are available on the market to stabilize the soil or reduce dust. However, not all of these products will work on every soil type. The objective of this study was to survey county road officials about their use of chemical additives to stabilize the soil and reduce dust. Questionnaires were mailed to each of the county engineers or road supervisors in the Mountain-Plain states of Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming. According to the survey results, sixty agencies used 90 chemical additives for dust control/soil stabilization. Of the categories identified, the chloride additives were the most widely used (64 percent), while the clay additives, bituminous binders, and adhesives were used by 18, 8, and 6 percent, respectively, of the respondents. Most of the agencies that used chemical additives stated that they had success with the products. This study contains results of the six-state survey regarding usage and effectiveness of several chemical additives. In addition, a description and more in-depth information on the various categories of chemical additives are presented within this study.

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CHAPTER 1

INTRODUCTION

More than one-half of North Dakota's 106,000 miles of road are gravel. A recent study identified that several counties in the state are experiencing or will experience a shortage of quality gravel (Hough, Smadi, and Schulz). Solutions may include importing quality gravel from surrounding states; however, the nearby states, including South Dakota and Montana, also are experiencing a shortage of quality aggregate. In addition, counties that import gravel will have to pay transportation costs for the product.[1] Paving is another option, but a benefit cost analysis may indicate that it is not feasible to pave the road. Use of chemical additives such as soil stabilizers and dust suppressants may be a viable method to address the gravel shortage. Use of chemical additives may reduce the loss of aggregate, therefore reducing the need for gravel applications. The use of chemical additives may be a cost effective approach counties can take to address the gravel shortage problems and also to possibly reduce gravel road maintenance. This study identifies several chemical additives available for local, county, and state use to combat the gravel shortage problem.

Information and attributes of each chemical identified for potential use in the Mountain Plain States are the basis of this report. Information for this report was collected from a literature review, manufacturer information, and survey results from road officials within six Mountain Plain States. This

[1] Transportation options are discussed in more detail in the MPC Report 96-65 by Hough, Smadi, and Schulz.

chapter will contain general background information on some of the benefits and reasons to use soil stabilizers and dust suppressants, the methodology used in this study, and organization of the report.

BACKGROUND

Nation-wide, counties spend approximately 31 percent of their budget on gravel road maintenance (*Better Roads*, 1992). Gravel road maintenance includes roadside maintenance, grading, ditching, snow and ice control, signing, dust control, rehabilitation/regrading, and other steps. Results of a study conducted by *Better Roads*, identified that more engineers called dust their most serious gravel road maintenance problem than any other. However, counties spend approximately only 8.5 percent of their time and 8.4 percent of their budget on dust control (*Better Roads*, 1992).

Dust control is a serious problem that impacts individuals and agricultural production. A 1973 Iowa State University study by Hoover identified that each car may generate one ton of fugitive dust per year from every mile traveled on an unpaved road. According to Hoover (1973), a car traveling 35 mph on a moderately dusty road generates the concentration of silt-sized particles equal to that of about 100 times the pollution concentration in the air of an industrial city. There are several risks involved with these airborne dust particles. First, they can obscure the vision of drivers, thereby leading to crashes and possible fatalities. Second, this dust can penetrate homes and contribute to allergies and hay fever. Third, the dust scattered can cover nearby crops and vegetation and at times stunt growth due to the shading effect and the clogging of plant pores (Hoover, 1973).

A study conducted by T.G. Sanders et al. at Colorado State University (1997) indicated the use of three dust suppressants studied (lignin derivatives, calcium, and magnesium chloride additives)

reduced fugitive dust emission by 50 to 70 percent on unpaved roadways. Results of control test sections revealed the dust suppressant sections resulted in total aggregate losses of 42-61 percent less than untreated roads. The estimated cost savings of using these dust suppressants were 30-46 percent over untreated roads (T.G. Sanders et al., 1997). Therefore, dust suppressants potentially may help reduce the need for additional aggregates and thereby address the gravel shortage in North Dakota. These chemical additives may assist county road officials to reduce maintenance on gravel roads and also reduce hazards to individuals traveling or living along the unpaved road.

METHODOLOGY

There are several potential dust suppressants and soil stabilizers, also referred to as chemical additives in this report, that are available for use on unpaved roads. Information for this study was collected from a literature review to identify types of chemical additives that previously have been studied, manufacturers' product listings, and a mail survey.

Survey Instrument Design

A survey was developed to identify chemical additives that county road engineers or road supervisors use on their road system. The survey was mailed to the road official for each of the counties in the Mountain Plain States including Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming. The survey contained questions regarding product use and effectiveness. County road officials were asked to list chemical additives they have used and answer several questions about each of the products, individually. Questions included average daily traffic levels of the road receiving the

chemical treatment, the form of the products applied, e.g., liquid, and how the produce was applied. Data also were collected regarding time of year the product was applied, application rate, and length of time the product was effective. Road officials were asked to rate the products ranging between good, fair, poor, or not considered for how well the product helped to control potholes, washboards, frost heave, how well the product increased soil strength, an overall product rating, and also the level of customer service the manufacturer provided.

Mailings

Local Technical Assistance Program (LTAP) administrators from each of the Mountain Plains States, with the exception of Montana, assisted in the mail survey procedure. The Montana Department of Transportation Secondary Road Official assisted in distributing surveys to the Montana county road officials. A total of 251 questionnaires were mailed to county engineers or county road supervisors. Table 1.1 illustrates the number of surveys mailed in each state and the number of questionnaires returned. Out of the 173 surveys returned (69 percent), only 57 surveys (23 percent) were useable. Several of the responses indicated that no chemical additives were used in the counties. However, most road officials did express an interest and request the survey results. Based on survey responses, more Montana counties use chemical additives than other counties in the Mountain-Plains states. Fourteen Montana counties indicated the use of soil stabilizers/dust suppressants for their roads whereas, only four counties in North Dakota indicated use of soil stabilizers (Table 1.1).

Table 1.1. Chemical Additive Usage Survey Responses from Mountain-Plains County Road Officials.

State	Number Mailed	Number Returned	Useable Surveys
Colorado	23	10	8
Montana	57	41	14
North Dakota	53	37	4
South Dakota	66	36	10
Utah	29	20	8
Wyoming	26	26	13
TOTAL	254	170	57

Manufacturer Information

Various manufacturing companies of dust suppressants and soil stabilizers were identified through the literature review and searches on the internet. Each identified manufacturer was contacted and asked to mail product information including application rate for the product, specifics on the proper application method, costs, and soil types for which the product would be effective. Appendix C contains detailed information obtained from the manufacturers.

REPORT ORGANIZATION

The remainder of this report is divided into three parts. Results of the questionnaire mailed to county road officials about their use of chemical additives as dust suppressants and soil stabilizers are presented in Chapter 2. A summary and conclusions are contained in Chapter 3. Finally, there are several appendices in this report, which include the following: a summary of the chemical additive

characteristics (Appendix A); detailed information related to the properties/qualities, effective soil types, special considerations, and past studies/reports of each chemical additive category (Appendix B); company product information (Appendix C); a complete listing of survey results (Appendix D), the chemical additive survey (Appendix E); program record keeping forms (Appendix F), and a glossary of terms (Appendix G).

CHAPTER 2

SURVEY RESULTS FOR CHEMICAL ADDITIVES ON UNPAVED ROADS

A variety of dust controlling and soil stabilization products currently are available on the market. Although their physical characteristics and chemical formulations may vary, most of these products can be classified into distinguishable categories including *chloride additives, clay additives, bituminous binders,* and *adhesives*. Some products exhibit characteristics and properties that do not fall under any of these categories or they may be similar to two or more of these categories; however, most products on the market fall under the previously listed categories. A summary of the chemical additive characteristics is located in Appendix A, while each category will be discussed in more detail in Appendix B. This chapter discusses some of the survey results, keys for success, and record keeping practices of dust control/soil stabilization programs.

SURVEY RESULTS

The survey contained several questions regarding the use of chemical additives. Not all of the results are contained in this chapter, however, additional survey results are shown in Appendix D. Several questions regarding chemical additive usage and effectiveness deserve further discussion. According to the survey results, 60 agencies, primarily located in the Mountain Plains States, use 90 chemical additives for dust control/soil stabilization (Table 2.1.). Therefore, several agencies use more than one product for their dust control/soil stabilization program. Most agencies that responded to the survey were counties in Mountain Plains States, however, some respondents were city officials in rural

areas located in the region and three respondents were from Michigan and Canada. Surveys were sent to these three locations because they either had many years of experience using chemical additives or they used some additives that currently were not being used by the surveyed states. The number of agencies that used chemical additives for dust control/soil stabilization ranged from 4 in North Dakota to 14 in Montana.

Table 2.1. Number of Agencies and Additives Currently Used by State.

State	Number of Agencies	Number of Additives Used
Montana	14	18
Wyoming	13	17
South Dakota	10	14
Colorado	8	17
Utah	8	12
North Dakota	4	6
Other*	3	6
Total	60	90

* 3 responses were obtained from Michigan and Canada using 5 products

Survey results determined that chlorides are the most widely used chemical additive in the Mountain Plains States (Table 2.2). Of the 90 chemical additives used for dust control/soil stabilization, 58 (64 percent) of those consisted of chloride additives. Seventy-six percent of the chloride additives consisted of magnesium chlorides while the remaining 24 percent were calcium chlorides. North Dakota was the only state that did not use chloride additives more than any other chemical additive category.

Clay Additives accounted for 16 of the 90 chemical additive usages. North Dakota used clay additives more than any other type of chemical additive, however, the usage was only based on four responses; only one specific brand of clay additive was applied. Chemical additive usage of the bituminous binders, adhesives, and water accounted for seven, five, and four responses, respectively. Although water normally is a common ingredient in chemical additive products, it is not a cost effective dust control/soil stabilization product by its self. Therefore, the responses pertaining to using water will not be discussed in this chapter, but they are in

Appendix D.

Magnesium chloride had a large number of survey responses, therefore, more reliable and accurate results can be obtained when analyzing the survey responses of this category. It is difficult to accurately assess effectiveness and experience of the other chemical additive categories due to the smaller number of survey responses. Therefore, Appendix B provides additional information regarding experiences and effectiveness ratings obtained from past reports/studies about each of the four chemical additive categories.

Table 2.2. Road Officials' Representation to the Chemical Additive Survey.

Category	Additives Used by Respondents							
	Total	CO	MT	ND	SD	UT	WY	Other[1]
Chloride Additives	58	11	13	2	10	8	12	2
Calcium Chloride	14	3	2	1	1	3	2	2
Magnesium Chloride	44	8	11	1	9	5	10	-
Clay Additives	16	-	1	4	2	3	3	2
Enzymes	5	-	1	-	-	3	1	-
Ionic	3	-	-	-	-	-	-	2

Other Clay Additive[2]	8	-	-	4	2	-	2	-
Bituminous	7	2	3	-	-	-	1	1
Adhesives	5	2	1	-	2	-	-	-

[1] Three responses were obtained from Michigan and Canada using five products.
[2] A proprietary product that is not classified as either an enzyme or ionic additive.

Duration of Effectiveness

An important characteristic of a dust control/soil stabilization product is its duration of providing effective control. The agencies were asked to select a range of months that most accurately describes the products effective duration, which included less than 3, 3-6, 6-12, and other (Table 2.3). Overall, most the chemical additives provided at least 3-6 months of dust control/soil stabilization effectiveness. The survey results also indicate that the magnesium chlorides, clay additives, and bituminous binders provide higher durations of effectiveness. In fact, some agencies stated that these products were effective for several years after the initial application.

Table 2.3. Chemical Additive Duration, by Months.

Category	# of	<3	3-6	6-12	Other*
		Percentage Response			
Chloride Additives	59	3	42	37	17
Calcium Chloride	14	0	71	21	7
Magnesium Chloride	45	4	33	42	20
Clay Additives	14	0	7	29	64
Enzymes	5	0	20	40	40
Ionic	2	0	0	0	100
Other Clay Additive	7	0	0	29	71
Bituminous	5	0	20	60	20
Adhesives	4	25	50	25	0

* See Appendix Table D-7 for further explanation.

Product Effectiveness

Respondents were asked to rate the chemical additives using several questions including potholes, washboards, frost heave, soil strength, and a question regarding the overall product rating

(Tables 2.4 - Table 2.6). The survey respondents could rate these questions as "Good," "Fair," "Poor," and "Not Considered." Most of the chemical additives were reported as being "Good" or "Fair" for pothole effectiveness. The additives that had the highest potholes effectiveness were ionic, enzyme, and magnesium chloride additives having "Good" or "Fair" effectiveness percentages of 100, 100, and 87, respectively (Table 2.4). The chemical additives that provided the lowest pothole effectiveness were bituminous binders and calcium chloride having "Good" or "Fair" effectiveness percentages of 72 and 50, respectively.

The effectiveness of chemical additives regarding washboards was similar to the pothole effectiveness. Ionic, enzyme, and magnesium chloride additives had "Good" or "Fair" effectiveness percentages of more than 90 percent (Table 2.4). More than 50 percent of the respondents reported that the remaining chemical additives exhibited at least a "Fair" effectiveness rating.

Table 2.4. Ratings of Chemical Additive Effectiveness, by Percentage Response.

Category	# of Responses	Potholes				Washboards			
		Good	Fair	Poor	NC	Good	Fair	Poor	NC
Chloride Additives	58	28	50	10	12	36	50	9	5
Calcium Chloride	14	21	29	7	43	21	50	7	21
Magnesium Chloride	44	30	57	11	2	41	50	9	0
Clay Additives	15	53	27	7	13	53	40	0	7
Enzymes	5	40	60	0	0	60	40	0	0
Ionic	3	100	0	0	0	100	0	0	0
Other Clay Additive	7	43	14	14	29	29	57	0	14
Bituminous	7	29	43	14	14	13	63	13	13
Adhesives	5	60	20	20	0	80	0	20	0

According to the survey results, frost heave effectiveness was not a major concern when using chemical additives (Table 2.5). Ionic additives were the only additives that did not report a significant number of responses for the "Not Considered" effectiveness response (Table 2.5). Two of the three respondents using ionic additives reported that it provided "Good" effectiveness for frost heave.

In general, soil strength is a more important attribute of soil stabilization programs rather than of dust control programs. The agencies that used clay additives reported positive soil strength experiences (Table 2.5). According to survey results, all of the ionic and enzyme additive users reported a 100 percent "Good" effectiveness soil strength rating. Bituminous binder users also reported positive soil strength effectiveness that had 86 percent "Good" or "Fair." Adhesives had mixed responses of "Good" and "Non Considered," while most of the agencies that used chloride additives reported "Fair" and "Not Considered" soil strength ratings (Table 2.5).

Table 2.5. Ratings of Chemical Additive Effectiveness, by Percentage Response.

Category	# of Responses	Frost Heave				Soil Strength			
		Good	Fair	Poor	NC	Good	Fair	Poor	NC
Chloride Additives	58	11	12	25	53	11	47	5	37
Calcium Chloride	14	14	14	29	43	0	50	14	36
Magnesium Chloride	44	9	12	23	56	14	47	2	37
Clay Additives	15	27	20	7	47	60	40	0	0
Enzymes	5	20	20	0	60	100	0	0	0
Ionic	3	67	0	33	0	100	0	0	0
Other Clay Additive	7	14	29	0	57	14	86	0	0
Bituminous	7	0	0	43	57	43	43	0	14
Adhesives	5	20	20	0	60	40	0	0	60

Respondents were asked to give an overall product rating for each of the chemical additives they have used. Each of the chemical additive categories had at least 80 percent "Good" or "Fair" overall effectiveness rating (Table 2.6). One hundred percent of the ionic additive and bituminous binder users reported a "Good" overall effectiveness.

Table 2.6. Overall Ratings of Chemical Additive Effectiveness, by Percentage Response.

Category	# of Responses	Overall Rating		
		Good	Fair	Poor
Chloride Additives	58	67	29	3
Calcium Chloride	14	57	29	14
Magnesium Chloride	44	70	30	0
Clay Additives	15	47	47	7
Enzymes	5	60	40	0
Ionic	3	100	0	0
Other Clay Additive	7	14	71	14
Bituminous	7	100	0	0
Adhesives	5	60	20	20
Water	3	33	0	67

Cost Effectiveness

Several survey questions also attempted to determine the costs and savings of dust control/soil stabilization programs. The survey requested the program's costs, which were divided into labor (equipment and employees) and product costs. A limited number of agencies responded to these two

questions and a large variance occurred in the responses that were given, therefore, no conclusions regarding the cost of such programs can be derived from the data (Table 2.7).

Table 2.7. Road Officials' Labor and Product Cost Information.

Category	Labor $/yd^2				Product $/yd			
	Resp. #	Min.	Ave.	Max.	Resp. #	Min.	Ave.	Max.
Chloride Additives	18	.01	.15	.62	22	.06	.25	.96
Calcium Chloride	9	.05	.19	.62	11	.04	.21	.45
Magnesium Chloride	13	.01	.13	.62	15	.06	.27	.96
Clay Additives	6	.03	.43	1.50	7	.020	.20	.50
Enzymes	5	.14	.20	.25	2	.13	34	.54
Ionic	1	1.50	1.50	1.50	N/A	N/A	N/A	N/A
Other Clay Additive	3	.03	.05	.08	4	.02	.21	.50
Bituminous	4	.05	.30	.77	4	.10	.26	.50
Adhesives	2	.15	.23	.30	4	.18	.37	.67

An attempt also was made to determine the cost savings of using chemical additives on road systems. Cost savings information for the dust control/soil stabilization programs included regraveling, patching, and blading. The savings in regraveling and blading are shown in Table 2.8, however, the savings in patching were not tabulated since only two agencies provide responses. Similar to the cost data, it is difficult to make any conclusions of the cost savings when using chemical additives since there were a small number of responses having a large range of values.

Table 2.8. Average Road Officials' Savings and Effectiveness by Percentage Response.

Category	Regraveling $/yd^2				Blading $/yd^2			
	Resp. #	Min.	Ave.	Max.	Resp. #	Min.	Ave.	Max.
Chloride Additives	7	.05	.45	1.50	8	.02	.18	.52
Calcium Chloride	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Magnesium Chloride	7	.05	.45	1.50	8	.02	.18	.52
Clay Additives	1	.30	.30	.30	3	.030	.67	1.83
Enzymes	N/A	N/A	N/A	N/A	1	.15	.15	.15
Ionic	N/A	N/A	N/A	N/A	1	1.83	1.83	1.83
Other Clay Additive	1	.30	.30	.30	1	.03	.03	.03
Bituminous	2	.10	.44	.78	2	.02	.92	1.83
Adhesives	1	1.5	1.5	1.5	1	.15	.15	.15

Respondents were asked if the specific chemical additives they used were cost effective from a maintenance perspective. According to survey results, all of the chemical additive categories received a positive cost effectiveness rating. Eighty-one percent of the agencies that used chloride additives reported that they were cost effective from a maintenance perspective. Eighty-six percent of the magnesium chloride users reported that the product was cost effective in dust control/soil stabilization, where as 67 percent of the calcium chloride users reported it was cost effective from a maintenance perspective (Table 2.9).

Sixty-seven percent of the road officials indicated that clay additives as a whole were cost effective, however, this occurred because of the respondents' poor evaluation of the other clay additive category, a product that primarily consists of surfactants and tri-silicants (Table 2.9). This small sample size and the use of only one type of product makes it difficult to make any conclusions on this

additive category. It should be noted, that all of the agencies using the remaining types of clay additive products (ionic and enzyme additives) reported that these products were cost effective.

Respondents using bituminous binders and adhesive additives also reported that these products were cost effective from a maintenance perspective. One hundred percent of the bituminous binder users reported that the products were cost effective, while 60 percent of the adhesive additive users state the products were cost effective (Table 2.9).

Table 2.9. Road Officials' Cost Effectiveness Information.

Category	Cost Effective		
	Resp. #	Yes	No
Chloride Additives	54	81	19
Calcium Chloride	12	67	33
Magnesium Chloride	42	86	14
Clay Additives	12	67	33
Enzymes	5	100	0
Ionic	2	100	0
Other Clay Additive	5	20	80
Bituminous Binders	6	100	0
Adhesives	5	60	40

KEYS FOR SUCCESS

Although agencies may be tempted to select an additive based on the lowest initial cost and the ease of application, these two characteristics may not be the most economical in the long run. Successful dust control/soil stabilization programs are achieved by first selecting the appropriate chemical additive based on the soil type, climate, etc. The most important step is to apply the chemical

with the correct and consistent application methods. Other factors also will be discussed that may influence the success of using a specific product or achieving a successful and cost effectiveness program.

Soil Analysis

Before selecting a dust control/soil stabilization product, it is important to evaluate the soil on the road surface. Some product manufacturers and/or distributors produce or sell several different types of chemical additives, and they will recommend a product that will achieve the best results for specific soil types within a region. Soil commonly is classified under the Unified Classification System (UCS) or the American Association of State Highway and Transportation Officials (AASHTO) Classification System. These systems determine the grain size distribution of soil particles and cohesive nature of the fine sized particles. Most product manufacturers recommend certain soil requirements to achieve effective results with their product. They may require a specific type of soil based on a classification system or they may require the soil to have certain percentages of soil particles, i.e., a percentage of soil particles passing a No. 200 sieve or a soil that has a specific plasticity index (PI) value or range of values. Soil tests can be performed by the agency or samples can be sent to the product manufacture for evaluation. In fact, some manufacturer's require potential users to send a soil sample to the company so they can perform tests on the soil. These tests determine how the soil sample reacts with the product. If a negative reaction occurs, the manufacturer will advise the agency not to use the product.

Based on survey results, few of the agencies perform soil tests prior to additive selection. In fact, only 4 of the 60 agencies, or approximately 7 percent, performed soil tests. All agencies that

performed soil tests reported a “Good” overall effectiveness and they were cost effective from a maintenance perspective.

Methods of Application

Proper application procedures also are important to insure a successful dust control/soil stabilization program. Product manufacturers and distributors recommend specific application methods for using their product or products. Some companies provide consultants that will aid in the application process, while other companies attempt to insure consistent success by applying their products using their own personnel, equipment, and application methods. Application methods generally include the following:

- ✓ Scarify the road surface to a recommended depth
- ✓ Dilute the product with water to achieve the proper dilution ratio
- ✓ Apply the correct amount of product for a specific amount of soil
- ✓ Mix the solution and loose soil and crown the road surface
- ✓ Compact the road surface using various types of compacting equipment

The application methods listed above are generic in nature and vary from product to product, however, insuring a proper crown on the road surface is an important step in the application process of any product. Generally a type "A" crown is recommended for gravel roads. A type "A" crown incorporates one-half inch drop for every foot from the center line (Figure 2.1). A proper crown will limit the amount of water that may infiltrate the surface, therefore, causing less product to be leached further into the soil. A proper crown also limits the amount of product that may be carried off the road surface. This phenomenon primarily occurs to water soluble products since they dissolve in the water and are carried off the road surface. A proper crown also reduces puddles on the road, which cause soft spots.

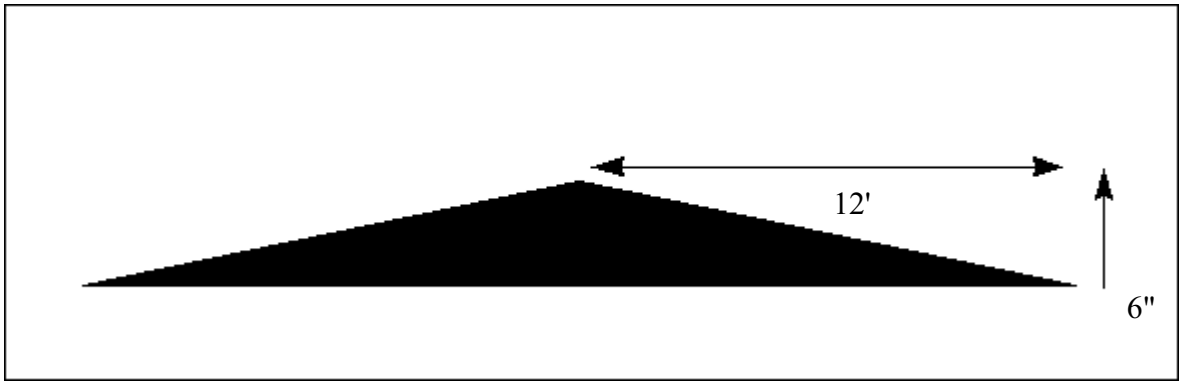


Figure 2.1. "A" Crown

Other Factors

Analyzing the soil and performing proper application methods are two important components of successful dust control/soil stabilization programs, however, special considerations must also be given to the climate of the area and the traffic volumes on the roadway. It also is important to consider possible hazards that may damage application equipment, vehicles, and motor vehicles due to the nature of the chemical additive, such as being acidic. Plant vegetation and ground water contamination also may occur, therefore, proper application methods must be performed to reduce or eliminate this problem. For the most part, chemical additives for dust control/soil stabilization are environmentally safe or hazardous effects are only evident during the application process.

RECORD KEEPING

Detailed and accurate record keeping is necessary to evaluate a dust control/soil stabilization program. The agency must record information including when and where the product was applied, the amount of product applied, product costs, and labor and equipment costs. The costs of blading,

regraveling, and patching should be recorded before and after implementing a dust control/soil stabilization program. This allows agencies to compare road maintenance costs and will enable them to determine the effectiveness of the chemical additive.

Appendix E contains two sample forms: 1) application record keeping, and 2) a form to record program benefits.

Benefits from using chemical additives can be classified as tangible and intangible. Tangible benefits are probably the more obvious benefits of a dust control/soil stabilization program and include reduced blading, regraveling, and patching. Although it is hard to place a monetary value on intangible benefits, these benefits provide valuable feedback regarding a chemical additive's effectiveness. Intangible benefits include reductions in vehicle accidents, vehicle damage, and complaints from the public. Using these forms will allow agencies to accurately evaluate their dust control/soil stabilization programs.

According to survey results, most of the agencies that use chemical additives did not have detailed cost information. As preciously mentioned, some of the agencies had cost information pertaining to product and labor, however, cost data related to savings in blading, regraveling, and patching was limited.

CHAPTER 3

CONCLUSIONS

Dust control/soil stabilization programs that use chemical additives exhibit several benefits. The applications of chemical additives assist in creating a dense, dust-free road surface; therefore, road maintenance including blading, regraveling, and patching are greatly reduced. The reductions in road maintenance equate to savings in gravel, labor, and equipment costs. Many intangible benefits also can be noted by implementing dust control/soil stabilization programs. Some of these benefits include reductions in vehicle accidents, vehicle maintenance, airborne pollution, and public complaints due to poor road conditions and dust.

According to the survey developed for this study, 60 agencies, mainly within the Mountain Plains States, used 90 chemical additives for dust control/soil stabilization. The chloride additives were the most widely used (64 percent of the respondents), while the clay additives, bituminous binders, and adhesives were used by 18, 8, and 6 percent of the respondents, respectfully. The survey also determined that most of the agencies that used chemical additives stated that they had success using the products. Each of the four chemical additive categories displayed favorable performance ratings ranging from 80 percent ("Fair" to "Good") to 100 percent ("Good").

Another important issue related to chemical additives was related to cost effectiveness. The survey respondents were asked if application of chemical additives was cost effective from a maintenance perspective. Based on survey results, the chemical additive categories were reported to have a cost effectiveness ranging from 60 to100 percent.

RECOMMENDATIONS

A successful dust control/soil stabilization program should incorporate a soil analysis to determine the appropriate chemical additive for application, perform the proper application procedures once a product has been selected, and carry out detailed and accurate record keeping to determine if the product is cost effective from a maintenance perspective. These practices should help create a more effective or successful dust control/soil stabilization program. If problems or shortfalls occur, accurate record keeping may provide insight to determine the cause of poor performance, such as errors in application process or a breakdown in the chemical additive.

LIMITATIONS

It is important to note that some of the chemical additive categories identified in the study did not report a high usage in the region. The chloride and clay additives were used by many agencies, however, the bituminous binders and adhesives were not used to such a high extent. Therefore, questions related to the chlorides and clay additives may be more accurate or representative for the Mountain Plain States.

NEED FOR FURTHER STUDY

Gravel shortage continues to be a problem in many states, therefore, road officials must determine innovative methods to reduce gravel use, such as applying chemical additives. Many chemical additives exist on the market for dust control/soil stabilization and are used throughout the country. However, except for magnesium chloride, little information is known about effectiveness of

other products in the region. Test sites could be established to evaluate different categories of chemical additives on various types of soils, traffic etc. Another method to reduce gravel road maintenance costs, which was not discussed in this report, is to evaluate the use of recycled pavement on unpaved roads to improve soil stabilization.

APPENDIX A
SUMMARY OF CHEMICAL ADDITIVE CHARACTERISTICS

CHLORIDE ADDITIVES				
Product	**Attributes**	**Limitations**	**Soil Types**	**Sources**
Calcium Chloride	• Starts to absorb water from air at 29% relative humidity (77°F). • Reduces rate of evaporation 3.4 times. (vapor pressure of saturated solution at 77°F is 7 mm Hg). Note: the lower the vapor pressure, the greater the ability to resist evaporation. • Significantly increases surface tension of water film between particles, helping to slow evaporation and further tighten compacted soil as drying progresses. • Lowers freezing point of water solution to -60°F, minimizing frost heave (30% solution). Freezing of a treated road not only begins at lower temperature, but also is gradual and seldom complete. • Treated road can be regraded and recompacted with less concern for losing moisture and density.	• Slightly corrosive to steel and highly corrosive to aluminum and its alloys; attracts moisture, thereby prolonging active period for corrosion. • Rainwater tends to infiltrate and leach out highly soluble chlorides, but if the road has proper crown, most water is deflected sideways into ditches. • During dry periods, upward capillary action may cause chlorides to crystallize near the road surface, where they can be leached away by sudden rain. • Low cementing action. • Exothermic; releases heat as it dissolves, enough to be a safety hazard to workers mixing the dry form in water. • Do not apply the product if rain is likely to occur within 24 hours; rainfall will create a slick surface. • Spills of concentrate may kill or burn vegetation so reasonable care in handling required. • Quickly cleanup spills to prevent slick spots.	• Most effective when used on well-graded road surfaces. • Some manufacturers recommend a certain amount of fines in the soil ranging from 3-25% passing #200 sieve.	• Consists of by-product brine from manufacture of sodium carbonate by ammonia-soda process and of bromine from natural brines. • Three forms: Flake or Type I: (77 to 80% conc, 100# bags). Pellet or Type II: (94 to 97% conc. 80# bags). Clear liquid (32/35/38% conc., tankers). • Some brand names: LIQUIDOW, DOWFLAKE, SURPERFLAKE, ROADMASTER, IPC 1185, PELADOW

Magnesium Chloride	● Starts to absorb water from air at 32% relative humidity (77°F). ● Reduces rate of evaporation 3.1 times (vapor pressure of saturated solution at 77°F is 7.6 mm Hg). ● More effective than calcium chloride solutions for increasing surface tension, resulting in a hard road surface. ● Lowers freezing point of water solution to -27°F (22% solution). Freezing of treated road not only begins at lower temperature, but also is gradual and seldom complete. ● Treated road can be regraded and recompacted with less concern for losing moisture and density.	● In concentrated solutions, very corrosive to steel; attracts moisture, thereby prolonging active period of corrosion. Some products contain corrosion-inhibiting additive. ● Rainwater tends to infiltrate and leach out highly soluble chlorides, but if road has proper crown, most water is deflected sideways into ditches. ● During dry periods, upward capillary action may cause chlorides to crystalize near road surface, where they can be leached away by sudden rain. ● Low cementing action. ● Do not apply the product if rain is likely to occur within 24 hours; rainfall will create a slick surface. ● Spills of concentrate may kill or burn vegetation so reasonable care in handling required.. ● Spills must be cleaned quickly to prevent slick spots.	● Most effective when used on well-graded road surfaces. ● Some manufacturers recommend a certain amount of fines in the soil ranging from 3-25% passing #200 sieve.	●

Source: Colorado Transportation Information Center, Bulletin #3, *Road Dust Suppressants*, Dept. of Civil Engineering, Colorado State University, Fort Collins CO, 1989, and various chemical additive product information.

CHLORIDE ADDITIVES (Continued)				
Product	**Attributes**	**Limitations**	**Soil Types**	**Sources**
Sodium Chloride	● Starts to absorb water from air at 76 % relative humidity (77°F). ● Reduces rate of evaporation 1.3 times (vapor pressure of saturated solution at 77°F is 18 mm Hg). ● Increase surface tension slightly less than calcium chloride. ● Lowers freezing point of water solution to -6°F (25% solution). ● When mixed into road base, effectively improves mechanical stability.	● Moderately corrosive to steel in diluted solutions; attracts moisture, thereby prolonging active period for corrosion. ● As it becomes diluted or leaches out, disperses clay which shrinks on drying and becomes more susceptible to blowing. ● If over applied, may pose a threat to plant and animal life, as well as possible ground water contamination. ● Not an effective dustproofer; thus typically used to stabilize road base and topped with calcium chloride to control dust.	● Most effective when used on well-graded road surfaces.	● Occurs naturally as rock salt (mined mechanically or hydraulically) and brines (refined or evaporated). ● Some brand names: MORTON SALT, DIAMOND SALT
Calcium Chloride and Sodium Chloride Mix	● Combines stabilizing action of sodium chloride with dust control of calcium chloride ● Compared to calcium chloride alone, reduces cost 20% while losing less than 5% dust control.	● Same limitations as for these salts used individually.	● Most effective when used on well-graded road surfaces.	● Salts mixed before applying equal parts by weight of CC-grade rock or evaporated salt with flake calcium chloride (if pellet, use 100# salt/80# pellet). No premixed solutions.
CLAY ADDITIVES				
Ionic	● Chemically react with clay minerals in the soil to produce a material that excludes water from the clay lattice. ● Compaction can now occur and results in a stabilized road surface. ● Creates a water resistant layer around the clay particles which limits the swelling potential of the clay mineral.	● Since most of these products consist of strong acids, safety equipment will be needed during the application process. ● Once the product is applied, however, there is no concern about it leaching away and harming the environment.	● Effective with soils that have cohesive fines (clay). The amount may range from 10% to at least 20%. ● Some products may not work well in organic soils or if soil has more than 40% sand.	● Consist of strong oxidizing agents (acid) and may be combined with dispersing agents, solvents, and resins. ● Some brand names: BASE ONE, CBR PLUS, ROADBOND EN1, CLAYPACK
Enzymes	● Used to accelerate cohesive binding of the soil particles. ● Allow larger organic molecules to attach to the clay lattice which presents any further water to be adsorbed. ● Compaction near optimum moisture content will create a dense surface.	● May cause eye and skin irritation, therefore safety equipment should be worn during application. ● However, these products generally are non-toxic and environmentally safe.	● Effective with soils that have cohesive fines. The amount needed varies with different products.	● Primarily consist of a compaction enzyme and a dispersion agent. ● Some brand names: PERMAZYME 11X, EMC SQUARED, PACZYME, ENZYMATIC SS

Lime Derivatives	• Create cementitious properties that bind soil particles together. • One of the oldest methods of stabilization.	• Engineering tests should be conducted to determine how the additives react with the soil.	• Effective with a variety of soil types (sand, gravel, crushed stone, and clay).	• Consists of various mixtures that use lime as the main active ingredient.

Source: Colorado Transportation Information Center, Bulletin #3, *Road Dust Suppressants*, Dept. of Civil Engineering Colorado State University, Fort Collins CO, 1989, and various chemical additive product information.

BITUMINOUS BINDERS				
Product	**Attributes**	**Limitations**	**Soil Types**	**Sources**
Petroleum Resins and Modified Asphalt Emulsions	• Binds soil particles together because of their adhesive properties resulting in a dense road surface. • Creates a water-resistant road surface.	• Under dry conditions, some products may not maintain resilience; can form a crust and fragment under traffic loads. • Waste oil subject to state regulations for handling and disposing of hazardous substances. • Road closure may be needed to allow product penetration.	• Effective on a variety of soil types including soils that have a high percentage of sand, silt, and clay along with well-graded soils.	• Bitumens (residues form crude oil) that may be combined with dispersing agents, catalysts, etc. • Some brand names: • COHEREX, CONSOLID, PENNZSUPPRESS D, PETRO TAC, ENVIRO-ADL-200
ADHESIVES				
Organic Non-Bituminous	• Binds soil particles together to form a hard crust on the road surface. • During rain, disperses clay, which in turn swells and plugs pores, reducing water penetration. • Creates a water resistant surface • Tends to remain slightly plastic, permitting reshaping and additional traffic compaction. • Most products are environmentally safe, biodegradable, and non-corrosive	• Material pickup may occur for some products immediately after application; therefore, road closure or reduced speeds may be necessary. • May exhibit corrosive effects to aluminum and its alloys; however, some products contain additives that neutralize this effect. • The binding capability may be reduced by excessive heavy rain or dry periods because the product is biodegradable. • Road closure may be needed to allow product penetration.	• Most effective on soils that have approximately 15% clay; however, positive results have occurred with a variety of soil types.	• Consists of by-products of lumber and soybean industries. • Some brand names: DUSTAC, DUSTBLOC 315 (lignins); DUSTROL EX, ENDURASEAL 100, ENDURASEAL 200, PINE SAP EMULSION, ROAD OYL (tree resins); SOAPSTOCK (soybean oil)
Polymers	• Dispersion agents allow the product to penetrate the surface while the polymers undergo a chemical reaction between the soil partides. • Chemical reaction creates a cementitious effect that achieves a dense water resistant road.	• Undiluted products can cause headache and nausea in unventilated areas. • May cause eye and skin irritation, therefore safety equipment should be used during application • Concentrated spills should be contained and recovered. • Overall, these products are non-toxic to humans and non-corrosive to metals.	• Effective in a variety of soil types.	• Consists of by-products of the adhesive and paint industries • Some brand names: SOIL-SEMENT, POLYMER/ENZYME, EMS, MARLOC

WATER			
Water	• Poses no threat to the environment. • Normally, readily available.	• Evaporates readily, controlling dust generally for less than a day. • Costs more than other inorganic chemical suppressants because of repeated application needed to achieve same level of control (labor intensive).	• Used on a variety of soil types.

Source: Colorado Transportation Information Center, Bulletin #3, *Road Dust Suppressants*, Dept. of Civil Engineering Colorado State University, Fort Collins CO, 1989 and various chemical additive product information.

APPENDIX B
CHEMICAL ADDITIVE INFORMATION

CHEMICAL ADDITIVE CATEGORIES FOR UNPAVED ROAD SYSTEMS

As previously discussed, typical chemical additive categories for dust control/soil stabilization programs include *chloride additives*, *clay additives*, *bituminous binders*, and *adhesives*. Information related to the properties/qualities, effective soil types, special considerations, and past studies/reports of each category will be discussed in the following sections.

CHLORIDE ADDITIVES

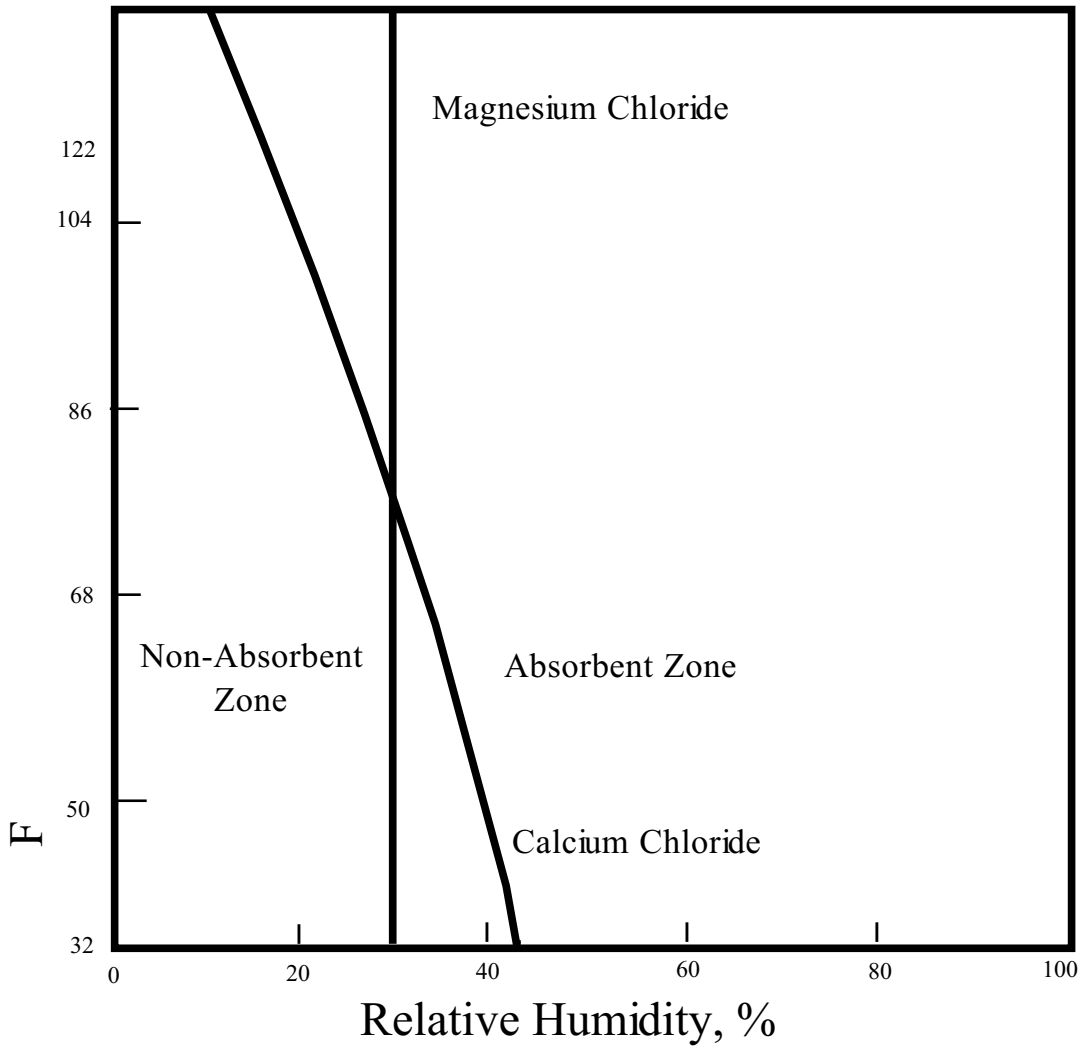
Properties/Qualitites _

A chloride is a compound combining an element of chlorine and another element. Chlorides, which are used for road systems, generally consist of calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), sodium chloride (NaCl), and natural brines that contain chloride salts. These compounds can be mixed with other various elements, compounds, and ingredients, such as anti-corrosive agents, and are applied in either a liquid or solid state. Chlorides are well suited for dust abatement because they reduce the effort needed to maintain a moist road surface, and the effort needed for compaction for better soil stabilization.

Calcium chloride is a by-product from the ammonia-soda process during the production of sodium carbonate and also is found in natural brines. Magnesium chloride is a by-product brine from potash production, and occurs in natural brines. Sodium chloride, known as table salt, occurs naturally as the mineral halite (rock salt), and takes place in both refined and natural brines (Lowenheim and Moran, 1975). Sodium chloride is typically used in de-icing paved

roadways in northern climates, but it generally is not used in dust control/soil stabilization programs.

Chlorides, primarily $MgCl_2$ and $CaCl_2$, display both hygroscopic and deliquescent properties. Hygroscopic means the product draws moisture from the air to keep the road surface moist. Deliquescent describes the tendency to resist evaporation to maintain in a liquid state. These two properties help hold the fines to the road surface and keep a dense roadway. As shown in Figure 3.1, calcium chloride starts to absorb water from the atmosphere at 29 percent relative humidity (77° F), while decreasing the rate of evaporation by 3.4 times. Magnesium chloride starts to absorb water at 32 percent (77° F) relative humidit, and decreases evaporation by 3.1 times. Sodium chloride is not as effective in attracting or retaining moisture since the relative humidity must be greater than 75 percent (77° F), and decreases evaporation by only 1.3 times (Colorado Transportation Information Center, 1989). The amount of water absorbed by chlorides can be significant. For example, at 75 percent relative humidity and 77° F, calcium chloride absorbs more than two times its own weight (Nebraska T^2 Interchange, 1955).



Appendix Figure B-1. Absorption zone as it relates to relative humidity and temperature for calcium chloride and magnesium chloride.
Source: UMA Engineering Ltd. "Guidelines for Cost Effective Use and Application of Dust Palliatives," Roads and Transportation Association of Canada, Ottawa, Canada, 1987, pp. 14.

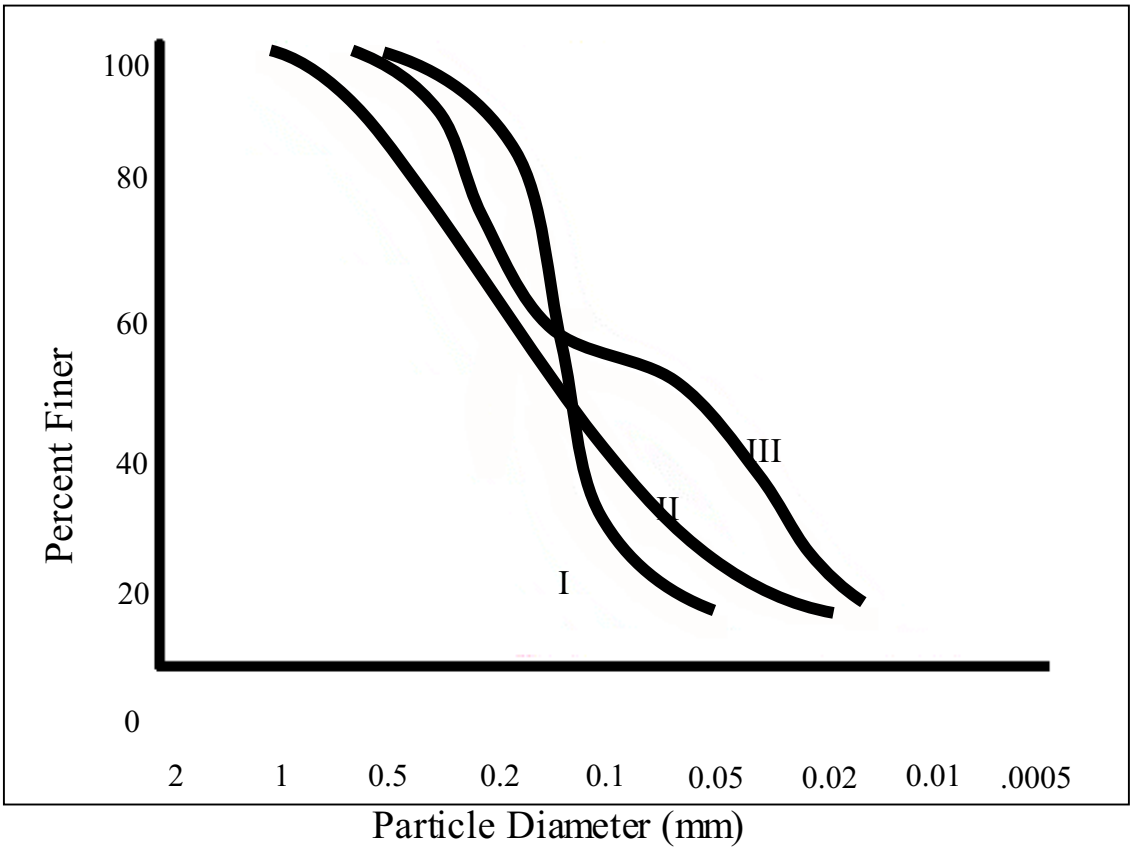
Chlorides also decrease the freezing point of aqueous solutions with respect to their concentrations. This property is more evident in $CaCl_2$ and $MgCl_2$, rather than NaCl. A water solution containing 30 percent $CaCl_2$, 22 percent $MgCl_2$, and 25 percent NaCl will lower the solution's freezing point to -60° F, -27° F, and -6° F, respectively (Woods, 1960). The freezing of a chloride-treated road not only occurs at a lower temperature, but is gradual and seldom complete; therefore, they minimize frost heave and they reduce freeze-thaw cycles (Colorado Transportation Information Center, 1989). Frost heave occurs when water in the soil pores freezes. When water freezes, its volume increases about 10 percent (Garber and Hoel, 1997). Due to increase in volume, pressure is created in the soil, which may cause some road sections to heave or expand out of the road surface. This natural phenomenon can inflict major structural damage to construction projects, such as road systems.

Chloride products consist of three basic types: liquid, flake, and pellet. The liquid solution normally contains 32-38 percent solid product dissolved in water. Flakes are solid in form, and generally are 77-80 percent pure. Pellets also are in a solid state, and are 90-93 percent pure. Liquid solutions are used in dust control and soil stabilization applications, while flakes and pellets normally are used only in dust control applications.

Recommended Soil Types

Chlorides work most effectively on road surfaces that consist of well-graded soils, and can be applied using either topical or mixed-in-place methods. A well-graded soil has particle sizes of a wide range (Figure 3.2). Since chlorides aid in the retaining of moisture, they allow soil "fines" to remain on

the road surface. This characteristic helps maintain a dense road surface, which will be less susceptible to potholes, washboards, rutting, etc.



Appendix Figure B-2. Various particle-size distribution curves.
Source: Das, Braja M. *Principles of Geotechnical Engineering*, 3rd edition, 1994, pp. 24.

Curve I illustrates a soil that consists of soil particles that are the same size. It commonly is known as poorly graded soil. Curve II illustrates a soil that has soil particles over a wide range of sizes, which is referred to as well-graded soil. Curve III illustrates a soil that has a

wider range of particle sizes than poorly graded soils, however, some particle sizes are not represented. This soil can be described as gap graded (Das, 1994).

Special Considerations

Chloride products have many attributes; however, they do display some negative features. Some safety issues must be considered before applying chloride products. These products may cause ground water contamination, and also may be toxic to some plants. If the water table is within 25 feet of the road surface, chloride products should not be used because increased chloride concentrations may cause ground water contamination (Cargill, Inc.). Chlorides are most toxic to maple, hemfir, birch, and some pines; therefore, these species should be planted at least 30 feet from the road to limit these negative effects (Better Roads, 1991). The amount of chloride concentration in the ground or surface water varies with: 1) the amount of product applied, 2) the amount and intensity of precipitation, 3) the soil type, and 4) the drainage characteristics of the road surface (Pollock and Toler, 1973). Safety equipment is recommended for the workers during application since chlorides may cause eye and skin irritation.

Chlorides also can exhibit corrosive effects to steel and aluminum alloys; however, some products contain anti-corrosive additives that can greatly reduce these corrosive effects. One manufacture even claims that their product is approximately 20 percent less corrosive than tap water (Cargill, Inc.). If the road surface is not crowned properly, rainfall may penetrate the road surface causing the highly soluble chloride to leach out of the soil. During dry periods, the chlorides rise near the surface due to capillary action and crystallize. If heavy rain occurs, the chlorides may be leached away. Therefore, periodic spraying of roads can reduce this effect during dry periods.

Past Studies/Reports

Chloride additives have been used for dust control/soil stabilization for the last century. Several studies and reports show that chloride additives have been used extensively throughout the Midwest, and most agencies have had good results. A report conducted by Braun Intertec Pavement, Inc. for the Minnesota Department of Transportation summarizes results of a dust control survey given to Minnesota county and city agencies. The survey showed that 86 percent of the 83 respondents, who applied dust controlling additives, used chloride additives. The study also reported that most of these agencies were satisfied with the products effectiveness (Chunhua, 1992).

Chloride additives also have been used by the U.S. Department of Agriculture (USDA) - Forest Service. A report sponsored by the USDA discussed several studies and products that have been used by the Forest Service in the Pacific Northwest. One study from this report occurred in the Lolo National Forest, which is located in western Montana. The 1992 study evaluated eight dust controlling products with a control section. It concluded that magnesium chloride outperformed the other products and had one of the lowest costs (Bolander, 1997).

Another study, which was conducted in Colorado during 1993-1994, concluded that chloride additives were effective in reducing the amount of aggregate loss. When compared to the untreated test section, calcium chloride and magnesium chloride treated sections reduced the amount of aggregate loss by 43 and 60 percent, respectively (Sanders et. al., 1997).

As previously discussed in Chapter 2 of this study, 64 percent of the 90 product respondents used chloride additives. As a whole, 96 percent of the chloride users reported an overall product rating

of either "Good" or "Fair," while 86 percent of the magnesium chloride users and 67 percent of the calcium chloride users stated these products were cost effective from a maintenance perspective.

CLAY ADDITIVES

Clay additives consist of products that chemically react with clay minerals in the soil. The chemical reaction binds the cohesive fines (clay minerals) together creating a dense mixture that excludes water from the clay lattice; therefore, the damage caused by freeze/thaw cycles is limited. Clay additives can be classified into three main types: ionic exchange additives, enzyme additives, and lime derivatives. These three types vary in chemical composition and properties, but all react with the clay minerals in a similar manner.

Ionic Exchange Additives

Properties/Qualities

Ionic exchange additives are products that primarily consist of strong oxidizing agents (acid), but often are combined with other ingredients such as dispersing agents, solvents, and resins. These products chemically react with the clay minerals in the soil to produce a mixture that excludes water from the clay lattice. Clay minerals generally are microscopic flaked-shaped particles consisting of mica, clay minerals, and various other minerals (Das, 1994). Clays can be defined as particles that become plastic when mixed with water (Grim, 1953). Plasticity is the capability to become molded or putty-like, and it is related to the amount of clay mineral in the soil.

Clay minerals consist of complex aluminum silicates which can combine into silica or octahedral sheets. Different combinations and arrangements of these sheets result in clay minerals such as Kaolinite, Illite, Montmorillonite, etc. The surfaces of clay particles carry a net negative charge; therefore, these particles are attracted to positively charged ions or cations (Das, 1994). In dry clay, cations such as Ca^{+2}, Mg^{+2}, Na^{+1}, and K^{+1} surround the clay particles to balance the negative charge. When water is combined to the clay, these cations and a few anions are suspended around the clay particles (Das, 1994). This layer of water is referred to as a diffuse double layer.

Water is considered to be a dipole — two equal and opposite electric charges that are separate by a small distance. The two hydrogen atoms of a water molecule are bonded at angles of 105 degrees from each other on the oxygen atom. This occurrence creates a negative charge on one side of the molecule and a positive charge on the other side. Dipolar water is attracted to the negative charge of the clay particles and the positive charge of the ions suspended in the double layer. All of the water attracted to the clay particles by electrostatic forces is known as double-layer water. The innermost coating of this double-layer water is called adsorbed water, and it is held firm by clay particles (Das, 1994).

Some clays, such as Montmorillonite, have spaces between the silica sheets, which allow the clay particles to absorb water causing them to expand. As the clay expands, they create a large amount of pressure that causes the soil to shift. This expansive nature can cause failures to occur in foundations of buildings and road systems (Louw, 1992).

Ionic exchange additives expel or prevent the absorption of water by adding smaller, powerful, positive molecules to balance the negative charge on clay particles. The positive molecules of the

additives disassociate and replace the larger and weaker cations, such as sodium and water. Compaction can now occur with minimal effort and results in a stabilized road surface.

Ionic additives also contain ingredients that create a hydrophobic (water resistant) layer around the clay particles. This layer permits water to travel through small capillaries between the soil particles without being attracted to the clay particles.

Effective Soil Types

Ionic additives require cohesive fines for effective binding to occur. This required amount of clay fines varies depending on the product; however, they can range from 10 percent to at least 20 percent. Some products may not work well in organic material or if the soil consists of 40 percent or more sand. Certain manufacturers request soil samples from potential customers to determine if the soil will positively react with their product.

Special Considerations

Only one major special consideration exists with ionic exchange additives. This concern deals with the application process. Since most of these products contain strong acids, safety equipment must be used by the workforce. Because the products create a permanent reaction with the soil, there is no concern about the product leaching out of the soil and harming the environment.

Enzymes

Properties/Qualities

Enzyme formulations are solutions that primarily consist of a compaction enzyme and a 47 dispersing agent. An enzyme is made up of complex proteins that act as an organic catalyst, which rapidly completes the process of a chemical reaction. Enzymes are used to accelerate cohesive binding of the soil particles. Use of the dispersing agent in the formulation is to allow enzymes to penetrate the road surface more effectively.

One example, the formation of shale from the compaction of clays and silts, explains how the enzymes work. Shale is formed from the settlement of sediments and on the ocean floor. Overlying material compresses sediments and expels most of the water in the material, which creates the rock formation known as shale. The process of creating shale takes millions of years to occur; however, enzyme formulations attempt to drastically reduce this time to days or even hours to achieve similar results. The enzymes allow larger organic molecules to attach to the clay lattice, which prevents any further water to be adsorbed. Compaction near optimum moisture content (OMC) will create a dense surface. The resulting surface resists water penetration, vehicle wear, and weathering.

Effective Soil Types

Enzymes work with soils that contain cohesive fines. The amount of cohesive fines may vary with different products. According to the product information received from manufacturers, one manufacturer recommends using their product on a soil that contains 18-30 percent cohesive fines. Another manufacture recommends a soil that has a plasticity index (PI) of eight or greater.

Special Considerations

Enzymes exhibit few safety concerns. In general, these products are non-toxic and are environmentally safe; however, enzymes may cause eye and skin irritation during the application process. Therefore, safety equipment such as goggles and rubber gloves should be used. If a spill occurs, dilute the product with water to eliminate pooling and to reduce the slippery nature of the product.

Lime Derivatives

Properties/Qualities

Lime derivatives are comprised of various mixtures that use lime (CaO) as the main active ingredient. Soil stabilization can occur when using lime (quicklime) by itself, while other products, such as pozzolans and portland cement, combine lime with various other chemical formulations. These additives create cementitious properties that bind soil particles together to create a dense road surface.

Lime is one of the oldest products that has been used to stabilize soil. Lime is produced by burning calcitic or dolomitic limestone at high temperatures. The resulting product generally consists of calcium and magnesium oxides and hydroxides; however, the most commonly used compounds for lime stabilization are calcium hydroxide [$Ca(OH)_2$], and dolomite, [$Ca(OH)_2 + MgO$]. When lime is added to the soil, a cationic exchange takes place that decreases the tendency of clay to expand. Lime is an essential component of fly ash and portland cement (common types of pozzolans), since it behaves like an activator in the cementing reaction (Garber and Hoel, 1997).

Pozzolans can be defined as finely divided particles consisting of siliceous or siliceous and aluminous material, which in the presence of water, chemically react with calcium hydroxide (lime) to

form a cementitious compound. Pozzolans were main components of the first hydraulic cement that was used some 2,000 years ago by the Greeks and Romans. Pozzolanic reactions occur when lime is combined with fine grained soils, such as clay minerals, quartz, and feldspars, since they may consist of silica and alumina; however, lime stabilization is most effective in clayey soils (Garber and Hoel, 1997).

Fly ash is a common pozzolan that has been used in soil stabilization. Fly ash is a by-product from coal-fired power plants, and is mainly composed of siliceous and aluminous materials, as well as lime. Two types of fly ash exist, Class F and Class C. The major difference between the two types is that Class C fly ash contains approximately twice as much lime as Class F fly ash. Class F fly ash does not have enough lime to create the pozzolanic reaction; therefore, additional lime will be needed if it is used in road stabilization. Fly ash works on a variety of soils including sands, gravel, and crushed stones; however, since this category draws moisture from the soil, it exhibits positive results with soils having higher quantities of clay.

Portland Cement is produced by pulverizing and burning specific quantities of selected raw materials where the end product, portland cement, is primarily made up of lime (CaO) and silica (SiO_2). The binding property of portland cement occurs from the chemical reaction between the cement and water, commonly known as hydration. According to the Portland Cement Association, cement can stabilize nearly all types of soil (Soil Cement Laboratory Handbook, 1971).

Other clay additives can consist of a variety concentrations and mixtures. Some additives are used individually or they may be combined with two or more other products to obtain positive results. For example, fly ash may be added to cement to achieve a stronger strength concrete at a lower price.

Another example is that lime may be added to fly ash, especially Class F, because it normally does not have enough lime to be self cementing.

Past Studies/Reports

Several studies have been conducted to determine effectiveness of clay additives. These additives have been used by several governmental entities, including the USDA-Forest Service, several state and county agencies, and the military.

Clay additives have had numerous uses with the USDA-Forest Service. National Forests located in Arkansas, Florida, Montana, New Mexico, Oklahoma, Tennessee, and Texas have experienced positive results with clay additives (Scholen, 1992). Effectiveness of these areas range from performing minimum maintenance to no maintenance after the products were applied.

An enzyme formulation called Permazyme 11X has exhibited positive results based on past experiences. One study conducted by the Alaska Department of Transportation and Public Facilities Central Region reported that Permazyme 11X has been used on several roads throughout the region. The roads treated with this product have maintained a hard and stable road surface (Brownfield, 1994).

The Emery County Road Department in Castle Dale, UT also has used Permazyme 11X on its unpaved road system. The use of Permazyme has allowed Emery County to eliminate one motor grader position using his services in other areas. Specifically, after seven years of using Permazyme 11X on Ferron Canyon road, blading only was required four times a year, compared to every two-to-three weeks prior to application. Based on these factors, Emery County considers Permazyme 11X to be an extremely cost effective product (Funk, 1993).

Earth Materials Catalyst (EMC) is another clay additive that has showed positive effectiveness. EMC, which is an enzyme formulation, has been successfully used on unpaved roads by military installations, such as Fort Carson and Fort Ord; and on federal lands, such as the Ozark and Coronado

National Forests (Randolph, 1997). Fort Carson, located near Colorado Springs, CO, has used EMC on a dirt road consisting of expansive clay soils and was used by heavy equipment. The soil had an AASHTO classification of A-7-6, and after two years of inspection, the treated road continues to withstand the heavy vehicle traffic without damage to the road surface. Fort Ord, CA has used EMC on haul roads to reduce the environmental pollution of airborne particles. The Ozark National Forest in Arkansas successfully used EMC on several road projects. After seven years of use, the USDA-Forest Service reported the stabilized surface experienced minimal wear or no maintenance except on portions with extreme grades. The Coronado National Forest in Arizona also used EMC on unpaved roads reporting excellent product performance after one year of service (Randolph, 1997).

Several ionic additive products are available; however, no specific studies, which evaluated their performance, existed during the literature review period of this study. At the time of review, the Texas DOT, the U.S. Department of Defense, and the USDA Forest Service have experienced positive results using RoadBond EN1 (C.S.S. Technology, Inc.). Another ionic product, CBR Plus, has been effectively used in South Africa, and most recently by governments and local authorities from the Far East to South and North America, Africa, Australia, the Middle East, and Europe (Robertson Technologies, Corp.). Base One, an ionic additive, has been used in Minnesota, South Dakota, and North Dakota. Users of this product have experienced various level of effectiveness.

Chapter 2 of this study stated that approximately 18 percent or 16 of the 90 product respondents used clay additives. Ninety-four percent of the respondents reported an overall product effectiveness of either "Good" or "Fair," while 67 percent of the respondents stated clay additives were cost effective from a maintenance perspective.

BITUMINOUS BINDERS

Properties/Qualities

Bituminous materials are composed of various mixtures of hydrocarbons that occur naturally or are obtained as residues after heat-refining natural substances. Two well known types of bituminous materials are tar and petroleum. Tar is manufactured by the destructive distillation of organic material (i.e., wood, coal, etc.). Due to some unsuitable physical characteristics and health hazards, tar use in the United States is limited in road construction. Petroleum can occur naturally in the veins of certain rock formations that are located throughout the world, but they primarily are produced by the distillation of crude oil (Roberts et al., 1991). Derivatives of petroleum such as resin, asphalt, and oil are commonly used for road construction.

Bituminous dust controlling and soil stabilization products consist primarily of petroleum resins or modified asphalt emulsions that are combined with other chemicals or ingredients to form proprietary products. These products may include catalysts, dispersing agents, and/or penetration accelerators, which assist in the agglomeration of soil particles. The asphalt emulsion products can be classified as anionic (negatively charged), cationic (positively charged), and nonionic (neutral). The chemical charge affects what type of soil will work with the product. After application, bituminous binders coat soil particles decreasing their ability to become airborne; create a water resistant surface; and exhibit cementitious properties, which aid in creating a dense road surface.

Effective Soil Types

These products are effective on a wide variety of soil types ranging from well-graded to soil with at least 30 percent clay fines. One source recommends that the soil should not contain more than 25 percent of sample passing a No. 200 sieve, and it should have a plasticity index (PI) of less than 10[2] (Garber and Hoel, 1997). Cationic emulsions work effectively with soil types that have negatively charged particles, such as siliceous material (clay); whereas, anionic emulsions are more effective with positively charged soil particles, such as limestone (Garber and Hoel, 1997). Depending on the product used and the recommended level of service, bituminous binders may be applied using either the topical or mixed-in-place methods.

Special Considerations

Some precautions must be taken when using bituminous products. Certain products may be mildly alkaline, slightly toxic, and flammable; therefore, safety equipment should be used when handling bituminous products. If these types of products are accidentally sprayed on vegetation or buildings, immediately spray them off with water. Buildings also may need to be wiped with rags containing petroleum solvents to effectively clean the products from the structures.

Past Studies/Reports

Past experiences also indicate that bituminous binders have shown positive results. Studies

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[2]The term plasticity index is used to classify soil under the AASHTO Classification System and reflects the amount of clay mineral present in the soil. A higher PI value represents a soil with more clay minerals.

have determined that products, such as Pennzsuppress D, Coherex, CSS-1, and Petro Tac, have controlled dust throughout the United States. Pennzsuppress D has been used by the

Pennsylvania Department of Transportation for at least three years with good results (Better Roads, 1995).

A study performed by J.M. Hoover for the Arizona Department of Transportation discussed several types of chemical additives that may be used on unpaved roads. Chemical additive experiences throughout United States were collected to select potential additives that could be used in the Phoenix, AZ area. The report stated that several types of bituminous binders provided positive results in dust control/soil stabilization programs. One product that provided effective results was a petroleum resin named Coherex. Three out of the four agencies that used Coherex had good overall results when using the product (Hoover, 1987). Coherex was effective in two counties in Iowa having soil types of A-2-4 and A-6(4) under the AASHTO soil classification system. The third county was located in Arizona and used the product on a soil type that had 96 percent of the soil sample passing a No. 4 sieve and 60 percent passing a No. 200 sieve (Hoover, 1987).

According to a 1989 study conducted by the Arizona Department of Environmental Quality, coherex (petroleum resin) was used by four Arizona agencies. All of the agencies reported that the product exhibited good dust suppression. One agency stated it had a concern with the cost, while another agency reported that the product lasted two years before potholes developed (Zaniewski, 1989). A third agency stated that Coherex was the most effective dust palliative, and reported the product had a control efficiency near 90 percent (Harley, Hunts, and Cass, 1989).

Another bituminous binder, CSS-1 (asphalt emulsion), also has been used in several areas. The Arizona Department of Transportation study reported that CSS-1 showed good results

in three out of four counties in Iowa. The soils that had good reactions with the product in Iowa were A-2-6, A-6(2), and sandy clay soils (Hoover, 1987).

CSS-1 was successfully used by the U.S. Army in Desert Shield/Desert Storm. A report conducted by the U.S. Army Corps of Engineers Waterways Experiment Station, which will be discussed in more detail on page 60, compared 32 potential products to CSS-1. It was determined that the CSS-1 product was as effective as, or greater, than any other product on the wheeled-vehicle test section located in the desert region, and also was recommended for use on wheel-vehicle traffic in tropic and temperate climates (Grau, 1993).

A report conducted by Midwest Research Institute for the U.S. Environmental Protection Agency evaluated Petro Tac (asphalt emulsion), Coherex (petroleum resin), and water on unpaved roads at two iron and steel plants near Kansas City, MO. The report stated that the control efficiency of water was observed to decrease at a rate of 10 percent per hour; therefore, it was determined not to be an economical method of dust control. After 40 days and nearly 5,000 vehicles (average weight of approximately 75,000 lbs.), the control efficiency of Coherex was 25 percent. The Petro Tac had a control efficiency of 59 percent after 120 days and nearly 50,000 vehicles (average weight of approximately 60,000 lbs.). This study calculated the product cost per pound of PM_{10} (Particulate Matter smaller than 10 μm in aerodynamic diameter) of the three products, and determined that Petro Tac was more cost effective than Coherex and water by 10 and 22 times, respectively (Muleski et al., 1983).

There are a few factors to consider when analyzing results of this study. The vehicles that drove on the water and Coherex treated sections weighed significantly more than the Petro Tac treated

roadways. Economies of scale also made Petro Tac's cost per unit area much lower than the costs for water and Coherex. These factors may have made the results favor the Petro Tac product to a greater extent (Muleski et al., 1983).

As previously discussed in Chapter 2 of this study, approximately 8 percent or 6 of the 90 product respondents used bituminous binders. All the users reported an overall product effectiveness of "Good," and stated these products were cost effective from a maintenance perspective.

ADHESIVES

Adhesives consist of several types of organic non-bituminous binders and various types of polymer solutions. These products exhibit cementitious properties that bind soil particles together to make a dense road surface.

Organic Non-Bituminous Binders

Properties/Qualities

Organic non-bituminous binders generally consist of several industrial waste by-products. Some of these additives include molex, molasses residues, tree resin, soybean oil (soapstock), and lignin derivatives. When applied, these products bind soil particles together to form a hard crust on the road surface. The crust adheres the soil particles together, thereby reducing the amount of dust that is released into the air.

Molex is a by-product beet processing. Similar to chloride additives, molex also displays hygroscopic properties that help maintain a moist road surface. The moisture agglomerates soil particles together, which become too heavy to get airborne by traffic. An article stated that molex is considered to be less corrosive than chloride products (The Bridge, 1992).

Molasses Residues are by-products produced in the sugar industry. These residues can be used in unpaved road systems since they bind soil particles together. Molasses residues are water soluble; therefore, constructing a proper crown will reduce the leaching effects caused by heavy rains. Positive dust controlling results have been encountered when slaked lime and charcoal are added to molasses (Compendium 12: Surface Treatment, 1980).

Soybean Oil Soapstock is a by-product of the caustic refining process of soybean oil. Soapstock binds soil particles together, and can be used on gravel roads with various soil types and traffic conditions; however, a well-graded soil may have the best results (EDC Inc.).

After application, soapstock generally takes four-to-six hours for adequate penetration to occur. Therefore, signs should be posted to slow traffic down to minimize the product from being transferred to the vehicles. Soapstock has had few problems with corrosive effects over short periods of time; however, if soapstock is transferred to vehicles, industrial strength soap and a pressure sprayer should be used for best results (EDC, Inc.).

Overall, soapstock has been proven to be environmentally safe and biodegradable. Tests have shown that soapstock does not pose any threat to workers or the environment. Under current Department of Labor designations, soapstock does not contain any hazardous materials. The Minnesota Department of Transportation's (MN/DOT) environmental unit has tested samples from test sections and found that no water quality problems existed (EDC, Inc.).

Tree Resins primarily consist of natural resinous materials of various types of trees (i.e., pine and spruce). Tree resin products generally consist of tree sap and tall oil. Tree sap is obtained by tapping into trees by making lateral incisions in the bark, while tall oil is manufactured from the pulping process of the lumber industry. These products may contain proprietary blends of minerals and other additives, surfactants, and water. The resulting mixtures or emulsions exhibit excellent cementitious and waterproofing properties (Mzuch and Maco, 1990). Tree resins work on a variety of soil types ranging from loose sand to well-graded soils.

Tree resins may be applied using either the topical or mixed-in-place method.

Some special considerations must be noted when using tree resins. In concentrated quantities, some tree resin products may exhibit corrosive characteristics. This characteristic is greatly reduced when the products are diluted with water. Since some of these products are acidic, workers should use protective equipment such as goggles, rubber gloves and boots, and respirators when handling these products. Product leaching into ground water supplies is minimal because the binding properties of the product keep it near the surface of the road.

Lignin Derivatives are by-products of the paper industry that consist of calcium, ammonium, and sodium lignosulfonates. Lignin can be described as the natural cement that binds wood fibers together in trees (Brauns, 1952). Therefore, lignin will form a cementitious bond with soil particles when added to a road surface. The sulfite process commonly is used to extract the lignin from the pulping liquor. This process modifies the lignin into a water soluble solution called lignosulfonate. It normally consists of a solution having 50 percent water and 50 percent solids (Langon and Williamson, 1983). Not only does lignosulfonate have cementitious properties, but it also acts as a clay dispersant. The dispersion process allows the soil particles to compact closer togther, and it increases the plasticity property of clay at lower moisture contents resulting in a more compact, hard surface (Woods, 1960). For this reason, lignosulfonate should be used on soils that contain around 15 percent clay. Depending on the level of service, lignin products may be applied using either the topical or mix-in-place method.

Although lignin derivatives have been used effectively throughout the country, these products exhibit some negative aspects. These products have been known to display corrosive effects to aluminum and its alloys; however, some products contain additives that neutralized the corrosive nature. These products also are water soluble and biodegradable. As a result, the

binding action of the lignin products could be severely reduced or even destroyed by heavy rains and additional treatments would be needed to maintain its effectiveness.

Lignin derivatives are classified as non-hazardous according to the Occupational Safety and Health Administration (OSHA). If large spills occur, workers should contain the material with dikes and pump the material into salvage containers. These products may cause eye and skin irritation; therefore, safety equipment such as goggles and impervious gloves should be used during application.

Past Studies/Reports

Organic non bituminous binders have been used world wide; however, most of the reports conducted about these additives discuss tree resins and lignin derivatives. A 1992 study, which was conducted by the Forest Engineering Research Institute of Canada, evaluated a tall oil pitch (top) emulsion, which is a type of tree resin (Bennett and Gleeson, 1994). A 5.1 km treated section and a 5.0 km untreated section near Prince George, British Columbia, were monitored and compared. A present worth of a five-year period was used to analyze the treated and untreated road sections. The analysis accounted for initial application and maintenance costs, regular grading, patching, watering, and regraveling costs. The analysis concluded that the treated section had a present worth that was approximately 21 percent less than the untreated section. The local residents were extremely satisfied with the results.

Similar to chloride additives, lignin sulfonates also have been used by the USDA - Forest Service. In 1988, the Gifford Pinchot National Forest, located in southwest Washington, evaluated four dust controlling products with a control section. The study concluded that lignin sulfonate would

be a better choice for the Gifford Pinchot National Forest. Several other projects, which have been conducted in the Pacific Northwest, determined that lignin sulfonate is one of the most effective dust suppressants for unpaved roads having between 8-20 percent passing the 75 μm sieve (Bolander, 1997).

An extensive research study was conducted by the U.S. Army Corps of Engineers Waterways Experiment Station. This evaluation was divided into two separate studies. The first study evaluated dust controlling products in desert climates, while the

second study evaluated products in tropic and temperate climates. Both studies evaluated potential products that could be used for dust control by comparing their performance to CSS-1 which had been using during Desert Shield/Desert Storm with positive results. Potential products were eliminated if their product cost was more than the CSS-1 product. Their performance had to be equal to or better than the CSS-1 product. The products applied in the desert regions were given laboratory tests and field tests, while the products in the tropic and temperate regions only were evaluated using laboratory tests. The soil used on the desert field tests was classified as poorly graded sand or SP according to the Unified Classification System. This study evaluated 32 products in between the two regions, and the products were tested by three military vehicles: UH-1 Huey helicopters, M927 trucks (6X6 5 ton), and M2 Bradley tanks; however, we primarily are concerned with the results of the wheeled-vehicle (M927 truck). The results of the investigation showed Lignosulfonate Road Binder (calcium lignosulfonate) and Road Oyl (pine sap emulsion) as two of the four products that withstood wheeled-vehicle traffic on unpaved roads in desert climates (note: the other two products are classified as polymer additives). The study also stated that these two products should effectively work on road

surfaces in tropic and temperate climates (Grau, 1993).

Sanders et. al. also evaluated effectiveness of ligninsulfonate. The road section that was applied with ligninsulfonate had a 61 percent reduction in aggregate loss compared to the control section. This reduction was greater than the values for calcium chloride and magnesium chloride, which were 43 and 60 percent, respectively (Sanders et. al., 1997).

Chapter 2 of this study determined that 5.5 percent or 5 of the 90 product respondents used organic non-bituminous. Eighty percent of the organic non-bituminous users reported an overall effectiveness of either "Good" or "Fair," while 60 percent of them stated the products were cost effective from a maintenance perspective.

Polymeric Additives

Properties/Qualities

Polymeric additives primarily consist of acrylic or acetate polymers and dispersing agents that are specifically produced for dust control/soil stabilization or are by-products from the adhesive or paint industries. After application, these products penetrate the soil via dispersing agents, while polymers cause a chemical bond to occur between the soil particles. The polymer molecules are chemically attracted to each other, forming large chains or grid like structures. This process continues until the chemical reaction is interfered with, or no other monomers are available. The bond creates a cementitious effect, which achieves a dense and water-resistant road surface.

Effective Soil Types

Polymeric additives may work in a variety of soil types. Depending on the specific polymeric additive, manufacturers recommend which type of soil effectively performs with their product. Examples of some recommendations are to use their products with various types of soils and with soils having 10-30 percent clay.

Special Considerations

Polymeric additives pose some safety concerns for workers during application procedures. When exposed in unventilated areas, the undiluted product can cause headache and nausea. These products also may cause slight eye and skin irritation, therefore goggles and rubber gloves are recommended.

These products generally are classified by OSHA as non-hazardous; however, some precautions should be taken when using them. If a concentrated spill occurs, a dike should be constructed to contain the solution. An effort should be made to keep the products out of sewers and bodies of water. The liquid should be transferred to containers for recovery or disposal. Overall, these products are non-toxic to humans and fish, and non-corrosive to metals.

Past Studies/Reports

Soil stabilization studies have evaluated the performance of polymeric additives for many years. The report conducted by J.M. Hoover for the Arizona Department of Transportation stated that polymeric additives appear to provide effective dust control and soil stabilization in a variety of soil types (Hoover, 1987).

Another study, conducted in the Mojave Desert region in Southern California, evaluated several products for dust control on unpaved roadways. The study applied a pine tar resin, magnesium and calcium chlorides, lignin sulfonate, two petroleum resins, and Soil-Sement (polymeric additive). These products were evaluated at intervals of 3, 6, and 12 months. The analysis showed that Soil-Sement was still 90 percent effective in controlling dust after 12 months. The product with the next highest percent of effectiveness was the pine tar resin, which was at 30 percent effective (Midwest Industrial Supply, Inc.).

A study performed from July 1995 to August 1996 by the Desert Research Institute evaluated four dust suppressant products near Merced, CA. The study applied the products to 1/3 mile road sections and the particulate matter loss over a 12- month period was compared to an untreated section. Two of the products, Soil-Sement (polymeric additive) and Non-Hazardous Crude-Oil-Containing Materials (bituminous binder), were effective at controlling dust emissions. The study determined that these two products had control efficiencies in excess of 80 percent over the 12-month evaluation period (Watson et al., 1996).

The U.S. Army Corps of Engineers Waterways Experiment Station study also recommended using some polymeric additives. A polymeric additive named Sand Glue showed positive results on wheeled-traffic in desert regions, while Dirt Glue, another polymer product, was recommended on roadways in tropic and temperate climates (Grau, 1993).

The Pacific Northwest also has used polymer emulsions to some degree. Three types of these products have been applied on unpaved roads in the region. Several levels of success have been encountered, ranging from one month of effectiveness to roads that have not had to be bladed for

several years (Bolander, 1997).

APPENDIX C
COMPANY PRODUCT INFORMATION
(BASED ON 1997 DATA)

Product Name	***Company***	***The Best Soil to Use With Product***	***Page #***
Adhesives			
Organic Non-Bituminous Binder			
Dustac (**DC/SS**)	Georgia-Pacific, Inc.	Surface needs approximately 15% clay	83
Dustbloc 315 **(DC/SS)**	Baker Performance Tech.	Surface needs approximately 15% clay	84
Dustrol EX Emulsion **(DC)**	BC Chemicals, Ltd.	Well-graded road surface	85
Enduralseal 100 **(DC)**	Cascadia Tech., Ltd.	Various types of soil	86
Enduraseal 200 **(DC/SS)**	Cascadia Tech., Ltd.	Various types of soil	87
Pine Sap Emulsion **(DC/SS)**	Cousins, Corp.	Surface should have some compressible fines or loose aggregate	88
Road Oyl **(DC/SS)**	Soil Stabilization Products Co.	Various types of soil	89
Soapstock **(DC)**	EDC, Inc.	Well-graded road surface	90
Polymeric Additives			
EMS **(DC/SS)**	Soil Stabilization Products Co.	Surfaces containing small amounts of clay to heavy clays	91
Marloc **(SS)**	Reclamare Co.	Well-graded road surface, and a low clay content	92
Polymer/Enzyme **(SS)**	Durasoils Inc.	Surface should contain 10- 30% clay	93
Soil-Sement **(DC/SS)**	Midwest Industrial Supply, Inc.	Various soil types (sand, silt, and clay)	94

Dowflake — Calcium Chloride

General Description: Dowflake is a 77-80% pure calcium chloride flake.

Manufacturer: The Dow Chemical Company
Midland, Michigan 48674
Phone: 800-447-4DOW

Distributor: Van Waters & Rogers
845 Terrace CT
St Paul, MN 55101
Phone: 612-774-9400

Cost: $380 per ton, including product and delivery

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Pounds of product per square yard	$ per square yard
Well-graded soil	No water added	1.5	.29

Methods of Application:

1. Scarify the top 6 inches of road surface.
2. Windrow or pulverize the material then blade and shape the surface to a type "A" crown.
3. Spread the product on the road surface.
4. Compact the road surface with either a pneumatic or steel wheel roller.

Special Comments:

1. The product should be applied when the road surface is moist, or sprinkle the surface immediately after application. This will speed the dissolving of the product and the bonding process.

Flake Calcium Chloride — Calcium Chloride

General Description: The product is a 77% pure calcium chloride flake.

Manufacturer: General Chemical Corporation
90 East Halsey Road
Parsippany, NJ 07054
Phone: 800-631-8050
Fax: 201-515-2468

Distributor: Van Waters & Rogers
845 Terrace CT
St Paul, MN 55101
Phone: 612-774-9400

Cost: $380 per ton, including product and delivery

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Pounds of product per square yard	$ per square yard
Well-graded soil, 3-12% fines	No water added	1.5-2.0 Initial application	.29-.38
Well-graded soil, 3-12% fines	No water added	.5-.75 Maintenance application	.10-.14

Methods of Application:

1. Blade and shape the surface to a type "A" crown.
2. Apply the product with a pressurized spray bar.

Special Comments:

1. The product should be applied when the road surface is moist, or sprinkle the surface immediately after application. This will speed the dissolving of the product and the bonding process.

IPC 1185 Calcium Chloride

General Description: IPC 1185 is a liquid solution of calcium chloride.

Manufacturer: Baker Performance Technologies
318 Commerce Drive
Exton, PA 19341
Phone: 610-594-5559
Fax: 610-594-6959

Cost: $1.15 per gallon of concentrate, including product and delivery

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
Well-graded soil	Volume of water to volume of product	Gallons of diluted solution per square yard	$ per square yard
Very compact soil	Initial app. = 1:1	.25	.14
	Preceding app. = 4:1	.25	.06
Loose soil	Initial app. = 1:1	.5 - .75	.29-.43
	Preceding app. = 4:1	.5 - .75	.12-17

Methods of Application:
1. Blade the road surface to eliminate potholes, washboards, etc., then crown.
2. Apply the mixture from pressurized spray bar.
3. Compact the road surface with either a pneumatic or steel wheel roller.
4. Restrict traffic until road surface hardens.

Special Comments:
1. The product should not be applied when rainfall is likely to occur within 24 hours. Rainfall will create a slick surface.
2. The product may cause eye and skin irritation, therefore, safety equipment should be used during the application process.

Liquid Calcium Chloride — Calcium Chloride

General Description: The product consists of a 35% liquid calcium chloride solution.

Manufacturer: General Chemical Corporation
90 East Halsey Road
Parsippany, NJ 07054
Phone: 800-631-8050
Fax: 201-515-2468

Distributor: Van Waters & Rogers
845 Terrace CT
St Paul, MN 55101
Phone: 612-774-9400

Cost: $.60-$.65 per gallon, including product, delivery, and application

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallons of product per square yard	$ per square yard
Well-graded soil, 3-12% fines	Pre-mixed	.40 Initial application for dust control	.24-.26
	Pre-mixed	.10 Maintenance application for dust control	.06-.07
Well-graded soil, 3-12% fines	Pre-mixed	1.0 For soil stabilization	.60-.65

Methods of Application:

Dust Control

1. Blade and shape the surface to a type "A" crown.
2. Apply the product with a pressurized spray bar.
3. Apply a second time later in summer for proper road maintenance.

Soil Stabilization

1. Scarify the existing surface.
2. Apply .75 gal/sq. yd. of solution to the road surface.

3. Blade mix and shape the surface to a type "A" crown.
4. Compact the road surface with either a pneumatic or steel wheel roller.
5. Apply .25 gal/sq. yd. top dressing to the road surface.

Special Comments:
1. The product should not be applied when rainfall is likely to occur within 24 hours. Rainfall will create a slick surface.
2. The product may cause eye and skin irritation, therefore, safety equipments should be used during the application process.

LiquidDow — Calcium Chloride

General Description: LiquidDow consists of a 38% liquid calcium chloride solution.

Manufacturer: The Dow Chemical Company
Midland, Michigan 48674
Phone: 800-447-4DOW

Distributor: Van Waters & Rogers
845 Terrace CT
St Paul, MN 55101
Phone: 612-774-9400

Cost: $.60-$.65 per gallon, including product, delivery, and application

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallons of product per square yard	$ per square yard
Well-graded soil	Pre-mixed	.27 for Dust Control	.16-.18
Well-graded soil	Pre-mixed	.60 for Soil Stabilization	.36-.39

Methods of Application:

Dust Control
1. Blade and shape the surface to a type "A" crown.
2. Apply the product with a pressurized spray bar.
3. Apply a second time later in summer for proper road maintenance.

Soil Stabilization
1. Scarify the top six inches of road surface.
2. Apply .4 gal/sq. yd. of solution to the road surface.
3. Windrow or pulverize the material then blade and shape the surface to a type "A" crown.
4. Compact the road surface with either a pneumatic or steel wheel roller.
5. Apply .2 gal/sq. yd. top dressing to the road surface.

Special Comments:
1. The product should not be applied when rainfall is likely to occur within 24 hours. Rainfall will create a slick surface.
2. The product may cause eye and skin irritation, therefore, safety equipment should be used during the application process.

Roadmaster — Calcium Chloride

General Description: Roadmaster consists of a 32-38% liquid calcium chloride solution.

Manufacturer: Tetra Chemicals
P.O. Box 73087
Houston, TX 77273
Phone: 800-327-7817
Fax: 713-298-7150

Distributor: Scotwood Industries, Inc.
PO Box 8089
Shawnee Mission. KS 66208
Phone: 800-844-2022

Cost: $.55-$.57 per gallon, including product, delivery, and application

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
Soil should contain 10-25% fines	Volume of water to volume of product	Gallons of product per square yard	$ per square yard
Well-graded soil	Pre-mixed	.5 for Dust Control	.28-.29
Well-graded soil	Pre-mixed	1.0 for Soil Stabilization	.55-.57

Methods of Application:

Dust Control

1. Scarify the surface to remove washboards, potholes, etc. then shape to a type "A" crown.
2. Pre-wet the surface before application.
3. Apply the product with a pressurized spray bar.
4. Compact the road surface with either a pneumatic or steel wheel roller.
5. Curing generally takes 24 hours, therefore traffic should be limited or reduced speeds should

be used.

6. Spray the surface with water 2 or 3 days after application to ensure penetration of the product.

Soil Stabilization

1. Scarify the top 4-6 inches of road surface.
2. Apply .75 gal/sq. yd. of solution to the road surface.
3. Windrow or pulverize the material then blade and shape the surface to a type "A" crown.
4. Compact the road surface with either a pneumatic or steel wheel roller.
5. Apply .25 gal/sq. yd. top dressing to the road surface.
6. Curing takes generally 24 hours.
7. Spray the surface with water 2 or 3 days after application to ensure penetration of the product.

Special Comments:

1. The product should not be applied when rainfall is likely to occur within 24 hours. Rainfall will create a slick surface.
2. The product may cause eye and skin irritation, therefore, safety equipment should be used.

Dust-off — Magnesium Chloride

General Description: Dust-off is a solution consisting of magnesium chloride, anti-corrosive additives, and water.

Manufacturer: Cargill Salt
7229 Central Avenue
Newark, CA 94560
Phone: 800-227-4455

Distributor: Fort Distributors, Ltd.
R.R. #1
Selkirk, Manitoba Canada
R1A 2A6
Phone: 204-785-2180

Cost: $.75 per gallon, including product, delivery, and application

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallon of product per square yard	$ per square yard
Well-graded soil, 6-15% clay	Pre-mixed	.50 Initial application	.38
	Pre-mixed	.25 Maintenance application	.19

Methods of Application:

1. Scarify the road surface to a depth of 3- 4 inches.
2. Apply the product with a pressurized spray bar.
3. Blade mix and shape the surface to a type "A" crown.
4. Compact the road surface with either a pneumatic or steel wheel roller.

Special Comments:

1. The product should not be applied when rainfall is likely to occur within 24 hours. Rainfall will create a slick surface.
2. The initial application should take place in early spring, while the preceding application occurs in the late fall.
3. In about three years, the application rates can be reduced by as much as 50%.
4. The product is 20-50% less corrosive than ordinary water.
5. The product may cause eye and skin irritation, therefore, safety equipment should be used during the application process.

Dus-Top — Magnesium Chloride

General Description: Dus-Top is a concentrated magnesium chloride solution.

Manufacturer: Tetra Chemicals
PO Box 73087
Houston, TX 77273
Phone: 800-327-7817

Distributor: Scotwood Industries, Inc.
Box 8089
Shawnee Mission, KS 66208
Phone: 800-844-2022

Cost: $.55-$.57 per gallon, including product, delivery, and application

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
Soil should contain 10-25% fines	Volume of water to volume of product	Gallons of product per square yard	$ per square yard
Well-graded soil	Pre-mixed	.5 for Dust Control	.28-.29
Well-graded soil	Pre-mixed	1.0 for Soil Stabilization	.55-.57

Methods of Application:

Dust Control

1. Scarify the road surface to remove washboards, potholes, etc. then shape the surface to a type "A" crown.
2. Pre-wet the surface before application.
3. Apply the product with a pressurized spray bar.
4. Compact the road surface with either a pneumatic or steel wheel roller.
5. Curing generally takes 24 hours, therefore traffic should be limited or use reduced speeds.
6. Spray the surface with water 2-3 days after application to ensure penetration of the product.

Soil Stabilization

1. Scarify the road surface to a depth of 4-6 inch.
2. Apply .75 gal/sq. yd. of solution to the road surface.
3. Windrow or pulverize the material then blade and shape the surface to a type "A" crown.
4. Compact the road surface with either a pneumatic or steel wheel roller.
5. Apply .25 gal/sq. yd. top dressing to the road surface.
6. Curing takes generally 24 hours.
7. Spray the surface with water 2 or 3 days after application to ensure penetration of the product.

Special Comments:

1. The product should not be applied when rainfall is likely to occur within 24 hours. Rainfall will create a slick surface.
2. The product may cause eye and skin irritation, therefore, safety equipment should be used.

Base One — Clay Additive

General Description: Base One is a proprietary blend of chemicals consisting of tri-silicants, emulsifiers, and extender carrier liquids.

Manufacturer: Team Laboratory Chemical Corp.
PO Box 1351
Bismarck, ND 58502
Phone: 800-522-8326

Cost: $9.95 per gallon, including only the cost of the product

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallons of diluted solution per square yard	$ per square yard
Well graded soil with 10-20% fines	1000:22	.71	.15

Methods of Application:

1. Scarify the road surface to a depth of 6-8 inches.
2. Apply the solution to the material with a distributor.
3. Mix the material with a blade, then windrow to one side of the road.
4. Blade the material back on the road surface in 2-inch lifts.
5. Compact each lift with a pneumatic roller.
6. Crown the top layer and compact with a steel wheel roller.
7. If a seal coat is intended for the road, allow the road to cure for six weeks.
8. Apply RC-70 (emulsion) over the stabilized surface.
9. A seal of MC800 with chips is recommended but not necessary.

Special Comments:

1. In cold climates, a top dressing must be applied in the spring using 30 gallons of the product per mile.
2. The road may be touched up by re-wetting the surface with the solution, blade, and compact.

3. The product may cause eye and skin irritation, therefore, safety equipment should be used during the application process.

CBR Plus — Ionic Exchange Additive

General Description: CBR Plus is an anionic surface active agent, which contains sulphonic acid derivatives.

Manufacturer: Con-Aid (Pty) Ltd.
23 Vieira Road, Amoraosa
Roodepoort 1725, South Africa

Distributor: Robertson Technologies Corp.
Suite 902, Hornby Street
Vancouver, B.C. V6C 3B6
Phone: 604-684-8072
Fax: 604-681-4166

Cost: $100 per gallon, including only the cost of the product

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
A-4 and higher by AASHTO	Volume of water to volume of product	Gallons of diluted solution per square yard	$ per square yard
A-4	500:1	1.70	.34
A-7	500:1	3.40	.68

Methods of Application:

1. Scarify the road surface to a depth of 6 inches.
2. Apply solution with a distributor. Add enough to achieve OMC +/- 1%.
3. Mix the soil and blade to final shape.
4. Compact the surface at +/- 1% of OMC. Initial compaction can be done by vibratory, sheeps foot, or steel wheel roller, then finish off with pneumatic roller.
5. Spray the surface with water at daily intervals for 5 days.

Special Comments:

1. If rainfall occurs after compaction, the road surface may become slippery and form a mud crust. Allow the surface to dry and grade the deformed mud crust from the surface.
2. A soil sample must be tested by The Robertson Tech. Corp. To determine the compatiblity of the product and the soil. If the product reacts with the soil in a positive manner, then the application rates and dilution rates will be determined.
3. This product consists of a strong acid, therefore, safety equipment must be used when handling the concentrated solution.

Clay Pack — Ionic Exchange Additive

General Description: Clay Pack is a solution consisting of sulfuric acid and resins.

Manufacturer: Soil Bond International
P.O. Box 550691
Dallas, Texas 75355
Phone: 214-429-1355

Cost: $54-$72 per gallon,* including product and delivery

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
Soils which contain at least 20% clay	Volume of water to volume of product	Gallons of diluted solution per square yard	$ per square yard
For normal use	300:1	2.35	.42 - .56
For extra water proofing	150:1	2.36	.84 - 1.13

* (1-3) 55 gallon drums costs $3,950, (80+) 55 gallon drums costs $2,950.

Methods of Application:
1. Scarify the road surface to a depth of 6 inches.
2. Apply the solution with a distributor in multiple passes.
3. Mix the surface with disc or grader and form.
4. Compact the surface with a vibratory or static roller.
5. Apply 1-3 applications of plain water to keep the surface moist for the next 24 hours.
6. It is recommended to apply a chip seal over the road surface.

Special Comments:
1. This product consists of a strong acid, therefore, safety equipment must be used when handling the concentrated solution.

Roadbond EN 1 — Ionic Exchange Additive

General Description: Roadbond EN 1 is a solution consisting of a strong oxidizer, solvent, and a natural dispersant.

Manufacturer: C.S.S. Technology, Inc.
P.O. Box 1355
Weatherford, Texas 76086

Distributor: Parklyn Marketing
3468 Assininboine Groove
Winnipeg, Man. R3K OH6
Phone: 204-885-6627

Cost: $150 per gallon, including only the cost of the product

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallons of diluted solution per square yard	$ per square yard
Soil with at least 10% clay	200:1	1.0	.75
Soil with at least 10% clay	500:1	1.0	.30

Methods of Application:

1. Scarify the road surface to a depth of 6 inches.
2. Apply the solution with a distributor.
3. Mix the material with a grader or disc.
4. Windrow the mixed material to either side of the road.
5. Blade the material break onto the road surface in two in lifts.
6. Compact each lift will a steel wheel roller.

Special Comments:

1. Depending on the soil characteristics, the dilution may range from 200:1-500:1.
2. The product consists of a strong acid, therefore, safety equipment must be used when handling the concentrated solution.
3. The product does not work well in organic material and if the sand content is greater than 40%.

EMC SQUARED — Enzyme Additive

General Description: EMC Squared consists of a biocatalyst formulation.

Manufacturer: Soil Stabilization Products
P.O. Box 2779
Merced, California 95344
Phone: 209-383-3296
800-523-9992
Fax: 209-383-7849

Cost: $30[1] per gallon, including only the cost of the product

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
Varies	Volume of water to volume of product	Gallon of product per cubic yard	$ per square yard
Soils containing small amounts of clay to heavy clays	Varies[2]	.067 (1 gal/15 yd^3)	.34[3]

1 Based on purchasing a 5-gallon pail.
2 Add the required amount of water to bring the soil to OMC.
3 Based on 6-inch depth.

Methods of Application:
1. Scarify the road surface to a depth of 6-12 inches.
2. Apply the solution to the material with a distributor. Save 5% of the solution for a final surface coat.
3. Mix the material with a grader, disk, or rotary mixer.
4. If rain is forecasted overnight, compact the material that day. If no rain is forecasted, leave the material overnight before compaction. Before compaction occurs on the next day, bring the material back up to OMC.
5. Compact the material with pneumatic or steel wheel rollers.
6. Apply the remaining solution during the final grading (crowning) and compaction operations.
7. If a coarse surface will be applied, allow seven days to cure.
8. If it will remain unsurfaced, allow traffic on the road surface.

Special Comments:
1. It is recommended that soil samples be analyzed to determine the performance of the product.

2. Maintenance occurs when the damaged area is saturated with the solution, scarify the material and mix with solution, grade the material, and final compact.
3. The product may cause eye and skin irritation, therefore, safety equipment should be used.

Paczyme — Enzyme Additive

General Description: Paczyme is a concentrated enzyme solution.

Manufacturer: Mason Enzymes Pty. Ltd.
198 Lord Street
Perth, Western Australia, Australia

Distributor: Rainstorm Enterprises Ltd.
21350 80th Avenue
Langley B.C. V2Y 2E2
Phone: 604-888-9540
Fax: 604-888-9398

Cost: $108 per gallon, including only the cost of the product

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallons of product per cubic yard	$ per square yard
PI of 8 or greater with 15% fines	Varies[1]	.051 (6.5 oz.)	.92[2]

[1] Add the required amount of water to bring the soil to OMC.

[2] Based on 6-inches of depth.

Methods of Application:
1. Scarify the road surface with a grader or pulverizer/mixer to the required depth.
2. Apply 6.5 oz. of Paczyme plus adequate water to achieve OMC for each cubic yard of material using a distributor.
3. Mix the material with a grader or pulverizer.
4. Windrow the material. The windrows can be left over night to maximize absorption. The following morning, add adequate water to achieve 1-2% below OMC.
5. Blade out the material over surface in one or two lifts, and compact each lift.
6. Compact the material with a sheeps foot, steel drum, or pneumatic roller.
7. If desired, the road surface can now be sealed.

Special Comments:
1. The product may cause eye and skin irritation, therefore, safety equipment should be used during the application process.

Perma-Zyme 11X — Enzyme Additive

General Description: Perma-Zyme 11X is a concentrated multi-enzyme solution.

Manufacturer: International Enzymes, Inc.
1706 Industrial Road
Las Vegas, Nevada 89102
Phone: 702-388-0145
Fax: 702-388-1319

Distributor: Idaho Enzymes, Inc.
1010 West Main
Jerome, Idaho 83338
Phone: 208-324-3642

Cost: $200 per gallon, including only the cost of the product

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallons of diluted solution per square yard	$ per square yard
Surface with 18-30% cohesive fines	1000:1* for dry material	1.0	.20

* Add 1 gallon of product to the necessary amount of water to bring to 165 cubic yards of soil to OMC. A dilution of 1000:1 is generally a good start.

Methods of Application:

1. Scarify the road surface to a depth of 6 inches.
2. Apply some of the solution over the surface and start blade mixing.
3. Continue adding the solution until the soil is at or near OMC.
4. If the soil gets too wet, blade to assist in drying. If the soil is too dry, add more water.
5. After the soil is mixed, leave the material in a windrow overnight to develop total absorption.
6. Before you blade out the windrow, always lay the material on a damp floor. Apply a solution diluted to 10,000:1 to the road base.
7. Lay the material in 2-3 inch lifts, and crown the final lift.
8. Compact the surface immediately. Use either a steel wheel or pneumatic roller.
9. Road closure may be necessary for 2-3 days if heavy, high speed traffic will be using the road. However, normal traffic will not harm the surface.
10. A wearing surface may be applied in 3-5 days after application.

Special Comments:

1. The product may cause eye and skin irritation, therefore, safety equipment should be used during the application process.

Coherex — Bituminous Binder

General Description: Coherex is produced by natural petroleum resins which consists of semiliquid petroleum resins(60%) and wetting solutions(40%).

Manufacturer: Witco Corporation
P.O. Box 456
Chandler, AZ 85244-0161
Phone: 602-963-2267
Fax: 602-963-2270

Cost: $1.50 per gallon,* including product and delivery

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallons of diluted solution per square yard	$ per square yard
Various soil types	4:1	.50-.75	.15-.23

* Based on a 6,000 gallon shipment. Enough to support about 2.8 miles.

Methods of Application:
1. Scarify the road surface to a depth of .5 to 1.0 inches.
2. Blade and shape the surface to a type "A" crown.
3. Apply half of the product with a pressure sprayer.
4. Apply the second half of the product one week later.
5. Road closure is not needed.

Special Comments:
1. The product should be applied in the fall. Depending on the surface condition, only one pass may be needed and/or the application rate may decrease.
2. The road surface may be graded with added water after the product is applied.
3. Product is slightly toxic and acidic, therefore, safety equipment should be used during application.
4. Immediately wash off any product that is sprayed on vegetation.

Consolid 444 — Bituminous Binder

General Description: Consolid 444 is a semi-viscose liquid of petroleum distillates with catalysts and penetration accelerators. It is used to agglomerate the fine soil particles.

Manufacturer: American Consolid Inc.
502 E. 32nd Street
Davenport, Iowa 52803
Phone: 319-323-4464

Manufacturer: Consolid Canada, Inc.
#1, 1715 27th Ave. NE
Calgary, Alberta T2E 7E1
Phone: 403-250-6688

Cost: $65 per gallon, including product and delivery

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to the volume of product	Gallons of diluted solution per square yard	$ per square yard
Soil with at least 30% clay/silt fines	1:4	.00625 per inch depth of loose soil	.81*

* Based on 10,000 square yards at a 8-inch compacted depth (10 inches loose).

Methods of Application:

1. Scarify the road surface normally to a depth of 10 inches. The depth of scarifying should be to the approximate depth of expected loosened soil stabilization.
2. Apply the solution with a distributor.
3. Mix the soil thoroughly with either a disc harrow or soil mixer.

Special Comments:

1. It is the first of two products that make up the Consolid Blend.
2. Non-cohesive soils, organic soils, and some heavy clays do not react well with the product.
3. A soil sample is tested by American Consolid Inc., and they advise the employer on application rates, pricing, and thickness needed.
4. The product is mildly alkaline and flammable, therefore, safety equipment should be used during the application process.

Conservex — Bituminous Binder

General Description: Conservex is a solution of petroleum distillates with catalysts and penetration accelerators. It protects the stabilized soil from water.

Manufacturer: American Consolid Inc.
502 E. 32nd Street
Davenport, Iowa 52803
Phone: 319-323-4464

Manufacturer: Consolid Canada, Inc.
#1, 1715 27th Ave. NE
Calgary, Alberta T2E 7E1
Phone: 403-250-6688

Cost: $65 per gallon, including product and delivery

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of MC-30 to volume of product	Gallons of diluted solution per square yard	$ per square yard
Soil with at least 30% clay/silt fines	1:19	.025 per inch depth of loose soil	.81*

* Based on 10,000 square yards at a 8-inch compacted depth (10 inches loose).

Methods of Application:

Continuing from the Consolid 444:

4. Apply the solution with a distributor.
5. Mix the soil thoroughly with either a disc harrow or soil mixer.
6. Compact the soil with sheeps foot and rubber wheel rollers.
7. A surface course can be applied after some time has passed.

Special Comments:

1. It is the second of two products that make up the Consolid Blend.
2. Non-cohesive soils, organic soils, and some heavy clays do not react well with the product.
3. A soil sample will be tested by American Consolid Inc., and they will advise the employer on the application rates, pricing, thickness needed.
4. The product is mildly alkaline and flammable, therefore, safety equipment should be used during the application process.

Enviro-ADL-200 Bituminous Binder

General Description: Enviro-ADL-200 is a liquid consisting of asphalt and bituminous materials, an emulsifier, and a surfactant.

Manufacturer: Pacific Chemicals Inc.
286 Chancellor Drive
Kamloops, BC V2E 2K7
Phone: 250-828-0218
Fax: 250-828-6835

Cost: $2 per gallon, including product, delivery, and application

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallons of diluted solution per square yard	$ per square yard
Various types of soil	2:1	.35-.50	.23-.33

Methods of Application:
1. Blade and shape the surface to a type "A" crown.
2. Apply the solution with a distributor.
3. Road closure will be needed for a few hours.

Special Comments:
1. The product normally lasts 5-6 months.
2. The product may cause eye and skin irritation, therefore, safety equipment should be used during the application process.

Pennzsuppress D — Bituminous Binder

General Description: Pennzsuppress D is a water emulsified petroleum resin which contains binding agents, wetting agents and emulsifiers.

Manufacturer: Pennzoil Products Company
607 Robert Lane
Green Bay, WI 54311-7543
Phone: 800-843-8910
Fax: 414-468-2052

Cost: $3.25-$3.50 per gallon, including product and delivery

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallons of diluted solution per square yard	$ per square yard
Well-graded soils	4:1	.50	.33-.35

Methods of Application:

1. Blade and shape the surface to a type "A" crown.
2. Apply the product in two passes with a pressure sprayer.
3. Road closure is generally not needed, however, material may pick up on tires and shoes for a few hours.

Special Comments:

1. The dilution ratio and the frequency of treatments will vary depending upon soil conditions, porosity, anticipated traffic, etc.
2. The product is considered to be non-hazardous.

Petro Tac — Bituminous Binder

General Description: Petro Tac is an emulsion consisting of semi-liquid petroleum resins, dispersing agents, and sequestering agents. It is a cationic solution.

Manufacturer: Syntech Products Corporation
520 E. Woodruff
Toledo, Ohio 43624
Phone: 800-537-0288
419-241-1215
Fax: 419-241-6943

Cost: $1 per gallon, including product and delivery

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallons of diluted solution per square yard	$ per square yard
Dirty mix of gravel	5:1	1.0	.17

Methods of Application:
1. Blade and shape the surface to a type "A" crown.
2. Apply the product with pressure sprayer.
3. Close the road for eight hours if possible, or reduce the speed limits to control the amount of pick up on tires.

Special Comments:
1. Do not apply the product to wet surfaces, since penetration can be affected.
2. The product may cause eye and skin irritation, therefore, safety equipment should be used during the application process.

Dustac — Organic Binder

General Description: Dustac is a calcium lignosulfonate product developed from lignin.

Manufacturer: Georgia-Pacific
300 West Laurel Street
P.O. Box 1236 (98227)
Bellingham, Washington 98225
Phone: 360-733-4410
Fax: 360-676-7206

Cost: $.40 per gallon,* including product and delivery

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallons of diluted solution per square yard	$ per square yard
Soil with 15% clay	1:1	.50 for Dust Control	.10
Soil with 15% clay	1:1	1.0 for Soil Stabilization	.20

* Cost was calculated to be railed to Beulah, ND (18,000 gallons). It would cost about two times as much if trucked from Park falls, WI.

Methods of Application:

Dust control

1. Scarify the road surface to a depth of .5 to 1.0 inches, and grade to an "A" type crown.
2. If the surface is dry, spray water on it until it is saturated.
3. Apply the product with either a gravity flow or pressure sprayer.

Soil Stabilization

1. Scarify the road surface to a depth of 6 inches.

2. If the surface is dry, spray water on it until it is saturated.
3. Blade the top 3 inches of loose material into two windrows on both sides of the road.
4. Apply 1.0 gal/yd^2 of solution with either a gravity flow or pressure sprayer.
5. Blade mix the scarified soil and solution, then spread out the material over the road surface.
6. Compact the material with a pneumatic roller. Do not use a sheeps foot compactor.
7. Blade the windrowed material to the center of the road and spread uniformly.
8. Apply 1.0 gal/yd^2 of solution with either a gravity flow or pressure distributor.
9. Blade-mix, crown, and compact the road immediately.

Special Comments:

1. The product does not have good results in sandy soils (too porous).
2. Allow the solution to penetrate the surface before permitting traffic on the road.

Dustbloc 315 Organic Binder

General Description: Dustbloc 315 is consists lignin liquor concentrate.

Manufacturer: Baker Performance Technologies
318 Commerce Drive
Exton, PA 19341
Phone: 610-594-5559
Fax: 610-594-6959

Cost: $1.15 per gallon, including product and delivery

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
Soil containing 15% clay	Volume of water to the volume of product	Gallons of diluted solution per square yard	$ per square yard
Very compact soil	4.5:1	.25	.05
Loose soil	4.5:1	.50-.75	.10-.16

Methods of Application:

Dust Control

1. Blade and shape the surface to a type "A" crown.
2. Apply the product with a pressurized spray bar.

Soil Stabilization

1. Scarify the top 3 inches of road surface.
2. Blade material into two windrows on each side of the road.
3. Apply 1/3 to 1/2 of mixture to the road surface between the windrows
4. Blade most of the windrowed material back on the road surface, then blade mix the material and spread across the roadway.
5. Apply another 1/3 of solution onto the newly graded material.
6. Blade the remaining windrowed material back on the road surface, and mix with grader or pulverizer.
7. Crown the road surface.
8. Apply the rest of the solution as a top coat.
9. Compact the surface preferably with a pneumatic roller.

Special Comments:

1. The product may cause eye and skin irritation, therefore, safety equipment should be used

during the application process.

Dustrol EX — Organic Binder

General Description: Dustrol EX is made from natural resinous materials of pine and spruce trees, which consists of wood extractives (50%) and water(50%).

Manufacturer: B.C. Chemicals Ltd.
P.O. Box 6000
2711 Pulp Mill Road
Prince George, B.B. V2N 2K3
Phone: 604-563-0607
Fax: 604-562-5423

Distributor: Pacific Chemical Inc.
286 Chancellor Drive
Kamloops, BC
Canada, V2E-2K7
Phone: 250-828-0218
Fax: 250-828-6835

Cost: $.50 per gallon, including product, delivery, and application

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallons of product per square yard	$ per square yard
Well-graded soil	Pre-mixed	.50	.25

Methods of Application:
1. Blade and shape the road surface to a type "A" crown.
2. Spray the product evenly on the road surface.
3. Curing generally takes 12 hours.

Special Comments:
1. Immediately after application some of the emulsion-coated aggregate will stick to the tires of vehicles, therefore road closure is recommended.
2. The product normally lasts 5-6 months.

Enduraseal 100 — Organic Binder

General Description: Enduraseal 100 is a water-based emulsion consisting of Tall Oil Pitch (tree resin), water, and a proprietary blend of additives. It is a cationic solution.

Manufacturer: Cascadia International Inc.
602 - 626 West Pender Street
Vancouver, B.C. Canada
V6B 1V9
Phone: 800-665-2994
Fax: 604-689-8020

Distributor: T Bar S. Enterprises
4700 Hwy. 93 S.
Missoula, MT 59801
Phone: 406-251-5995

Cost: $1.75 per gallon, including product and delivery

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallons of diluted solution per square yard	$ per square yard
Various types of soil	1:3-4	.68*	.24-.30

* Quantity for 3 inches of loose soil.

Methods of Application:

1. Scarify the road surface to a depth of 2-6 inches.
2. Apply the solution to the surface using a distributor.
3. Blade mix or till the material.
4. Windrow the material, lay back down in 2-inch lifts.
5. Compact each lift with a steel wheel or pneumatic roller.
6. Road closure is recommended for 1 hour.

Special Comments:

1. Maintenance applications consisting of a topcoat can be applied at intervals of 3 to 12 months.
2. The initial and maintenance application rates may vary with soil conditions and experience.
3. Enduraseal 100 is used more for dust control while Enduraseal 200 is used primarily for soil stabilization.

Enduraseal 200 — Organic Binder

General Description: Enduraseal 200 is a water-based emulsion consisting of Tall Oil Pitch (tree resin), water, and a proprietary blend of minerals and other additives. It is a cationic solution.

Manufacturer: Cascadia International Inc.
602 - 626 West Pender Street
Vancouver, B.C. Canada
V6B 1V9
Phone: 800-665-2994
Fax: 604-689-8020

Distributor: T Bar S. Enterprises
4700 Hwy. 93 S.
Missoula, MT 59801
Phone: 406-251-5995

Cost: $1.75 per gallon, including product and delivery

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallons of diluted solution per square yard	$ per square yard
Various types of soil	1:3-4	.68*	.24-.30

* Quantity for 3 inches of loose soil.

Methods of Application:
1. Scarify the road surface to a depth of 2-6 inches.
2. Apply the solution to the surface using a distributor.
3. Blade mix or till the material.
4. Windrow the material, lay back down in 2-inch lifts.
5. Compact each lift with a steel wheel or pneumatic roller.
6. Road closure is recommended for 1 hour.

Special Comments:
1. Maintenance applications consisting of a topcoat can be applied at intervals of 3 to 12 months.
2. The initial and maintenance application rates may vary with soil conditions and experience.
3. Enduraseal 100 is used more for dust control while Enduraseal 200 is used primarily for soil stabilization.

Pine Sap Emulsion — Organic Binder

General Description: Pine Sap Emulsion is an organic emulsion which is produced from pine sap, surfactants, and water.

Manufacturer: Cousins Dust Control
1801 E. Matzinger Road
Toledo, Ohio 43612
Phone: 800-433-6754
Fax: 419-729-8506

Cost: $1.25-$1.50 per gallon, including only the cost of the product

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
Soil with compressive fines or loose aggregate	Volume of water to volume of product	Gallons of diluted solution per square yard	$ per square yard
Loose sand	4:1	Proprietary	N/A
Limestone	25-30:1	Proprietary	N/A

Methods of Application:

1. Methods of application are proprietary, but generally the product is mixed into the surface while giving special consideration to the depth and soil characteristics.

Special Comments:

1. The initial application each year may be reduced on following years due to the products residual effects. Maintenance applications may be needed throughout the season.

Road Oyl — Organic Binder

General Description: Road Oyl is a non-ionic emulsion consisting of selected fractions of natural tree resins.

Manufacturer: Soil Stabilization Products
P.O. Box 2779
Merced, California 95344
Phone: 209-383-3296
800-523-9992
Fax: 209-383-7849

Cost: $2.50 per gallon,* including product and delivery

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallon of diluted solution per square yard	$ per square yard
Various types of soil	5:1	Proprietary	N/A

* Cost based on truckload quantity of 6,000 gallons.

Methods of Application:

1. Blade and shape the surface to a type "A" crown.
2. Apply the solution using several passes with a pressure or gravity flow distributor.
3. Compact the surface immediately following application.
4. Road closure will be needed for curing.

Special Comments:

1. The product may cause eye and skin irritation, therefore, safety equipment should be used during the application process.

Soapstock — Organic Binder

General Description: Soapstock is a byproduct of the refining process of soybean oil.

Distributor: Environmental Dust Control, Inc.
1729 260 Avenue
Currie, MN 56123
Phone: Howard Hamilton, 507-763-3481
Robert Nelson, 507-274-5163
Arland Moger, 507-274-5131

Cost: $2 per gallon,* including product, delivery, and application

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallons of product per square yard	$ per square yard
Well-graded soil	Pre-mixed	.25	.50

* Cost based on 150 mile radius Currie, MN. Beyond 150 miles, a freight charge of $1.80 per mile will be added. A 10% discount will be given to shipments of more than 3200 gallons.

Methods of Application:
1. Scarify the road surface to a depth of 1-2 inches and grade to an "A" type crown.
2. Apply the product using either a gravity flow or pressure sprayer.
3. Penetration normally takes 4-6 hours, therefore traffic speeds should be reduced to limit the amount of pickup on vehicle tires.

Special Comments:
1. It is recommended that the road surface be dry preceding the application.
2. If the product is transferred onto a vehicle immediately after application, it can be removed with industrial strength soap and a power sprayer.
3. It is recommended to break up or grade the surface before winter. This is to avoid having to apply salt or sand in the winter.
4. The product can have some residual affects, therefore the application rate may be decreased.

EMS — Polymer Additive

General Description: EMS is a non-petroleum, resinous polymer emulsion. It is used when additional moisture resistance is required beyond EMC Squared's (Enzyme) capability.

Manufacturer: Soil Stabilization Products
P.O. Box 2779
Merced, California 95344
Phone: 209-383-3296
800-523-9992
Fax: 209-383-7849

Cost: $25 per gallon, including only the cost of the product

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
Varies	Volume of water to volume of product	Gallon of product per cubic yard	$ per square yard
Soils containing small amounts of clay to heavy clays	Varies[1]	.133 (2 gal/15 yd^3)	.55[2]

[1] Add the required amount of water to bring the soil to OMC, [2] Based on 6-inch depth.

Methods of Application:

1. Scarify the road surface to a depth of 6-12 inches.
2. Apply the solution to the material with a distributor. The ratio of EMS to EMC Squared is of 2:1. Therefore, 1 gallon of EMC Squared and 2 gallons of EMS will be needed for every 15 yd^3 of soil. Save 5% of the solution for a final surface coat.
3. Mix the material with a grader, disk, or rotary mixer.
4. If rain is forecassted overnight, compact the material that day. If no rain is forecasted, leave the material overnight before compaction. Before compaction occurs on the next day, bring the material back up to OMC.
5. Compact the material with pneumatic or steel wheel rollers.
6. Apply the remaining solution during the final grading (crowning) and compaction operations.
7. If a coarse surface will be applied, allow seven days to cure.
8. If it will remain unsurfaced, allow traffic on the road surface.

Special Comments:
1. It is recommended that soil samples be analyzed to determine performance of the products.
2. The product may cause eye and skin irritation, therefore, safety equipment should be used.

Marloc — Polymer Additive

General Description: Marloc is a poly vinyl acrylic liquid copolymer with an acrylic base having 60% solvents(solids) and 40% water.

Manufacturer: Reclamare Company
20727 7th Avenue S.
Seattle, WA 98198-3408
Phone: 206-824-2385
Fax: 206-824-6798

Cost: $8.10 per gallon,* including only the cost of the product

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallons of diluted solution per square yard	$ per square yard
Well graded soil	30:1	.42	.11

* 55 gallon drum costs $8.10/gallon, 5 gallon pail costs $12.00/gallon. Cost based on 55 gallon drum.

Methods of Application:
1. Scarify the road surface to a depth of 4-6 inches and crown.
2. Apply the solution over the surface with a distributor.
3. Compact the surface with steel wheel or pneumatic roller.
4. Apply a heavy top coat to the surface.
5. Apply a second heavy top coat if heavy traffic will be encountered.
6. Top dress the surface if it starts to breakup.
7. If severe breakup occurs, scarify the surface and reapply the product.

Special Comments:
1. The product may cause eye and skin irritation, therefore, safety equipment should be used during the application process.
2. The application rates shown are for 1/4-1/2 inch penetration. If deeper penetration is required, more solution should be applied.

Polymer/Enzyme — Polymer Additive

General Description: The Polymer/Enzyme is a liquid consisting of polymer products, soil binders, adhesives, resin dispersion agents, and biocatalysts.

Manufacturer: Durasoils, Inc.
400 Sun Valley Drive, W.
PO Box 23613
Nashville, TN 37202
Phone: 800-713-2989

Cost: $82 per gallon, including only the price of the product

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
	Volume of water to volume of product	Gallons of product per cubic yard	$ per square yard
Soil with 10-30% clay	Varies[1]	.067 (1 gal/15 yd^3)	$.92[2]

[1] Add the required amount of water to bring the soil to OMC.

[2] Based on 6-inch depth.

Methods of Application:

1. Scarify the road surface to a depth of 8 inches and windrow the loose material.
2. Apply the solution to the surface with a distributor and the windrowed material with a distributor to obtain OMC.
3. Blend material with blade, disc, or pulverizer. Keep spraying with water to maintain OMC. If too wet, blade and allow to dry, if too dry, add water.
4. Blade and shape the surface to a type "A" crown.
5. Compact with sheeps foot or pneumatic rollers, and finish rolling with vibratory roller.
6. Allow 3-5 days for the road to cure if a wearing surface will be applied.
7. Always cover the base with wearing surface (1 inch chip seal is sufficient).

Special Comments:

1. The product may cause eye and skin irritation, therefore, safety equipment should be used during the application process.

Soil-Sement — Polymer Additive

General Description: Soil-Sement is a polymer emulsion consisting of acrylic and acetate polymers and water.

Manufacturer: Midwest Industrial Supply, Inc.
PO box 8431
Canton, OH 44711
Phone: 330-456-3121
Fax: 330-456-3247

Cost: $2.25 per gallon,[1] including product and delivery

Application:

SOIL TYPES	DILUTION	APPLICATION RATE	COST
Various types of soils	Volume of water to volume of product[2]	Gallons of diluted solution per square yard	$ per square yard
Dust Control	9:1	.75 - 1.49	.17 - .34
Maintenance	9:1	.22 - .60	.05 - .14
Soil Stabilization	4:1	.90 - .2.25	.41 - 1.01
Maintenance	9:1	.22 - .60	.05 - .14

[1] Bulk quantities of 3,000-5,000 gallons

[2] Dilutions range from 4:1 to 19:1. Typical applications are at 9:1

Methods of Application:

Dust Control

1. Blade and shape the road surface to a type "A" crown.
2. Apply the mixture over the surface in several passes using a distributor.

Soil Stabilization

1. Scarify the road surface to the desired depth (typically 3-4 inches), then crown the surface.
2. Apply 70-85% of the total volume on several passes, blending the mixture with a motor grader after each pass. Blade to "A" crown and compact using a steel or rubber tire roller.
3. Apply the remaining solution to the road surface as a top coat.

Special Comments:

1. The traffic speeds should be reduced after application to avoid splashing and material pick up.
2. The product will not corrode or pit equipment.
3. The initial and maintenance application rates are dependent on traffic, spillage, tracking, etc.

4. Soil samples are evaluated by Midwest Industrial Supply, Inc. to determine the application rates, schedules, and costs.

APPENDIX D
SURVEY RESULTS

Appendix Table D-1. Number of Agencies and Additives Currently Used By State.

State	Number of Agencies	Number of Additives Used
Colorado	8	17
Montana	14	18
North Dakota	4	6
South Dakota	10	14
Utah	8	12
Wyoming	13	17
Other	3	6
Total	60	90

Appendix Table D-2. Road Officials' Representation to the Chemical Additive Survey.

Category	Additives Used by Respondents							
	Total	CO	MT	ND	SD	UT	WY	Other*
Chloride Additives	58	11	13	2	10	8	12	2
Calcium Chloride	14	3	2	1	1	3	2	2
Magnesium Chloride	44	8	11	1	9	5	10	--
Clay Additives	16	--	1	4	2	3	3	2
Enzymes	5	--	1	--	--	3	1	--
Ionic	3	--	--	--	--	--	--	2
Other Clay Additive	8	--	--	4	2	--	2	--
Bituminous	7	2	3	--	--	--	1	1
Organic Non-Bituminous	5	2	1	--	2	--	--	--
Water	4	2	--	--	--	1	1	--

* 3 responses were obtained from Michigan and Canada using 5 products

Appendix Table D-3. Road Officials' Use of Chemical Additive Based on Average Daily Travel (ADT) by Percentage Response.

Category	# of Responses	Light ADT	Medium ADT	Heavy ADT
Chloride Additives	58	40	50	26
Calcium Chloride	14	50	43	21
Magnesium Chloride	44	36	52	27
Clay Additives	16	25	50	31
Enzymes	5	40	60	20
Ionic	3	0	67	33
Other Clay Additive	8	25	38	38
Bituminous	6	17	50	33
Organic Non-Bituminous	5	60	40	40
Water	4	0	33	67

Appendix Table D-4. Road Officials' Responses of How The Chemical Additives Were Applied by Percentage Response.

Category	# of Responses	Sprayed	Spread	Mixed-In-Place
Chloride Additives	58	93	5	12
Calcium Chloride	14	79	14	7
Magnesium Chloride	44	98	2	14
Clay Additives	16	38	0	88
Enzymes	5	40	0	100
Ionic	3	0	0	100
Other Clay Additive	8	50	0	75
Bituminous	6	83	0	17
Organic Non-Bituminous	5	80	0	60
Water	4	75	0	25

Appendix Table D-5. Road Officials' Responses of When The Chemical Additive Were Applied by Percentage Response.

Category	# of Responses	Spring	Summer	Fall	Necessary Follow-up
Chloride Additives	57	60	5	35	65
Calcium Chloride	14	79	7	14	71
Magnesium Chloride	43	53	5	42	63
Clay Additives	16	31	13	56	33
Enzymes	5	60	0	40	40
Ionic	3	0	33	67	0
Other Clay Additive	8	25	13	63	50
Bituminous	7	14	14	71	71
Organic Non-Bituminous	5	20	0	80	40
Water	5	40	20	40	80

Appendix Table D-6. Road Officials' Ratings of Chemical Additive Effectiveness by Months Based on Percentage of Response.

Category	# of Responses	<3	3-6	6-12	Other
Chloride Additives	59	3	42	37	17
Calcium Chloride	14	0	71	21	7
Magnesium Chloride	45	4	33	42	20
Clay Additives	14	0	7	29	64
Enzymes	5	0	20	40	40
Ionic	2	0	0	0	100
Other Clay Additive	7	0	0	29	71
Bituminous	5	0	20	60	20
Organic Non-Bituminous	4	25	50	25	0
Water	4	50	0	25	25

Appendix Table D-7. Road Officials' Responses of Necessary Follow-up and Other Durations of Effectiveness From Tables 5 and 6.

Category	Necessary Follow-up (Months)					Other Effectiveness (Months)				
	Resp. #	# Value	Min.	Ave.	Max.	Resp. #	# Value	Min.	Ave.	Max.
Chloride Additives	38	37	1	9.2	15	10	5	15	22.2	36
Calcium Chloride	10	10	1	8.3	12	14	1	18	18	18
Magnesium Chloride	28	27	3	9.5	15	9	4	15	23.5	36
Clay Additives	6	6	6	11.5	15	9	2	24	24	24
Enzymes	2	2	12	13.5	15	2	0	N/A	N/A	N/A
Ionic	0	0	N/A	N/A	N/A	2	0	N/A	N/A	N/A
Other Clay Additive	0	4	6	10.5	12	5	2	24	24	24
Bituminous	5	5	12	12	12	1	1	30	30	30
Organic Non-Bituminous	2	2	3	7.5	12	0	0	N/A	N/A	N/A
Water	4	2	3	4.5	6	1	1	.25	.25	.25

Written responses for effectiveness duration for respondents that answered "Other" to Appendix Table D-6):

Magnesium Chloride
- 4- Depends on weather and traffic
- 1- Still checking

Enzymes
- 1- Several years
- 1- 6 years

Ionic
- 1- It has lasted two seasons so far
- 1- It has been in place for three years now without any sign of breakup

Other Clay additives
- 1- Unknown
- 2- Chip sealed over product to keep out water

Appendix Table D-8. Road Officials' Ratings of Chemical Additive Effectiveness by Percentage Response.

Category	# of Responses	Potholes				Washboards				Frost Heave			
		Good	Fair	Poor	NC	Good	Fair	Poor	NC	Good	Fair	Poor	NC
Chloride Additives	58	28	50	10	12	36	50	9	5	11	12	25	53
Calcium Chloride	14	21	29	7	43	21	50	7	21	14	14	29	43
Magnesium Chloride	44	30	57	11	2	41	50	9	0	9	12	23	56
Clay Additives	15	53	27	7	13	53	40	0	7	27	20	7	47
Enzymes	5	40	60	0	0	60	40	0	0	20	20	0	60
Ionic	3	100	0	0	0	100	0	0	0	67	0	33	0
Other Clay Additive	7	43	14	14	29	29	57	0	14	14	29	0	57
Bituminous	7	29	43	14	14	13	63	13	13	0	0	43	57
Organic Non-Bituminous	5	60	20	20	0	80	0	20	0	20	20	0	60
Water	3	33	0	67	0	33	0	67	0	33	0	67	0

Appendix Table A-D. Road Officials' Ratings of Chemical Additive Effectiveness by Percentage Response.

Category	# of Responses	Soil Strength				Overall Rating			Customer Service			
		Good	Fair	Poor	NC	Good	Fair	Poor	Good	Fair	Poor	NC
Chloride Additives	58	11	47	5	37	67	29	3	67	25	0	7
Calcium Chloride	14	0	50	14	36	57	29	14	64	21	7	7
Magnesium Chloride	44	14	47	2	37	70	30	0	65	26	2	7
Clay Additives	15	60	40	0	0	47	47	7	60	40	0	0
Enzymes	5	100	0	0	0	60	40	0	40	60	0	0
Ionic	3	100	0	0	0	100	0	0	100	0	0	0
Other Clay Additive	7	14	86	0	0	14	71	14	57	43	0	0
Bituminous	7	43	43	0	14	100	0	0	100	0	0	0
Organic Non-Bituminous	5	40	0	0	60	60	20	20	80	0	0	20

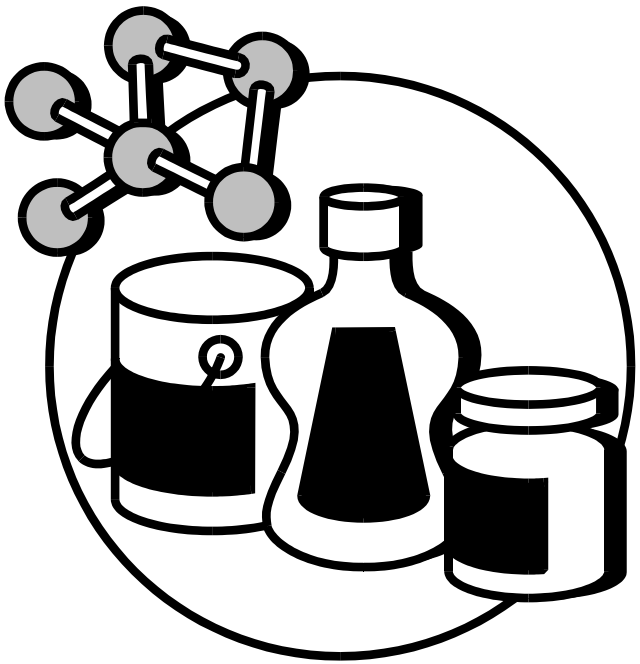
Water	3	33	0	67	0	33	0	67	0	

Appendix Table D-10. Road Officials' Labor and Cost Information.

Category	Labor Required				Labor $/yd²				Product $/yd			
		Min.	Ave.	Max.		Min.	Ave.	Max.		Min.	Ave.	Max.
Chloride Additives	53	1	3.1	8	18	.01	.15	.62	22	.06	.25	.96
Calcium	14	1	2.9	8	9	.05	.19	.62	11	.04	.21	.45
Magnesium	39	1	3.2	6	13	.01	.13	.62	15	.06	.27	.96
Clay Additives	14	2	4.5	8	6	.03	.43	1.50	7	.020	.20	.50
Enzymes	5	3	3.8	6	5	.14	.20	.25	2	.13	34	.54
Ionic	1	5	5	5	1	1.50	1.50	1.50	N/A	N/A	N/A	N/A
Other Clay	7	2	4.9	8	3	.03	.05	.08	4	.02	.21	.50
Bituminous	5	1	3.6	7	4	.05	.30	.77	4	.10	.26	.50
Organic Non-	5	1	3.6	6	2	.15	.23	.30	4	.18	.37	.67
Water	3	2	2.7	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

APPENDIX E
CHEMICAL ADDITIVE SURVEY

Low Volume Road Chemical Additive Survey



DUST CONTROL/SOIL STABILIZATION SURVEY
What COUNTY/ AGENCY are you reporting for?

Does your COUNTY/ AGENCY use dust control or soil stabilizing chemicals on the gravel road system? _____

❑YES ❑ NO

If NO, please tear out this page and return it to us, so that we do not send you follow up surveys.

How many miles of gravel road do you have in your county?

How many gravel road miles do you treat with: _____

DUST CONTROL CHEMICALS *SOIL STABILIZERS*

How many years have you been using chemical additives on the gravel road system?

What chemical based *DUST CONTROL/SOIL STABILIZERS* products have you used (please check all that you have used and circle how the product was used)?

❑	Calcium Chloride	Dust Control		Soil Stabilizer
❑	Magnesium Chloride		Dust Control	Soil Stabilizer
❑	Organic binders	Dust Control		Soil Stabilizer
❑	Resinous adhesives		Dust Control	Soil Stabilizer
❑	Surfactants		Dust Control	Soil Stabilizer
❑	Enzymes		Dust Control	Soil Stabilizer
❑	Flyash		Dust Control	Soil Stabilizer
❑	Lime		Dust Control	Soil Stabilizer
❑	Water		Dust Control	Soil

Stabilizer

❑ Other Dust Control Soil Stabilizer
❑ Other Dust Control Soil Stabilizer
❑ Other Dust Control Soil Stabilizer

Please write the previously mentioned product(s) in the space provided and answer the questions about each particular product.

PRODUCT

Product distributor
Distributor's address

Did you perform any initial soils testing to determine which product to use? ❑ YES ❑ NO

If so, what kind of testing was performed (i.e., plasticity index, grain size distribution, etc.)?

How would you describe the soil characteristics in your area?

What is the average daily traffic (ADT) of your roads treated with this dust controlling product?

Light (< 100)
Medium (100-250)
Heavy (> 250)

In what form is the product applied? ❑ solid ❑ liquid

How do you apply the product?

❑ Sprayed on surface ❑ Spread on surface ❑ Mixed in place

Have you experienced any difficulties with applying the product?

❑ YES ❑ NO

If YES, please explain:

What time of the year do you make the first application?

Spring
Summer
Fall

What is the application rate? (lbs/yd^2) (gal/yd^2)

How do you determine this rate?

In your experiences, how long does this application remain effective?

❑ Less than 3 months
❑ 3-6 months
❑ 6-12 months
❑ Other

Do you apply a follow up application? ❑ YES ❑ NO

If YES, when is the second application made (i.e., 3, 6, or 12 months later)?

What is the follow up application rate? (lbs/yd^2)
(gal/yd^2)

How do you determine this rate?

In your experiences, how long does the follow up application remain effective?

- ❑ Less than 3 months
- ❑ 3-6 months
- ❑ 6-12 months
- ❑ Other

Do you need to temporarily close the road after applying the product?

❑ YES ❑ NO

If YES, for how long?

Have any failures occurred? ❑ YES ❑ NO

If YES, please explain:

How would you rate the product in controlling potholes?

- ❑ Good
- ❑ Fair
- ❑ Poor
- ❑ Not considered

How would you rate the product in controlling washboards?

- ❑ Good
- ❑ Fair
- ❑ Poor
- ❑ Not considered

How would you rate the product in controlling frost heave?

- ❑ Good
- ❑ Fair
- ❑ Poor
- ❑ Not considered

How would you rate the product in increasing soil strength (i.e. California Bearing Ratio)?

- ❑ Good
- ❑ Fair
- ❑ Poor
- ❑ Not considered

How would you rate the product in overall *SOIL STABILIZATION/DUST SUPPRESSANT*?

- ❑ Good
- ❑ Fair
- ❑ Poor

How would you rate the company's customer service?

- ❑ Good
- ❑ Fair
- ❑ Poor
- ❑ Not Considered

Comments:

What equipment do you use to apply the product?

- ❑ Motor grader
- ❑ Water truck
- ❑ Rubber-tired roller
- ❑ Asphalt distributor
- ❑ Steel wheel roller
- ❑ Other

How may people are normally needed to apply the product?

What is the approximate labor costs to apply the product?

$ per yd^2

What is the approximate cost of the product?

$ per yd^2

How much does this procedure save annually in regraveling cost?

$ per yd^2

How much does it save in patching each year?

$ _____ per yd^2

Do you feel this procedure is cost effective from a maintenance perspective?

❑ YES ❑ NO

General Comments:

THANK YOU FOR YOUR TIME AND COOPERATION

❑ Please send me a copy of the final report.

Name: _____

Address: _____

APPENDIX F
PROGRAM RECORD KEEPING FORMS

Record for Dust Control/Soil Stabilization Program

Department: _____ Date: _____

Road Identification: _____ ADT Estimate: _____

Project Location:

From: _____ Length: _____ miles

To: _____ Width: _____ feet

Product Used: _____

Initial Application Rate: _____ gal/yd^2 or lb/yd^2

Follow-up Application Rate: _____ gal/yd^2 or lb/yd^2

Item	Total Cost	Cost/mile
A. Road Improvement Cost • Drainage Improvements • Geometric Improvements • Repair of Failed Areas • Addition of Gravel Surfacing		
B. Surface Preparation Cost • Addition for Selected Material (fines, etc.) • Scarifying, Watering, Shaping, Compacting		
C. Product Supply and Application Cost • Material Supply • Transportation & Application Cost		
D. Miscellaneous Cost • Traffic Control, Detours • Inspection, Supervision • Other Costs		
Total Cost of Program		
Cost Excluding Item "A" Above		

Source: UMA Engineering Ltd. “Guidelines for Cost Effective Use and Application of Dust Palliatives,” Roads and Transportation Association of Canada, Ottawa, Canada, 1987, page 17.

Benefit Record for Dust Control/Soil Stabilization Program

Tangible Benefits	Estimated Savings /mile/year
1. Reduced maintenance cost (estimated 25-75% savings over previous blading costs; use local figures, if available). 2. Reduce regraveling (estimate based on traffic volume and climate impacts or use local figures if available). 3. Other tangible benefits.	
Total Tangible Benefits/mile	

Intangible Benefits

1. Reduced vehicle accidents.
2. Reduced vehicle damage.
3. Higher quality of life and property values.
4. Reduced cleaning costs.
5. Reduced dust-induced respiratory problems.
6. Reduced sedimentation in water bodies.
7. Reduced impact on dust sensitive vegetation.
8. Reduced complaint from the public.

Source: UMA Engineering Ltd. "Guidelines for Cost Effective Use and Application of Dust Palliatives," Roads and Transportation Association of Canada, Ottawa, Canada, 1987, page 18.

APPENDIX G
GLOSSARY OF TERMS

Acetate - something as a textile fiber made from cellulose acetate**.**

Acrylic Resin - a glossy thermoplastic made by polymerizing acrylic or methacylic acid or a derivative of either and used for cast and molded parts or as coating and adhesives.

Amorphous - having no definite form.

Aromatic - characterized by increased chemical stability resulting from the delocalization of electrons in a ring system containing usually multiple conjugated double bonds.

Adhesive - an adhesive substance (as glue or cement).

Asphalt - a dark brown to black cementitious material that is either naturally occurring or is produced by petroleum distillation.

Bitumen - any of various mixtures of hydrocarbons (as tar) often together with their nonmetallic derivatives that occur naturally or are obtained as residues after heat-refining natural substances (as petroleum).

Bituminous - containing or impregnated with bitumen.

Cellulose Acetate - any of several compounds insoluble in water that are formed especially by the action of acetic acid, anhydride of acetic acid, and sulfuric acid on cellulose and are used for making textile fibers, packaging sheets, varnishes, etc.

Cohesion - the act or state of sticking together tightly.

Colloid- a substance that consists of particles dispersed throughout another substance which are too small for resolution with an ordinary microscope.

Deliquescent - tending to undergo gradual dissolution and liquefaction by attraction and absorption of moisture from air. It resists evaporation and stays in solution.

Derivative - A chemical substance related structurally to anotther substance and theoretically derivable from it.

Dispersant - a substance for promoting the formation and stabilization of a dispersion of one substance in another.

Dispersion- a system consisting of a dispersed substance and the medium in which it is dispersed.

Distillate - a liquid product condensed from vapor during distillation.

Distillation - the process of purifying a liquid by successive evaporation and condensing.

Emulsified Asphalts - (also simply called emulsion) is a mixture of asphalt cement, water, and emulsifying agent. The emulsifying agent imparts an electric charge to the surface of the asphalt droplets, which causes them to repel one another.

Types of emulsified asphalts:

1. Anionic - electro-negative charged asphalt droplets.
2. Cationic - electro-positive charged asphalt droplets.

Emulsifier - a surface active agent(as a soap) promoting the formation and stabilization of an emulsion.

Emulsify - to convert (2 or more) immiscible liquids into an emulsion.

Emulsion - a system consisting of a liquid dispersed with or without a emulsifier in an immiscible liquid usually in droplets of larger than colloidal size.

Enzyme - any numerous complex proteins that are produced by living cells and catalyze specific biochemical reactions at body temperature.

Hygroscopic - take up and retained under some conditions of humidity and temperature. It draws moisture from the air.

Ion - An atom or group of atoms that carries a positive or negative electric charge as a result of having lost or gained one or more electrons.

Lignin - an amorphous polymer related to cellulose that provides rigidity and together with cellulose forms the woody cell walls of plants and the cementing material between them.

Lignosulfonate - any of various compounds produced from the spent sulfite liquor in the pulping of softwood in papermaking and used especially for binders and dispersing agents.

Maximum Dry Unit Weight - The maximum weight of the soil solids in a unit volume. The highest degree of compaction is achieved at this unit weight.

Optimum moisture content - The moisture content where the maximum dry unit weight is achieved.

Oxidize - To combine with oxygen.

Oxidizing agent - A substance that oxidizes something especially chemically (such as by accepting electrons).

Petroleum - an oily flammable bituminous liquid that may vary form almost colorless to black, is a complex mixture of hydrocarbons with small amounts of other substances.

Plasticity - the ability to retain a shape attained by pressure deformation.

Polymer - a chemical compound or mixture of compounds formed by polymerization and consisting essentially of repeating structural units.

Polymerization - a chemical reaction in which two or more molecules combine to form larger molecules that contain repeating structural units.

Resin - any of various solid or semisolid amorphous fusible flammable natural organic substances that are usually transparent or translucent and yellowish to brown, are formed especially in plant secretions, are soluble in organic solvents (such as ether) but not in water.

Scarify - to break up and loosen the surface.

Silicate - any of numerous insoluble often complex metal salts that contain silicon and oxygen in the anion, constitute the largest class of minerals, and are used in building materials (such as cement, bricks, and glass).

Surfactant - a surface-active substance (as a detergent). When surfactants are added to a liquid, it reduces its surface tension, thereby increasing its spreading and wetting properties[2].

Tar - a brown to black bituminous usually odorous viscous liquid obtained by destructive distillation of organic material (such as wood, coal, or peat).

Windrow - a long low ridge of road-making material scraped to the side of a road.

Source: Term descriptions were provided by *Merriam-Webster's Collegiate Dictionary* (1996), the *Hot Mix Asphalt Materials, Mixture Design and Construction* (1991), and the *Principles of Geotechnical Engineering* (1994).

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