

## EVALUATION OF NONTRADITIONAL SOIL AND AGGREGATE STABILIZERS: A SUMMARY

### Introduction

Proprietary chemical products are marketed by a number of companies for stabilizing pavement base and subgrade soils. Usually supplied as concentrated liquids, these products are diluted in water on the project site and sprayed on the soil to be treated prior to mixing and compaction. If effective, these products might be used as alternatives for treating sulfate-rich soils, which are susceptible to excessive heaving when treated with traditional, calcium-based stabilizers such as lime, cement, and fly ash. However, the chemical composition, stabilizing mechanisms, and performance of these liquid products are not well understood. In this study, we investigated the mechanisms by which clay soils are modified by these liquid chemical agents. We also attempted to quantify changes in the engineering properties of different clays following treatment.

We selected three representative commercial products for study: an ionic product, an enzyme product, and a polymer product. The chemical composition of each was characterized using a variety of chemical test methods. The three products were then reacted with three reference clays (kaolinite, illite, and montmorillonite) and several native Texas soils.

In the “micro-characterization” study, we studied the mechanisms of soil modification at the particle level using physical-chemical analyses of untreated and treated soil samples. Extremely high product application rates were used so that possible soil modifications could be observed.

In a paired “macro-characterization” study, we performed standard geotechnical laboratory tests on untreated and treated compacted soil specimens. The products were mixed at the suppliers’ recommended application rates

and at ten times the recommended application rates. These tests failed to show significant, consistent changes in the engineering properties of the test soils following treatment with the three selected products at the application rates used.

### What We Did...

We began by selecting three commercially available, liquid soil stabilizer products for evaluation. Although no effort was made to assemble and classify a comprehensive list of available products and suppliers, it appears that the most readily available liquid soil stabilizers can be classified as one of three types:

- (1) *Ionic stabilizers*, reported to work through cation exchange within the clay mineral
- (2) *Enzyme stabilizers*, described as consisting of various organic catalysts
- (3) *Polymer stabilizers*, comprised of various organic and inorganic polymers

A representative product of each type was chosen and samples were obtained from the suppliers. We have not identified the specific product names to avoid endorsement of particular products and to avert disclosure of the chemical components of proprietary materials.

Next, we analyzed the selected products to identify the primary or active ingredients and quantify the physical and chemical characteristics of each. The analytical techniques included pH, conductivity, ion chromatography (IC), potentiometric titrations, total organic carbon (TOC) analysis, Fourier transform infrared (FTIR) spectroscopy, gas chromatography/mass spectrometry (GC/MS), high performance liquid chromatography/mass spectrometry (HPLC/MS), gel permeation chroma-

tography (GPC), UV/Vis spectroscopy, and nuclear magnetic resonance (NMR) spectroscopy. In some cases, we synthesized the stabilizer components in the laboratory or purchased them from other chemical supply companies to verify our conclusions.

The three stabilizer products were then reacted with three reference clays and five native Texas clay soils. We tested samples of the well-characterized, reference clays (kaolinite, illite, and montmorillonite) to increase the likelihood of observing subtle physical-chemical changes. The five mixed, native clays were all highly plastic, fat clays; one had a high sulfate content.

Because the test results are influenced by details of how the test specimens are prepared, we developed and followed a detailed, rational protocol for preparing the soil test samples. The same water content was used to prepare untreated and treated specimens of a given soil, so that the effect of the stabilizer on the measured soil properties could be distinguished from the effects of varying the moisture content. For the same reason, the samples were maintained at a constant water content during a seven-day curing period. The specimen preparation protocol was sent to a number of industry and TxDOT representatives for comment, from which a final, thirteen-step protocol was developed.

In the micro-characterization study, we characterized the soils at the particle level before and after treatment, in an effort to observe the clay/stabilizer interactions. The clay materials were characterized using BET surface area analysis, cation exchange capacity (CEC), environmental scanning electron microscopy (ESEM), scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDX), and X-ray diffraction (XRD). For most



of the tests in this part of the study, we used a product application mass ratio of 1:2 (mass of concentrated stabilizer to mass of dry soil), which is much higher than the application rates suggested by the manufacturers. The extremely high application rates were used to maximize any chemical changes in the structure and morphology of the clay minerals and increase the likelihood of observing the underlying stabilizer mechanisms.

In the macro-characterization study, we used standard geotechnical laboratory tests to assess whether the engineering properties of the test soils were altered by chemical treatment. Tests included measurement of the Atterberg limits (liquid limit, plastic limit, and plasticity index), compaction characteristics (evaluated by comparing the compacted density of untreated and treated specimens), undrained shear strength (measured using unconsolidated undrained triaxial compression tests), and free swell potential (determined from one-dimensional swell tests). Tests on the three reference clays and two of the native soils were conducted using the suppliers' recommended application rates. These tests failed to show conclusive results, so follow-up tests were conducted on three other native clays with the stabilizers applied at ten times the recommended application rates. To better judge the efficacy of the liquid stabilizers, we also tested the soils in this last test series

following conventional treatment with 6% hydrated lime.

### What We Found...

Chemical analysis of the liquid products, coupled with the results from the micro-characterization study, allow us to suggest the mechanisms by which these selected products may affect a clay soil.

The main ingredient of the ionic stabilizer was sulfonated limonene, which we were able to synthesize in our laboratory. The hypothesized mechanism for the ionic stabilizer was cation exchange with subsequent alteration in the clay mineral lattice. It was hypothesized that the sulfonated limonene could preferentially extract aluminum from a clay mineral. However, even at the high application ratios we employed, significant changes in clay mineralogy were not apparent in the ESEM images, the d-spacings measured in XRD tests indicated the continued presence of expansive clay minerals, and decreases in Al:Si ratio were not significant in many cases. Examples of this test data are presented in Figure 1.

For the enzyme stabilizer, we identified polyethylene glycol as the principal ingredient, but it appears that polyethylene glycol is used only as a protein/enzyme deactivator. It is likely that the active ingredient is micro-biological in nature, which is why it wasn't identified through our testing. The enzyme

stabilizer is reported to act in several ways, including the breakdown of clay minerals with expulsion of water from the double layer, the binding of clay particles by aggregation, internal or external adsorption to clay layers preventing water absorption, or interlayer expansion with subsequent moisture entrapment. The XRD results from clays treated at the high application ratios were consistent with interlayer expansion. In addition, the surface area results following the enzyme treatment generally showed the largest decrease in surface area of all of the stabilizers tested. For the nonexpanding clay minerals, the hypothesized mechanism of providing an adsorbing surface complex on the edges of clay particles was supported by surface area measurements, pore size distributions, ESEM images, and EDX Al:Si ratios.

We identified sodium silicate as the principal component of the polymer stabilizer. The hypothesized mechanism involved formation of a strongly adhesive, aggregated material. Furthermore, the polymer stabilizer was alleged to coat the surface of soil particles rather than chemically altering the clay inner layers. The results of polymer treatment for all soils tested supported the proposed mechanism of surface coating and aggregation. This was confirmed consistently by the ESEM images and BET analysis. No changes in d-spacing or Al:Si ratio were reported, which is as expected because of the interaction of the polymer stabilizer and clay by physical rather than chemical means.

In the first part of the macro-characterization study, we treated the soils at the suppliers' recommended application rates, which ranged from 1:50,000 to 1:1000 (0.002% to 0.1% by mass). The amount of chemical product added to the soil was thus very small. Much of the differences in the engineering properties we measured could be attributed to sample variation, particularly minor differences in the water content of the compacted test samples. Overall, we observed no significant, consistent improvement in the engineering properties when the five soils tested were treated with the three selected stabilizer products at the suppliers' recommended application rates.

We then undertook additional tests in a follow-up study that was not part of the project work plan. Using three different natural clay soils, the same three stabilizer products were tested. Here, we applied the stabilizers to the soils at ten times the application rates recommended by the product suppliers, to see if higher application rates would lead to noticeable soil improvements. Following treatment with the three liquids at the elevated application rates, the strength and swell potential of the soil were within the trends and scatter for the untreated soil (Figure 2). For comparison, the same test soils were also treated with 6% hydrated lime, which produced noticeable changes in the properties (Figure 2). As before, no consistent, significant improvement in the engineering

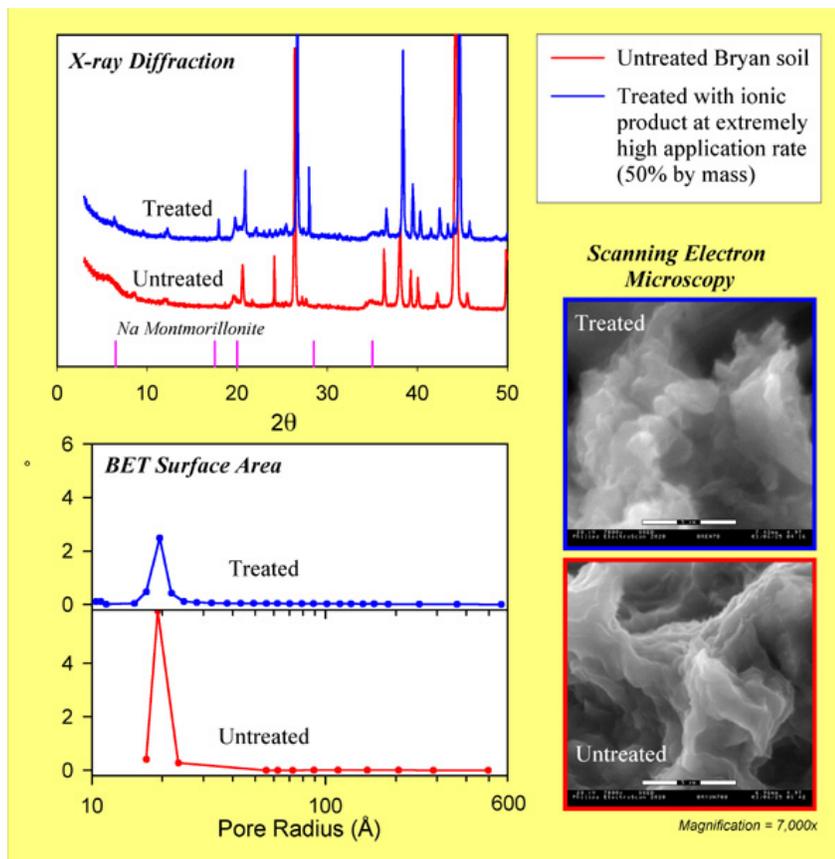


Figure 1: Example data from physical-chemical study of stabilizer reactions with the test soils at very high application rates



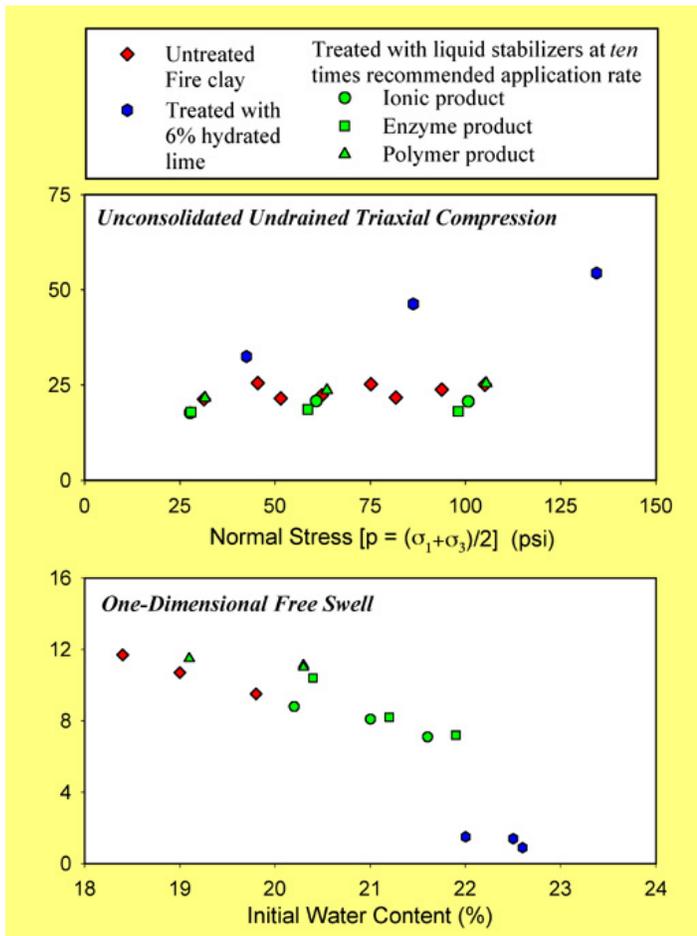


Figure 2: Measured undrained strengths and swell potentials of untreated and treated samples of one test soil

properties of these soils were observed, even with the high application rates used.

Although evidence of the physical-chemical reactions of the three products was obtained in the micro-characterization study, those tests were conducted at extremely high application rates (50% by mass). Those rates would not be economical or practical in the field. Tests in the macro-characterization study at the suppliers' recommended application rates (0.002% to 0.1% by mass) and at ten times the recommended rates failed to show significant improvements in the engineering properties of the soils tested.

### The Researchers Recommend...

The findings of this study clearly point to the need to conduct standard laboratory tests, prior to using these products in field applications, to prove the effectiveness of the treatment on a particular soil type at a given chemical application rate. Although effective liquid chemical soil stabilizers may exist, we think it is prudent to view supplier claims with skepticism until the performance of such products can be clearly quantified through objective laboratory testing or controlled field trials. In future evaluations of nontraditional soil stabilizers, we

recommend:

(1) Potential suppliers of chemical soil stabilizers should provide independent, objective data on the performance of their products. Testimonials from other users should be considered inadequate and unreliable for demonstrating effectiveness.

(2) Application rates should be expressed in a consistent manner, such as the application mass ratio (AMR, defined as the mass of concentrated chemical product per mass of oven-dry soil). The application rate, and not the degree of dilution in water, is the key parameter for expressing how much product should be applied to the soil.

(3) The application rate needed for obtaining the desired performance is likely to depend on the specific characteristics of the soil to be treated, including the clay content and nature of the clay mineral. Hence, before using these chemical products, an appropriate product application rate should be determined for the project-specific soils.

(4) We did not attempt to determine how much improvement in the engineering properties of a soil is needed to justify the application of a soil stabilizer. More research may be needed to provide guidance on what minimum engineering properties are desired for pavement applications.

(5) Laboratory investigations of the effectiveness of chemical soil treatments should include multiple tests on identically prepared specimens, with tests on both the untreated soil and soil treated over an appropriate range of application ratios. Standard, accepted test methods should be followed to measure the engineering properties of interest.

(6) Initial estimates of the appropriate application ratios can be determined through micro-characterization studies of treated and untreated samples. X-ray diffraction (oriented and glycolated samples) and BET surface area analysis were found to be the

most useful for assessing changes in soil characteristics.

(7) The results from laboratory tests on chemically treated soils will depend on how the test specimens are prepared. Variations in water content and compaction can lead to measurable differences in the soil properties that obscure the possible effects of a chemical additive. A rational protocol for specimen preparation, which includes control of specimen water content and a seven-day cure at constant moisture, was developed in this study with input from TxDOT and industry representatives.

(8) In this study, the test specimens were prepared using ASTM standard impact compaction methods (standard and modified Proctor compaction efforts). Other standard impact compaction methods for soils would also be appropriate. To reduce the variations in the test data, it may be possible to produce more uniform, repeatable test specimens using static compaction methods.

(9) The shear strength of treated soils should be evaluated using standard test methods. In this study, soils strengths were evaluated using unconsolidated undrained triaxial compression tests following ASTM standard methods. Other standardized test methods for measuring soil strength may also be appropriate. However, unconfined compression tests are not recommended.

(10) The expansiveness or potential swell of treated soils should be evaluated using standard test methods. In this study, one-dimensional free swell potential under a nominal seating pressure was measured using ASTM standard methods. Other standardized test methods measuring expansiveness, including three-dimensional swell tests on unconfined specimens, may also be appropriate.

(11) Pavement performance is closely related to the stiffness of the underlying base and subgrade materials. Tests to measure the stiffness of untreated and treated soils, such as resilient modulus tests, should be considered.

(12) If a stabilizer product under consideration shows favorable results in a laboratory study, field tests may be warranted. Field tests of soil stabilizers in pavement base or subgrade layers must include untreated control sections and quantitative measurements of performance.

(13) For products that are found to produce significant improvements in soil properties, additional studies will be needed to assess the permanence and long-term effectiveness of the product.



## For More Details...

Research Supervisor: Alan F. Rauch, Ph.D., 512-232-3687  
email: [arauch@mail.utexas.edu](mailto:arauch@mail.utexas.edu)  
TxDOT Project Director: Darren G. Hazlett, P.E., 512-232-1902  
email: [dhazlet@mailgw.dot.state.tx.us](mailto:dhazlet@mailgw.dot.state.tx.us)

The research is documented in the following reports:

1993-1, *An Analysis of the Mechanisms and Efficacy of Three Liquid Chemical Soil Stabilizers (2 Volumes)*, May 2003

To obtain copies of a report: CTR Library, Center for Transportation Research,  
(512) 232-3138, email: [ctrlib@uts.cc.utexas.edu](mailto:ctrlib@uts.cc.utexas.edu)

## TxDOT Implementation Status December 2003

The recommendations of this study have been implemented in several TxDOT districts to deal with non-standard soil stabilizers. These recommendations are also being applied in a new research project, 0-4240. This project includes the evaluation of several non-standard soil stabilizers.

For more information contact: Dr. German Claros, P.E., Research and Technology Implementation Office  
(512)465-7403, [gclaros@dot.state.tx.us](mailto:gclaros@dot.state.tx.us).

### Your Involvement Is Welcome!

## Disclaimer

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3208 Red River, Suite #115  
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