Nonstandard Stabilization of Aggregate Road Surfaces

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A study of the performance of aggregate road surfaces treated with nonstandard stabilizers is described. Over 100 mi of road surfacing in a broad range of environments was treated with three general types of stabilizers: (a) pozzolans, (b) bioenzymes, and (c) an electrolyte. These stabilizers are byproducts of other industries and are generally unknown to road builders. When used appropriately, they have been found to be more effective than standard stabilizers. Factors considered in the evaluation included the aggregate gradation, types of failures reduced or eliminated, improvement in surfacing resilience, and economic benefits. The cost of application of these stabilizers was found to be comparable to the cost of aggregate replacement. The stabilization effected is permanent and long lasting. The benefits include substantial reductions in aggregate loss, reduced maintenance frequency, and improved road serviceability. Sources, recommended application percentages, and methods of application and mixing are described for each stabilizer. Several test or demonstration road sections are also discussed for each. Data on Clegg Impact Values obtained from these roads are presented. It is concluded that substantial economic and service benefits are to be realized from the use of these stabilizers.

During the past decade, a number of relatively unknown soil and aggregate stabilizers have been made available to the construction industry. Most of these materials are byproducts of unrelated processes, produced or modified specifically for use as stabilizers. Unlike traditional stabilizers such as lime, Portland cement, and bitumens, there are no standard laboratory tests in use to effectively predict the performance of these stabilizers in the field. Because their producers are generally unfamiliar with the construction industry, effective communication with builders has been lacking. The considerable benefits of the stabilizers remain undiscovered to large segments of the construction industry, many of whom are seeking effective solutions to longstanding problems.

An attempt was made to bridge this gap in communication by identifying some of the advantages and limitations of these products, and thereby help builders reap the benefits of the years of research that have gone into the development of these materials for use as stabilizers. Efforts were concentrated on three types of materials: (a) pozzolans, (b) bioenzymes (biocatalysts), and (c) an electrolyte. Brief descriptions of an acrylic polymer and a pine tar derivative are also included.

Because standard laboratory tests were not available, construction of test and demonstration road sections was primarily used. During the past few years, well over 100 mi of road surfacing or subgrade have been stabilized with these materials at sites scattered across the United States. The majority of these sites are on forest development roads (FDRs) on National Forest land of the U.S. Department of Agriculture (USDA) Forest Service, Southern Region. The prolonged and often intense rainfall of this area, together with the thousands of miles of highly erosive aggregate surfacing and vast exposures of expansive clay subgrade soils, had provoked an early interest in low-cost stabilizers among National Forest road managers. Other users of these materials include several state, county, and local government organizations, as well as private enterprise.

Region 8 of the Forest Service began trial installations of these materials in 1982. Initial efforts were based on reports from New Zealand (*1*) on their experience with modifying soils and aggregates using low percentages of Portland cement or lime. Attention shifted to other stabilizers as they became known. Project specifications have been developed for treatment of subgrades, aggregate bases, and aggregate surfacing. In 1987, the Federal Lands Highways Coordinated Technology Implementation Program (CTIP) approved a project to evaluate and report on these materials. The final CTIP report is scheduled for February 1992 and will include additional products and projects. This progress assessment includes evaluation of sections currently completed.

EVALUATION FACTORS

In evaluating the performance of nonstandard stabilizers, several factors dominated the concerns and benefits under consideration. These factors include aggregate gradation, surfacing resilience, and economy.

Aggregate Gradation

Aggregate gradation was noted to be an important factor in the performance of the treated aggregate surfaces, regardless of the type of stabilizer used (see Figure 1). The best performance was obtained from aggregates with 30 to 50 percent retained on the No. 4 sieve, and within this range the better graded aggregates showed the least surface damage under prolonged use without maintenance. These surfaces developed a well-armored appearance under traffic, similar to a bituminous surface treatment. Aggregates with less than 20 percent retained on the No. 4 sieve developed excessive fines on the surface and developed shallow ruts. Aggregates with more than 50 percent retained on the No. 4 sieve developed

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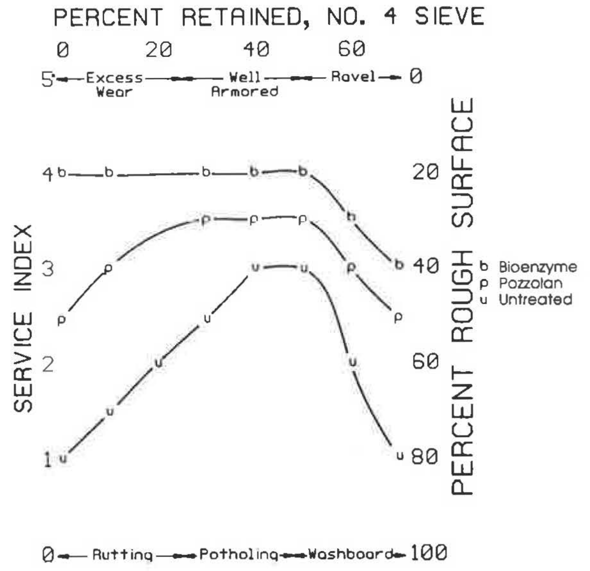

FIGURE 1 Performance of treated surfaces as related to percentage of coarse material in aggregate.

excessive surface ravel in large aggregate, which has an abrasive effect on the surface under traffic. As this layer of loose material thickens, corrugations occasionally develop on grades.

Surfacing Resilience

The absence of standard testing procedures for evaluating the performance of these stabilizers leaves much to be desired in developing an objective report. However, the Clegg Impact Hammer has provided some small measure of improvement in surface resilience following treatment. The 10-lb hammer imparts only a small impact to the aggregate mass, enough to loosen an unbound aggregate but not enough to differentiate between a clay binder and the more effective stabilizer binder. Therefore, the Clegg Impact Values (CIVs) obtained show the greatest benefit for treatment of nonplastic aggregates, and generally no improvement for those aggregates with plasticity. Figure 2 shows a definite trend of increasing CIVs from the tests on untreated aggregates to those on treated aggregates.

Economy

The short- and long-term cost benefits are of paramount importance in evaluating a stabilizer. Surface aggregate replacement is the most costly item in maintaining aggregate surfaced roads (see Figure 3). The cost of blading is related less to grader operation than to the influence of blading on surface degradation and increasing the rate of aggregate loss. To provide long-term benefits, an effective stabilizer locks the aggregate particles in place and indefinitely maintains the original compacted density achieved during construction, preventing or substantially reducing aggregate loss and reducing or eliminating the damaging effects of frequent blading (see Figure 4). In the short term, the cost of initial stabilization should be in the same cost range as a single aggregate replacement operation to avoid unwanted increases in already strained budgets (see Figure 5).

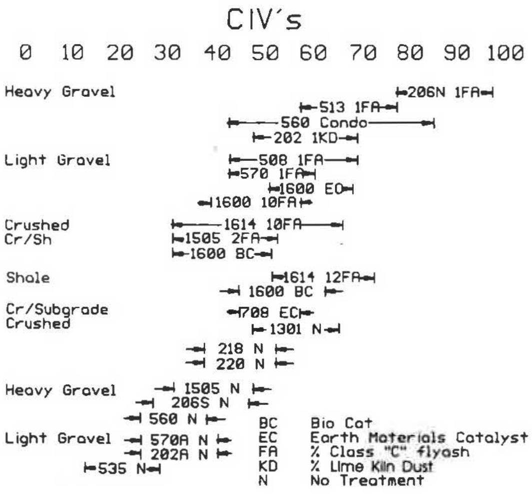

FIGURE 2 CIVs for untreated and treated aggregate surfaces.

Another long-term benefit is reduced wear on user vehicles, resulting in substantial savings to haulers, school buses, local residents, and recreationists. User satisfaction promotes a greater willingness to pay for additional treatment.

POZZOLANS

The benefits offered by pozzolan treatment include reduced aggregate loss and improved serviceability, with maintenance reduced to one or two light bladings per year on roads carrying average daily traffic (ADT) of 50 to 400, including logging trucks and oil well maintenance vehicles. At least half of the test sections, in Arkansas and North Carolina, are subjected to freeze-thaw conditions during 1 or 2 months each year. Investigators (*2*) report that lime-stabilized soils lose an estimated 10 to 12 percent strength with each cycle but regain strength during the hot months.

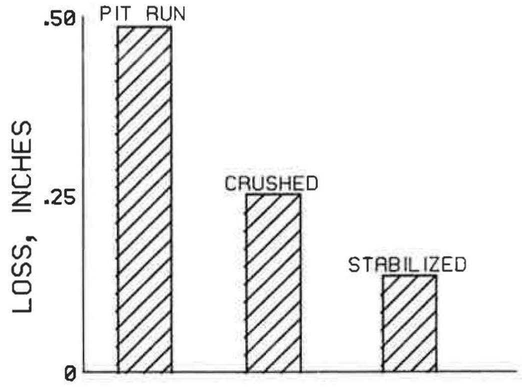

FIGURE 3 Comparison of aggregate loss for treated aggregate, untreated crushed aggregate, and pit run aggregate surfaces.

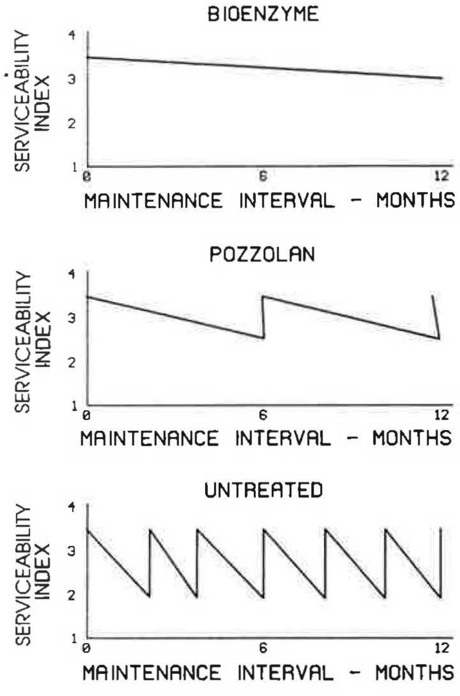

FIGURE 4 Serviceability index comparison for treated and untreated aggregate surfaces.

The pozzolans currently being tested include lime kiln dust, Class C fly ash, hydrated lime with Class F fly ash, and cement kiln dust. These materials are similar in that they are all hydraulic cements. Although they are waste materials, the distributors provide for periodic chemical analyses and make the results available to prospective users. Effects of variations in chemistry have not been noted in the field, but some differences might be observed in laboratory test results when smaller quantities are used. The pozzolans differ from Portland cement in not having a quick set. Strength gain is due to hydration and develops uniformly from initial compaction. The pozzolans are very effective in small percentages with nonplastic, coarse-grained aggregates and coarse sandy gravels. These treated aggregates can be scarified or rebladed at any time with moisture present and will resume strength gain upon recompaction. Silts and fine sands require substantially more additive, resulting in problems with mixing and development of slabs of cemented material in the roadbed that complicate maintenance. Pozzolan-treated aggregates with plasticity become extremely slippery during wet weather and must be covered with a traction course of crushed rock or washed gravel; the bioenzymes are a far more effective stabilizer for these aggregates.

The percentage of additive used in the test sections has varied from 0.5 to 2 for lime kiln dust and from 1 to 10 for Class C fly ash. Six percent cement kiln dust has been used in several projects, and 1 and 2 percent mixes of lime and Class F fly ash in a 1:1 ratio have been used on two 2-mi sections. The evaluation periods for these projects have ranged from a few months to 7 years. On the basis of observations to date, the percentage of additive required for satisfactory performance of a coarse aggregate is estimated to vary with the road grade from 1 percent for grades less than 2 percent to 3.5 percent kiln dust or 7 percent Class C fly ash for grades over 7 percent (see Figure 6). Using lower percentages than these resulted in development of surface corrugations. Occasional shallow potholing develops on flat graded sections due to washing of fines in puddles under traffic. A light blading once or twice each year provides for optimum service.

Kiln dust and Class C fly ash are both applied dry by pneumatic pumping through a spreader bar on the 24-ton tanker or by spreading from a dump truck with the tailgate cracked open. The road surface is shaped and scarified, and wet down thoroughly to blot the powder. In extremely windy areas, a slurry application is sometimes necessary. Mixing can be accomplished using scarifiers, rippers, chisel plows, or rotary mixers. To achieve optimum performance, 3 to 5 percent extra water is allowed for hydration of the quicklime fraction in the additive. Compaction with pneumatic or vibratory roller is accomplished to 95 percent of Standard Proctor or better and

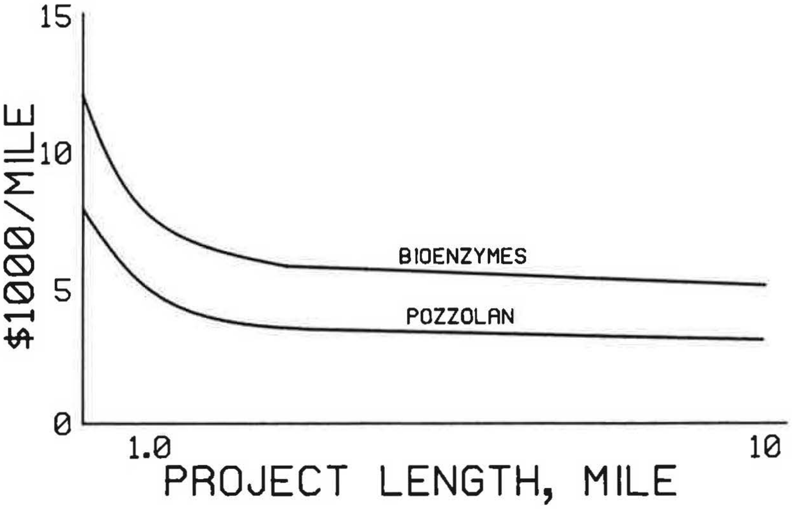

FIGURE 5 1988 construction costs for aggregate surface treatment with nonstandard stabilizers.

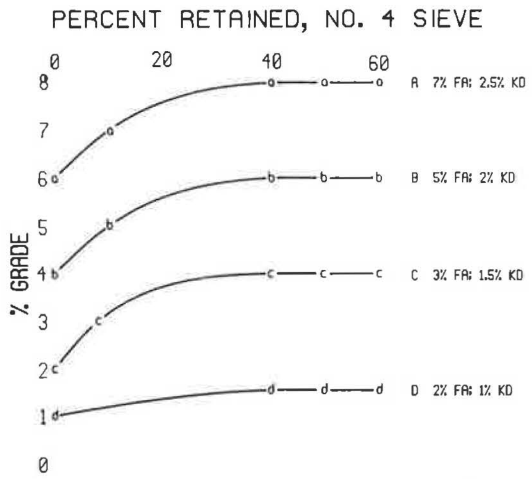

FIGURE 6 Estimated minimum percentages of Class C fly ash and kiln dust required to prevent corrugations on grades.

is followed by final shaping. Construction costs range from $3,500 to $7,000 per mile (1988 dollars), varying inversely with the project length (see Figure 3). Work production averages about 1 mi per day.

Lime Kiln Dust

Lime kiln dust is a byproduct of the lime manufacturing process. Crushed limestone and coal are fired together in a revolving kiln at high temperatures to produce quicklime. During this process, a waste dust is drawn from the kiln. The dust contains a percentage of fines similar to that of Portland cement and contains 35 to 45 percent quicklime, with the remainder being coal ash. When mixed with water, the dust hydrates, reacts, and hardens to form a cemented mass. It must be provided with dry storage and cooled for use as a stabilizer. Pozzalime is a lime kiln dust distributed by Mineral By-Products, Inc., in Marietta, Georgia. Soildry is a lime kiln dust distributed by Industrial Rock Mineral By-Products Company in Birmingham, Alabama.

Projects using lime kiln dust are located in Alabama, Virginia, Tennessee, North Carolina, Mississippi, and Florida, and all were constructed by the Forest Service.

National Forests in North Carolina

In 1985, North Carolina agreed to construct a test section on Davidson River Road using a very small percentage of Pozzalime with crushed rock containing about 25 percent fines. Twenty-four tons of Pozzalime were spread over 2 mi of 18-ft road, disked in to a 4-in. depth, watered, and compacted to 95 percent of AASHTO T99 density. This process amounted to about 0.6 percent additive overall, and 2.4 percent of fines only.

Blading on this road was reduced from nine to two times per year following this construction, and the surface performed satisfactorily during the 18-month period following construction. Grader operators noted substantial hardening on the treated sections during 1986. The winter of 1986–1987 was unusually warm, resulting in many freeze-thaw cycles (estimated at one per day). During a recent inspection, it was not possible to discern any difference in hardness between the treated and untreated sections.

On the basis of this performance and reports from Mississippi, the Forest Service elected to increase the Pozzalime application to 24 tons/mi on an additional 13.1 mi of gravel-surfaced road constructed during October and November of 1987 (Davidson River Road, 1.7 miles; Yellow Gap Road, 3.5 miles; Cathy's Creek Road, 1.4 miles; Headwaters Creek Road, 6.4 miles). The locations selected were primarily on grades where maximum gravel loss had been occurring.

The Pozzalime sections have been bladed once in the spring and once in the fall since construction. The Pozzalime has been effective in preventing separation of the coarse and fine fractions and in holding the shape of the section. However, blading was required in a few areas to repair shallow potholing on flat sections and corrugations on grades. The blading was accomplished with moisture present, and the bladed material knitted well to the roadbed, again providing performance superior to the untreated road sections.

National Forests in Mississippi

Construction of the FDR 202 test section, consisting of mixing 24 tons (1 percent) of Pozzalime into the top 4 in. of the first mile of road east of State Highway 15, was completed under contract in early October 1986. Because gravel replacement and renovation of 11 additional miles of FDR 202 were already planned for 1987, the Forest Service included Pozzalime treatment at the same rate in the project. The project was completed under contract in early September 1987. Most of the road has grades of less than 2 percent.

During an inspection in August 1990, the first mile of FDR 202, which had no gravel added with only 18 percent retained on the No. 4 sieve, now appears to lack coarse aggregate and had a full inch of loose silty sand showing wheel tracks and occasional shallow ruts. The section provides a smooth ride with slight fishtailing. The remainder of FDR 202 (11 mi) was treated with added gravel, and now has a thin float of sandy gravel over a hard cemented or packed aggregate with no corrugation, potholes, or ruts on the 8 mi west of FDR 206. It also has some slight corrugations east of FDR 206 due to sections of steeper grade or poor subgrade. The entire road provides a pleasant, easy ride at 40 mph with good control on smooth curves.

Class C Fly Ash

Class C fly ash is collected by electrostatic precipitators from the stacks of power plants burning Wyoming coal. This coal contains limestone, which converts to quicklime during combustion. Fly ash developed from this coal contains about 25 percent quicklime, considerably less than the 40 percent in the lime kiln dust.

Projects using Class C fly ash are located in Mississippi, Louisiana, Arkansas, and Texas, and all were constructed by Region 8 of the Forest Service. Class C fly ash is distributed throughout the South by Ash Management Corporation of Georgia. Another local distributor is Flyash Products, Inc., in Little Rock, Arkansas.

Ozark National Forest in Arkansas

Sorghum Hollow Road, FDR 1614, had 1,000 ft of shale surfacing treated with 10 percent Class C fly ash in 1984. This section of heavily traveled road (80 to 100 ADT) has been bladed only twice since then and has shown little sign of wear, indicating that considerable hardening on the black thissle shale resulted from the treatment. On another 1.5-mi section of FDR 1614, a 2-in. open graded base aggregate (Arkansas Gradation SB-2) was mixed in equal quantities with the black shale and treated with 10 percent Class C fly ash in 1988. This section has not been bladed since and provides a smooth ride to the user.

New Blaine Road, FDR 1600, has a traffic count of around 200 ADT. On 2 mi of this road, a mixture of SB-2 and GB-3 was mixed with equal quantities of silty clay subgrade by scarification and treated with 10 percent Class C fly ash in 1988. These sections have been given a light blading twice per year and provide excellent service in all types of weather.

The successful use of 1 percent Pozzalime in Mississippi prompted interest in reducing Class C fly ash percentages in Arkansas. White Rock Road, FDR 1505, is a high-use road with grades up to 9 percent. On 5 mi of this road, the ¾-in. minus well-graded rock with clay fines was treated with 2, 5, and 10 percent Class C fly ash on separate sections 2 years ago. The road has been bladed once per year plus one time following a heavy hauling contract. Moderate corrugations have developed on all grades over 5 percent in the 2 percent fly ash section. No corrugations have been noted in the 5 percent fly ash section, which includes grades of 6 percent; in the 10 percent fly ash section, which includes grades of 9 percent; or in the 2 percent fly ash section on grades of 5 percent or less. A uniform, thin float of coarse aggregate was noted on all sections.

These sections have provided particularly useful insights to the percentages of additives required to prevent corrugations on steeper grades (see Figure 6).

National Forests in Mississippi

Two roads on poor subgrades had aggregate added and were treated with 1 percent Class C fly ash in June 1989. Both rutted during the winter months due to saturation of the expansive clay subgrade. This winter was the worst in recorded history, with double the normal rainfall. Both of these roads have now been recommended for subgrade treatment with Condor SS (described in a later section). Grades on these roads are less than 2 percent. FDR 513, which is 2.5 mi long, currently has a hard cemented appearance, with coarse aggregate well locked up in the fines. There are no corrugations or chuckholes, and wheel tracks are dished out from slight to occasionally heavy, indicating subgrade deformation. There is a thin float on the shoulders but no raveling, and the road provides a smooth, easy ride. FDR 508, 14.8 mi long, was recently bladed and has a uniform, hard surface without corrugations, rutting, or potholes.

FDR 206 North, located mainly on a good subgrade, had aggregate added and was treated with 1 percent Class C fly ash in June 1989. This section fared well through the winter and has an extremely hard, cemented, well-gravelled surface with minor float and no potholes or rutting. There is only an occasional minor washboard, and the road provides easy driving at 40 mph. It carries heavy oil well maintenance traffic year-round.

FDR 206 South, surfaced with the same aggregate as the northern section, has not been treated and exhibits extremely heavy corrugations, especially on the curves. This section is difficult to drive, and loss of steering control occurs at 35 mph.

Kisatchie National Forest in Louisiana

During September 1988, 4.7 mi of surfacing was completed using Class C fly ash, with a 24-ton load on each ¾ mi. Before adding the fly ash, portions of the road aggregate were thickened with a pit run sand and gravel mix of plasticity index (PI) 17. This unfortunate selection of material resulted from a lack of good aggregate sources in the immediate area. The remainder of the road had the original nonplastic sand and gravel surfacing. Following completion of construction, heavy rains caused slippery conditions on the high PI aggregate on grades, and a traction course of gravel was added on steeper grades. On sections of high PI aggregate that did not receive a traction course, the surface was softened by the unusually heavy winter rains, and 1- to 2-in. ruts developed. No problems were encountered on the nonplastic sections, which required no maintenance. This experience emphasized the importance of careful coordination in selecting aggregates and construction procedures.

Future Studies on Fly Ash Use

At the Department of Energy in Laramie, Wyoming, plans were developed during 1989 for implementing a $350,000 project to determine the chemistry and mechanics behind the successful use of Class C fly ash. Facilities at the Western Research Institute and the University of Wyoming were selected for the project. These facilities include an electron microscope, X-ray and spectrographic analyses, a full-scale climate and hydrology simulation laboratory, and geotechnical engineering testing capabilities. Concurrent with a 1-year laboratory study to determine optimum percentages of fly ash and to develop standard testing procedures and specifications, test strips will be constructed by state, county, and Forest Service organizations in Wyoming. These will be monitored over a 3-year period, after which the technology will be extended statewide and to other areas as appropriate. One of the goals will be to develop a standard laboratory procedure that can predict performance of fly ash–treated aggregates.

BIOENZYMES

Bioenzyme soil and aggregate stabilizers were developed as a byproduct of the enzyme industry, which specializes in food processing, cleaning agents, and cosmetics. Industry personnel have only vague notions about procedures used in earth construction. Effective communication with the construction industry has been achieved only through the efforts of the better-trained product distributors.

The mechanisms of bioenzyme stabilizers are proprietary and secret. However, their general nature is understood by biochemists and is alluded to in advertising material. Bioenzyme stabilizers provide a bacterial culture in an enzyme solution. When exposed to the carbon dioxide in the air, the bacteria multiply rapidly and produce large organic molecules, which the enzyme attaches to the clay molecules in the aggregate, blanketing ion exchange points in the clay. This action prevents further absorption of moisture and results in a stable construction material. During the hydration that follows compaction, ionized water forms linkages between the closely packed particles, providing the cementing bond. The stabilizing effect of organic ions on clays has been discussed by Grim (*3*).

The observations made during and after construction on several projects support the premise that an ion exchange takes place between the alkali ions in the clay lattice and the organic ions provided by the biochemistry of the stabilizer solution. During mixing on the project in Montana, with ample clay present, clay lumps were noted to break down rapidly and lose plasticity. On the Montana project, and those in Texas and South Carolina that had clay present, the road surface hardened noticeably after 24 hr, indicating that hydration was causing cementation of adjacent sand grains. Full strength is reached well within the 4 or 5 days curing time recommended by the manufacturers (see Figure 7).

With clean crushed basalt in Washington and Oregon, where the only fines were rock dust, no reaction was observed and no reduction in maintenance was reported. Some clay content is essential to a successful bioenzyme project; a well-graded mix provides the best performance.

Bioenzymes are applied at the rate of 1 gal of bioenzyme per 9 to 15 yd^3 of aggregate. The bioenzyme is added to the compaction water and applied from the water truck in raising the aggregate moisture content to optimum. Wet aggregates must be dried back at least 2 points below optimum before application. Compaction is critical to good performance; the density will not change after compaction, and a poorly compacted surface can ravel. The highest density practically possible should be obtained. The road surface should be scarified before application to prevent runoff of solution. Mixing can be done with scarifiers, rippers, chisel plows, or rotary mixers, followed by compaction with a pneumatic or vibratory roller and a final shaping. About 5 days are required for a full cure, but light traffic need not be interrupted by construction. Construction costs in 1988 ranged from $6,000 to $12,000 per mile, varying inversely with project length (see Figure 3). Work production averages about 1 mi per day.

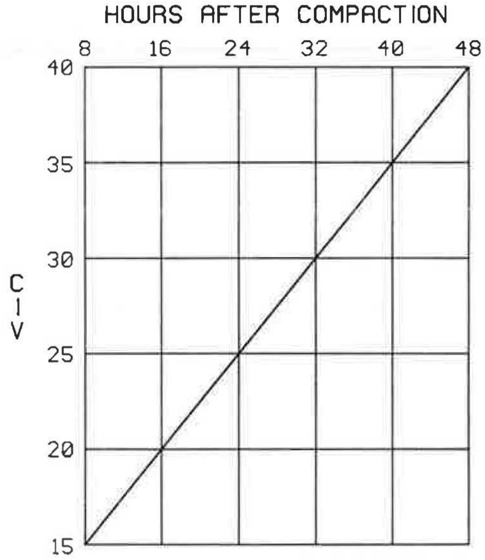

FIGURE 7 **Rate of curing for bioenzyme stabilizers, expressed as a function of CIVs.**

Test sections and trial roads using a variety of bioenzymes are located in several states. Four types are discussed in the following paragraphs.

BIO CAT 300-1

BIO CAT 300-1 is a bioenzyme manufactured in Nevada and distributed by the Soil Stabilization Products Company of Merced, California. The application rate is 1 gal/9 yd^3. Test sections are located in Nevada, North Carolina, Texas, Montana, Georgia, South Carolina, Michigan, Pennsylvania, and Arkansas.

Rain Mine Access Road in Nevada

The Newmont Gold Company's 13-mi access road to the Rain Mine south of Carlin, Nevada, was constructed in 1987 and surfaced that fall with an exceptionally well-graded pit run siltstone talus, containing 10 percent clay fines. The aggregate was stabilized with BIO CAT and surface crusted with magnesium chloride ($MgCl_2$). The 20- to 30-ft-wide, balanced, cut-and-fill road winds upslope at grades up to 10 percent to the ridgetop mine location. The late season construction limited surface thickness to 4 to 6 in. on the first 5 mi and 2 to 3 in. over the remaining 8 mi. The full thickness was completed a year later. Following compaction under grid rollers, the BIO CAT–treated material was covered with 0.6 to 0.75 g/yd^2 $MgCl_2$, which crusted on the surface with minimal penetration.

Throughout the winter months of 1987–1988, traffic included daily commuting of 500 construction personnel working at the site, as well as transport of equipment and materials for the rock crusher and ball-and-roller processing plants. The only maintenance required during this period was snow removal, which was accomplished using a grader blade to scrape the hard aggregate surface and applying a sand and salt mixture.

Depending on exposure, some sections were subjected to repeated freeze-thaw cycles, whereas others endured prolonged freezing and a spring thaw. The road surface remained free of rutting, potholing, and corrugations, although some surface ravel was noted on curves in the 2-in. sections. The subgrade over most of the road is of broken shale and siltstone, and in some areas bedrock can be seen in the surfacing.

Maintenance has consisted of roller brushing the surface at 2-week intervals, snow removal during the winter, and an annual spring application of magnesium chloride. The completed surface gives the impression of a paved road rather than gravel.

Pisgah National Forest in North Carolina

During October 1987, BIO CAT was applied to a ½-mi section of Yellow Gap Road and mixed into the 4-in. crushed gneiss surfacing. This crushed rock contained about 15 percent fines, including a 2 percent clay fraction. The mixture had stiffened noticeably during reshaping on the second day and set up very hard after compaction. The performance of the section since construction has been exceptional. In all seasons, the road accommodates log hauling, hunting traffic, and other recreational traffic. Although untreated sections of this road are bladed three times annually and deteriorate rapidly after each blading, the BIO CAT section has required no blading other than ditch cleaning for over 2 years and essentially remains in its original condition. All surface gravel is firmly locked into the road surface, giving the effect of a surface treatment.

Sam Houston National Forest in Texas

In August 1989, BIO CAT was applied to 4.5 in. of aggregate surfacing on 2.5 mi of 20-ft double-lane road on FDR 204. This road has been in operation for many years, providing access for log hauling and to residential, day use, and lake areas. The entire road has an expansive clay subgrade. Before treatment, potholing often became so extensive that drivers resorted to using the road shoulders.

A mix of materials has been used during maintenance work, leaving at least five material types along the road. These included various combinations of poorly graded quartz gravels and crushed river rock, mixed with small amounts of sand, and red or brown clay binder (7 percent), crushed sandstone, and clay balls from the gumbo subgrade in one 200-ft section.

The surfacing hardened noticeably after construction and remained in excellent condition through the hunting season and heavy early winter. The unusually heavy winter rains resulted in subgrade failures, with minor rutting and shallow potholes developing. In March 1990, the surface was scarified, shaped, and recompacted at optimum moisture. Since then, it has developed a well-armored surface without potholes, corrugations, or rutting. Ravel is developing on some sections due to excessive amounts of 3- and 4-in. rock in the aggregate.

Lewis and Clarke National Forest in Montana

In September 1989, BIO CAT was applied to sections of Spring Creek Road. An inch of clay shale was added to the existing 4 in. of crushed sandstone surfacing over 32 mi of road to provide a binder, and the two materials were blended and compacted. BIO CAT was selected to stabilize 2.5 mi of this surfacing. The sections selected for application of the BIO CAT are on grades that had previously caused notable problems with corrugations. Mixing was accomplished using a combination of scarifiers and windrow blading, followed by compaction under a steel-wheel vibratory roller with two wide tires following. Except in shaded areas, the compacted surface was hard and uniform; after 24 hr, major portions had indurated and could not be scratched with a fingernail.

Treated sections have remained in excellent condition since construction, whereas untreated sections on gentler grades showed signs of deterioration in September 1990.

Chattahoochee National Forest in Georgia

In May 1990, a half-mile section of Tallulah River Road, FDR 70, had its poorly graded crushed-stone surface treated with BIO CAT. Before treatment, the surface was scarified into the subgrade to bring up plastic fines. The mix contained 11 percent passing a No. 200 sieve, and 1 percent clay. Mixing was accomplished with grader scarifiers. The entire section is on a flat grade and receives heavy traffic throughout the year. Soon after treatment, two 100-ft sections developed shallow potholes on the crown due to loss of fines in puddles. The potholes do not affect traffic and have not increased in size. The surface has a well-armored appearance, without ravel, and requires no maintenance.

Sumter National Forest in South Carolina

During July 1990, construction of 2.8 mi of bioenzyme-stabilized surface was completed on Burrell's Ford Road, FDR 708. The silty clay subgrade material was scarified into the existing poorly graded base rock, providing about 35 percent passing a No. 200 screen and including 2 percent clay. Several sections of the aggregate have excessive amounts of 2-in. coarse rock. The mixture was treated with BIO CAT on half of the road and with Earth Materials Catalyst (discussed in the following subsection) on the other half. Mixing was accomplished with an extra-heavy-duty chisel plow. Since construction, the surface has remained hard and smooth, except for a total of 600 ft on six sharp curves and a short, steep tangent. On these sections, some moderate raveling and corrugations have developed due to erosion rilling and excessive coarse rock in the aggregate. Traffic on this road, which has grades up to 9 percent, exceeds 90 veh/day during high-use periods.

Earth Materials Catalyst (EMC)

A bioenzyme known as Earth Materials Catalyst (EMC), also distributed by the Soil Stabilization Products Company, was applied to 1.0 mi of Logging Creek Road 968 and adjoining Lick Creek Road 67 in Lewis and Clarke National Forest during October 1989. It was also applied to half of Burrell's Ford Road in the Sumter National Forest as described in the previous subsection. A third test section was located in Arkansas. The performance of EMC has been comparable to that of BIO CAT. EMC is applied at the rate of 1 gal/12 yd^3, compared with 9 yd^3 for BIO CAT. EMC is manufactured in Arizona.

Permazyme

The bioenzyme Permazyme, also called Endurazyme, is distributed by American Enzymes of Alexandria, Virginia. Permazyme is recommended for use with subgrade soils containing clay. In April 1989, the Kisatchie National Forest completed the FDR 321 spur—1,000 ft on native clay. Logging in this area is expected to start early in 1991.

The city of Raleigh, North Carolina, recently constructed a 600-ft test section in Lake County on a dirt street. The treated soil set up hard and is performing well. California bearing ratio (CBR) tests run on the material showed a substantial gain in strength after treatment.

Two city streets in Stillwater, Oklahoma, were surfaced with 6 in. of silty clay subgrade material (PI, 20; LL, 40) stabilized with Permazyme. No other surfacing was added other than an inch of gravel to improve traction and provide a slime-free surface. One of the streets, a half-mile of Richmond Road, was completed in 1981 and has not required maintenance since then. Adjacent untreated sections rut easily following rainfall and become impassible during spring thaw. The test section has been used year-round without problems or signs of rutting, chuckholing, or corrugations, remaining as hard and firm as the dry, baked clay of mid-summer. Because most of the gravel layer had been lost to traffic, the surface appears to be clay with imbedded gravel fines.

Another test section is located in the Peoples Republic of China.

PSCS 320

PSCS 320 is a bioenzyme distributed by Alpha Omega Enterprises of Richardson, Texas. It is recommended for use with expansive clay subgrades. A recent project was a 0.4-mi timber haul road constructed by Temple-Eastex Corporation on their timber lands north of Houston, Texas.

ELECTROLYTES

Electrolytes affect the basic nature of the clay molecules in the aggregate, causing them to release absorbed water and coagulate into a dense, moisture-free mass that resembles rock. For this stabilizer to be effective, aggregates must have 35 percent passing the No. 200 sieve with a clay fraction. Once stablized and compacted, they remain unaffected by wet-dry or freeze-thaw cycles. The electrolyte travels through native soil moisture by osmosis, and thus does not have to be mixed mechanically with the soil layer. The treatment is best applied during periods of soil saturation and is highly effective in permanently reducing the moisture content in expansive clays, eliminating subgrade and foundation problems associated with these troublesome soils. The stabilizer solution can be applied by injection for a deep treatment or by scarifying and flooding for a shallow treatment. The latter produces an extremely slippery condition and requires addition of a traction course if no coarse aggregate is present.

Condor SS is currently the only known electrolyte on the market that can be effectively used for soil stabilization. It is distributed by Earth Science Products Corporation of Wilsonville, Oregon, the Pro Chemical Stabilization Company of Dallas, Texas, and the Soil Stabilization Products Company of Merced, California.

Condor SS was used by the Forest Service on FDR 3421 spur in the Gifford Pinchot National Forest in Washington State to stabilize an impassible steep grade on a saturated clay loam soil. It was injected at 6-ft intervals to a 3-ft depth using a high-pressure ceramic pump and jetting pipes. Immediately following the treatment, heavy construction equipment was able to pass over the section without rutting.

The Oregon Department of Transportation injected Condor SS to stabilize a pumping subgrade on 2 mi of Oregon State Highway 47 between Mist and Vernonia (near Portland).

Injection of the electrolyte by the city of Pocatello, Idaho, has prevented severe frost heave from developing in certain city streets underlain by a moisture-sensitive loess soil, compared with adjacent control sections. Pocatello plans to apply the electrolyte on 3 mi of streets per year until all problem areas have been completed.

The Dow Chemical Company has stabilized 2 mi of causeway by injecting Condor SS near Galveston, Texas, to eliminate subsidence. Also in Texas, the city of Houston and Houston County recently ran tests to compare the Condor treatment with lime treatment on expansive clays and found Condor by far the more effective.

The Kisatchie National Forest stabilized 2 mi of expansive clay subgrade on FDR 560 near Winnfield, Louisiana, using the injection method. In a second project in the Kisatchie, a half-mile logging spur with an expansive clay subgrade was scarified and flooded with the solution, allowed to drain, and then compacted. It now remains brick hard through intense rainfall.

OTHER STABILIZERS

Several other stabilizers have been included in the study. Among these are Exxon Polybuilt 4178, Road Oyl, and materials traditionally used for dust control.

Polybuilt is an acrylic polymer used for erosion control on earth slopes and distributed by Exxon in Atlanta, Georgia. The Chattahochee National Forest used this material to prevent erosion on a roadside slump in a highly erosive granite saprolyte. The polymer was sprayed on with the grass seed, and effectively held the seed in place while the grass took root, despite several intense rainfalls. The slope across the 1-acre area ranged from 50 to 70 percent. Polybuilt can also be mixed with sand to form a pavement. A study test section has been planned but not yet constructed.

Road Oyl is a pine tar derivative manufactured near Knoxville, Tennessee, and distributed by the Soil Stabilization Products Company of Merced, California. Road Oyl can be substituted for asphaltic materials used in bituminous pavements and surface treatments and will achieve a Marshall stability of 4000 to 5000 lb, compared with 1,500 to 2,000 lb for asphalt. The product has been used primarily on mine access roads in the Knoxville area. Several study test sections are in the planning stage.

Dust palliatives such as magnesium chloride and lignin sulfonate provide temporary stability to road aggregates. Because they are water soluble, however, they must be reapplied periodically depending on rainfall frequency and intensity. Although light rainfall will improve performance, intensive rainfall with flooding rapidly leaches these materials from the road surface. Study test sections for lignin sulfonate have been constructed by FHWA and the Forest Service in the states of

Washington, Oregon, New Mexico, and North Carolina. Magnesium chloride is being tested by the Forest Service in Washington and Arkansas.

CONCLUSIONS

The final report for this study is due in February 1992, providing an additional winter for evaluation of the test sections. The performance through September 1990 shows an exceptional improvement over control sections wherever the appropriate stabilizer has been used. Failures in the test sections have been attributed to misuse of the stabilizer or poorly graded aggregates.

The observed improvements in performance and reductions in maintenance far exceed those of control sections or any other untreated aggregate surfaces. The bioenzymes and Condor SS have been particularly outstanding, in some cases extending maintenance frequencies from biweekly to biannually for similar performance. The low construction costs for these materials and for the pozzolans can easily be offset in reduced aggregate loss, reduced maintenance, and improved serviceability.

The primary drawback is the absence of standard testing procedures capable of predicting performance. The proposed laboratory study by the Department of Energy in Laramie, Wyoming, may provide some relief. Hopefully, other agencies, industry, and users will also contribute to developing the needed design and construction standards.

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