UPGRADING MARGINAL AGGREGATE MATERIALS WITH LIME

Basic Mechanisms

Lime can be used to upgrade highway construction aggregates that do not initially meet specification requirements for base and subbase materials. Many aggregates fail to meet specified strength, plasticity, or sand equivalent requirements because of higher than desirable percentages of clay material that cannot be removed from the aggregate easily or economically.

Lime reacts with the clay fraction of a soil or aggregate to change the properties of the clay and to actually transform the clay fraction into a beneficial constituent within the aggregate system. This is done primarily through a combination of "cation exchange" and "pozzolanic reaction" processes. During the initial cation exchange process, calcium ions adsorb to negatively charged sites on the clay mineral surfaces, causing flocculation and agglomeration of the clay particles that results in reduced plasticity. Following these initial exchange reactions, calcium hydroxide remaining in the system results in elevated pH levels that cause reactions between the lime, clay minerals, and water to produce calcium silicate and calcium aluminate hydrates. These are cementitious products that bond or cement the aggregate matrix together, providing increased structural support within pavement systems. Lime has been used successfully to substantially improve the engineering properties of marginal aggregates with both high and low percentages of clay binder. The amount and type of clay binder present will determine the amount of lime needed to drive the cation exchange and pozzolanic reaction processes.

The benefits of lime are not limited to aggregates containing clay. Research and field studies in Florida and Texas have shown substantial strength increase when lime is added to limestone and caliche bases (Graves and Little, 1996). In this role, lime reacts with carbon dioxide in the soil-water-air system to form a matrix of calcium carbonate cement which bonds the carbonate aggregate particles together, enhancing strength and stiffness or modulus of the aggregate base.

Importance of Engineering Property Changes Due to Lime Treatment of Marginal Aggregates

When added to marginal aggregates containing higher than acceptable clay contents, or to caliche or limestone aggregates, lime will improve shear strength and stiffness. Low shear strength bases and subbases may become unstable under heavy wheel loads, especially when wet. Unstable bases and subbases rut, become rough, and provide poor support for hot mix asphalt or portland cement concrete surface layers. Increasing the shear strength and stiffness of these layers can significantly improve pavement performance and reduce life cycle costs.

High stresses produced by heavy wheel loads in the subgrade result in shear failures and rutting that shorten pavement life. The stiffness or modulus enhancement offered by lime stabilization of bases and subbases provides improved load-spreading ability. This means that the wheel load is spread more effectively, and the native subgrade is protected from damage by high shear stresses. Additionally, higher stiffness bases provide better support for the overlying surface layers. This can lead to less fatigue cracking and less rutting and shoving in hot mix asphalt concrete surface layers.

Level of Stabilization Required

The amount of lime required to improve marginal aggregates normally is low. Most marginal aggregates with a plasticity index of the binder fraction lower than about 20% can be stabilized effectively with between 1% and 3% lime by weight of the dry aggregate. Objectives of the aggregate treatment should be considered when determining lime addition levels. Plasticity reduction alone typically requires a low level of lime addition. Slightly higher addition levels are required to achieve a lime-saturated (pH 12.4) system for development of structural strength through pozzolanic reactions. The level of lime addition that results in a lime-saturated, pH 12.4 system is recommended to insure permanency of material alteration. Carbonate aggregates with little or no clay content typically require about 1% to 2% lime addition for strength and modulus improvements.

Method of Lime Addition

The process of adding lime to marginal aggregates does not require expensive or sophisticated equipment. Maximum benefits of lime treatment are achieved when lime slurry is added to the aggregate or dry lime is added to moist aggregate with pugmill-type mixers. However, a system as simple as applying lime to the aggregate on a conveyor belt containing belt plows for mixing also can be effective if properly designed.

Three Recent Case Histories

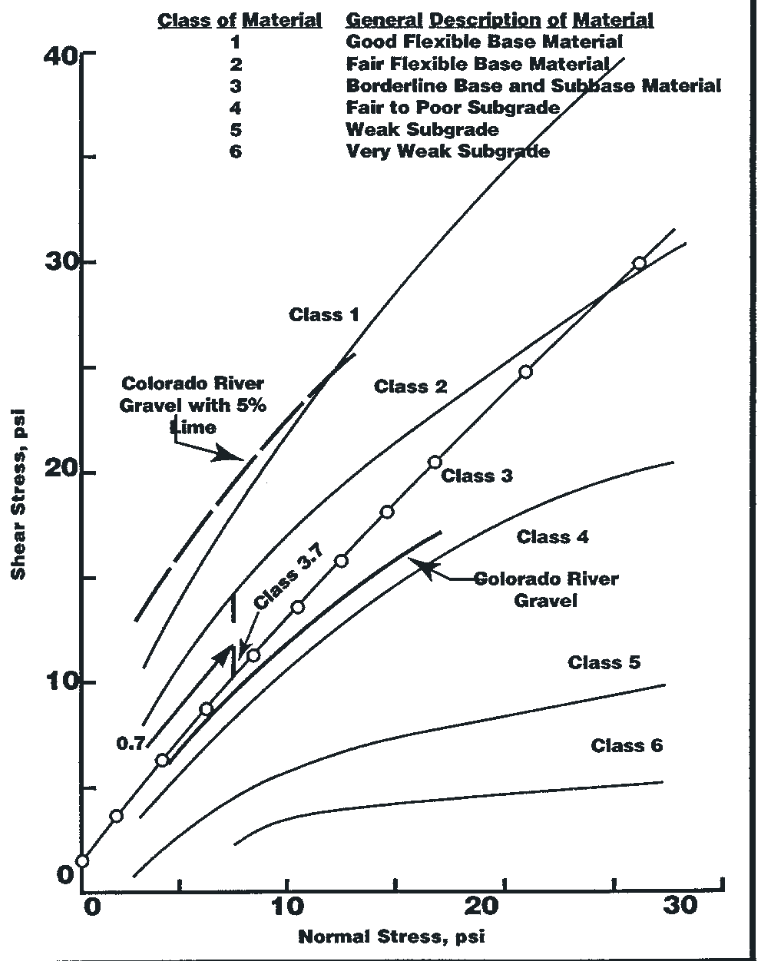
Three recent case histories illustrate the substantial benefits of treating marginal aggregates with lime. In the first project, lime was added to a crushed, siliceous gravel mined from the Colorado River in south Texas that contained a high percentage of plastic clay binder (Little, 1995). In the second project, lime treatment was utilized for a Phoenix, Arizona granite aggregate that did not meet specifications as a base course aggregate due to the presence of clay in the binder fraction (Little, 1990). In the third case, a low percentage of lime was used to improve strength and modulus properties of a south Texas caliche and a low-quality central Texas limestone (Bhuyian et al., 1995).

Neither of these carbonate aggregates contained a significant clay mineral fraction.

Colorado River Gravel

The Colorado River aggregate from Texas consisted of a crushed, siliceous gravel with a clay binder (plasticity index of 35%). When treated with 2.5% hydrated lime, followed by only seven days of curing at 23^{o} C, the Texas Triaxial classification improved from Class 4 (typical of a fair to poor subgrade) to Class 2 (typical of a fair flexible base)

Figure 1
Chart for Classification of Subgrade and Flexible Base Material



Class of Material	General Description of Material
1	Good Flexible Base Material
2	Fair Flexible Base Material
3	Borderline Base and Subbase Material
4	Fair to Poor Subgrade
5	Weak Subgrade
6	Very Weak Subgrade

(Figure 1). The addition of 5% hydrated lime improved the Texas Triaxial classification to Class 1 (typical of a good flexible base). Class 1 is the highest Triaxial base classification. Therefore, project engineers were able to design a better road for less total cost with the improved base material.

Arizona Granite

A Falling Weight Deflectometer (FWD) was used to evaluate the effect of lime treatment on the Phoenix, Arizona aggregate. The FWD produces a force impulse on the pavement layers which closely simulates a moving wheel load. The deflection basin produced under the application of the load is measured and analyzed using a computer-based deflection matching technique to back-calculate the stiffness or modulus of the pavement layers. The modulus is essentially the ratio of applied stress (load per unit area) to strain induced by that level of stress.

Figure 2

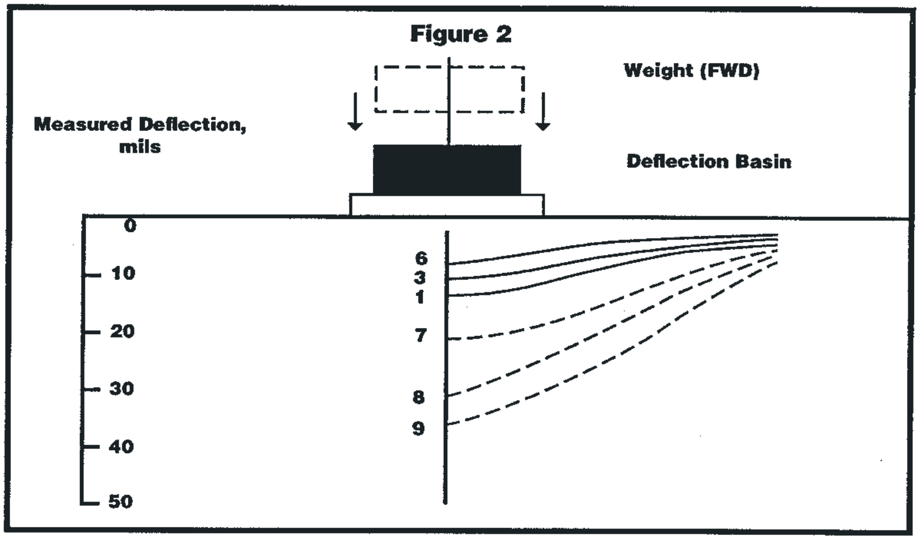


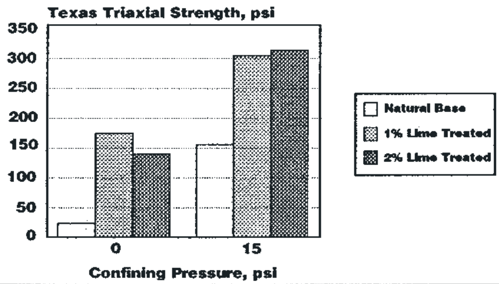
Table 1
Average Base Course Resilient Moduli from the Six Phoenix Pavement Sections

Pavement Section	Layer Structure	Average Resilient Modulus (psi)
1	3.5-in. HMA 10-in. ABC (with 1% Lime)	54,300
3	3.1-in. HMA 13-in. ABC (with 1% Lime)	224,100
6	3.5-in. HMA 10-in. ABC (with 1% Lime)	406,800
7	3.5-in. HMA 10-in. ABC	34,800
8	3.5-in. HMA 10-in. ABC	13,400
9	3.5-in. HMA 10-in. ABC	19,700

Deflection basins were measured using the FWD for six pavement sections. Each of the six pavements evaluated had similar structural cross-sections. The granite aggregate base course underlying the hot mix asphalt surface was from the same source and met the same specifications in each pavement section. The aggregate binder fraction consisted of approximately 10% to 13% minus No. 200 sieve material and had a plasticity index of approximately 12 to 15. The base course was stabilized with 1% lime by weight of aggregate in pavement sections 1, 3, and 6. The base course was not treated in pavement sections 7, 8, and 9. The deflection basins illustrated in Figure 2 represent the average of at least 70 deflection readings for each pavement section. The resilient moduli calculated from these average deflections for the aggregate base course in each pavement section are summarized in Table 1 and indicate the significant increase in modulus or stiffness resulting from lime treatment.

The significant improvement in base layer moduli resulting from the use of lime is predicted to have a substantial effect on pavement performance life. The stabilized base layers offer better support for the pavement surface and reduce the potential for fatigue cracking and rutting within the hot mix asphalt.

Figure 3
Texas Triaxial Test Results
Central Texas Limestone Base



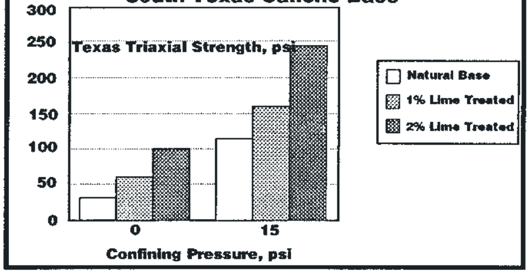
South Texas Caliche and Limestone

Two carbonate aggregates from south Texas with a relatively high plasticity index (approximately 15%) were substantially improved with lime treatment. X-ray diffraction analyses revealed that the plasticity resulted from a very fine-sized calcium carbonate fraction and not from the presence of clay minerals. Despite the lack of clay minerals, which normally are relied upon to provide strength through pozzolanic reactions, 1% to 2% hydrated lime substantially improved strength properties of the carbonate aggregates. Scanning electron micrographs revealed that the mechanism of strength enhancement was due to development of a calcium carbonate matrix within the aggregate particle system. Figures 3 and 4 illustrate the strength improvements resulting from stabilization with 1% and 2% lime. These are presented in terms of the Texas Triaxial test at 0 and 15 psi confining pressures. The strength improvements resulting from 1% lime treatment improved classification of both aggregates from marginal quality to high quality, Class 1 materials.

Conclusions

The addition of from 1% to 3% lime can substantially improve the engineering properties of marginal or unstable aggregate, enhancing performance of the aggregate as a structural material in pavement systems. In addition, increased resource utilization and improved economics of the aggregate operation is realized.

Figure 4
Texas Triaxial Test Results
South Texas Caliche Base



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