Recent Experiences with Lime – Fly Ash Stabilization of Pavement Subgrade Soils, Base, and Recycled Asphalt

Joel H. Beeghly

Carmeuse Lime Co. 3600 Neville Rd., Pittsburgh, PA, 15225

KEYWORDS: fly ash, lime, soil stabilization, pavement, subgrade

ABSTRACT

Pavement engineers have long recognized long term benefits of increasing the strength and durability of pavement subgrade soil by mixing in a cementitious binder during reconstruction or new construction. Federal and state highway engineers have a renewed interest in “perpetual pavement” which will benefit from “perpetual foundations”. Millions of dollars can be saved by soil subgrade stabilization in comparison to cutting out and replacing the unstable subgrade soil. When included in pavement design, stabilizing the subgrade can result in reducing the thickness of other pavement layers. In one case 5 inches of bituminous base course and 2 inches of granular crushed stone base were eliminated.

Lime alone has traditionally been used in clay-bearing, highly cohesive soils whereas Portland cement has been used to bind non-cohesive, granular or poorly cohesive soils. Likewise Portland cement is mainly used to stabilize an aggregate subbase or base course. For a low cohesive, silty soil or for reclaiming full depth asphalt pavement recent investigations and some recent practice has shown that lime and Class F fly ash stabilization can be economically engineered for long-term performance. For appropriate soils, LFA can offer cost savings by reducing material cost by up to 50% as compared to Portland cement stabilization.

BACKGROUND

Fine-grained soils with high clay (<0.005 mm) and silt (<0.074 mm) content are generally less desirable as pavement subgrade than natural soil containing higher amounts of granular material such as gravel and sand. Soils with more than 25% passing the 74 micron (0.074 mm or 200 mesh) sieve and a plasticity index (PI) of at least 10 are amenable to lime stabilization.(1) High silt, low clay subgrades with 25-75% passing the 74 micron and a PI of 10-20 will greatly benefit in terms of bearing capacity and strength from a combination of lime and fly ash more than lime alone due to the pozzolanic reaction of the lime-fly ash (LFA) combination. The lack of reactive silica and alumina due to the lower clay content is made up by the silica and alumina added from the fly ash. The lime increases the soil's pH, solubilizing alumina and silica for the pozzolanic formation of calcium silicates and calcium aluminates.

Lime-fly ash or portland cement can be used to stabilize soils with PI less than 20. However, the lime is better to react with and breakdown the clay fraction than Portland cement.[2] Portland cement is thought to be more applicable to lower PI soils, i.e., less than 12, because the strengths desired are attained faster and the clay content for lime modification is low. Publications by the U.S. Army Corps of Engineers and Transportation Research Board recognize the utility of lime-fly ash for coarser-grained soils that have little clay or plastic fines, including silt.[1][3]

The form of the lime could be either quicklime (calcium oxide, CaO), or hydrated lime, (calcium hydroxide, $Ca(OH)_2$). Quicklime hydrates with the soil moisture to become hydrated lime and therefore acts as a better drying agent before providing the calcium to react with the silica and alumina in the clayey soil and from the coal fly ash addition.

Lime kiln dust (LKD) contains the key ingredients of lime (20-40% calcium oxide) and fly ash (8-15%) from the coal used to burn or calcinate the limestone to lime. LKD is used for soil modification and, in proper quantities, for soil stabilization.

A distinction should be stated between soil modification and soil stabilization. Soil modification from moderate rates of additives (i.e. 3% quicklime) causes improvements such as drying and swell reduction. Soil stabilization from higher rates of application is the focus of this presentation where long-term strengths for freeze-thaw protection are desired.

Lime – Fly Ash Pozzolanic Reactivity

The objective of this paper is to relate new and recent experiences and information regarding recent investigations at the Carmeuse Technology Center and some pertinent work of others on the use of lime together with coal fly ash for the pozzolanic reaction to stabilize soil subgrade and granular base coarse under pavements or foundations.

The pozzolanic cementitious strength-gaining reaction between a given fly ash and hydrated lime can be characterized or measured with the plastic mortar cube test method outlined in ASTM C-593. The graded standard ASTM sand is used as the aggregate for 73.3% of the solid mix. Lime constitutes 8.9% and fly ash constitutes 17.8% of the dry mixture, a 1:2 proportion. For non self-cementing Class F fly ash, this procedure is preferred over that used for self-cementing fly ash (ASTM D-5239), which does not use any standard graded sand.

The amount of water added is governed by the fixed flow method as opposed to the fixed water/cement ratio method. Water is added to get a standard flow of water or fluidity (i.e. slump cone test) to be within a certain range after 10 blows on the drop table. Some fly ashes will demand more water to get this fluidity depending upon their fineness and surface characteristics.

The loss on ignition (LOI) of the fly ash is less critical for soil stabilization than for concrete and the LOI limits of ASTM C-618 need not apply. However, the effect of LOI above 10 is not known.

In total about 18 fly ashes, both Class F and Class C, have been tested at the Carmeuse Technology Center, Pittsburgh, PA. The results are shown in Table 1. All of the fly ashes tested above 600 psi when tested with lime. Four Class C ashes are tested with and without lime. Three of them showed dramatic improvement when used with lime. Only the Cleveland area Lakeshore C ash performed better without lime.

Table 1: Lime-fly ash pozzolanic reactivity results per ASTM C-593 mortar cube procedure

Fly Ash Description	Lime/Fly Ash Proportion	Water (grams)	% Flow	7 Day (psi)
CLASS F:				
Hatfield, American Electric Corporation, dry	33% hydrated lime/67% fly ash	315	68	1110
Hatfield Conditioned (10.2% water)	33% hydrated lime/67% fly ash	280	72	970
Brunners Island, Pennsylvania Power & Light, dry	33% hydrated lime/67% fly ash	380	68	1290
Brunners Island, Pennsylvania Power & Light, conditioned	33% hydrated lime/67% fly ash	260	76	880
Zimmer, Cinergy	33% hydrated lime/67% fly ash	285	65	1070
Detroit Edison		400	65	660
CLASS C:				
Bayou "C" 12/02 (New Roads)	33% lime/67% fly ash	280	72	650
Hansen Station, Louisiana Class "C"	33% lime/67% fly ash	280	67	1160
Hansen Station, Louisiana Class "C"	100% fly ash	230	72	150
Eastlake Unit #1 - #4	33% hydrated lime / 67% fly ash	285	65	970
Eastlake Unit #1 - #4	100% fly ash	260	70	320
Lake Shore C Ash	100% fly ash	236	68	1670
Lake Shore C Ash	33% hydrated lime/67% fly ash	285	64	1085
Lake Shore C Ash	100% fly ash	239	75	1470
Lake Shore C Ash	33% hydrated lime / 67% fly ash	307	66	1200

NOTE: Hydrated lime conforming to ASTM C-977 used for all tests.

For this lime-pozzolanic mortar cube strength test for plastic mixes, ASTM C-593 suggests a minimum of 600 psi after curing 7 days at 130°F.

Mixture Design and Testing Protocol

Moisture-Density Relationship and Lime Demand:

Before making strength tests, the dosage of lime or LFA blend and the optimum moisture content (OMC) of the soil stabilized mixture must be determined. The Eads-Grim soil pH test (ASTM D-6276) is used to estimate the lime dosage rate, called the lime demand. OMC tests determine the maximum dry density using the ASTM standard compaction procedure D-698. It is interesting to compare the OMC of both the untreated and treated soils in order to show how the lime or LFA modifies the material handling aspects (i.e. plasticity reduction and soil drying) and ease of attaining the required compaction/density.

When LFA is added, the lime changes the soil characteristics so that more moisture is needed for compaction – the optimum moisture increases and the maximum dry density decreases. Likewise the soil's plastic index (PI) is reduced which also indicates easier compaction. The shift of the moisture-density curve after treatment to a higher moisture content and lower maximum dry density is illustrated in Figure 1.

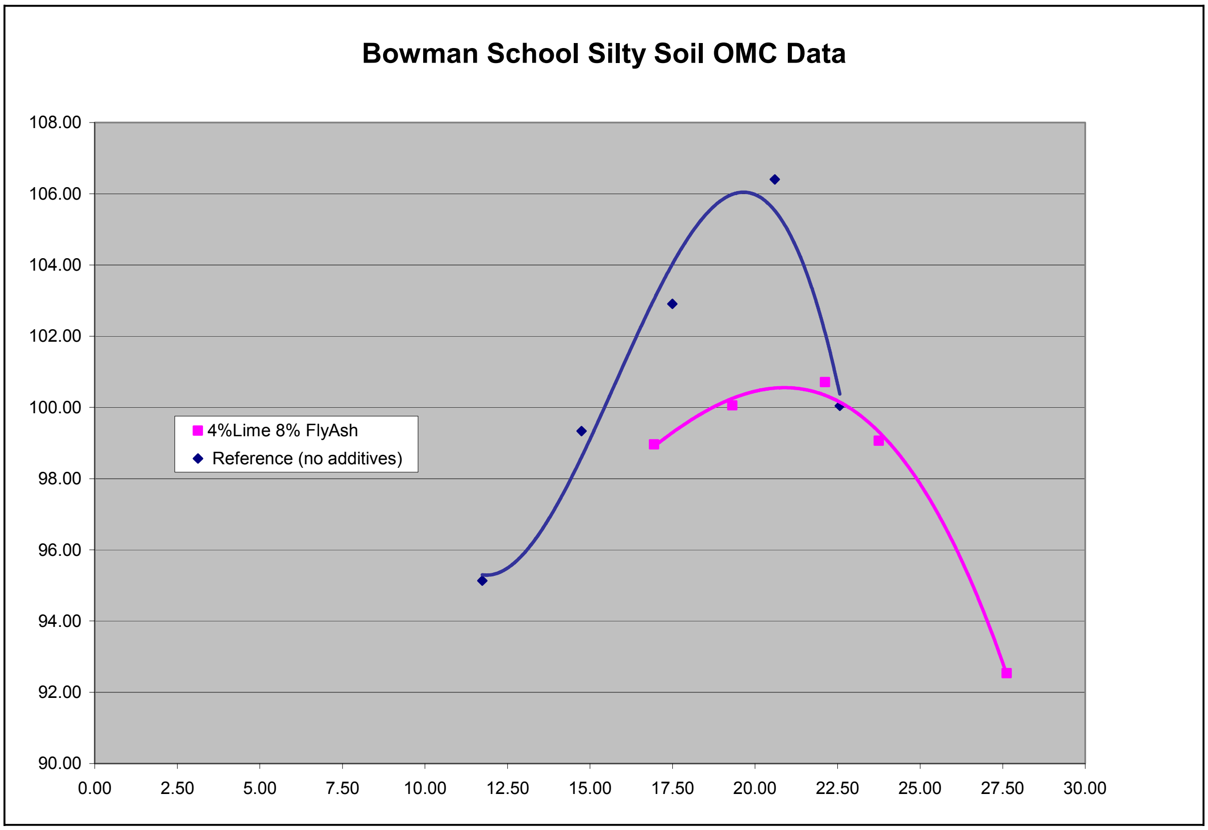

Figure 1: Moisture-Density Relationship of Untreated (reference) and Treated Soil

Strength Gain and Moisture Sensitivity via UCS Testing:

Unconfined compressive strength (UCS) tests were determined using ASTM D-5102. Both untreated and treated samples are prepared for strength testing at their respective OMC contents. The curing conditions (time and temperature) are chosen from three techniques:

1) accelerated curing for 3 days at 49-50°C; (120°F);
2) accelerated curing for 7 days at 40°C (104°F)
3) ambient temperature curing for 28 days at 22°C (72°F).

Various research studies have found that each of these curing conditions and times should yield approximately equivalent strengths[(4)(5)].

Moisture susceptibility can be determined by allowing some of the cured UCS cylinders (i.e., after 7 days accelerated temperature curing) to be subjected to a capillary soaking technique for 24 hours prior to strength testing. This capillary soak protocol consists of placing the 4-inch diameter UCS cylinder, that is wrapped in a wet absorptive fabric, on a porous stone sitting in water. Extensive laboratory testing has demonstrated that untreated clayey soils will typically degrade to a compressive strength of less than 10 psi following capillary soak.[(1)(3)] A stabilized soil may typically lose only 15-25% of its strength but should meet target requirements for “various anticipated service conditions”. Strength requirements for “various anticipated service conditions” (i.e., soaking or cyclic freeze-thaw conditions) for subgrade, subbase, and base application have been determined[(3)]. Depending on the application and the service condition, the strength requirements range from 50 to 200 psi. The U.S. Army requirement for subgrade under asphalt is 250 psi and 200 psi for rigid concrete.[(2)]

CBR Testing:

The California Bearing Ratio (CBR) strength test is done with a piston-like penetration force and is performed at a specific density and moisture (usually the OMC) after soaking for 4 days at ambient temperature. The test can be used to compare untreated and treated soil, with and without a curing period (i.e. 7 days at 40°C). A strain gauge measures the swelling or expansion during the soaking period. The CBR is a relative measure (%) compared to crushed stone. Moisture absorption after the 4-day soak is measured.

CBR data is used to determine the need for soil subgrade stabilization and the required overall pavement thickness above the subgrade. Lab CBR results can be related to other tests, such as the dynamic cone penetrometer (DCP) and resilient modulus stiffness testing.[(1)(4)]

Recent Pennsylvania Activity

In the late 1990's, PennDOT District 12 (southeast of Pittsburgh) and the Pennsylvania Turnpike Commission treated the subgrade during the reconstruction of two major highway sections: I-79 south of Washington, Pa. and 9 miles of Turnpike near New Stanton, PA.(7) In addition, the hot mix asphalt industry in Pennsylvania has discussed a subgrade design and construction philosophy to assure a strong foundation for "Perpetual Pavement".(6)

The Pennsylvania Turnpike specified a "lime-pozzolan" by-product (LKD) from lime production for subgrade stabilization. After complete removal of the existing roadway, LKD treatment was used to stabilize the subgrade in lieu of undercutting and removing two feet of existing soil and backfilling with shot rock. The LKD application rate was reported to be between 6% and 8%. The cost of lime-pozzolan treatment was reported to be about $\$4.28/m^2$ ($\$3.58/yd^2$) for lime treatment as compared to $\$28/m^2$ ($\$23.41/yd^2$) for undercutting and backfilling.(8)

In one of their current reconstruction projects, the Pennsylvania Turnpike design has shown that the stabilization subgrade attains adequate strengths to substantially reduce the total pavement section.(9) Although they report uncured CBR strengths of about 37, they conservatively used a CBR of 15 for pavement thickness design, reducing the pavement thickness by about 33%. AASHTO is now favoring the resilient modulus dynamic stiffness test for characterizing the strength of pavement material.(4)(9)

Although it is economical, LKD is a by-product of limited supply and contains only 25-40% available lime as CaO and 10-15% fly ash (Si + Al + Fe). It should be pointed out that the use of lime and Class F fly ash is used normally in a proportion of 1 part CaO and 2-4 parts fly ash. In the C-593 test for lime-pozzolan reactivity, the proportion is 1:2. Hanks reported extensive testing of LFA mix designs including the ASTM C-593 mortar cube procedure using the Ottawa silica sand as the aggregate. The optimum lime-fly ash ratio found was 1:4.(10)

Recent Ohio, Kentucky and Indiana Activity

The Ohio DOT is also exploring more extensive treatment of pavement subgrades. If chemical stabilization is warranted based on penetration tests or CBR data on borings, ODOT typically specifies portland cement for PI soils < 20 and lime for PI soils > 20. Kentucky DOT has a similar policy.

In the 1980's, The Kentucky Transportation Cabinet (KTC) sought to improve the bearing strengths of clay soils when exposed to water. Chemical stabilization was found to be effective. Recently a field and laboratory investigation was completed on the longevity of lime, portland cement, and LKD used at fourteen job sites, varying in age from about 8 to 15 years. Based on cores of treated subgrades, in-situ CBR tests were reported to be 12-30 times greater than the in-situ CBR values of the untreated subgrades.(11)

Neither Ohio DOT nor Kentucky DOT have used Class C or Class F with lime for soil stabilization. However, in 1997 the UK KTC, after a thorough study, recommended a lime-Class F fly ash mixture for stabilization of a clay subgrade for a county airport. The soil was initially classified as A-7-6 (or CH) as a fat clay and a very poor subgrade. A combination of 3% quicklime and 10% fly ash decreased the PI from 26 to 14 where the ash alone (10% and 20%) only decreased the PI from 26 to 24.[12]

The City of Indianapolis has permitted lime-fly ash for subgrade stabilization for nearly 15 years. The increased subgrade strength can be used in design, reducing the overall pavement design thickness. The City of Columbus and some Ohio counties have recently approved similar guidelines.

PennDOT District 8, SR-283

2002 Construction Season

In 2001, PennDOT initiated a pilot program to gain experience with lime stabilized subgrade for pavement reconstruction. Hydrated lime was specified for reconstruction of a portion of SR-283 between Harrisburg and Lancaster. The required UCS was 100 psi at 3 days using the Virginia Test Method, VTM 11, with accelerated curing temperature at 120°F. The soil, called the Gettysburg shale, was a red shale soil with high silt but low clay having a PI below 20. With a limited amount of mix design testing, a dosage rate of 8% hydrated lime was chosen.

In 2002, the UCS tests on the westbound soil attained 100 psi by only a small margin. Therefore, the Carmeuse Technology group elected to evaluate lime and coal-fired power plant fly ash. The lab test strength at 4 days at 120°F for the 6% hydrated lime dose was 140 psi while the 3% lime – 6% fly ash mix was 330 psi.

Dust Control

PennDOT's first experience with lime stabilization identified the need to minimize fugitive dust during both the lime and fly ash application. An improvement in both transferring lime to the spreader truck and lime spreading in areas adjacent to traffic were mandatory. Three changes in lime addition were proposed for the 2003 construction season for SR 283. First, the use of a coarser size gradation using quicklime fines rather than hydrated lime. It would be less dusty and more economical. Second, the Stoltzfus Co. of Morgantown, Pa. improved the pneumatic transfer of lime into the spreader trailer. Stoltzfus also developed a fog nozzle spray system around the drop auger and dust curtain. Third, the use of fly ash was suggested to supplement the lime's need for silica and alumina for the pozzolanic cementitious reaction. Fly ash must be added with minimal fugitive dust.

Control of fly ash fugitive dust was demonstrated by PennDOT District 3 about ten years ago by simply spreading moisture conditioned fly ash by a self-propelled asphalt paver with a crawler track like that, as shown in Figure 2. This technique was successfully tried for applying 6% fly ash, resulting in a layer about 2 inches thick. This moisture conditioned fly ash is the same material the power plant prepares for compacting at a landfill or structural fill. It is delivered by a triaxle truck which then attaches to the paver. The moisture content would vary from plant to plant from about 15 to 30%.

Figure 2: Moisture-conditioned fly ash from the PP&L Brunner's Island Power Plant being applied at 6% by dry weight soil on PennDOT SR-283.

<u>2003 Construction Season</u>

PennDOT decided to use lime fly ash for the eastbound sections of SR-283 in 2003. Quicklime fines and coal fly ash were applied at 3% and 6%, respectively. The lime fines were first added dry, followed by enough water, about 10 gal.per sq. ft., to reach the optimum moisture content of 15% OMC. The lime and water were then mixed into the subgrade to a depth of 12 inches. The moist fly ash was added with an asphalt paver on the following day as shown in Figure 2. The moisture content is checked for OMC and more water was added, if needed. After addition of necessary water, the fly ash is mixed in, as shown in Figure 3. Mixing a second time also allowed for complete dispersion of all lime particles, now hydrated and available for pozzolanic reaction.

Figure 3: On PennDOT SR-283, a "road reclaimer" mixes moist-conditioned fly ash from Brunner Island, PP&L plant near Harrisburg, PA, to a depth of 12 inches. Lime had been similarly added on the previous day.

Before compaction, samples of the lime-fly ash treated soil were collected by both PennDOT Central Lab and the Carmeuse Technology Center for molding/compacting in the lab UCS cylinders, followed by lab curing. Results of UCS tests from each lab generally agreed.

There were two subgrade sections treated with lime and fly ash – one in May 2003 and one in June 2003. Unconfined compressive strength and CBR test results by Carmeuse Technology are seen in Table 2 from two samples taken in May (Samples #1 and #2) and two samples taken in June (Samples #3 with lime treated only – before fly ash addition and #4). This data is summarized as follows:

- Three-day and 7-day UCS at accelerated curing temperatures for the four samples are shown in Table 2. Specimens for 28-days and 56-days UCS tests were cured at room temperature. Sample #3 contained lime only, no fly ash. All strength tests show satisfactory results (100 psi minimum), but the lime-fly ash specimens show higher strength than the lime-only specimens.

- Some data for the "7-day accelerated test" with and without the capillary soak are not easily comparable as some specimens had only 6 days of curing.

- All samples continued to gain strength from 28 days to 56 days. Additional strength gain (beyond 56 days) can be expected.

- The differences in strength between Sample #1 and Sample #2 is likely due to the different moisture contents.

- Comparing Sample #3 and Sample #4 shows that the addition of fly ash considerably increased the UCS.

- CBR specimens were cured for 7 days at 40°C and then soaked under water for 4 days. Comparing Sample #3 and Sample #4 again shows that fly ash improved the strength of the stabilized soil.

Table 2: PennDOT Route 283 Test Results

UCS Results on Red Shale LFA= 3%Quicklime/6%flyash; Lime only= 3% Quicklime		Curing Condition	Compressive Strength (PSI)
3 Day:			
Sample #1	LFA :17.3% Moisture, May 20, 2002	50°C	190
Sample #2	LFA:14.75% Moisture, May 20, 2002	50°C	310
Sample #3	Lime only: 15.2% Moisture, June 20, 2002	50°C	250
Sample #4	LFA: 19.2% Moisture, June 20, 2002	50°C	350
7 Day:			
Sample #1		40°C, 7 days	140
Sample #1		40°C, 6 days + 1 day soak	100
Sample #1	test repeated – compaction delayed for 4 days	40°C, 7 days	160
Sample #1	test repeated – compaction delayed for 4 days	40°C, 6 days + 1 day soak	125
Sample #2		40°C, 7 days	290
Sample #2		40°C, 6 days + 1 day soak	200
Sample #3		40°C, 7 days	308
Sample #3		40°C, 7 days + 1 day soak	219
Sample #4		40°C, 7 days	522
Sample #4		40°C, 7 days + 1 day soak	604
28 and 56 Day:			
Sample #1		Ambient temp. , 28 days	160
Sample #1		Ambient temp. , 56 days	190
Sample #2		Ambient temp. , 28 days	250
Sample #2		Ambient temp. , 56 days	310
Sample #3		Ambient temp., 28 days	220
Sample #4		Ambient temp., 28 days	310

CBR Data: Samples Cured 7 Days At 40C and Soaked 4 Days Before Testing

	CBR @ 0.100	CBR @ 0.200	Moisture Before Soak	Moisture After Soak	Dry Unit Wt. Before Soak	Dry Unit Wt. After Soak	% Swell
Sample #1 LFA	21	36	17.3%	21.3%	108.1 PCF	105.6PCF	0.0%
Sample #3 Lime only	124	108	14.8%	18.1%	107.5PCF	106.9 PCF	0.0%
Sample #4 LFA	278	222	18.6%	22.4%	104.7 PCF	103.6PCF	0.0%

PennDOT I-83, York, PA

Another problematic silt soil, called "micaceous silt" is common in southeastern Pennsylvania, Maryland and Virginia. It is present on a current interstate highway reconstruction project, I-83 near York, PA. The soil has a high silt content with about 80% passing the 200 mesh sieve, but contains very little clay. After adding lime, the treated soil had a high OMC content near 23%. Initial unconfined compressive strength tests demonstrated that the LFA combination of 3% quicklime and 6% fly ash had greater strengths than 6% lime alone. Additionally, specimens containing 4% lime and 8% fly ash were tested. Unconfined compressive strength test results are shown in Figure 4. PennDOT later specified the 4% quicklime and 8% fly ash for subgrade stabilization.

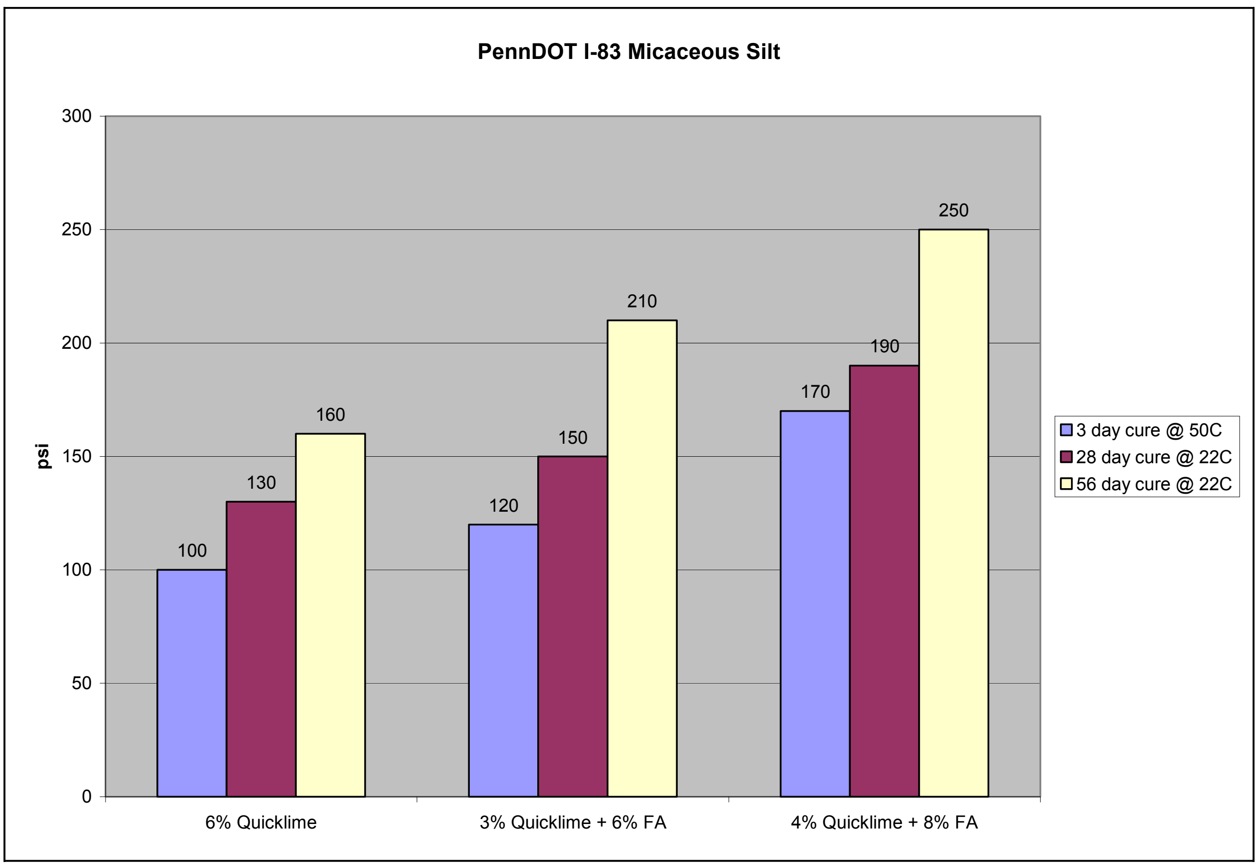

Figure 4: Lime and lime-fly ash unconfined compressive strengths.

Bowman School Site, Warren County, Ohio

Carmeuse provided technical assistance to CBC, a geotechnical engineering firm, and Kelchner Environmental, a site/land development contractor, for preparing a new school site near Lebanon, Ohio. This project would lead to consideration by Warren County to include the stabilized subgrade in pavement thickness design. The use of a lime-fly ash mixture is one of the chemical additives being promoted by several suppliers in the Ohio-Indiana area.

The soil sample was from a known problematic soil layer with high silt content. It had been previously classified as CL (lean clay) using the Unified Soil Classification System (ASTM D-2487).

Carmeuse tests compared treatment with 7% quicklime to 4% quicklime and 8% Zimmer Cinergy fly ash. Results are described below from Table 3 and shown graphically in Figure 5.

Table 3: Sample Analysis Report – Bowman School Site

Soil Classification = CL	Units	7% Quicklime fines (1/4" x 0")	4% Quicklime + 8% Zimmer Fly Ash	Control (No lime or fly ash)
Plasticity index				15
Liquid limit / plastic limit				35/20
% finer than 200 mesh	% passing			81
OMC (standard compaction)	%	22.9	22.1	20.6
Maximum dry density	pcf	98.0	100.7	106.4
UCS: 3 Day @ 50^0C	psi	190	220	
UCS: 7 Day @ 40^0C	psi	160	180	40
UCS: 7 Day+24 hr soak	psi	130	150	
UCS: 28 Day @ 22 C	psi	120	170	35
UCS: 56 Day @ 22 C	psi	150	200	
CBR w/o curing	**%**	22	24	5.5
Moisture before soak	%	22.5	24.0	19.5
Moisture after soak	%	25.1	24.3	25.3
% Swell after 4 days	%	0	0	1.2
CBR w/ 7 day curing	%	62	43	
Moisture before soak	%	24.1	25.3	
Moisture after soak	%	25.4	25.7	

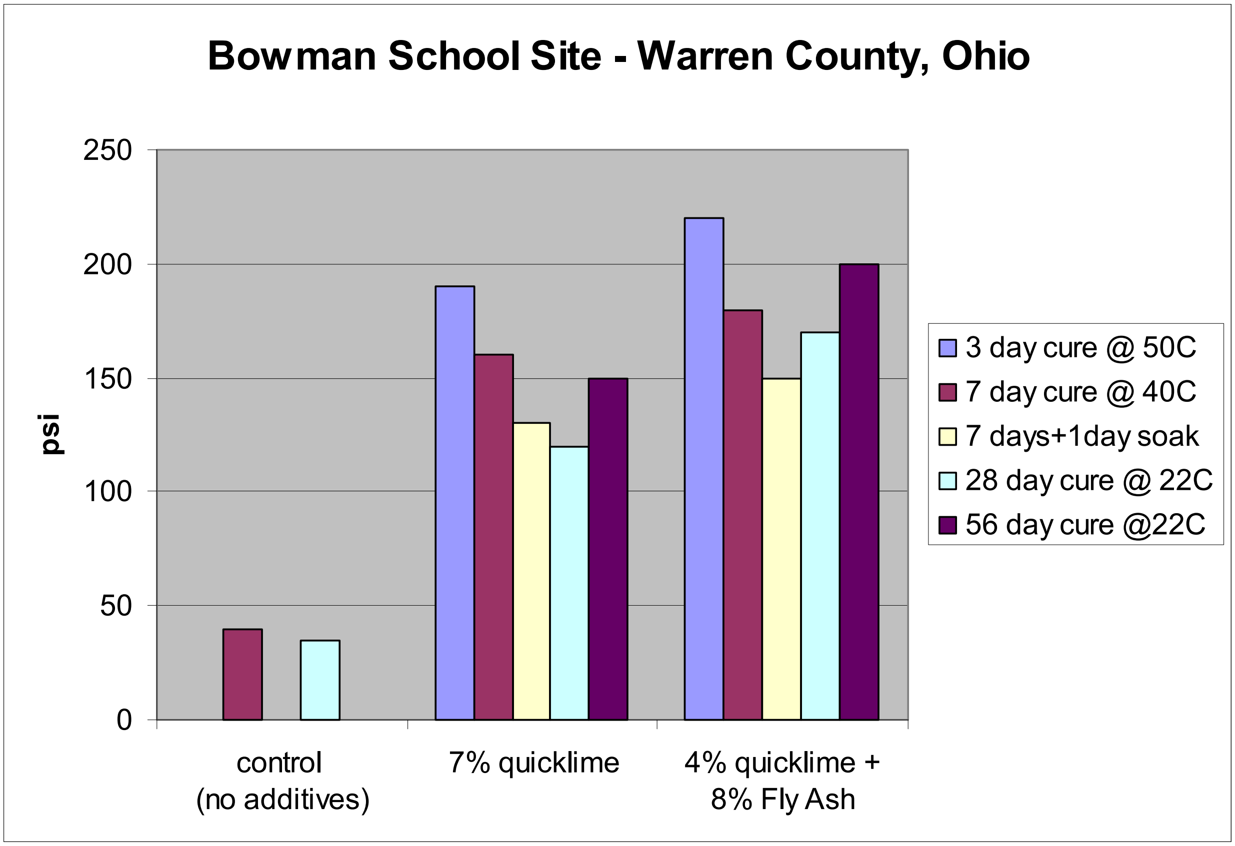

Figure 5: Lime and lime fly ash unconfined compressive strength test results.

Key points include:

- Both additives (lime and LFA) achieved the desired USC of 100 psi, the desired value for long-term durability in this instance.
- Both additives increased the optimum moisture content while decreasing the maximum dry density compared to untreated material.
- Both additives significantly increased the CBR compared to untreated material.

Lime – Fly Ash with Full Depth Reclamation

Full depth reclamation (FDR) is a bituminous concrete recycling technique in which the entire or full depth pavement section and a predetermined portion of the underlying subgrade are uniformly crushed, pulverized, or blended, resulting in a stabilized base course. FDR is particularly applicable where the entire base has structurally failed, and/or the granular base is no more than 6 inches thick.

Before the pavement is pulverized and mixed, chemical stabilizing additives, in either a dry or liquid form, can be added. Dry chemical additives include lime and coal fly ash. To date, there is little documentation of FDR projects using LFA.

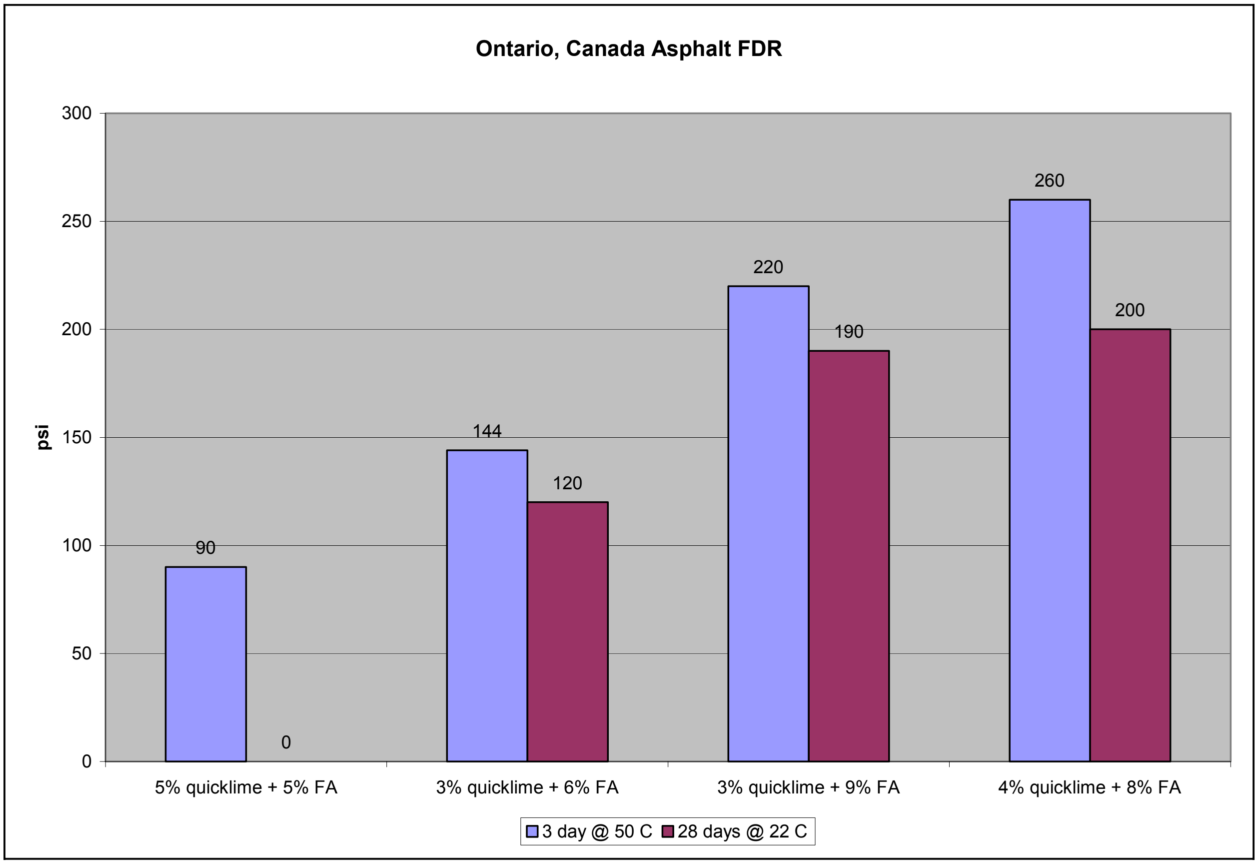

Figure 6: Lime fly ash unconfined compressive strengths of full depth reclamation asphalt and base/subbase.

Figure 6 shows the unconfined compressive strength test results of four mixtures of lime-fly ash and material obtained from a full-depth reclamation project in Ontario, Canada.

Economics Discussion

Soil modification leads to savings in lost time by correcting wet soil conditions that otherwise would slow down or stop a construction project. Such economic savings are case by case and not addressed here.

The following discussion highlights three ways that soil modification and stabilization can benefit the designed cost of construction.

Cost of Materials

With the appropriate soil conditions, a suitable combination of lime and fly ash typically costs less than a suitable amount of lime-only or portland cement. Contractor bids for soil stabilization are often in the $3.50 to $6.00 per square yard range, assuming 12-inch deep mixing. If 6% portland cement costs $85/ton, the resulting material cost is $2.70 per square yard. The cost of 6% lime fines costs $70/ton, the resulting cost is $2.20 per square yard. If 6% fly ash costs $8/ton, the cost of materials for a 3% lime ($1.10 per square yard) and 6% fly ash combination would be $1.35 per square yard.

Lime Stabilization vs. Cut and Replace

Recently a project to reconstruct a portion of the Pennsylvania Turnpike included chemical stabilization with lime kiln dust as well as removal and replacement of unsuitable subgrade material. The comparative costs, about $3.50/sq.yd. for lime stabilization compared to about $23.50/sq.yd. for remove and replace, showed a significant savings for stabilization.(8)

Another example is described in a report based on Kentucky DOT bid data from 1997.(13) Eight inches of lime stabilized soil is compared to the cost of replacing the soil with 8 inches of crushed stone.

Eight inches stabilized soil:		
1. soil mixing	=	$1.49/sq.yd.
2. hydrated lime @ 5%	=	$1.46/sq.yd.
3. bituminous curing seal	=	$0.26/sq.yd.
		$3.21 sq.yd.

Eight inches crushed stone plus fabric:		
1. excavation @ $2.90/cu.yd.	=	$0.64 sq.yd.
2. crushed stone @ $16.33/ton	=	$4.85/sq.yd.
3. geotextile fabric	=	$1.41/sq.yd.
		$6.90/sq.yd.

Construction Savings in Pavement Thickness

The permanent improvement to pavement subgrade from lime-fly ash stabilization can realize substantial reduction of the total required pavement thickness. For example, Illinois DOT studies show by increasing the CBR from 2 to 8, the pavement granular base thickness can be reduced from 15 to 7 inches.(6)

Reducing the overall pavement thickness by eight inches of crushed stone base offers a significant savings. Assuming an in-place cost of $18/ton and 140 lbs/ft^3, eight inches of crushed stone costs about $7.50 per square yard.

On the reconstruction project of the Somerset County section of the Pennsylvania Turnpike, stabilization allowed for the reduction of 5 inches of bituminous concrete base course and 2 inches of granular base aggregate, savings more than $4 million. This is equivalent to over 20% of the cost of the pavement design based on untreated subgrade.(9)

Summary and Conclusions

The objective of this paper is to relate recent experiences and information pertaining to the use of lime together with coal fly ash in stabilization of soil subgrade and granular aggregate base course beneath the flexible asphalt layer or rigid concrete layer.

1) Federal and state highway engineers along with geotechnical consultants have renewed interest in soil subgrade stabilization as a means to both reduce construction costs and increase life of the pavement system. Costs can be reduced by stabilizing the existing poor soil subgrade rather than removing (undercutting) and replacing it with granular material. Second, because lime stabilization increases the subgrade structural strength and stiffness, asphalt and granular base layers can be reduced in thickness.

2) While lime-alone works well to stabilize clay soils, a combination of lime and fly ash is beneficial for lower plasticity, higher silt content soils. The fly ash provides the pozzolanic reactants, silica and alumina, lacking in such soils.

3) To screen compatible mixtures before testing a given soil, Class F and Class C ashes are examined for their lime-pozzolanic reactivity per the ASTM C-593 mortar cube test. Strength after 7 days curing surpasses the suggested minimum UCS of 600 psi for all samples.

4) Primarily due to the lime components, the use of lime and a Class F fly ash combination is shown to have a dramatically beneficial effect in compacting a wet soil by allowing the maximum density to be achieved at a higher moisture content. Excavation contractors can work under wetter soil conditions, thus extending their season.

5) Illustrated with both UCS tests and CBR penetration tests, three soils of moderate plasticity (PI < 20) and high silt content (i.e. > 50%) show that a LFA mixture can achieve greater strength than lime alone, even though more lime was used in the lime-only tests.

6) A simple method to test for moisture susceptibility is introduced as part of the UCS procedure by providing for some molded cylinders to be exposed to a capillary soak after being allowed to cure. This capillary soak resulted in a loss of 15-25% UCS.

7) Controlling fugitive dust from the application of fly ash successfully means applying moisture-conditioned fly ash via an asphalt paver was demonstrated in Pennsylvania.

8) Full depth reclamation (FDR) using LFA is not well documented. Results of limited testing show that it is a viable option deserving attention.

9) Examples of cost benefits from LFA stabilization are illustrated three ways.

    a. In terms of material cost, the use of less costly fly ash can reduce the required amount of lime. Also LFA can offer cost savings compared to portland cement stabilization by reducing material cost by up to 50%.
    b. Assuming the area to be stabilized is large enough, the cost of stabilization with LFA is less expensive than undercutting and replacement with suitable soil or granular material. Two examples with greater than 100% savings at actual jobs are reported, one in Pennsylvania and one study in Kentucky.
    c. Permanent improvements to the pavement subgrade allow for a reduction in pavement thickness. In one case, this reduction saved over 20% of the cost of the pavement without stabilization.

Acknowledgements

The author wishes to recognize with sincere appreciation several Carmeuse Lime people for their help and contribution to this paper. Significant contributors were Steve Tutokey for his hard work and dedication in the soil testing laboratory, Larry Cole for his guidance and support and Patty Randall for her skills in presentation. Grateful appreciation is also extended to Rich Mackow of CPM, Inc. for his technical support with the PennDOT S.R. 283 project.

References:

[1] Little, D., "Evaluation of Structural Properties of Lime Stabilized Soils and Aggregates", prepared for the National Lime Association, Arlington, Va., Vol. 3, Mixture Design and Testing Protocol for Lime Stabilization, Mar., 2000, p.4.

[2] "Soil Stabilization for Pavements", Army TM 5-822-14, Oct., 1994, p.2-1.

[3] "Lime Stabilization: State of the Art Report 5", Transportation Research Board, National Research Council, Washington, D.C., 1991, p. 1.

[4] Little, D., "Evaluation of Structural Properties of Lime Stabilized Soils and Aggregates", prepared for the National Lime Association, Arlington, Va. Vol. 1, Summary of Findings, 1999, p. 49.

[5] ASTM D 5102-90, "Standard Test Method for Unconfined Compressive Strength of Compacted Soil-Lime Mixtures", Vol. 04.01, 1990, p. 1199.

[6] Newcomb, D.E., "A Perpetual Pavement Needs a Perpetual Foundation", Paving the Way, c/o Pennsylvania Asphalt Pavement Association, Harrisburg, Pa., Vol. 5, 2002, pp 1-3.

[7] Lockhart, J. et.al, "Pennsylvania Turnpike Reconstruction – Part III: Lime-Pozzolan Meets the Reconstruction Challenge", Pennsylvania Asphalt Pavement Association, Website, Harrisburg, Pa., Sept. 2001.

[8] Heirndt, K., "Subgrade Soil Stabilization", Presentation at Ohio Transportation Engineering Conference, c/o Ohio Department of Transportation, Columbus, Oh., Oct. 23, 2002, powerpoint, pp 1-3.

[9] Qubain, B.S., et.al., "Incorporating Subgrade Lime Stabilization into Pavement Design", presented at the Transportation Research Board, Jan, 2000, p. l.

[10] Hanks, D.L., Solidification of Lime-Fly Ash Mixtures: Influence of Mix Proportions, Curing Temperature, and Time of Curing on Compressive Strength, Proceedings: 12th International Symposium on Coal Combustion By-Product Management and Use – Vol. 1 EPRI Proceedings / TR-107055-VI, Jan., 1997, pp 16-4.

[11] Hopkins, T.C., et.al., "Long-Term Benefits of Stabilizing Soil Subgrades", Kentucky Transportation Center, University of Kentucky, Research Report KTC-02-19/SPR-99-196-1F, June 2002, p.1.

[12] Hopkins, T. and Beckham, T., "Stabilization of an Airport Subgrade using Hydrated Lime and Fly Ash", Kentucky Transportation Center, University of Kentucky, Lexington, Ky., Research Report KTC-97-20, pp 1-9.

[13] Mathis, H., "Soil Modification and Soil Stabilization Utilizing Lime", presented for Dravo Lime Company, Pittsburgh, Pa, 1997, Section 13.