Class C Fly Ash Stabilization of Recycled Asphalt Pavement and Soil – A Case Study

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KEYWORDS: stabilization, undrained shear strength, RAP

ABSTRACT

Delays due to road construction cost millions of dollars in lost productivity every year. These costs impact the general public especially local businesses. Unstable subgrade is one major construction setback that increases costs. Unstable subgrade causes a wide variety of problems such as: asphalt pavement rutting, premature pavement failure, and construction difficulties. To address unstable subgrade problems, civil engineering experts need to adopt the use of new materials or construction practices. The purpose and goal of this study was to evaluate the suitability of one particular construction process and specific materials (soil, self-cementing fly ash, and recycled asphalt pavement (RAP)) for asphalt parking lot subgrade stabilization. Dynamic Cone Penetrometer (DCP) tests were used to evaluate strength gain in the field. Laboratory testing consisted of unconfined compression strength tests and consolidated undrained (CU) triaxial compression tests. DCP test results show time dependent strength-gain due to the cementing and pozzolanic action of the fly ash. Falling weight deflectometer (FWD) results show increased pavement durability and performance. CU triaxial load tests show normally consolidated behavior for the soil and soil-RAP mixtures and overconsolidated behavior for self-cementing fly ash-soil-RAP mixtures. Self-cementing fly ash-soil-RAP mixtures demonstrate an undrained shear strength gain of about 2 to 4 times of the soil-RAP mixture. Depending upon the back calculation method applied to falling weight deflectometer measurements, the fly ash-soil-RAP mixtures demonstrated increases stiffness leading to 7 to 21 times greater traffic capacity.

INTRODUCTION

Unstable subgrade can cause a wide variety of problems such as: rutting, premature pavement failure, and construction difficulties. Subgrade becomes unstable when it is no longer able to support construction traffic. Usually unstable subgrade has high water content and large fines content, i.e. a large fraction passing the number 200 sieve, leading to low soil shear strength. Typical California Bearing Ratio (CBR) values for unstable subgrade are below three.

In May of 2002 reconstruction was initiated to replace a large section (25,350 m^2) of deteriorating asphalt pavement at Iowa State University's Jack Trice Football Stadium (shown in Figure 1). Previous construction activity in the area revealed wet unstable subgrade conditions, which was believed to have contributed to the existing poor pavement performance.

Figure 1. Jack Trice Stadium parking lots

Several alternatives to improve unstable subgrade are: addition of a drainage layer such as granular backfill underneath the pavement, lime stabilization, self-cementing fly ash stabilization, and Portland cement stabilization. Granular backfill is particularly attractive since the increased CBR value of the granular material provides additional support for the pavement layer while removing excess water from the structure. Lime stabilization is useful as it provides long-term strength gain due to pozzolanic action in clayey soils while acting as a drying agent. Portland cement stabilization increases the strength of unstable subgrade, but due to the large amount of Portland cement required, 10-15% by dry weight, it is usually not cost effective due to the high cost of Portland cement. Self-cementing fly ash is attractive due to the drying capabilities and the initial strength gain due to the hydration process. Long term strength gain from pozzolanic activity also makes self-cementing fly ash stabilization an attractive solution.

The Kansas Department of Transportation constructed and subsequently tested from 1992 to 1996 on Kansas Route 27. A total of 11 test sections were constructed. Three sections were stabilized using a cationic, medium setting, polymerized asphalt emulsion; five were constructed using a cationic, medium setting asphalt emulsion; and three were constructed using 13% ASTM Class C fly ash as the binder. All layer thicknesses were 4 inch, with a 1.5 inch hot mix asphalt overlay[1].

One conclusion from this study was cold in place recycled pavements (CIPR) with class C fly ash as a binder reduces the potential of rutting when compared to the other test sections built with conventional binders. The self-cementing fly ash sections consistently showed the lowest surface deflection values for Falling Weight Deflectometer (FWD) testing. Shear strains in the fly ash treated layer were very uniformly distributed across the pavement layers. Lastly, for pavement damage, rutting controlled this project, not fatigue[1].

93rd Street in Shawnees County Kansas was constructed in June of 1987, this 1.5-mile section of rural road carries a high volume of truck traffic. The surface course varied in thickness from 2 to 6 inches with a 1 to 8 inch granular base overlying a clay subgrade. The design process concluded that 18% class C fly ash and 10% moisture content was needed to stabilize the material[2].

The construction process began with recycling the existing pavement and base to a depth of 6 inches and compacting it. The fly ash was deposited in windrows and spread uniform and mixed with a Bomag MPH 100 Recycler. For this project, water was added through nozzles in the mixing drum. Initial compaction was completed with a vibratory padfoot roller while final compaction was completed with a smooth drum or pneumatic-tired roller. The surface was kept moist for the five-day cure period. A layer of asphalt was then applied followed by a chip seal wearing surface two months later. Observations four years after construction yield no distress or deterioration[2].

The city of Mequon, Wisconsin built two test sections 250 m long on the eastern end of Highland Avenue. Both sections had a surface thickness of about 140 mm overlying a 170 to 450 mm base course overlying a cohesive subgrade. The project was started and completed in August of 1997[3].

For construction, both sections were pulverized to a depth of 200 mm. The asphalt emulsion section was repulverized to a depth of 100 mm and emulsified asphalt was added at the rate of 7 L/m2. The section was then graded, compacted, and an 87.5 mm HMA surface was placed. The fly ash section was constructed by placing the ash at 7% by dry weight on the RAP and mixing to a depth of 125 mm. The layer was graded and water was applied to the surface to achieve 5% moisture content. The stabilized layer was then graded, compacted, and a 100 mm HMA surface was applied. FWD testing shows excellent performance through the first year for the fly ash section due to the increased structural capacity of the pavement[3].

The purpose and goal of this study was to evaluate the suitability of the construction process and final product for parking lot stabilization and subsequent reconstruction. This paper documents construction process, details the results of a detailed laboratory analysis of materials, and reports on the results of a field analysis to evaluate the suitability of the final product.

MATERIALS AND TEST METHODS

Materials

Two class C fly ash sources were used for the construction of this project and they included Ottumwa Generating Station (OGS) located in Chillicothe, IA, and Ames Municipal Generating Station located in Ames, IA. The Ames fly ash was the predominate source used during the construction project. Note that another source Prairie Creek was investigated in the laboratory, but never used on the actual construction site.

The existing asphalt pavement was milled and then mixed with the subgrade soil. The existing pavement conditions (Figure 2 to Figure 4) demonstrated a wide number of patches with extensive areas of fatigue and alligator cracking, and large potholes. A falling weight deflectometer (FWD) was used to determine structural numbers before and after reconstruction efforts.

Figure 2. Existing asphalt pavement showing pothole and fatigue cracking

Figure 3. Severe alligator cracking

Figure 4. Alligator cracking with large patches

Test Methods

The following test methods were used throughout the course of this study.

- ASTM D422 [Standard Test Method for Particle Size Analysis of Soils][4]
- ASTM D2487 [Standard Test Method for Classification of Soils for Engineering Purposes][5]
- ASTM C 4318 [Standard Test for Liquid Limit, Plastic Limit, and Plasticity Index of Soils][6]
- ASTM C618 [Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete][7]
- ASTM D698 [Standard Test Methods for Moisture Density Relations of Soils and Soil-Aggregate Mixtures Using 5.5 lb. (2.49kg) Rammer and 12 in (305 mm) Drop][8]
- ASTM D 4767 [Standard Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils][9]
- Iowa Set Time Test
- Dynamic Cone Penetrometer (DCP) testing was completed on the in-situ soil and several times after stabilization operations were completed

The procedure for the Iowa Set Time Test is as follows:

1. Weigh out approximately 500 grams of fly ash.
2. Weigh the proper amount of water for 27.5 percent water content.
3. Mix with a mixer that conforms to ASTM C305 on speed one for 10 seconds, and then switch to speed two and mix for 50 seconds using a wire whip[8].
4. Spread mixture evenly in a suitable size container and determine the penetration resistance of the mixture about every 5 minutes using a pocket penetrometer.
5. Plot the elapsed time versus the penetration resistance. Initial set is determined to be the time at which the material exerts some penetration resistance, and the final set is determined to be when the penetration resistance is 4.5 tons per square foot.

RESULTS AND DISCUSSION

Laboratory Materials Characterization Results

The class C fly ashes used in this study are typical of those found in Iowa. Table 1 shows the XRF chemical analysis for the fly ash sources. Figure 5 shows the Iowa Set Time Test results. Note that the time to final set is significantly less for the Ames ash source compared to the OGS fly ash source. This indicates that the Ames ash is most likely better suited for soil stabilization due to its increased reactivity.

In-situ soils in the affected area lie in the floodplain of the South Skunk River and are highly saturated and unstable under construction equipment. The high in-situ moisture content of the soil makes it nearly impossible to move construction machinery around without severe rutting and deformation. The area soils generally classify as a sandy clay material. Figure 6 shows the subgrade soil gradation curve, and Table 2 shows the subgrade soil classification. It is important to note that the addition of RAP to the in-situ soil acts like a mechanical stabilizer. The grain size distribution curves are shifted to the left indicating more gravel and sand size particles.

Table 1. XRF chemical analysis results for Ames and OGS fly ash

Sample Name	OGS	AMES
SiO_2	37.10	33.42
Al_2O_3	21.47	17.52
Fe_2O_3	5.71	5.89
SUM	64.28	56.84
SO_3	2.19	3.46
CaO	22.51	26.65
MgO	4.27	5.90
Na_2O	3.27	2.41
K_2O	0.52	0.52
P_2O_5	1.44	1.08
TiO_2	1.53	1.64
SrO	0.42	0.30
BaO	0.75	0.73
Total	101.20	99.54

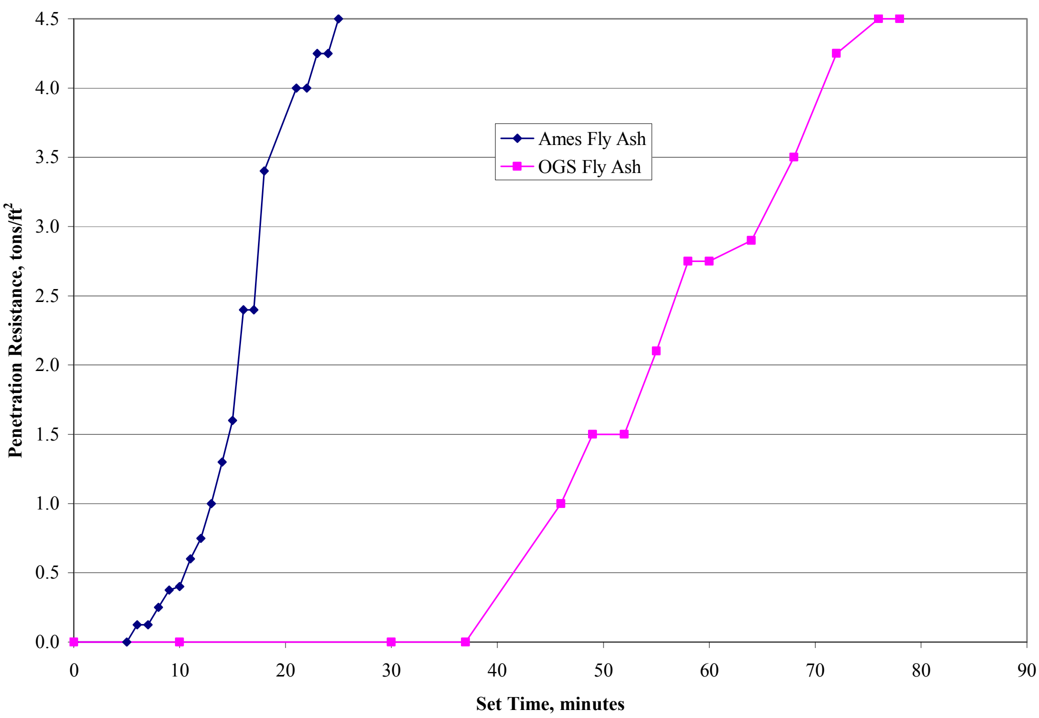

Figure 5. Iowa set time results for Ames and OGS fly ash

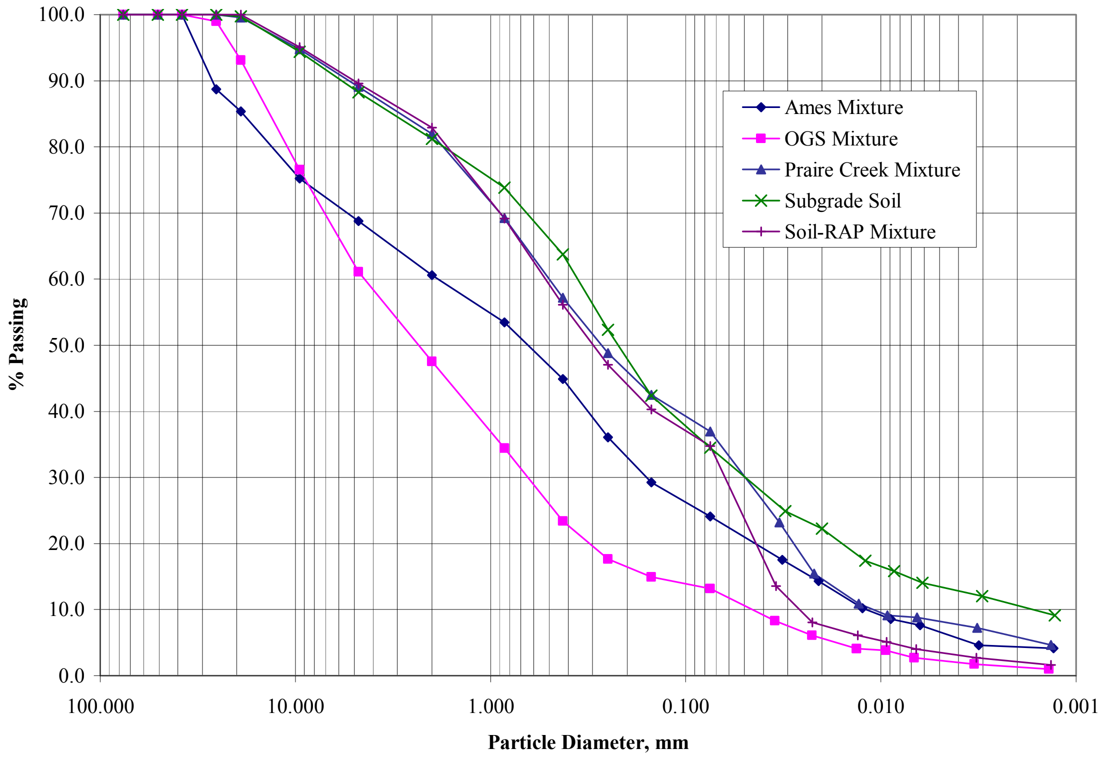

Figure 6. Grain size distributions for soil, soil-RAP, and soil-RAP-fly ash mixtures

Table 2. AASHTO and USCS soil classification for soil, soil-RAP, and soil-RAP-fly ash mixtures

Sample	AASHTO	USCS	LL	PI	% Gravel	% Sand	% Silt	% Clay
RAP/Soil	A-2-6	SC	24	11	17.1	48.1	32.8	2.0
Prairie Creek Fly Ash/RAP/Soil	A-4	SC	27	7	18.0	45.1	30.9	6.0
OGS Fly Ash/RAP/Soil	A-1-a	SC-SM	19	5	52.5	34.3	12.2	1.0
Ames Municipal Fly Ash/RAP/Soil	A-1-b	SM	29	2	39.4	36.5	19.1	5.0
Subgrade Soil	A-2-6	SC	25	11	18.8	46.7	24.5	10.0

Construction Operations

The parking lot construction went as planned. The parking lots were reconstructed in the following manner:

1. Mill existing asphalt pavement
2. Add water to optimum moisture content and add fly ash
3. Mix fly ash, RAP, and subgrade soil.
4. Compaction
5. Final grading
6. Paving

The specifications on compaction indicated a target compaction time delay of 30 minutes. Field observations indicated that the time from mixing to final compaction was about two hours. A more detailed account of the construction efforts can be found here[10, 11].

The results of the mechanical and chemical stabilization of the in-situ soil can be best illustrated when comparing Figure 7 and Figure 8. Note the unstable subgrade during mixing operations and the new paving platform performance in the same location.

Figure 7. Severe rutting due to unstable subgrade

Figure 8. New paving platform without rutting

Analysis of the FWD data shows increased AASHTO structural number and increased equivalent single axle load (ESAL's) to failure. Table 3 shows the relationship between the existing 8.84 inch pavement section and newly constructed pavement sections durability and performance. The new AASHTO structural number was about 1.3 times the existing AASHTO structural number, and the ESAL's increased 7 to 21 times depending upon the calculation method. Table 4 displays the comparative cost analysis for the 8.84 inch construction method to the stabilized subgrade technique used. Note that the two pavement replacement techniques are essentially the same in cost. Although they are the same in cost, the contractor noticed a significant decrease in construction time when stabilizing the material in-place compared to traditional construction methods.

Table 3. Structural comparison between the existing 8.84 inch and the newly constructed pavement sections (Courtesy of Brian Tomlinson of Snyder and Associates)

	Constructed	8.84 Inch
AASHTO Structural Number	5.04	3.09
ESAL's Using winPASS	51,460,300	7,434,500
ESAL's Using PEDMOD	11,919,000	557,500

Table 4. Comparative cost analysis for the existing 8.84 inch and newly constructed pavement sections (Courtesy of Brian Tomlinson of Snyder and Associates)

	Constructed	8.84 Inch
Cost per Square Yard	$21.62	$21.63

Field Results

DCP field testing results show a remarkable decrease in mean DCP index from 40 to 5 mm per blow. Figure 9shows the relationship between the mean DCP index and time after compaction for the Ames fly ash-soil-RAP mixture with 95% confidence intervals. This outcome is to be expected with the cementing and pozzolanic action of the self-cementing fly ash. Figure 10 and Figure 11 show the California Bearing Ratio (CBR) plots for the Ames fly ash-RAP-soil mixture immediately after compaction and 27 days after compaction, respectively. Note that the CBR is increased about 15 to 20 times.

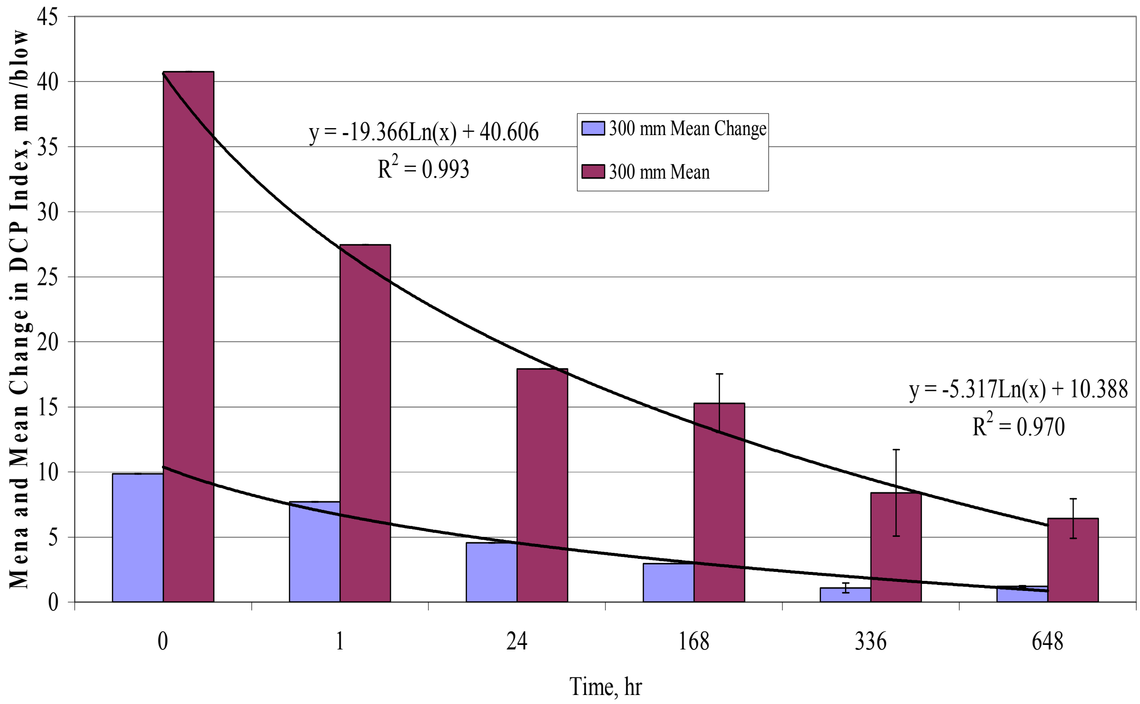

Figure 9. Mean and mean change in DCP index versus time after compaction for Ames municipal fly ash-RAP-soil mixture

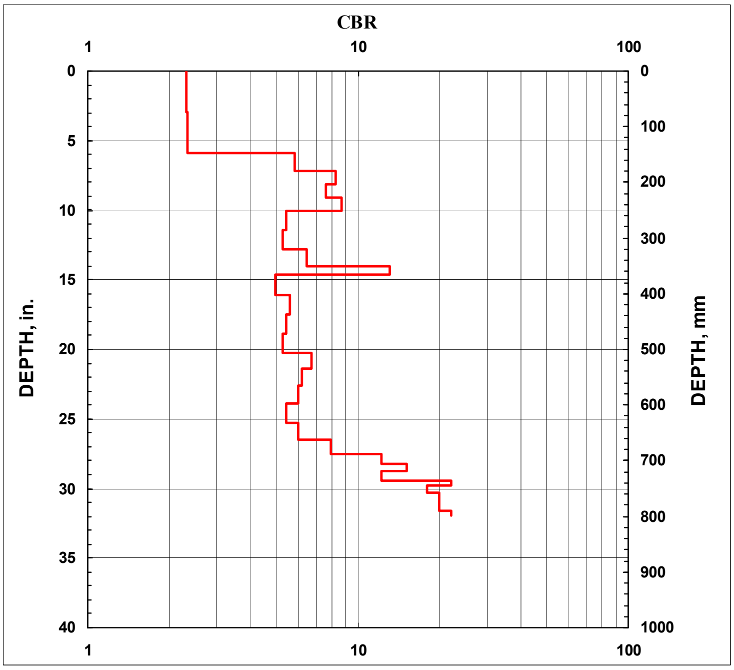

Figure 10. CBR profile for the Ames-RAP-soil mixture immediately after compaction

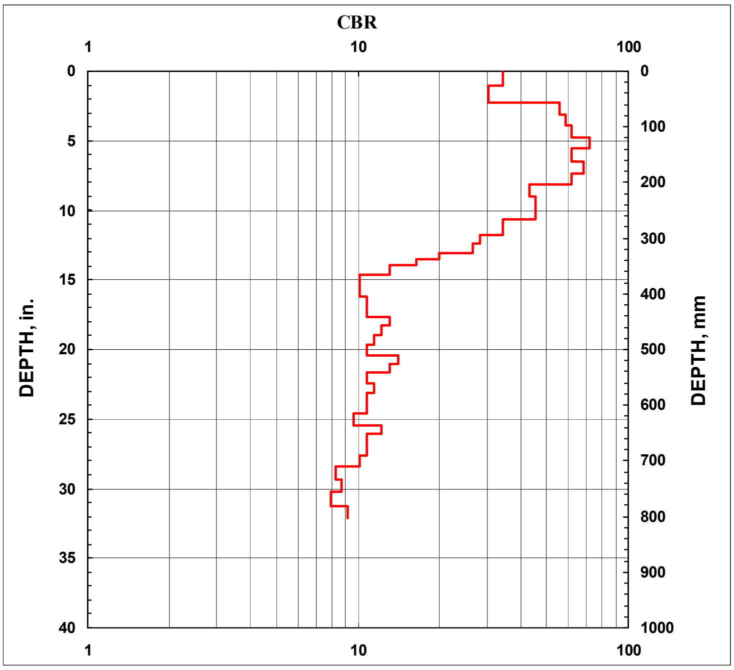

Figure 11. CBR profile for the Ames-RAP-soil mixture 27-days after compaction

FWD testing completed both before and after stabilization revealed that the stabilized basin (Lots S5) was reduced about 80% or a deflection reduction of about 30 mils. Figure 12 shows the FWD deflection basins for Lots S3 (control section) and S5 before stabilization, and Figure 13 shows the average FWD deflection basins for Lots S3 and S5 after completion of stabilization and paving operations. The FWD results indicate the modulus of rupture for the stabilized pavement base section is about 8.5 times that of the pre-constructed base section.

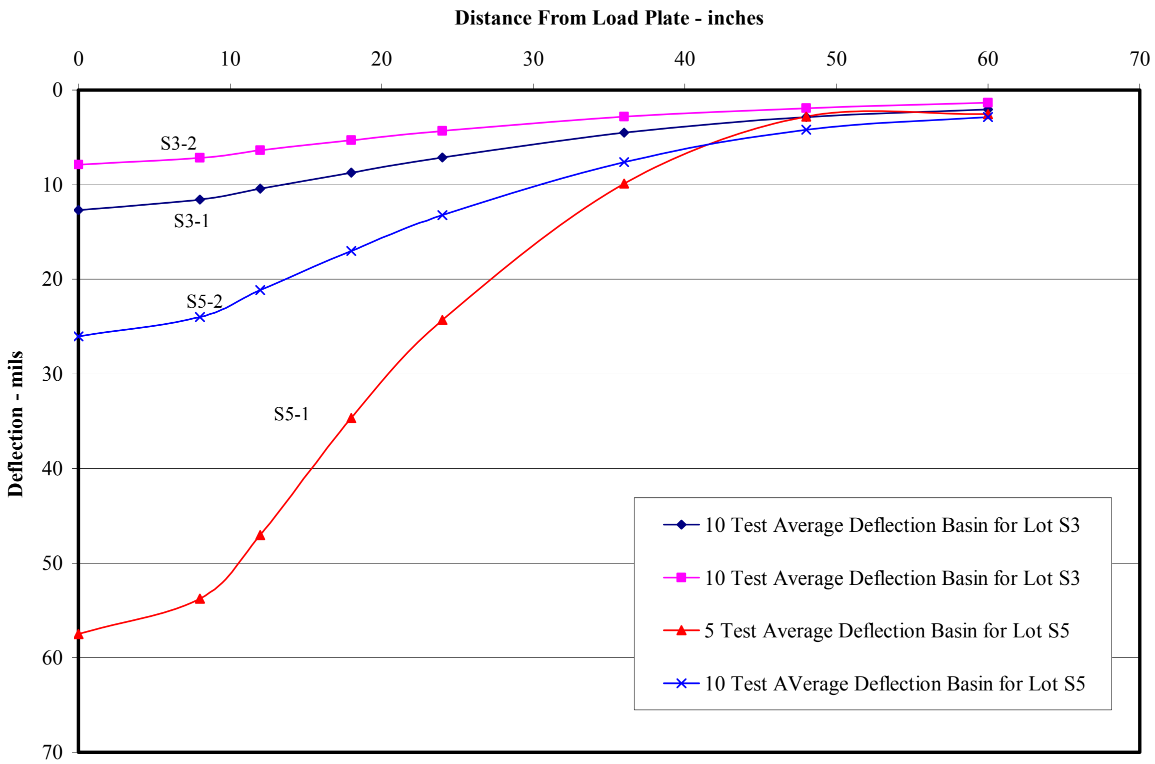

Figure 12. FWD deflection basins for parking Lots S3 and S5 before reconstruction

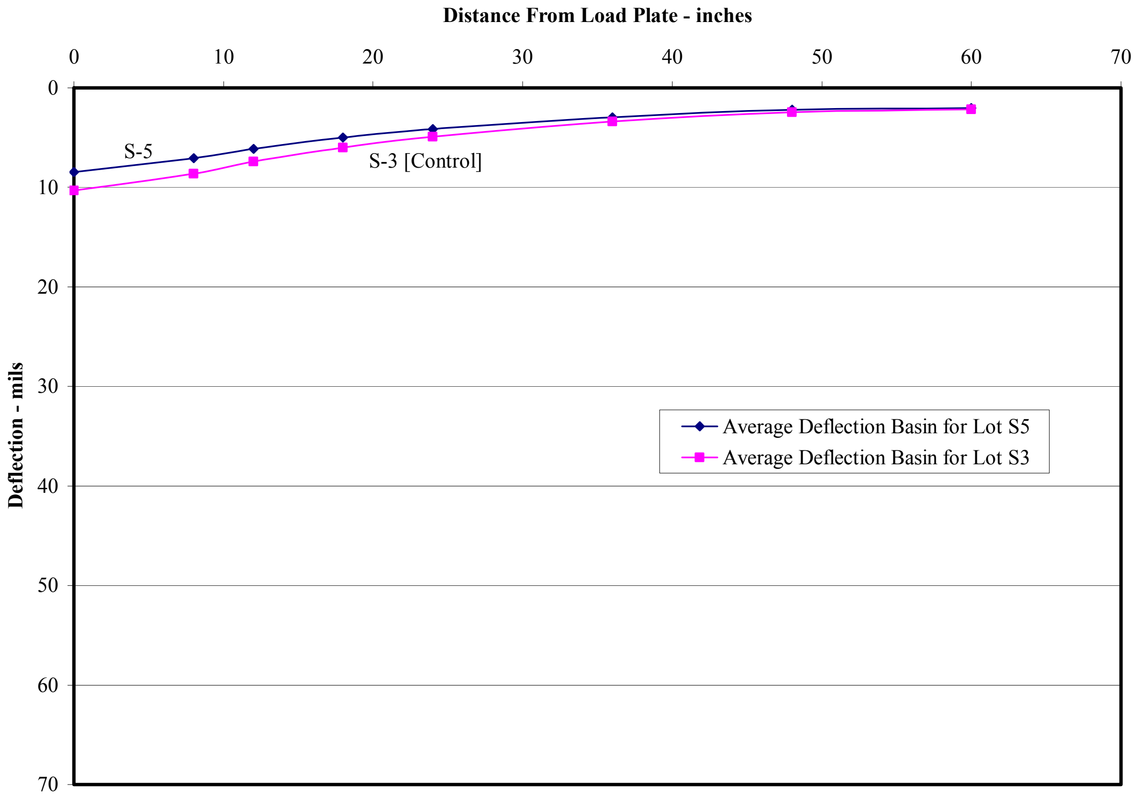

Figure 13. Average (10 Tests) FWD deflection basins for Lots S3 and S5 after reconstruction

The observed field results show a quality finished product. The increase in stiffness exhibited by the reduction in mean DCP index and FWD data shows an increased resistance to deformation. This resistance to deformation ultimately leads to a longer lasting and more durable pavement surface since rutting in asphalt pavement is controlled by compressive forces on the top of the subgrade layer. Increasing the strength of the supporting layers in pavement design allows for reductions in pavement thickness.

The DCP results show an increased stiffness or strength as curing time is increased. This shows that plotting the stiffness as a function of time provides important information as to when paving operations can start. The DCP can therefore be used as a fast, easy way to determine if construction operations can proceed

Laboratory Results

Compressive strength specimens were prepared and tested in both unsaturated and saturated conditions and the results can be found here[10]. Samples sized 6 x 12 inches were prepared for consolidated undrained (CU) triaxial loading. CU testing was chosen due to the high in-situ water table and saturated soil conditions.

The CU test results are shown in Table 5. Individual stress-strain and p-q diagrams during sample loading can be found here[10]. The negative pore water pressures indicate expansion at failure. The soil, soil-RAP, and Ames ash-soil-RAP mixtures exhibit strain-hardening behavior. The OGS-soil-RAP mixture shows a slight strain-softening behavior, and the Prairie Creek ash-soil-RAP mixture shows strain-softening behavior. The strength gain from the addition of fly ash is shown with the increasing major principle stresses.

Table 8 shows a summary of the effective cohesion and friction angle, as well as the modulus at 50% of failure. Note that there is no apparent friction angle for the subgrade soil-RAP and OGS fly ash-soil-RAP mixtures. Generally, the addition of self-cementing fly ash increased the friction angle 3 to 5 times compared to the subgrade soil.

The laboratory test results show a remarkable improvement for all materials used in this project. The addition of self-cementing fly ash increases the unconfined compressive strength significantly. This increased strength allows construction traffic to easily move about by eliminating an unstable subgrade situation.

The correlation between unconfined compressive strength and the mean DCP index of the stabilized layer leads to an interesting discussion. If a project was set up in several test sections, one could determine the characteristic DCP strength correlation curve for each section and eliminate field sampling to determine strength. This would save both time and money for the contractor and contracting agency by eliminating a set of samples. The DCP test is a quick easy test that requires no experienced personnel to conduct or interpret the results.

Laboratory analysis verified field results proving sufficient strength for stabilization. CU analysis showed about a 5 time increase in consolidated undrained shear strength over the subgrade soil and the soil-RAP mixtures. This result is an indicator of field behavior because the area soils have high in-situ moisture contents and are saturated for a good portion of the year.

Table 5. CU triaxial load test results for all samples

	Property at Failure						
Mixture	Confining Pressure (kPa)	Axial Strain %	Deviator Stress (kPa)	Pore Pressure (kPa)	Effective Major Principal Stress (kPa)	Effective Minor Principal Stress (kPa)	Effective Principal Stress Ratio
Subgrade Soil	20.7	1.3	18.5	-15.2	54.5	35.6	1.5
	48.3	1.3	18.0	2.1	64.2	46.2	1.4
Subgrade Soil-RAP	20.7	1.3	17.5	-9.7	47.9	30.3	1.6
	34.5	1.3	18.9	-9.7	63.0	44.1	1.4
	48.3	1.3	17.9	5.5	60.7	42.7	1.4
Ames Fly Ash-Soil-RAP	20.7	1.0	42.2	-6.9	70.0	27.6	2.5
	34.5	1.0	67.1	-5.5	107.1	40.0	2.7
	48.3	1.2	71.1	-37.9	157.2	86.2	1.8
Prairie Creek Fly Ash-Soil-RAP	20.7	1.2	73.8	-26.9	121.4	45.6	2.6
	48.3	1.2	92.6	-17.9	158.8	66.2	2.4
OGS Fly Ash-Soil-RAP	20.7	3.8	94.4	-209.6	324.7	230.3	1.4
	48.3	3.8	93.6	-171.7	313.6	219.9	1.4

Table 6. Effective cohesion, effective friction angle, and modulus at 50% of failure

Mixture	C' kPa	Φ' Degrees	E_{50} kPa
Subgrade Soil	11	2	18
Subgrade Soil-RAP	11	0	23
Ames Fly Ash-Soil-RAP	14	11	86
Prairie Creek Fly Ash-Soil-RAP	25	7	73
OGS Fly Ash-Soil-RAP	47	0	64

Current Field Conditions

A site visit was conducted by one of the authors March 5th of 2014. The photos (Figure 14 to Figure 15) show that the stabilized parking lot section is performing extremely well after 12 years of service.

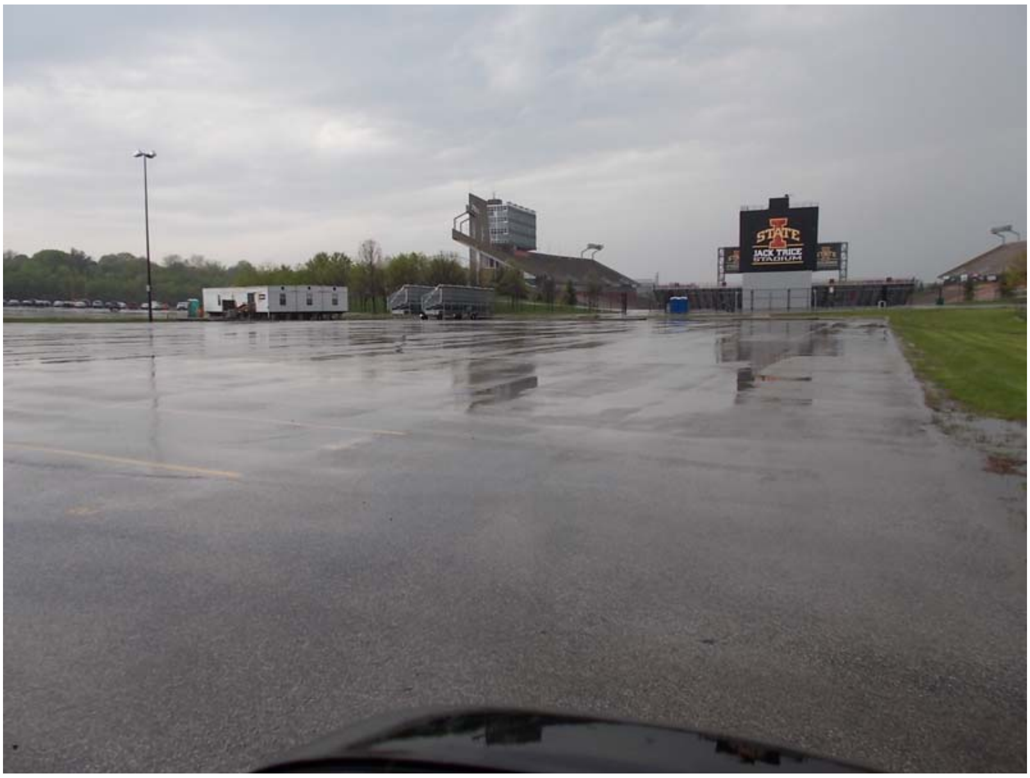

Figure 14. Stabilized parking lot section in March 5 of 2014


Figure 15. Stabilized parking lot section in November 25th of 2014

CONCLUSIONS

Chemical analysis showed that the Ames and OGS fly ash are well suited for soil stabilization, and the addition of RAP to the subgrade soil increased the gravel and sand content mechanically stabilizing the soil. The final product was able to withstand construction traffic, paving operations, and the resulting parking lot is performing well 12 years after construction.

The cost analysis proved that this construction method was cost effective. DCP and FWD results show a remarkable strength and stiffness gain 28-days after construction.

CU results also proved increased durability and suitability of the materials by increasing the CU shear strength about 5 times with the addition of self-cementing fly ash.

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