Subgrade Stabilization Using Recycled Asphalt Pavement and Fly Ash Mixtures

By

Tyson D. Rupnow
Undergraduate Research Assistant
Iowa State University
394 Town Engineering Building
Ames, Iowa 50011
Tel: (515) 294-7690
Fax: (515) 294-8216
Email: trupnow@iastate.edu

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ABSTRACT

This paper describes field and laboratory testing conducted to evaluate the performance of soft subgrade stabilized with combinations of fly ash as a chemical stabilizer and Recycled Asphalt Product (RAP) as a mechanical stabilizer. Field-testing consisted of Dynamic Cone Penetrometer (DCP) tests. Laboratory testing consisted of unconfined compression strength tests, and gradation analysis. The controlled laboratory testing provided the opportunity to compare results with field tests. DCP tests revealed a time dependant gain in stability due to the cementing action of the fly ash. Grain size distribution data also shows that the addition of RAP shifts the distribution curve left and increases the quantity of aggregate in the mixture. Laboratory results show that the unconfined compressive strength of fly ash treated soil/ RAP mixture is about five times that of non-fly ash treated samples. Soaking the sample prior to testing then showed that the unconfined compression strength is reduced by a factor two for samples compacted dry of optimum moisture content. Samples wet of the optimum moisture content show no strength loss.

INTRODUCTION

Fly ash is considered a soil-stabilizing agent due to its cementious properties and was selected to be a suitable method for stabilizing soil at the Iowa Sate University Jack Trice Stadium Parking Lot shown in Figure 1. The affected area lies in the floodplain of the South Skunk River where the soils are highly saturated and soft. The high moisture content of the soil makes it nearly impossible to move construction machinery around without severe rutting and deformation shown in Figure 2. In addition to fly ash, which is a chemical stabilizer, the existing asphalt pavement was milled and mixed into the subgrade to increase the aggregate content of the soil.

The sources of fly ash were as follows: (1) Prairie Creek fly ash from the Cedar Rapids, Iowa Power Plant, (2) fly ahs from the Ottumwa Generation Station in Chillicothe, Iowa, and fly ahs from Ames Municipal Generating Station located in Ames, Iowa. For the duration of the project, fly ash was added at the rate of about ten percent by dry weight.

CONSTRUCTION OPERATIONS

The existing pavement was first milled in place with a reclaimer. The RAP was then leveled with a motor grader. Windrows were created in order to contain the fly ash. Once the windrows were established, water was added to the subgrade to provide sufficient moisture to hydrate the fly ash. After the placement of the fly ash on the grade it was spread uniform with the use of the motor grader. Next the reclaimer was used to thoroughly mix the fly ash, RAP, and subgrade soil. A vibratory pad foot roller was then used to compact the mixture. Once compacted, a steel drum roller was used for final rolling to produce a smooth surface to prevent water infiltration from rain and to provide a suitable paving platform. The new paving platform is shown in Figure 3. Note that the absence of rutting.

EXPERIMENTS AND TESTING METHODS

Field Testing

Field-testing consisted of the Dynamic Cone Penetrometer (DCP) test. Field sampling consisted of Proctor sized (102 mm X 127 mm) unconfined compressive strength samples made on site.

The DCP test was used to provide a measure of the stability versus depth and is highly correlated to the California Bearing Ratio (CBR). For each fly ash used, a time delay DCP test was taken immediately after compaction, 1 hour after compaction, 24 hours after compaction, 3 days after compaction, 7 days after compaction, and as close to 28 days after compaction as construction timelines would allow. Testing stability as a function of time provides important information as to when paving operations can start.

Once the soil, RAP, and fly ash material was mixed in the field, several samples were taken to conduct grain size sieve analyses. Also, material was sampled for strength testing. Ames Municipal fly ash was the principal fly ash used on the project, and several field samples were prepared using Proctor size molds for unconfined compressive strength testing. Samples were made in triplicate for each set. Sets of specimens were produced for testing at 24 hours, 7 day, 14 day, and 28 days. A set of samples was also produced for each of the other ash mixes used on the project. These samples were tested for 28 day unconfined compression strength.

Laboratory Testing

Laboratory testing consisted of chemical analysis of the fly ash, the Proctor test (ASTM D 4318-84 [Standard Test Method for Moisture Density Relation of Soils and Soil-Aggregate Mixtures Using 5.5 lb. (249kg) Rammer and 12 in (305 mm) Drop]), gradation analysis (ASTM D 422-63 [Standard Test Method for Particle-Size Analysis of Soils]), and unconfined compression strength samples.

For the chemical analysis, fly ash was sampled from the Ottumwa Generating Station and Ames Municipal Generating Station. The chemical analysis included X-ray diffraction analysis (XRD), and x-ray flurences (XRF). XRD provides an indication of the chemical compounds and minerals while XRF provides analytical chemical content expressed as oxides. This information is used to classify the fly ash according to ASTM C-618-01 [Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as Mineral Admixture in Concrete].

RAP was obtained from a local asphalt plant, and subgrade soil was obtained from the project. The two were mixed at a fifty percent RAP to soil mixture by dry weight. The Proctor test was conducted to determine the optimum moisture content.

Once the optimum moisture contents were determined, unconfined compressive strength samples were produced at varying moisture contents to determine strength. The strength gain was then compared to field samples.

Once the samples were produced, they were placed in an oven at 38 °C to cure for 7 days. The samples were removed from the oven and capped with sulfur capping compound and tested. A separate set of samples was produced in order to measure durability from soaking the samples in a water bath. This was done in accordance with ASTM 593 [Standard Specification for Fly Ash and Other Pozzolans for Use With Lime].

Samples obtained from the field underwent the gradation analysis. A gradation analysis was done on each of the fly ash, soil, and RAP mixes. A gradation test was also conducted on the subgrade soil only as well as the soil RAP mix from the laboratory experiments. After the gradation analysis was completed, the soils were classified according to the AASHTO and Unified Soil Classification Systems.

RESULTS AND DISCUSSION

Field results are broken down into three categories: (1) unconfined compressive strength results, (2) DCP test results, and (3) grain size analysis. Laboratory results are broken into two categories: (1) chemical analysis of the fly ash, and (2) unconfined compression strength results.

Unconfined Compression Tests

The unconfined compression test results are indicative of field construction processes as they were produced in the field. Samples were made for each of the mixes in the field. All samples were tested at 28-day cure. Table 1 shows the unconfined compression strengths for the Chillicothe, Prairie Creek, and Ames fly ash samples.

A strength gain test was conducted on the Ames Municipal fly ash due to the majority of the project using fly ash from that source. Three samples were produced for each of the times shown. The tests show that the majority of the strength gain is done within the first ten days after compaction.

Dynamic Cone Penetrometer

The DCP test was used to determine the gain in stiffness due to the hydration process associated with Class C fly ash. The DCP test was completed to full depth, but for analysis of stiffness gain, the top 300 mm were analyzed as that was the treated layer. A test was taken immediately after compaction. This test was determined to be the baseline Mean and Mean Change in DCP Index value and considered to be at time zero. Subsequent tests were taken at one hour, three hours, twenty-four hours, seven days, fourteen days, and twenty-eight days after compaction. Figure 4 shows the stiffness gain for the Ames Ash treatment.

Note that the stiffness gain increases dramatically until approximately ten days and then begins to taper. This corresponds well with the strength gain shown in Figure 5.

Grain Size Analysis

Samples were collected for all fly ash mixtures and grain size analyses were conducted. Samples were also collected for the subgrade soil only, as well as the subgrade soil and RAP mix before addition of fly ash. Figure 6 shows the grain size distribution curves for the various samples collected. Note the left shift of the grain size distribution curve due to the addition of RAP. After the grain size analysis was completed, Atterberg Limit tests (ASTM D 4318-84 [Standard Test for Liquid Limit, Plastic Limit, and Plasticity Index of Soils]) were conducted, and the soil was classified according to the AASHTO and Unified Soil Classification Systems (ASTM D 2487-90 [Standard Test Method for Classification of Soils for Engineering Purposes]). Table 2 shows the classification of each soil tested.

Chemical Analysis

Chemical Analysis results for Ottumwa Generating Station (OGS) and Ames Municipal fly ash are shown in Table 3. Figure 7 shows the overlay of these results in a graphical form. Note that the OGS fly ash contains more glass than the Ames Municipal fly ash. Another observation is the levels of tricalcium aluminate, C3A, in each of the two samples. Note that the Ames fly ash has a greater amount of C3A. This is useful in showing that the Ames Municipal fly ash is a fast setting fly ash.

Laboratory tests were conducted in order to compare to field data. Specimens were made using fifty percent RAP and fifty percent subgrade soil by dry weight. A five point Proctor test was the conducted using standard energy.

Next, ten percent Ames Municipal fly ash, by dry weight, was added to the mixture and another proctor curve was done to determine the optimum moisture content. Three samples were produced at all moisture contents in order to use the samples for unconfined compression strength tests. After the sample's dry density had been determined, the sample was wet cured in the humidity room for seven days. After wet curing, the sample was capped and then sub sequentially tested. Figure 8 shows Proctor Test results for the RAP, subgrade soil, and Ames fly ash mixture.

After all the Proctor tests had been completed, the samples were then tested for the unconfined compressive strength. Samples tested for the unconfined compressive strength include: subgrade soil, RAP, and ten percent Ames Ash both soaked and non-soaked. Also included are the standard Proctor samples. Figure 9 shows the comparison of unconfined compressive strengths between the various samples versus the percent moisture.

Note that the soaked samples performed about half as well dry of optimum moisture content, but they performed comparable to the non-soaked samples wet of optimum moisture content. Also, the non-soaked samples strength curve continues upward dry of optimum moisture content, which is to be expected.

CONCLUSIONS

The results of the case study warrant the following conclusions:

- Addition of fly ash to soil RAP mixtures shows a stiffness gain in terms of DCP penetration resistance of about minus 30 mm/blow;
- Addition of RAP to soil shifts the grain size distribution curve and acts as a mechanical stabilizer;
- Fly ash at 10 percent increases the unconfined compressive strength about 5 times;
- Soaked fly ash treated samples have half of the unconfined compression strength of non-soaked ash treated samples when they are produced dry of optimum moisture content;

- Soaked ash treated samples have strength comparable to non-soaked ash treated samples when produced wet of the optimum moisture content; and
- The process of recycling existing asphalt into subgrade soils and stabilizing the mixture with fly ash was very effective at this site.

RECOMMENDATIONS

The author recommends studying the effects of varying the fly ash contents, varying the percent RAP in the mixture, and studying the same procedures in Western Iowa Loess to determine if this procedure would be an effective solution to stabilize Loess.

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LIST OF TABLES AND FIGURES

FIGURE 1 Jack Trice Stadium Parking Lots

FIGURE 2 Severe Rutting Due to Construction Traffic

FIGURE 3 Newly Constructed Paving Platform

TABLE 1 Average 28 Day Unconfined Compression Strengths

Fly Ash Treatment	Average Strength, PSI
Praire Creek	87
Chilocothe	126
Ames	86

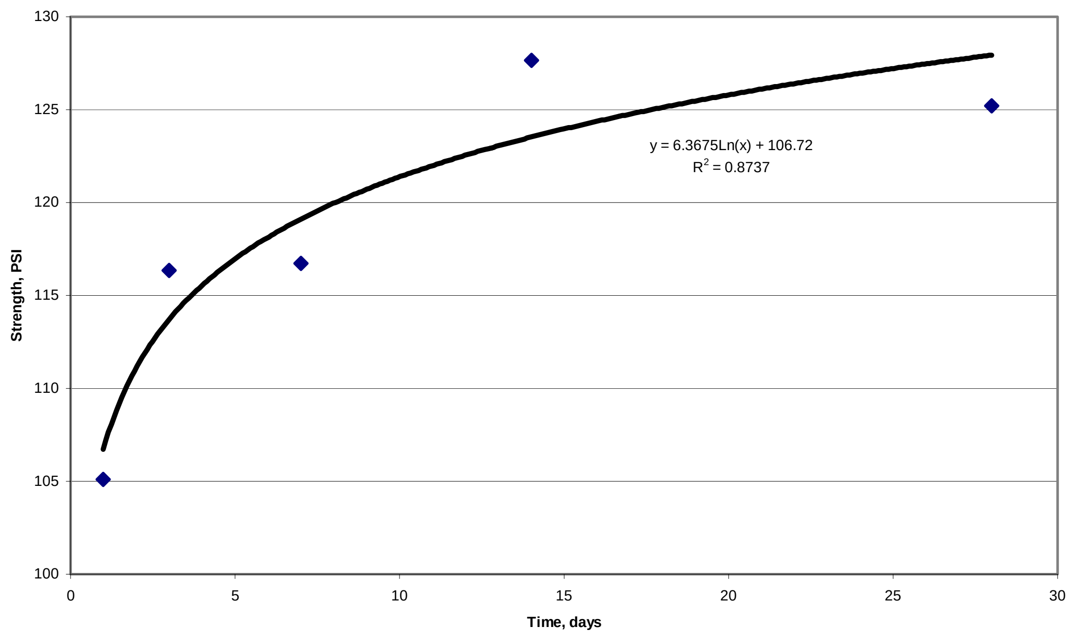

FIGURE 4 Sample Strength Gain Versus Time for samples containing Ames Fly Ash

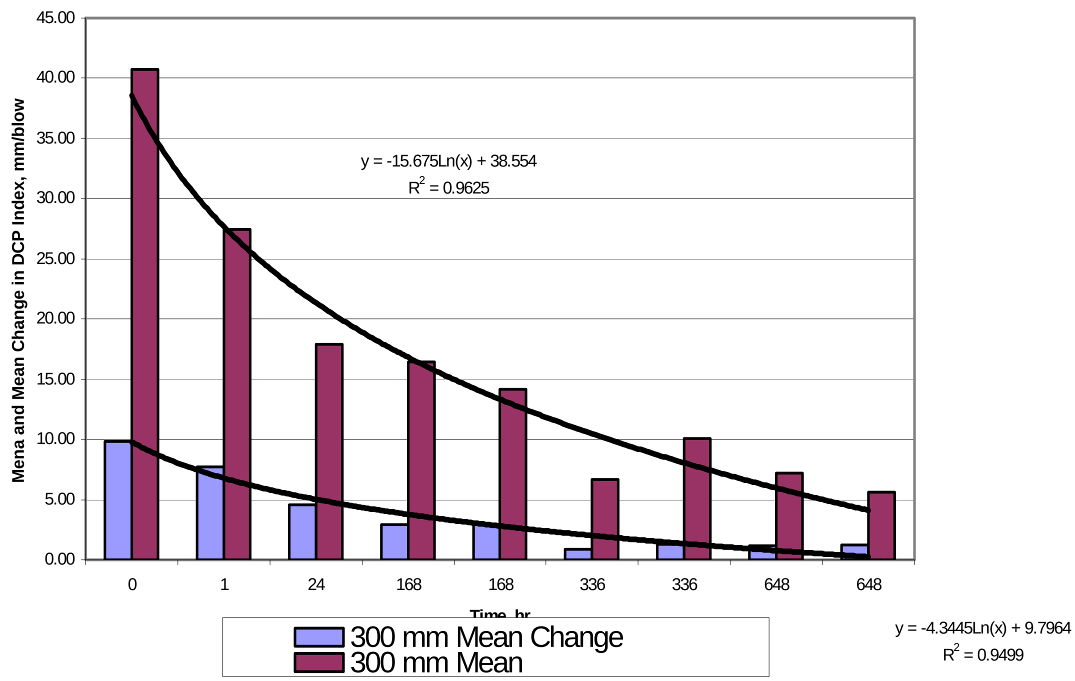

FIGURE 5 300 mm Mean and Mean Change in DCP Index for Ames Municipal Fly Ash Treated Subgrade

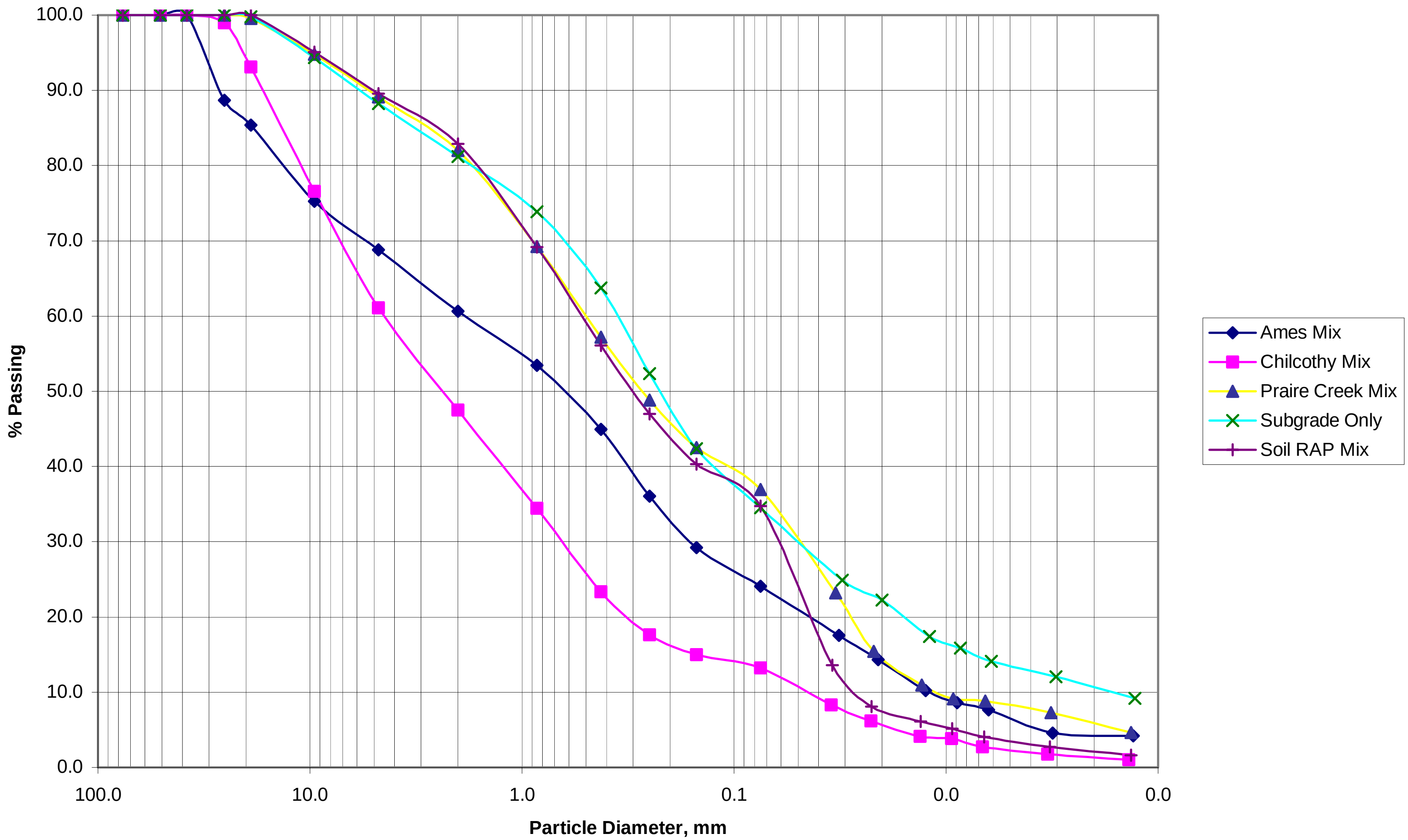

FIGURE 6 Grain Size Distribution Curves

TABLE 2 Soil Classifications

Sample	AASHTO	USCS
RAP/ Soil Mixture	A-2-6	SC
Praire Creek Fly Ash Mixture	A-4	SC
Ottumwa Generating Station Fly Ash Mixture	A-1-a	SC-SM
Ames Municipal Fly Ash Mixture	A-1-b	SM
Subgrade Soil	A-2-6	SC

TABLE 3 Chemical Analysis Results for Ottumwa Generating Station and Ames Municipal Fly Ash

Sample name	OGS	AMES
SiO2	37.10	33.42
Al2O3	21.47	17.52
Fe2O3	5.71	5.89
SUM	64.28	56.84
SO3	2.19	3.46
CaO	22.51	26.65
MgO	4.27	5.90
Na2O	3.27	2.41
K2O	0.52	0.52
P2O5	1.44	1.08
TiO2	1.53	1.64
SrO	0.42	0.30
BaO	0.75	0.73
Total	101.20	99.54

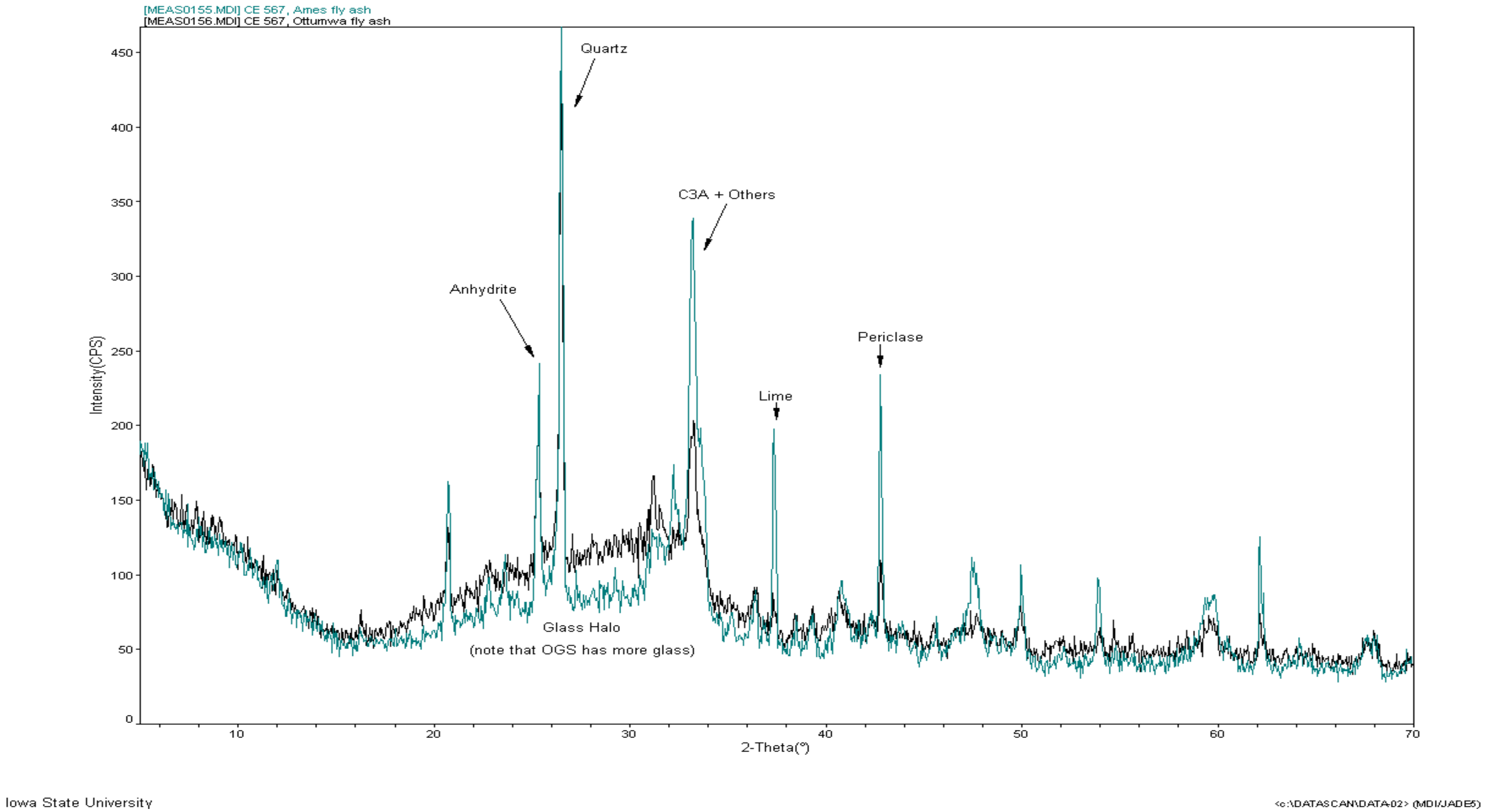

FIGURE 7 XRD Pattern Overlay for Ames Municipal and Ottumwa Generating Station fly ash.

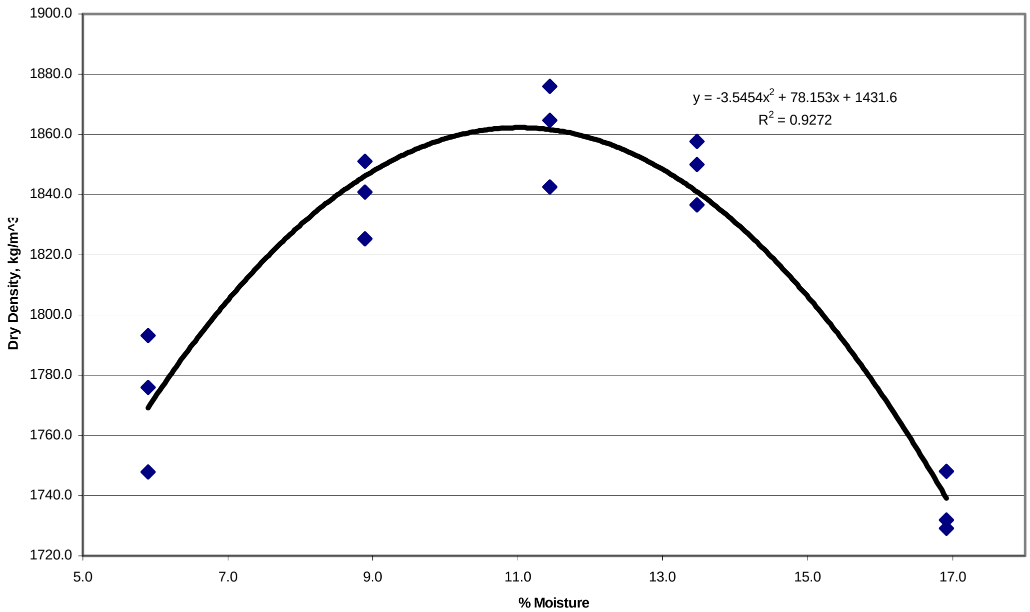

FIGURE 8 Proctor Curve for 50% RAP, 50% Subgrade Soil, and 10% Ames Municipal Fly Ash Mixture by Dry Weight

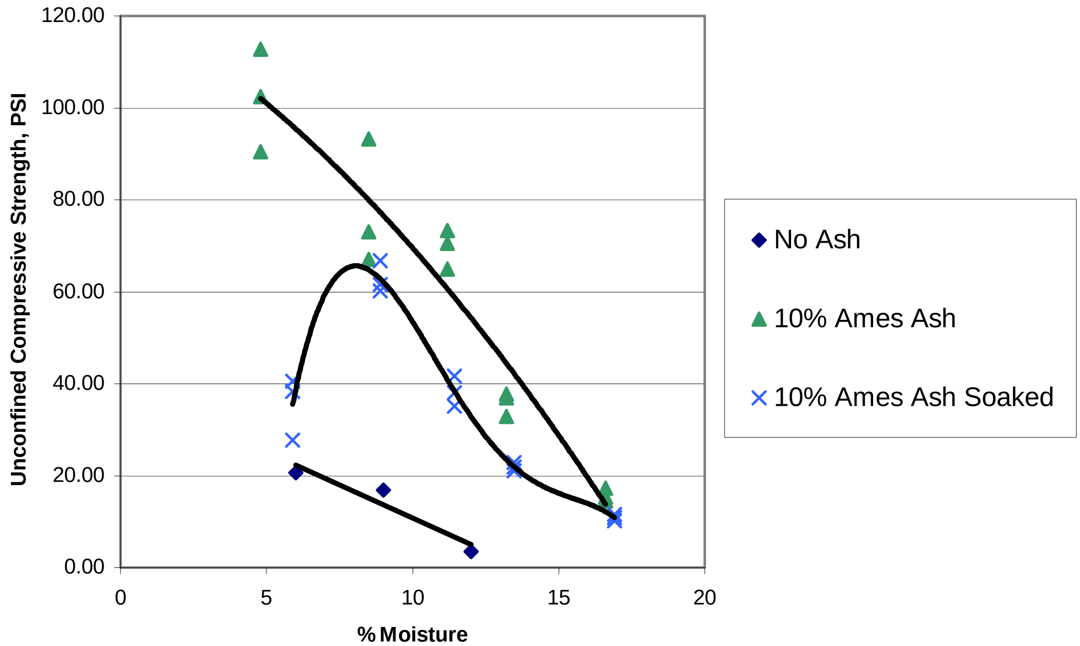

FIGURE 9 Comparisons of Unconfined Compressive Strengths Versus Percent Moisture