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Durability and strength of activated reclaimed Iowa Class C fly ash aggregate in road bases

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Durability and strength of activated reclaimed Iowa Class C fly ash aggregate in road bases

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Signatures have been redacted for privacy

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

The development of high-volume uses for coal-fired power plant waste creates both economic and environmental benefits. Approximately 90 million tons of coal combustion by-products are produced each year in the United States (16), including 70 to 80 million tons of fly ash (1). Only about 25% of the fly ash produced is utilized by other industries (29). Power plant waste such as fly ash, if not utilized in industrial or construction projects, must be disposed of in landfills or sluice ponds. Fly ash is commonly used as a partial replacement for Portland cement in concrete, where it has been shown to provide comparable strength for a significantly lower cost. A growing application for fly ash use is for the stabilization of soils that would otherwise be unsuitable construction materials. Fly ash has been economically used to increase strength, lower plasticity, and reduce the moisture content of soils that would have otherwise required Portland cement or lime stabilization. While both of these fly ash utilization methods provide clear economic and engineering benefits, only a relatively small portion of the fly ash produced can be utilized. Fly ash is usually limited to 15% replacement of Portland cement in concrete, and typical addition rates for soil stabilization are 5% to 15% by dry weight of soil. Higher volume uses for coal combustion products are necessary to significantly reduce the amount of waste that must be landfilled. The development of high-volume construction uses for a significant portion of this waste can reduce the landfilling costs as well as produce revenue from sale of the materials. A promising high-volume application of hydrated reclaimed Class C fly ash is as a replacement for aggregate in flexible pavement base courses.

II. OBJECTIVE

The focus of this research is to evaluate the properties of hydrated Iowa Class C fly ash aggregates reclaimed from sluice pond disposal sites. Bergeson and Barnes (11, 14) have recently developed a pavement thickness design method for the use of these aggregates in flexible pavement base courses based on the California Bearing Ratio (CBR) and unconfined compressive strength. To reinforce this strength-based pavement design, this research focuses on the freeze-thaw durability, volumetric stability, and long-term strength gain of hydrated reclaimed fly ash aggregate with different chemical activators.

III. LITERATURE REVIEW

Fly Ash

Production, Properties, and Types of Fly Ash

Fly ash is the fine residue produced from the burning of ground or powdered coal (5). Molten residue is carried out of the boiler by flue gases and solidifies into various amorphous, crystalline, and carbonaceous forms as it cools. The residue is collected from the exhaust gases by electrostatic precipitators, baghouses, or cyclone separators (10, 21). The electrostatic precipitator is the most common collection device (21). The precipitator creates a high-voltage ionizing field that causes the fly ash particles to adsorb free ions and become charged (15). The charged ash particles are then collected on grounded metal collection plates, which are periodically rapped to dislodge the ash into collection hoppers (10). The ash is then conveyed from the collection hoppers to storage silos. The ash may then be used or disposed of in sluice ponds or landfills (10).

Fly ash primarily consists of spherical glassy particles, along with some crystalline and carbonaceous matter (21). The four main chemical components of fly ash are silicon dioxide, aluminum oxide, iron oxide, and calcium oxide. Fly ash is a pozzolan because it is rich in silica and alumina. ASTM C 618, "Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete", defines pozzolans as "siliceous or silicious and aluminous materials which in themselves possess little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties" (5).

Class C fly ash is typically produced from the combustion of lignite or subbituminous coal, while Class F fly ash is the product of anthracite or bituminous coal. Both appear as a fine powder, with Class F usually dark gray in color, and Class C usually a tan or light brown color. ASTM C 618 lists chemical and physical requirements for Class C and Class F fly ashes (5). These requirements are summarized in Table 1.

Table 1. Selected Chemical and Physical Requirements for Fly Ash as Defined in ASTM C 618

Requirement	Class F Fly Ash	Class C Fly Ash
Silicon dioxide (SiO_2) plus Aluminum oxide (Al_2O_3) plus Iron Oxide (Fe_2O_3), min %	70.0	50.0
Sulfur Trioxide (SO_3), max %	5.0	5.0
Moisture content, max %	3.0	3.0
Loss on ignition, max %	5.0	5.0
Fineness, amount retained when Wet-sieved on No. 325 sieve, max %	34.0	34.0

The largest difference between Class C and Class F fly ash is calcium content. Class C fly ash has a much higher calcium content and is therefore lower in silica and alumina. Class F fly ash, which is higher in silica and alumina, is a pozzolan that forms cementitious reaction products only with the addition of a calcium source. Class C fly ash is also a pozzolan, but it possesses self-cementitious properties as a result of its high calcium content.

Table 2 shows typical chemical compositions for Class C and Class F fly ash (19). The wide variations within the Class C and Class F designations make the two-class system

Table 2. Typical Chemical Composition of Fly Ash

Oxide	Class F Fly Ash (% of total weight)	Class C Fly Ash (% of total weight)
SiO_2	40-55	20-40
Al_2O_3	25-35	10-30
Fe_2O3	5-24	3-10
CaO	0.5-4	10-32
MgO	0.5-5	0.5-8
Na_2O	0-1.5	0.5-6
K_2O	0.5-3	0.5-4
TiO_2	0.3-2	0.5-2
SO_3	0.5-5	1-8
Moisture	0-3	0-3

seem somewhat inappropriate to adequately describe the variation in fly ash compositions and properties.

Uses of Fly Ash

Historically, the largest use of fly ash has been as a partial replacement for cement in Portland cement concrete. This application is very effective, but it utilizes only a small portion of the fly ash produced each year. The use of fly ash for drying, modification, and stabilization of poor quality soils has also become fairly widespread (25). Other possible fly ash uses that are currently in development are as a lightweight structural fill and in the production of plastics and paints (29). The most promising high-volume uses of fly ash are geotechnical applications such as soil stabilization and road bases.

Freeze-Thaw Damage in Geomaterials

Frost action and subsequent frost heave is one of the most destructive forces acting on the components of a pavement. The surface course of a pavement can sustain severe damage if frost action damages, weakens, or causes expansion of the subgrade or base. Freeze-thaw damage typically takes the form of frost heave caused by the formation of ice lenses within the pores of the soil or aggregate. For freeze-thaw damage to occur, three main conditions must be present (24):

- Water
- Freezing temperatures
- Frost-susceptible material (the pores must be large enough to be interconnected but small enough that water cannot easily escape)

As water freezes, it expands and forms ice lenses in the void space of a frost-susceptible geomaterial. If the pores of the geomaterial are filled with enough water so that the expanding ice runs out of void space, the geomaterial may be subject to high expansion pressures exerted by the ice (25). The resulting high pressures, which have been measured at up to 135 psi in laboratory tests (24) can cause swelling of the soil or aggregate and damage overlying structures such as pavements or foundations. Compounding the problem, the soils or aggregates may become saturated as the ice thaws. Saturated soils have lower strength than partially saturated soils because they must rely on effective stress to carry the loads imposed on them (17). It is likely that many pavement failures caused by insufficient freeze-thaw durability can be attributed to weak soil during thawing conditions, rather than just expansion heave during freezing. The extent of freeze-thaw damage depends on many variables, including depth of frost penetration, amount of water present during freezing, number of freeze-thaw cycles, and length of freezing and thawing cycles (24).

The most common methods of controlling freeze-thaw damage to structures are (24):

- Locate the foundation of the structure below the maximum depth of frost penetration
- Replace frost-susceptible material within the zone of expected frost penetration with non-frost susceptible material
- Use additives to stabilize and change the permeability of the frost susceptible material
- Restrict the availability of capillary water to the frost zone to prevent the formation of ice lenses
- Insulate the material within the frost zone to prevent freezing temperatures

It is obvious that most of these methods are applicable in foundations for buildings and similar structures, but pavements cannot be economically insulated or located below the zone of frost penetration in most cases. This leaves the options of removal/replacement of frost-susceptible materials, stabilizing the materials by use of additives, or preventing capillary water from reaching the material in the frost zone. Removal/replacement is probably the most expensive of these three options, requiring large earthwork, hauling, and material costs. Stabilization may or may not be cost effective, depending on the type and amount of additive required. Capillary water can be prevented from reaching the material in the frost zone by the inclusion of a "capillary break" layer of material such as clean gravel or crushed stone with pores too large to allow the upward movement of water (24).

Freeze-Thaw Durability Tests

Several methods of evaluating the freeze-thaw durability of pavement materials have been developed. Commonly used freeze-thaw durability tests for Portland cement concrete are ASTM C 666, "Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing" (6), ASTM C 671, "Standard Test Method for Critical Dilation of Concrete Specimens Subjected to Freezing" (7), and the PCA method (26). The ASTM C 666 test subjects samples to 300 freeze-thaw cycles in a standard chamber at 6 to 12 cycles each day. The resonant frequency of the samples is measured, and a relation of this frequency to elastic modulus is used to determine freeze-thaw durability (6).

The ASTM C 671 critical dilation test is a method that records the dilation as the specimens freeze. One test cycle is completed every two weeks, and the number of cycles during which successive freezing dilations remain constant is defined as the period of frost immunity. When the period of frost immunity ends, the specimen dilations tend to increase quickly. The point at which this process ends is called the critical dilation (7). The PCA test method subjects samples to two freeze-thaw cycles per day. Specimen length and weight are recorded periodically and sonic measurements are taken that can be correlated to durability (26).

Freeze-thaw durability tests developed for soil-cement and other stabilized soil mixtures include ASTM D 560, "Standard Test Methods for Freezing and Thawing Compacted Soil-Cement Mixtures" (8), the Iowa Freeze-Thaw Test (20), and an adaptation of the test method outlined in ASTM C 593, "Standard Specification for Fly Ash and Other Pozzolans for Use With Lime" (4). The ASTM D 560 test subjects a specimen to 24 hour freezing cycles in a –10°F freezing chamber followed by 23 hour thawing cycles in a 70°F humidity room. The specimen is placed on a saturated felt pad to provide available capillary water during the freezing cycles. Weight and volume measurements of the specimen are recorded between cycles. A second specimen is subjected identical freezing and thawing cycles, but is subjected to brushings with a firm wire brush after each thawing cycle. At the end of 12 freeze-thaw cycles, the weight and volume change of the first specimen and amount of soil-cement material lost from the second specimen are determined. These results are factored into the calculations for determining the cement content necessary for soil stabilization. The Iowa Freeze-Thaw Test developed by George and Davidson (20) is similar to ASTM D 560. The major difference is the inducement of a temperature gradient in the sample by freezing the sample from the top down and holding the bottom of the sample to a temperature consistent with the higher-than-freezing ground temperatures expected at the bottom of the road base or subgrade in the field (20).

The ASTM C 593 vacuum-saturated compressive strength test (4) was developed from research by Dempsey and Thompson (18). Dempsey and Thompson subjected soil-cement, lime-fly ash, and lime-soil mixtures to freeze-thaw cycles and vacuum-saturated unconfined compressive strength tests. The results of these tests indicated very high correlation between the strength and moisture content of the vacuum-saturated samples and the strength and moisture content of samples subjected to 5 and 10 freeze-thaw cycles. A plot of the unconfined compressive strength of the vacuum-saturated method versus the freeze-thaw method yielded r-values of 0.96 for 5 freeze-thaw cycles and 0.98 for 10 freeze-thaw cycles (18).

Synthetic Aggregate

One of the most promising high volume applications of fly ash is in the production of synthetic aggregate for use in concrete and pavement. Montana State University researchers produced lightweight aggregate from Class C fly ash and combined the aggregate with Portland cement and additional fly ash to produce lightweight concrete masonry units (28). A combination of 90% Class C fly ash/10% Portland cement was allowed to cure as slabs. These cast slabs were crushed to produce aggregate. The strength of the manufactured aggregate compared favorably to that of standard lightweight aggregates (28).

An Iowa State University project compared strength and durability of synthetic aggregates produced with various mixtures of Class C fly ash, Class F fly ash, and atmospheric fluidized bed combustion (AFBC) residue with that of a high quality limestone (13). The study also included reclaimed Ottumwa fly ash aggregate from the sluice pond fly ash disposal site near the Ottumwa Generating Station near Chillicothe, Iowa. The study found that aggregates produced from some mixtures of Class C fly ash and AFBC residue performed with only slightly less durability and strength as a low quality limestone aggregate. The study also showed that reclaimed Ottumwa fly ash aggregate nearly met the allowable loss requirement for aggregate soundness and Los Angeles abrasion resistance for an Iowa DOT Class B stone (13).

Iowa Fly Ash Affiliate Field Demonstration Projects

Reclaimed Hydrated Class C Fly Ash

The material used in this research begins as raw Class C fly ash. Water is added and the resultant mixture is spread in lifts with a bulldozer blade near the coal-fired power plant sluice pond site. The spreading machinery may provide some compaction of the material, but the on-site quality control is minimal. The material is allowed to cure into a hardened mass, which may take weeks or months. The hardened mass is scarified and reclaimed for use as aggregate. Reclaimed fly ash aggregates from Ottumwa Generating Station, Council Bluffs Generating Station, and Sioux City Port Neal 3 Generating Station are marketed under the trade name ‘C-stone’. Reclaimed fly ash aggregate from the Prairie Creek Generating Station in Cedar Rapids is marketed under the trade name ‘Ecostone’. Work by Bergeson and Lapke (12) has shown that this manufactured aggregate nearly meets the Iowa DOT specifications for a Class B crushed stone.

Research by the Texas Department of Transportation (Texas DOT) and Texas Tech University has indicated that the use of reclaimed fly ash aggregate as a base material for flexible pavements has potential. The Texas DOT has utilized reclaimed fly ash aggregate in several projects with favorable performance thus far (27). The main concerns about the use of reclaimed fly ash aggregate include high water demand, proper curing to facilitate strength development, and loss in strength due to excessive moisture (27). Texas Tech and the Texas DOT are developing a standard for the use of hydrated Class C fly ash as a pavement base material.

Sutherland Power Plant Access Road

The Sutherland power plant access road was constructed in June 1994 by Con-Struct, Inc. of Marshalltown, Iowa and Midwest Fly Ash and Materials, Inc. of Sioux City, Iowa. The road provides access to the Sutherland Generating Station near Marshalltown, Iowa, and is 1700 feet long by 22 feet wide (23).

The pavement consists of an asphalt chip seal surface and nominal 10-inch thick base of activated reclaimed Prairie Creek Generating Station fly ash aggregate. The base was composed of cement kiln dust/reclaimed Prairie Creek fly ash aggregate for the southern 1000 feet, and of atmospheric fluidized bed combustion residue/reclaimed Prairie Creek fly ash aggregate for the northern 700 feet.

The cement kiln dust (CKD) section of the base contains roughly 15% CKD by dry weight of reclaimed fly ash aggregate. The dry CKD and reclaimed fly ash aggregate were mixed in place by a recycling-reclaiming machine. The materials were then mixed with the addition of water until compaction moisture content was achieved. A pad-footed vibrating roller was used for compaction and a steel smooth drum vibrating roller was used for finish rolling (23).

The atmospheric fluidized bed combustion (AFBC) residue section of the base contains roughly 15% AFBC by dry weight of reclaimed fly ash aggregate. The AFBC section was constructed similarly to the CKD section. The only construction difference was that the reclaimed fly ash aggregate was wetted prior to introduction of AFBC to reduce the water demand of this highly absorbent mixture.

As described above, the entire road was surfaced with an asphalt chip seal coating. Three inch deep transverse saw cuts were made on 30-foot center-to-center spacings to control shrinkage cracking.

Cores were extracted by ISU researchers in November 1994. Cores from the 15% CKD/85% reclaimed Prairie Creek fly ash aggregate base section exhibited average compressive strengths of roughly 1000 psi. Cores from the 15% AFBC/85% reclaimed Prairie Creek fly ash aggregate base section exhibited average compressive strengths of roughly 800 psi. Subsequent corings show similar strengths for the CKD section, but cores were no longer recoverable from the AFBC section. The reason for this disintegration has hypothesized to be either a freeze-thaw durability or volumetric stability problem (23). Despite the breakdown of the AFBC/reclaimed fly ash aggregate base, the pavement surface shows very little deterioration. The only obvious distress is located in a small area around the transition zone of the base from AFBC/reclaimed fly ash aggregate to CKD/reclaimed fly ash aggregate. The performance of the base in the AFBC/reclaimed fly ash aggregate section indicates that reclaimed fly ash aggregate may act as a strong granular base material even without the added strength of cementitious activators.

Ottumwa-Midland Landfill Access Road

The Ottumwa-Midland landfill access road was constructed in May and June of 1995, and is approximately 2500 feet long. The pavement was composed of a 1.5-inch hot mix asphalt concrete surface, an 11 inch activated reclaimed fly ash aggregate base, a 4-inch crushed limestone aggregate subbase, and a fly ash stabilized subgrade (22). The base was composed of 10% CKD/90% reclaimed Ottumwa fly ash aggregate for the western 1800 feet, and of 15% AFBC/85% reclaimed Ottumwa fly ash aggregate for the eastern 700 feet.

The fly ash aggregate base was compacted initially with a static pad foot roller in a single 11-inch compaction lift (the entire thickness of the base). Final compaction was conducted with a vibratory steel-wheeled roller. Nuclear density gauge testing performed by ISU personnel concluded that the bottom of the base was compacted to a lower density than the top of the base (22).

Cores were extracted by ISU researchers in August 1995. Cores from the 10% CKD/90% reclaimed Ottumwa fly ash aggregate base section exhibited average compressive strengths of roughly 800 psi. Cores from the 15% AFBC/85% reclaimed Ottumwa fly ash aggregate base section exhibited average compressive strengths of roughly 600 psi. Cores from the top half of the CKD base section showed significantly higher strengths than those from the bottom half of the section. This is probably a function of the lower compaction densities achieved in the bottom section of the base during construction. Subsequent corings have shown steady increases in the strength of the CKD base section, with the strengths still rising three years after construction. Conversely, subsequent corings have shown the breakdown of the AFBC section into aggregate-sized particles in a manner similar to that seen at the Sutherland road.

The only distresses evident on the surface of the Ottumwa-Midland landfill access road are some edge cracking in the AFBC base section, and transverse and longitudinal cracking in the CKD base section. The source of the cracks appears to be reflection cracking from the CKD/reclaimed fly ash aggregate base. Cores extracted directly on cracks confirmed that the surface cracks are extensions of cracks formed in the CKD base. Although the AFBC/reclaimed fly ash aggregate base is no longer cemented, the pavement surface shows no more structural distress than the CKD/reclaimed fly ash aggregate base section. The AFBC base section has many fewer cracks in the asphalt concrete surface than the CKD base section. This implies that the AFBC section of the base is acting in a manner similar to a crushed stone base and is achieving strength primarily through aggregate interlock rather than cementation by the AFBC activator.

IV. MATERIALS

Fly Ash

Ottumwa Fly Ash

Three twenty-gallon containers of Class C fly ash were sampled from the storage silo at the Ottumwa Generating Station near Chilliciothe, Iowa by ISU researchers on May 22, 1997. The Ottumwa Generating Station burns Wyoming sub-bituminous coal from near the Powder River basin. Ottumwa fly ash was used to stabilize reclaimed Ottumwa fly ash aggregate.

Council Bluffs Fly Ash

Three twenty-gallon containers of Class C fly ash were sampled from the storage silo at the Council Bluffs Generating Station near Council Bluffs, Iowa by ISU researchers on May 21, 1997. The Council Bluffs Generating Station burns Wyoming sub-bituminous coal from near the Powder River basin. Council Bluffs fly ash was used to stabilize reclaimed Council Bluffs fly ash aggregate.

Neal 3 Fly Ash

Three twenty-gallon containers of Class C fly ash were sampled from a freshly deposited stockpile beside the sluice pond at Port Neal Generating Station #3 near Sioux City, Iowa by ISU researchers on May 21, 1997. Port Neal Station #3 burns Wyoming sub-bituminous coal from near the Powder River basin. Neal 3 fly ash was used to stabilize reclaimed Neal 3 fly ash aggregate.

Prairie Creek Fly Ash

Three twenty-gallon containers of Class C fly ash were sampled from the storage silo at the Prairie Creek Generating Station in Cedar Rapids, Iowa by ISU researchers on May 22, 1997. The Prairie Creek Station burns Wyoming sub-bituminous coal. Prairie Creek fly ash was used to stabilize reclaimed Prairie Creek fly ash aggregate.

Reclaimed Fly Ash Aggregate

Reclaimed Ottumwa Fly Ash Aggregate

Seven forty-gallon containers of reclaimed fly ash aggregate from the Ottumwa Generating Station were sampled by ISU researchers on March 23, 1995. A second sample of three forty-gallon containers was collected by ISU researchers on May 22, 1997. All samples were taken directly from a stockpile beside the sluice pond.

Reclaimed Council Bluffs Fly Ash Aggregate

Six thirty-gallon containers of reclaimed fly ash aggregate from the Council Bluffs Generating Station were sampled by ISU researchers on July 11, 1996. A second sample of three thirty-gallon containers was collected on May 21, 1997. All samples were taken directly from a stockpile beside the sluice pond.

Reclaimed Neal 3 Fly Ash Aggregate

Six thirty-gallon containers of reclaimed fly ash aggregate from the Port Neal Generating Station #3 were sampled by ISU personnel on July 11, 1996. A second sample of three thirty-gallon containers was collected on May 21, 1997. All samples were taken directly from a stockpile adjacent to the sluice pond.

Reclaimed Prairie Creek Fly Ash Aggregate

Four thirty-gallon containers of fly ash aggregate from the Prairie Creek Generating Station were sampled by ISU researchers on December 14, 1996. This original material was conditioned fly ash rather than reclaimed fly ash aggregate. The original material was discarded, and four thirty-gallon containers of reclaimed fly ash aggregate were sampled on May 22, 1997 from a stockpile adjacent to the generating station.

Other Activator Admixtures

Cement Kiln Dust (CKD)

Cement kiln dust is a waste product produced from the manufacture of Portland cement. CKD was used as a calcium activator for reclaimed fly ash aggregate in this research. A sample of three thirty-gallon containers was collected from the Lafarge cement plant near Davenport, Iowa in March 1995. The high calcium content of CKD facilitates pozzolanic reactions in reclaimed fly ash aggregate. Recent changes in the Portland cement manufacturing process have raised environmental concerns about high levels of lead in CKD produced in Iowa. In addition, the quantities of CKD produced in Iowa have been greatly reduced in the last few years, making it commercially unavailable. Therefore, the use of CKD as an activator was discontinued in the latter portion of this research.

Atmospheric Fluidized Bed Combustion (AFBC) Residue

Ash produced from atmospheric fluidized bed combustion boilers was used as an activator in some early tests. This ash, like cement kiln dust, provides a source of calcium to facilitate pozzolanic reactions in reclaimed fly ash aggregate. A sample of three thirty-gallon containers was collected from Archer Daniels Midland in Cedar Rapids on March 16, 1995. Due to problems with field performance in demonstration projects at Marshalltown and Ottumwa, the use of AFBC as an activator was discontinued in the latter portion of this research.

Lime

Hydrated lime (calcium hydroxide) was used as a chemical activator to facilitate the pozzolanic reaction in reclaimed fly ash aggregates. Lime was obtained in three-kilogram containers from Fisher Scientific Company.

V. FREEZE-THAW DURABILITY TESTING OF ACTIVATED RECLAIMED FLY ASH AGGREGATE

A number of freeze-thaw durability test procedures were evaluated as potential predictors for the actual field freeze-thaw performance of activated reclaimed fly ash aggregate. All activator/reclaimed fly ash aggregate mixture percentages for the samples used in this research were calculated on a dry weight basis. All samples tested in this research were compacted at optimum moisture content for each mixture as determined by Barnes (11) or Anderson (2). The samples incorporating fly ash as an activator were conditioned for one half hour before compaction. This conditioning time was selected because Barnes (11) determined that all of the raw fly ashes used in this research achieve final set in less than one half hour. This conditioning period adversely affects strength, but it is intended to simulate field compaction delays. After the conditioning time, specimens were molded into 4-inch diameter by 4.58-inch tall cylinders using the Standard Proctor compactive effort of 12,400 ft-lb/ft^3, as specified in ASTM D 698, "Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort" (9).

The first method of freeze-thaw durability analysis performed on the mixtures was the vacuum saturated compressive strength test described in ASTM C 593 (4). A detailed description of this test method and its applicability to stabilized materials is provided in the following section of this thesis. Previous research using the ASTM C 593 test method as a freeze-thaw durability prediction test for AFBC activated reclaimed fly ash aggregate and CKD activated reclaimed fly ash aggregate mixtures indicated good freeze-thaw durability (2). However, the results of core data from the Ottumwa-Midland Landfill access road and the Sutherland Generating Station access road have indicated the possibility of freeze-thaw damage to these materials (22, 23). These results bring into question the applicability of the ASTM C 593 test procedure as a freeze-thaw durability prediction method for chemically activated reclaimed fly ash aggregate. As a result of the uncertainty about C 593 testing, a portion of this research has focused on developing a freeze-thaw durability test that more accurately represents the field conditions and evaluating the results of this test against C 593 results.

The second freeze-thaw test procedure was designed to subject activated reclaimed fly ash aggregate samples to actual freeze-thaw cycles using a laboratory freezer. Eight samples of 15%AFBC/85% reclaimed Ottumwa fly ash aggregate and eight samples of 10% CKD/90% reclaimed Ottumwa fly ash aggregate were prepared. The samples were wrapped in plastic and sealed in plastic bags within 30 minutes of preparation. After five days of sealed curing, four samples of each type were unwrapped and completely submerged in water for the next two days. Soaking the samples prior to the first freezing cycle was intended to represent freeze-thaw performance of the material in a nearly saturated condition. The other four samples of each activator type were left in the sealed cure for the final two days. At the end of the seven days, all sixteen samples were placed in a freezer set to 0°F (-17.8°C). All sixteen samples were frozen for three days. After the three-day freezing cycle, the samples were removed from the freezer and placed in plastic containers at room temperature for a four-day thawing cycle. The containers were sealed to prevent excessive moisture loss from the samples. After the four-day thawing cycle at room temperature, the samples were again placed in the freezer for another three-day freezing cycle. These freezing and thawing cycles were repeated each week for 16 cycles.

The second test method failed to provide the expected results. The samples subjected to 16 freeze-thaw cycles showed no evidence of freeze-thaw damage. It was determined that the samples were essentially being “freeze-dried”. Without available water, the freeze-thaw destructive mechanism could not function. It was determined that the samples should be sealed during the freezing cycle and saturated during the thawing cycle to determine the “worst case” scenario for freeze-thaw damage. This led to the development of the third freeze-thaw durability test, a slightly modified version of the second freeze-thaw test. The samples were thawed in water instead of sealed containers to allow enough free water for the freeze-thaw destructive mechanism to function.

The third method of freeze-thaw durability test was initiated to check the reliability of the ASTM C 593 method for predicting freeze-thaw durability of AFBC activated reclaimed fly ash aggregate and CKD activated reclaimed fly ash aggregate mixtures. The testing was also intended to evaluate the performance of fly ash/reclaimed fly ash aggregate and lime/reclaimed fly ash aggregate blends subjected to numerous freeze-thaw cycles.

Four samples of each activator/reclaimed fly ash aggregate mixture were prepared according to the Standard Proctor method referenced above. The samples were wrapped in plastic and sealed in plastic bags within 30 minutes of preparation. The samples were cured for seven days. After seven days, the samples were unwrapped, weighed, sealed in plastic bags, placed in a freezer set to 0°F (-17.8°C), and frozen for three days. After the three-day freezing cycle, the samples were removed from the freezer and completely immersed in a water bath at room temperature for a four day thawing cycle. At the end of the four-day thawing cycle at room temperature, the samples were again placed in the freezer for another three-day cycle. This freeze-thaw cycling was repeated until each sample had lost at least 50% of its original mass. Once the sample had lost greater than 50% of its original mass, it was considered destroyed and testing of that sample was discontinued.

V. ASTM C 593 TEST METHOD FOR PREDICTING FREEZE-THAW DURABILITY

ASTM C 593, "Standard Specification for Fly Ash and Other Pozzolons for Use With Lime," was originally developed for use with "fly ash and other pozzolans for use with lime in plastic mortars, nonplastic mixtures and other mixtures that effect lime pozzolanic reaction" (4). ASTM C 593 Sections 10 and 11 outline the "Compressive Strength Development and Freeze-Thaw Resistance of Nonplastic Mixtures" and the "Vacuum Saturation Strength Testing Procedure", respectively (4). Dempsey and Thompson studied the use of a vacuum saturation method to predict the freeze-thaw durability of stabilized materials such as soil-cement, lime-fly ash, and lime-soil mixtures. They determined very high correlation between vacuum saturated and actual freeze-thaw cycle compressive strength and moisture content (18). Their work became the basis for the C 593 test procedure. Due to the rapid nature of test, the vacuum saturated compressive strength test method has become a widely accepted technique in the practicing profession for the prediction of freeze-thaw durability of many stabilized materials.

A major focus of this research has been to determine if a reliable correlation exists between the results of ASTM C 593 and actual laboratory freeze-thaw durability of activator/reclaimed ash aggregate mixtures. The applicability of ASTM C 593 to freeze-thaw durability of AFBC/reclaimed ash aggregate mixtures has been brought into question by the deterioration of the AFBC section of the Ottumwa test road (apparently due to freeze-thaw damage) despite C 593 results that indicated sufficient freeze-thaw durability.

Specimens of the desired mixture were prepared according to the Standard Proctor method referenced previously, sealed in plastic bags, and cured in a circulating air cabinet at 100°F for seven days. At the end of the curing period, half of the specimens were placed in a dessicator under a vacuum of 11.8 psi for at least 30 minutes. The vacuum was used to remove air from the voids, allowing for nearly total saturation of the permeable voids with water. After 30 minutes of vacuuming, the samples were immediately saturated with the introduction of water and allowed to stand for 1 hour to allow the water to penetrate all of the permeable voids. The other half of the specimens were not vacuum-saturated, but were removed from the circulating air cabinet after seven days and completely submerged in a water bath for a minimum of four hours. All of the samples were then tested in unconfined compression. A significant loss in strength of the vacuum-saturated samples when compared to the non vacuum-saturated samples would indicate a possible problem with freeze-thaw durability. Samples with an average of 400 psi or greater for both vacuum-saturated and 4-hour soaked samples were considered to have adequate freeze-thaw durability.

VII. UNCONFINED COMPRESSIVE STRENGTH AND LONG TERM STRENGTH GAIN OF ACTIVATED RECLAIMED FLY ASH AGGREGATE

Long-term pozzolanic reactions are a source of strength gain in hydrated fly ashes for months or even years. The longest curing period evaluated in previous research of activated reclaimed Iowa fly ash aggregate was 56 days (2). Long-term strength gain tests over a period of one year were initiated for the evaluation of two goals. The first goal of the long term strength gain tests was verification of the possibility of autogenous healing of cracks by continued pozzolanic cementation reactions. The second goal of the long term strength gain tests was to reveal any possible long-term strength deterioration due to volumetric instability and expansion cracking. Tests were conducted to compare two different curing environments, sealed curing and humid curing.

For the sealed cured tests, eighteen samples of 15% AFBC/85% reclaimed Ottumwa fly ash aggregate and eighteen samples of 15% CKD/85% reclaimed Ottumwa fly ash aggregate were prepared at optimum moisture content and compacted using Standard Proctor energy described in ASTM D 698 (9). All 36 samples were wrapped in plastic and sealed in plastic bags within 30 minutes of compaction. The samples were cured at room temperature in this sealed condition. Unconfined compressive strength tests were run after 7, 28, 84, 168, 252, and 336 days of sealed curing. Unconfined compressive strength tests were run on three samples of each mixture for each curing period. Testing in triplicate was intended to provide a reliable average strength for each curing period.

For the humid cured tests, eighteen samples of 15% AFBC/85% reclaimed Ottumwa fly ash aggregate and eighteen samples of 15% CKD/85% reclaimed Ottumwa fly ash aggregate were prepared at optimum moisture content and compacted using Standard Proctor energy described in ASTM D 698 (9). All 36 samples were placed in a humidity room within 30 minutes of compaction. The humidity room was set to maintain a constant 100% relative humidity for the remainder of the sample curing periods. Unconfined compressive strength tests were run after 7, 28, 84, 168, 252, and 336 days of humid curing. As with the sealed cured samples, tests were run on three samples of each mixture for each curing period.

Fly ash/reclaimed fly ash aggregate and lime/reclaimed fly ash aggregate samples were prepared to determine 7, 28, and 56 day strength gains of the mixtures. The research on AFBC/reclaimed fly ash aggregate and CKD/reclaimed fly ash aggregate mixtures determined that strength gains were still occurring after one year of curing. Tests of these later samples were limited to 56 days for practical reasons. Long-term pozzolanic reactions are a source of continued strength gain after this time, but the previous tests determined that a large portion of the long-term strength gain was complete by the end of 56 days of curing. The tests on AFBC/reclaimed fly ash aggregate and CKD/reclaimed fly ash aggregate comparing two different curing environments (sealed curing and humid curing) showed no significant differences in strength gains between comparable samples. Therefore, sealed curing was the only method used for the fly ash/reclaimed fly ash aggregate and lime/reclaimed fly ash aggregate samples.

Nine samples of each activator/reclaimed fly ash aggregate mix were prepared at optimum moisture content. The lime activated samples were compacted immediately. The fly ash activated samples were conditioned for one half hour for the reason discussed in the section on freeze-thaw durability testing. After conditioning, the samples were compacted with Standard Proctor compactive effort (9). The samples were wrapped in plastic and sealed in plastic bags within 30 minutes of compaction, and were cured at room temperature. Unconfined compressive strength tests were run after 7, 28, and 56 day curing periods. As with the long term AFBC and CKD activated samples, tests were run on three samples of each mixture for each curing period. Testing in triplicate was intended to provide a reliable average strength for each curing period.

VIII. VOLUMETRIC STABILITY OF ACTIVATED RECLAIMED FLY ASH AGGREGATE

The volumetric stability of the activator/reclaimed fly ash aggregate mixtures was investigated using three different test procedures. The first test was run on samples compacted slightly above optimum moisture content. Nine samples of 15% AFBC/85% reclaimed Ottumwa fly ash aggregate were compacted at the optimum moisture content determined by Anderson (2) and sealed cured for 7 days. Nine samples of 10% CKD/90% reclaimed Ottumwa fly ash aggregate were compacted at optimum moisture content determined by Anderson (2) and sealed cured for 7 days. At the end of the curing period, three samples of each mixture were placed in air, three samples of each mixture were placed in a room set to maintain 100% relative humidity, and three samples of each mixture were submerged in water. The masses of the samples were recorded at regular intervals and the sample dimensions were measured with a caliper. The caliper measurements of sample length and diameter were taken at 3 separate points on each sample and the average of each dimension was recorded to the nearest 0.01 inches.

The second volumetric stability test was performed on mixtures compacted at about 2% to 3% dry of optimum moisture content. These tests were run to investigate a possible failure mechanism for the Sutherland test road, which may have been compacted drier than the optimum moisture content. Similar concerns were not raised about the Ottumwa test road because moisture and density quality control had been performed during construction of the road to ensure adequate moisture contents. Previous tests on raw AFBC ash indicated a large affinity for water and the tendency for ettringite formation (2). Given these qualities, it was considered very important to verify that the AFBC binder would be volumetrically stable if used as an activator for reclaimed fly ash aggregates. Volumetric stability tests on 15% AFBC/85% reclaimed Ottumwa fly ash aggregate and 10% CKD/90% reclaimed Ottumwa fly ash aggregate samples compacted at optimum moisture content showed no measurable volume expansion. The second test was intended to determine any expansion problems with AFBC/C-Stone mixtures compacted dry of optimum moisture content.

Nine samples of 15% AFBC/85% reclaimed Ottumwa fly ash aggregate were compacted at a moisture content of 27% (approximately 3% below optimum moisture content) and sealed cured for 7 days. Nine samples of 10% CKD/90% reclaimed Ottumwa fly ash aggregate were compacted at a moisture content of 25% (approximately 3% below optimum moisture content) and sealed cured for 7 days. At the end of the curing period, three samples of each mixture were placed in air, three of each mixture were placed in a room set to maintain 100% relative humidity, and three of each mixture were submerged in water. The masses of the samples were recorded at regular intervals and the dimensions were measured with a caliper. The caliper measurements of sample length and diameter were taken at 3 separate points on each sample and the average of each dimension was recorded to the nearest 0.01 inches.

A third test was initiated to determine the volumetric stability of fly ash/reclaimed fly ash aggregate mixtures. The first two volumetric stability tests indicated no volumetric stability problems with AFBC or CKD stabilized mixtures. It was determined that full-scale volumetric stability tests of lime activated and fly ash activated reclaimed fly ash aggregate samples were not necessary, since the results of the previous tests showed no volumetric stability problems with activated reclaimed fly ash aggregate samples. However, the volumetric stability of the raw fly ash was unknown. To determine this property, 2" cubes of hydrated raw fly ash from each of the four sources (Prairie Creek, Ottumwa, Council Bluffs, and Neal 3) were made according to the method in ASTM C109, "Compressive Strength of Hydraulic Cement Mortars Using 2-in. Cube Specimens" (3) and subjected to various curing environments. This research was intended to verify that the raw fly ashes (and by extension the fly ash/reclaimed fly ash aggregate mixtures) were volumetrically stable. Three samples of each fly ash type were compacted at optimum moisture. One of these samples was placed in air at room temperature, a second was submerged in water, and the third was placed in a room set to maintain 100% relative humidity. Each week, the masses of the samples were recorded and the dimensions were measured with a caliper. . The caliper measurements of sample height, length, and width were taken at 3 separate points on each sample and the average of each dimension was recorded to the nearest 0.01 inches.

IX. RESULTS OF FREEZE-THAW DURABILITY TESTS ON ACTIVATED RECLAIMED FLY ASH AGGREGATE

Figures 1, 2, 3, 4, 5, and 6 show the number of freeze-thaw cycles survived by each activator/reclaimed fly ash aggregate mixture. It was decided to discontinue the testing of AFBC and CKD as potential activators in future projects. This use of CKD was discontinued because of environmental concerns about high levels of lead in CKD in Iowa caused by a change in Portland cement production methods. The use of AFBC was discontinued due to concerns about the field performance of AFBC in the Ottumwa-Midland and Sutherland access roads. Therefore, the mixtures compared in Figure 1 were not included on Figure 2 because it is unlikely they will be used in any future field projects. Figure 2, a comparison of all of the fly ash and lime activated samples, shows that the lime/reclaimed fly ash aggregate mixtures possess far more resistance to freeze-thaw damage than the fly ash/reclaimed fly ash aggregate mixtures. Figures 3, 4, 5, and 6 provide a better understanding of the durability of individual activator/reclaimed fly ash aggregate mixtures.

Reclaimed Ottumwa Fly Ash Aggregate

Freeze-thaw durability results for 15% AFBC/85% reclaimed Ottumwa fly ash aggregate, 10%CKD/90% reclaimed Ottumwa fly ash aggregate, and 2.5% CKD/97.5% reclaimed Ottumwa fly ash aggregate are shown in Figure 1. From Figure 1, it can be seen that 10% CKD activated reclaimed Ottumwa fly ash aggregate samples have survived 59 freeze-thaw cycles without losing half of their original mass. Figure 1 shows the disparity

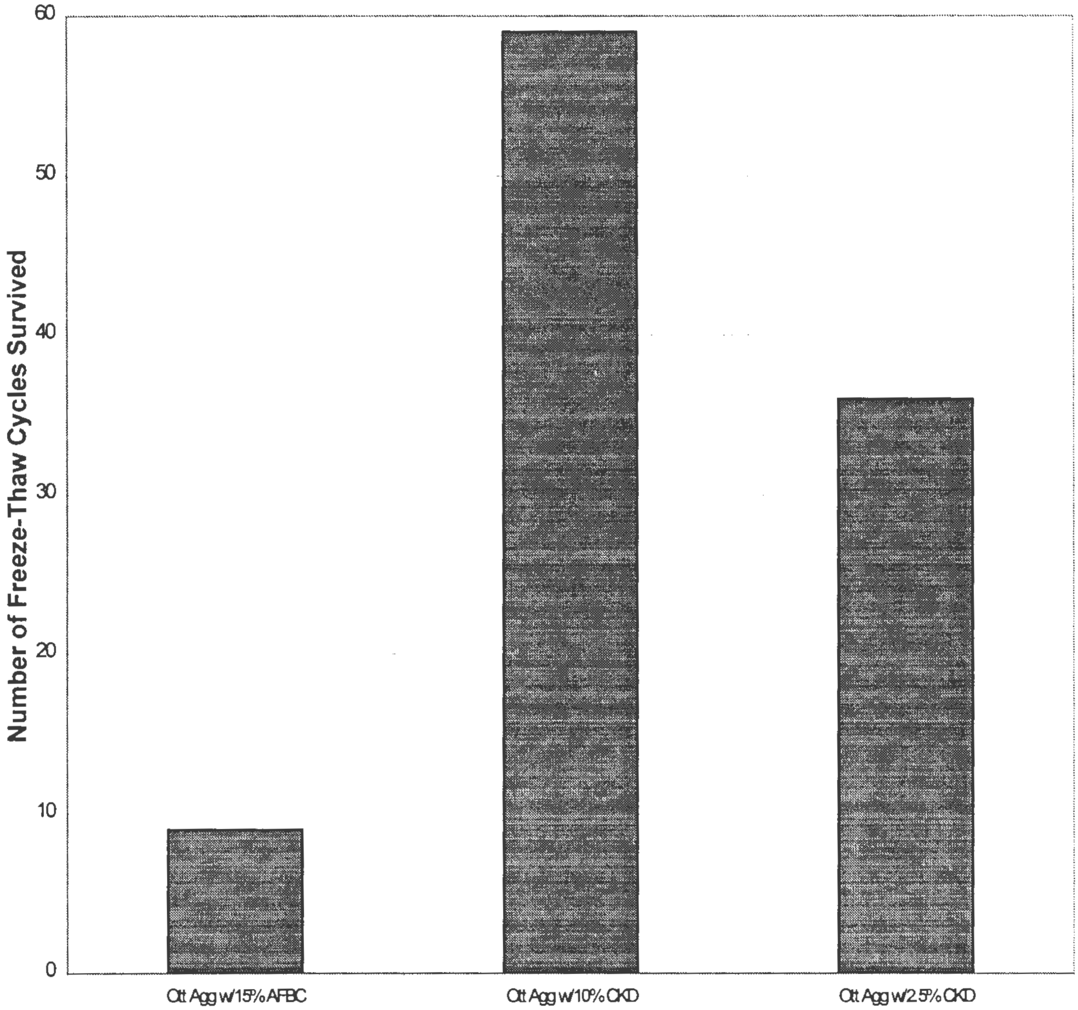

Figure 1. Freeze-Thaw Durability of AFBC and CKD Activated Reclaimed Fly Ash Aggregate

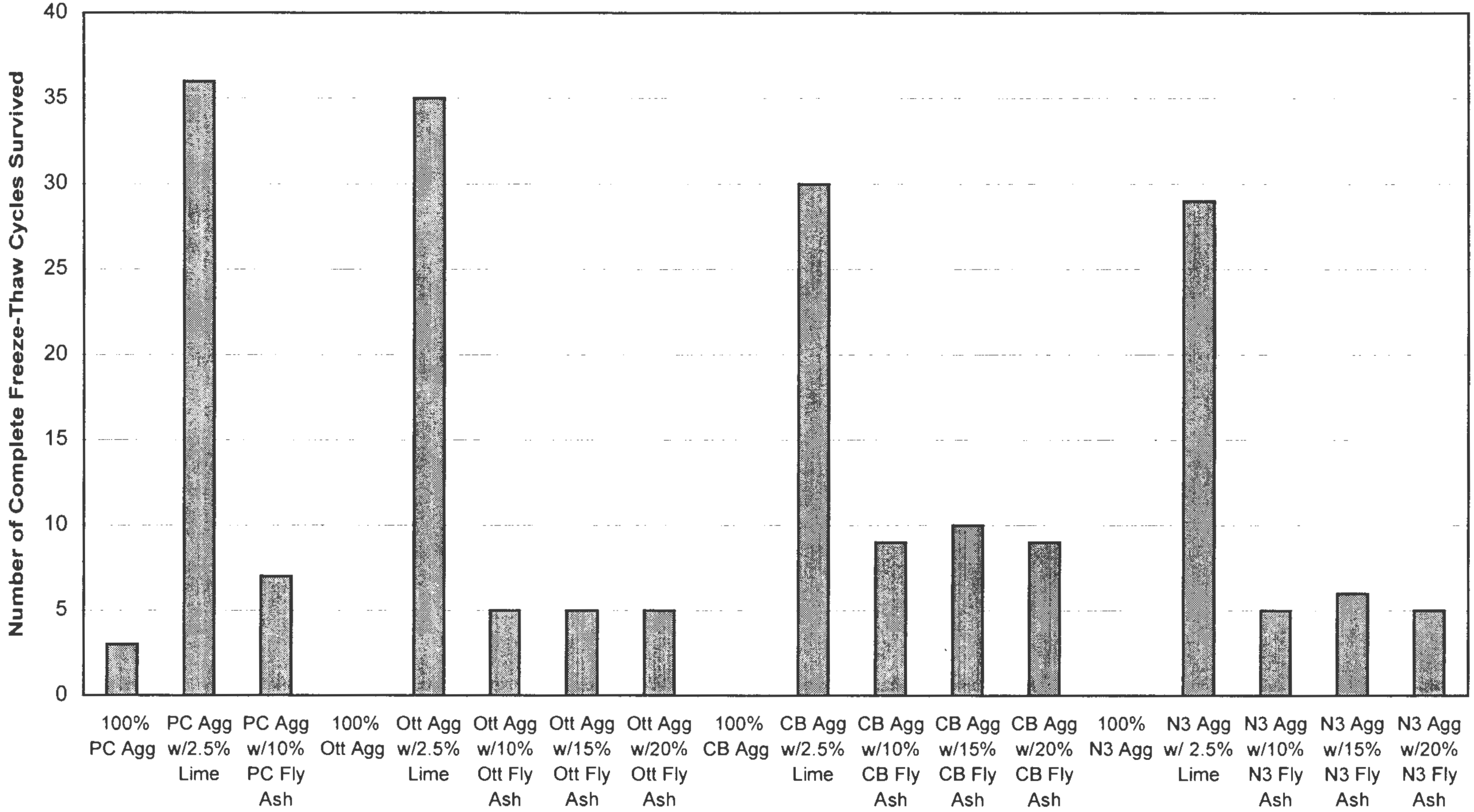

Figure 2. Freeze-Thaw Durability of Fly Ash and Lime Activated Reclaimed Fly Ash Aggregate

between the freeze-thaw durability of the 10% CKD/90% reclaimed Ottumwa fly ash aggregate samples and the 15% AFBC/85% reclaimed Ottumwa fly ash samples. In sharp contrast to the 59 freeze-thaw cycles survived by the 10% CKD samples, the 15% AFBC samples survived only 9 cycles. Figure 1 also shows the performance of 2.5% CKD/97.5% reclaimed Ottumwa fly ash aggregate samples tested early in this research. The 2.5% CKD samples survived 36 freeze-thaw cycles, indicating good freeze-thaw durability even at low CKD activator levels. For reasons stated above, testing of AFBC and CKD as activators for reclaimed fly ash aggregate was discontinued, and the latter portion of the research concentrated on the use of hydrated lime and fly ash as potential activators for reclaimed fly ash aggregate.

Figure 3 shows the performance of 100% reclaimed Ottumwa fly ash aggregate, and reclaimed fly ash aggregate stabilized by 2.5% lime and 10%, 15%, and 20% Ottumwa fly ash aggregate. From Figure 3, it can be seen that the 100% reclaimed fly ash aggregate did not survive one freeze-thaw cycle. The fly ash activated reclaimed ash aggregate fared only slightly better, surviving 5 freeze-thaw cycles, regardless of fly ash content. This trend repeated itself in the other fly ash activated aggregates, with 10%, 15%, and 20% fly ash additive samples of each aggregate performing very similarly. This suggested that little to no durability is gained by adding more than 10% fly ash activator to reclaimed ash aggregate. The lime activated aggregate exhibited excellent freeze-thaw durability, surviving 35 cycles. The lime activated Ottumwa aggregate was still not destroyed at the end of 35 freeze-thaw cycles, but testing was discontinued for practical reasons. Testing was also discontinued

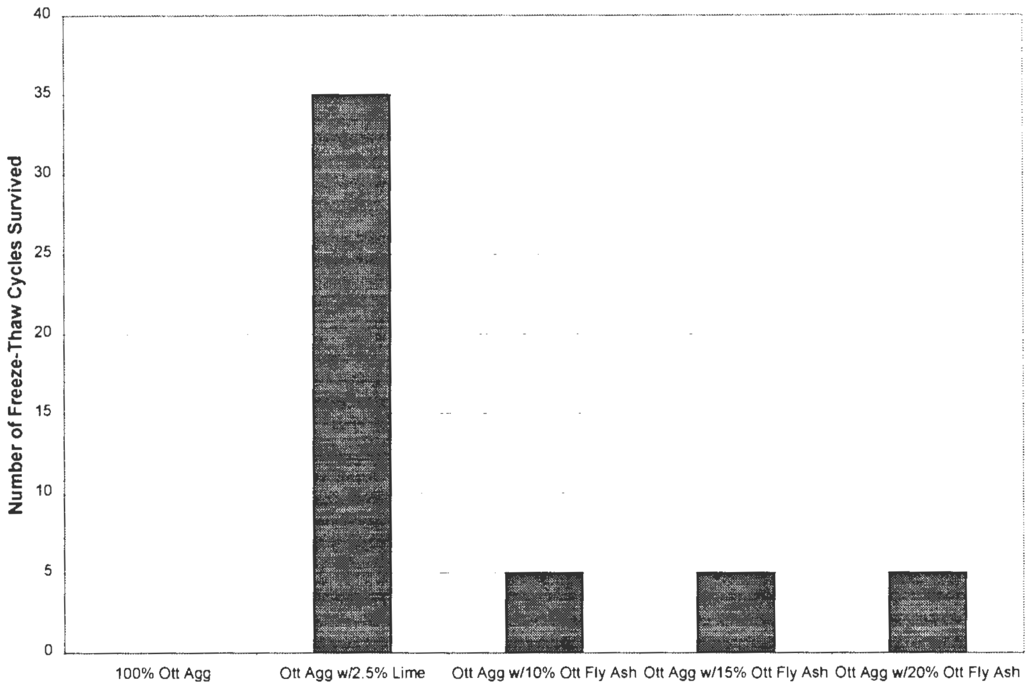

Figure 3. Freeze-Thaw Durability of Fly Ash and Lime Activated Reclaimed Ottumwa Fly Ash Aggregate

before the lime activated Council Bluffs, Neal 3, and Prairie Creek aggregate samples were destroyed.

Reclaimed Council Bluffs Fly Ash Aggregate

Figure 4 shows the performance of 100% reclaimed Council Bluffs fly ash aggregate, and reclaimed fly ash aggregate stabilized by 2.5% lime and 10%, 15%, and 20% Council Bluffs fly ash. From Figure 4, it can be seen that the 100% reclaimed fly ash aggregate did not survive one freeze-thaw cycle. The fly ash activated reclaimed fly ash aggregate exhibited slightly better durability, surviving 9 to 10 freeze-thaw cycles, with little variation between 10%, 15%, and 20% fly ash content. As with the Ottumwa fly ash stabilized aggregates,

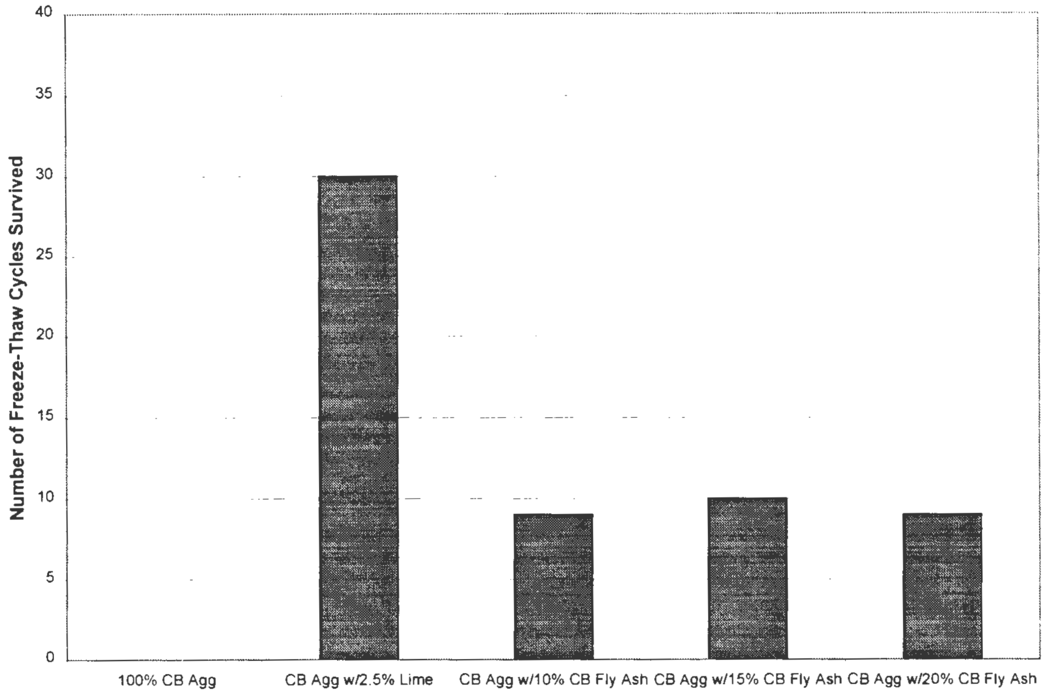

Figure 4. Freeze-Thaw Durability of Fly Ash and Lime Activated Reclaimed Council Bluffs Fly Ash Aggregate

little or no durability was gained by adding more than 10% Council Bluffs fly ash activator to reclaimed Council Bluffs fly ash aggregate. The lime activated aggregate exhibited excellent freeze-thaw durability, surviving 30 cycles before testing was discontinued.

Reclaimed Neal 3 Fly Ash Aggregate

Figure 5 shows the performance of 100% reclaimed Neal 3 fly ash aggregate, and reclaimed fly ash aggregate stabilized by 2.5% lime and 10%, 15%, and 20% Neal 3 fly ash. From Figure 5, it can be seen that the 100% reclaimed fly ash aggregate did not survive one freeze-thaw cycle. The fly ash activated reclaimed fly ash aggregate exhibited slightly better

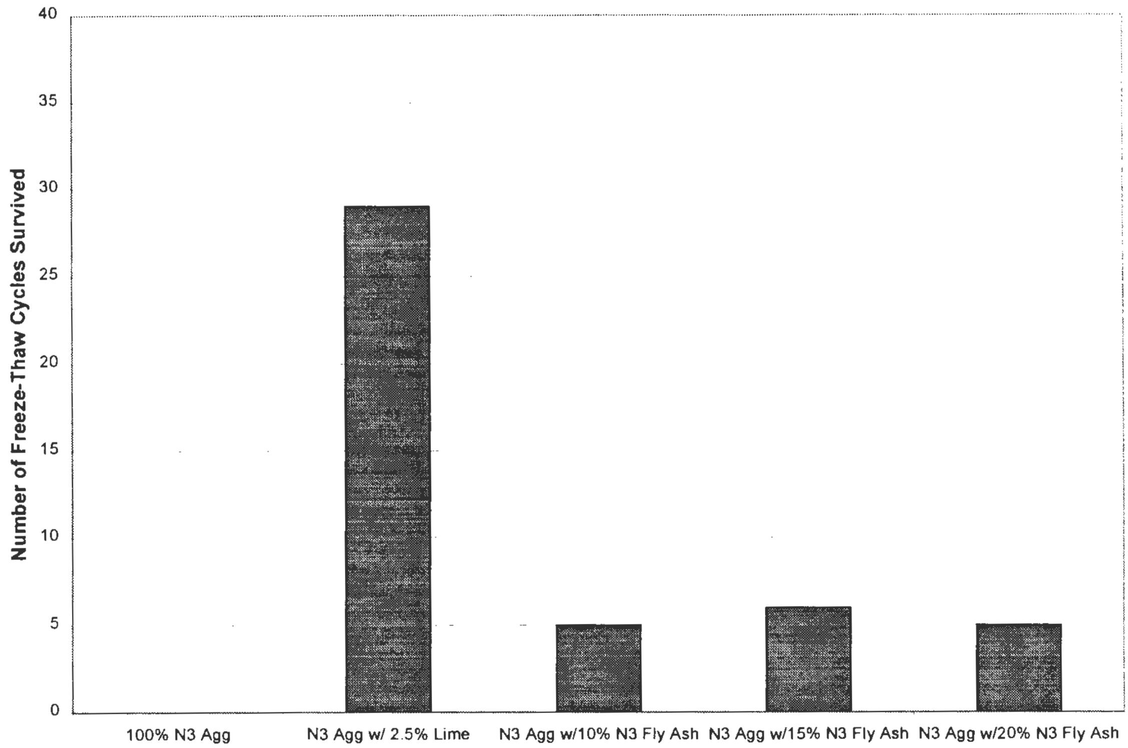

Figure 5. Freeze-Thaw Durability of Fly Ash and Lime Activated Reclaimed Neal 3 Fly Ash Aggregate

durability, surviving 5 to 6 freeze-thaw cycles, with little variation between 10%, 15%, and 20% fly ash content. As with the Ottuwma and Council Bluffs fly ash stabilized aggregates, little or no durability was gained by adding more than 10% Neal 3 fly ash activator to reclaimed Neal 3 fly ash aggregate. The lime activated aggregate exhibited excellent freeze-thaw durability, surviving 29 cycles before testing was discontinued.

Reclaimed Prairie Creek Fly Ash Aggregate

Figure 6 shows the performance of 100% reclaimed Prairie Creek fly ash aggregate, and reclaimed ash aggregate stabilized by 2.5% lime and 10% Prairie Creek fly ash. Figure 6

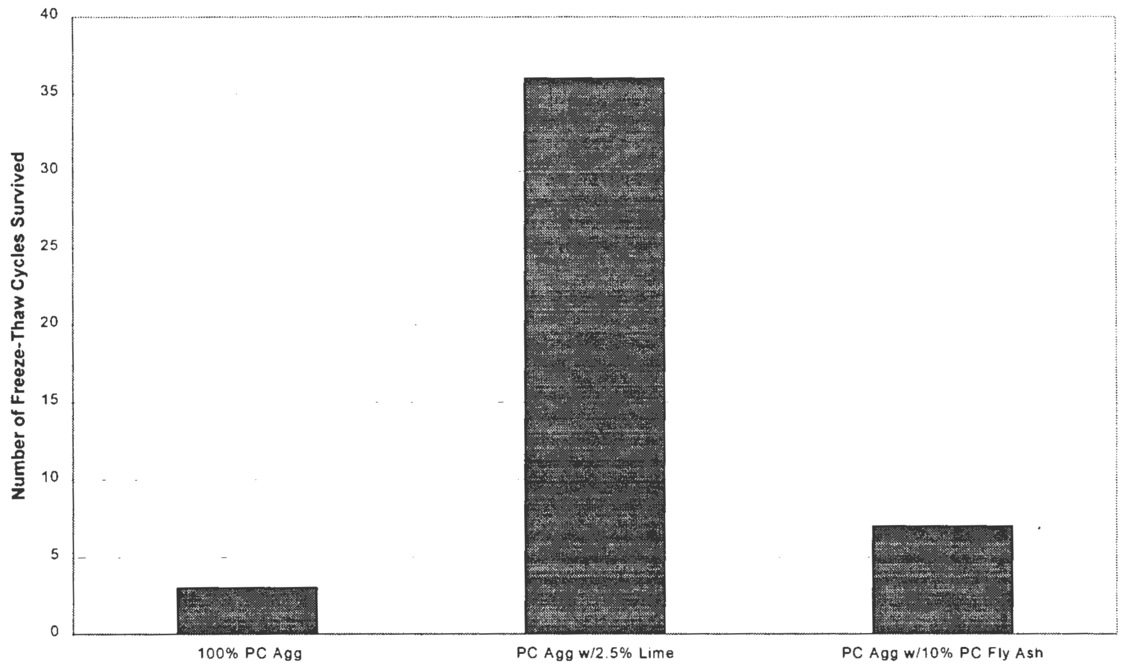

Figure 6. Freeze-Thaw Durability of Fly Ash and Lime Activated Reclaimed Prairie Creek Fly Ash Aggregate

shows that 100% reclaimed Prairie Creek ash aggregate was the only non-activated aggregate to survive a complete freeze-thaw cycle. The non-activated aggregate samples survived 3 freeze-thaw cycles. The fly ash activated reclaimed fly ash aggregate exhibited better durability, surviving 7 freeze-thaw cycles. Unlike the other 3 reclaimed fly ash aggregates, reclaimed Prairie Creek ash aggregate was only tested with 10% fly ash additive. Testing of higher fly ash contents was discontinued because the results of the Ottumwa, Council Bluffs, and Neal 3 fly ash stabilized aggregates had shown that little or no durability was gained by adding more than 10% fly ash activator to reclaimed fly ash aggregate. Increased fly ash contents would only increase cost of the mixture, increase the water required for compaction, and reduce workability in the field. The lime activated aggregate exhibited excellent freeze-thaw durability, surviving 36 cycles before testing was discontinued.

Summary

The performance differences for the fly ash activated Ottumwa, Neal 3, and Council Bluffs aggregates are minimal between fly ash additive levels of 10%, 15%, and 20%. This would indicate that, from a durability standpoint, the increased additive levels of 15% to 20% are not beneficial enough to justify the increased cost over a 10% fly ash additive level. This point is probably not very important when considered against the fact that none of the fly ash/reclaimed fly ash aggregate mixtures survived more than ten laboratory freeze-thaw cycles. These laboratory cycles are almost certainly harsher than actual field freeze-thaw cycles would be because the laboratory tests are on fully saturated samples. This nevertheless raises concerns about the use of fly ash/reclaimed fly ash aggregate mixtures in road bases. However, the field performance of the Ottumwa-Midland and Sutherland test roads discussed in the Literature Review suggests that the activator/reclaimed fly ash aggregate mixtures will perform adequately as base materials even if the materials break down from a stabilized base to a crushed-stone type base.

The lime activated samples of all four aggregates exhibited very good freeze-thaw durability, each surviving at least 29 freeze-thaw cycles before testing was discontinued.

X. RESULTS OF ASTM C 593 TEST METHOD FOR PREDICTING FREEZE-THAW DURABILITY OF ACTIVATED RECLAIMED FLY ASH AGGREGATE

Figures 7, 8, 9, 10, 11, and 12 show the results of the average ASTM C 593 test method compressive strength results for each activator/reclaimed fly ash aggregate mixture. As discussed in the freeze-thaw durability results, the testing of AFBC and CKD as potential activators in future projects was discontinued. Therefore, the mixtures compared in Figure 7 were not included on Figure 8 because it is unlikely they will be used in any future field projects. Figure 8 shows that the lime/reclaimed fly ash aggregate mixtures exhibit higher vacuum-saturated and soaked compressive strengths than the fly ash/reclaimed fly ash aggregate mixtures. Figures 9, 10, 11, and 12 provide a more detailed comparison of the individual activator/reclaimed fly ash aggregate mixtures.

Figure 8, an overall comparison of all the fly ash and lime activated mixtures, shows that only 2.5% lime/97.5% Prairie Creek reclaimed fly ash aggregate and 2.5% lime/97.5% Council Bluffs reclaimed fly ash aggregate met the ASTM C 593 minimum strength requirement for acceptable freeze-thaw durability of 400 psi.

The Ottumwa, Neal 3, and Prairie Creek fly ash activated samples (shown on Figures 9, 11, and 12, respectively) only reached strengths of 30 psi to 60 psi. The fly ash activated Council Bluffs samples, shown on Figure 10, developed compressive strengths of around 80 to 100 psi. As with the freeze-thaw durability results, the performance differences between fly ash additive levels of 10%, 15% and 20% were negligible.

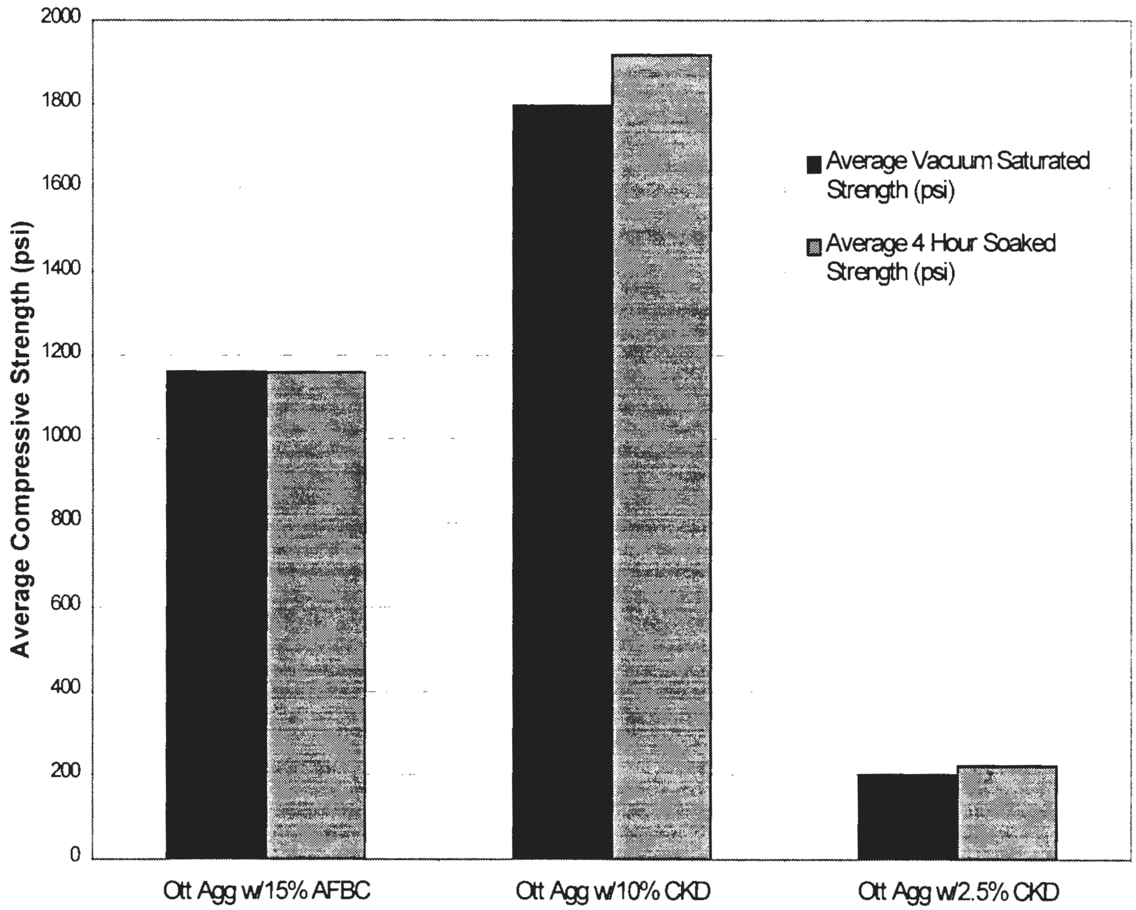

Figure 7. ASTM C 593 Compressive Strengths of AFBC and CKD Activated Reclaimed Fly Ash Aggregate

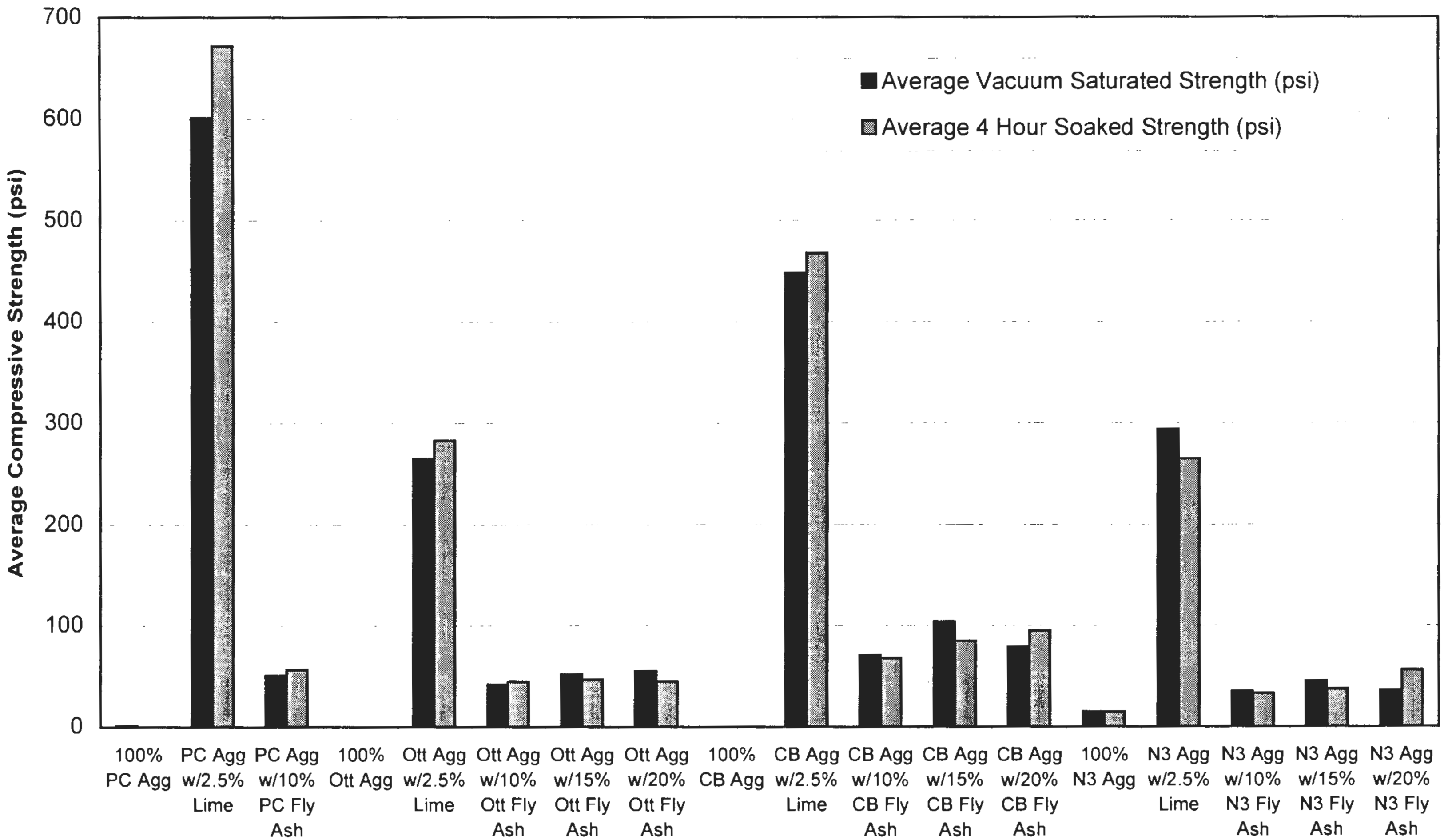

Figure 8. ASTM C 593 Compressive Strengths of Fly Ash and Lime Activated Reclaimed Fly Ash Aggregate

The AFBC activated samples were not included in the overall comparison of Figure 8 because it has already been established that C 593 is a poor predictor of freeze-thaw durability for these materials. The CKD activated samples were not included in Figure 8 because of the previously discussed environmental concerns and the low probability of the future use of CKD as an activator in field projects.

Reclaimed Ottumwa Fly Ash Aggregate

ASTM C 593 vacuum-saturated and soaked cure compressive strength results for 15% AFBC/85% reclaimed Ottumwa fly ash aggregate, 10% CKD/90% reclaimed Ottumwa fly ash aggregate, and 2.5% CKD/97.5% reclaimed Ottumwa fly ash aggregate are shown in Figure 7. Figure 7 shows that 10% CKD activated reclaimed Ottumwa fly ash aggregate samples reached vacuum-saturated and soaked compressive strengths of 1800 psi to 1900 psi.

The 15% AFBC/85% reclaimed Ottumwa fly ash samples achieved vacuum-saturated and soaked compressive strengths of roughly 1200 psi, far in excess of the 400 psi minimum specified for good freeze-thaw durability by the ASTM C 593 test method. However, as discussed in the preceding section, the 15% AFBC/85% reclaimed Ottumwa fly ash aggregate samples survived only 9 cycles of the freeze-thaw durability test. This shows that while ASTM C 593 is a good predictor of freeze-thaw durability in fly ash, lime, and CKD activated reclaimed fly ash aggregate mixtures, it is not applicable to AFBC activated mixtures. This indicates that AFBC activated reclaimed fly ash aggregate may possess a unique void structure that makes it susceptible to frost action but not to vacuum saturation.

Figure 7 also shows the vacuum-saturated and 4 hour soaked compressive strengths of 2.5% CKD/97.5% reclaimed Ottumwa fly ash aggregate samples tested early in this research. The 2.5% CKD samples reached compressive strengths of approximately 200 psi, only half the 400 psi minimum specified for good freeze-thaw durability by the ASTM C 593 test method. This strength is lower than expected because the freeze-thaw tests on this mixture indicated excellent freeze-thaw durability.

Figure 9 shows the vacuum-saturated and 4 hour soaked compressive strengths of 100% reclaimed Ottumwa fly ash aggregate, and reclaimed fly ash aggregate stabilized by 2.5% lime and 10%, 15%, and 20% Ottumwa fly ash. The 100% reclaimed fly ash aggregate samples failed to remain intact during the vacuum-saturation and 4 hour soaking cures, so Figure 9 indicates compressive strengths of zero for this material. The fly ash activated reclaimed fly ash aggregate strengths were all roughly 40 psi to 50 psi. As with the freeze-thaw test results, 10%, 15%, and 20% fly ash activated reclaimed Ottumwa fly ash aggregate samples performed very similarly. This supports the idea that fly ash additive levels greater than 10% do not provide enough benefit to justify the additional cost and effort. The 2.5% lime activated reclaimed Ottumwa fly ash aggregate samples achieved vacuum-saturated and soaked compressive strengths of 260 psi to 280 psi. This is below the ASTM C 593 specified minimum of 400 psi, but it is still a significant strength increase for the low activator level.

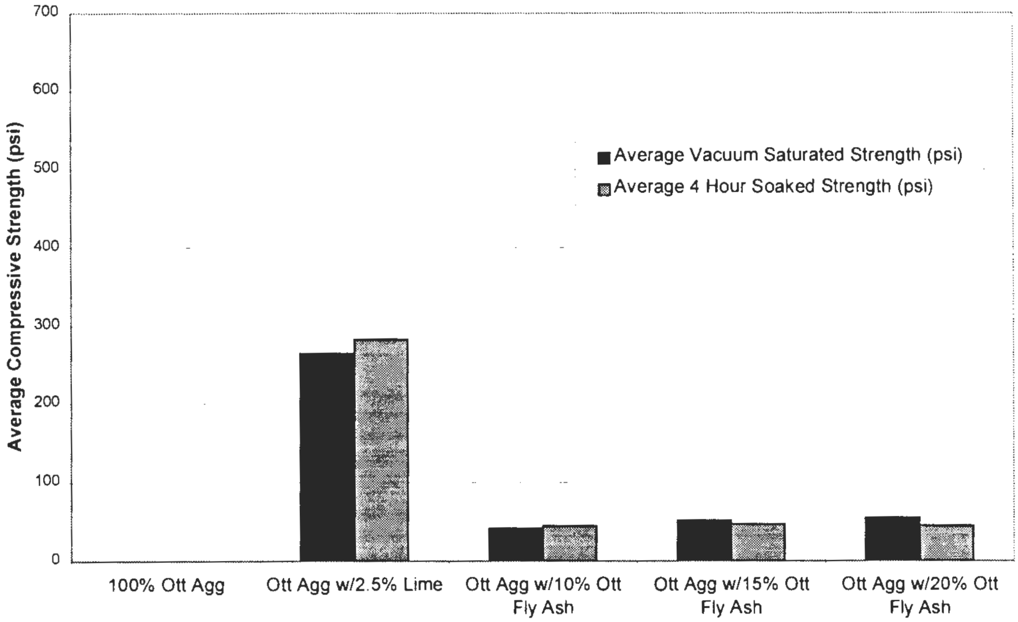

Figure 9. ASTM C 593 Compressive Strengths of Fly Ash and Lime Activated Reclaimed Ottumwa Fly Ash Aggregate

Reclaimed Council Bluffs Fly Ash Aggregate

Figure 10 shows the vacuum-saturated and 4 hour soaked compressive strengths of 100% reclaimed Council Bluffs fly ash aggregate, and reclaimed fly ash aggregate stabilized by 2.5% lime and 10%, 15%, and 20% Council Bluffs fly ash. Unlike the untreated Ottumwa and Neal 3 reclaimed fly ash aggregate samples, the 100% Council Bluffs reclaimed fly ash aggregate samples remained intact during the vacuum-saturation and 4 hour soaking cures. These untreated samples only achieved 15 psi compressive strengths after both curing conditions. The fact that the samples remained intact supports the evidence from the freeze-thaw tests and previous observations by Barnes (11) that Council Bluffs

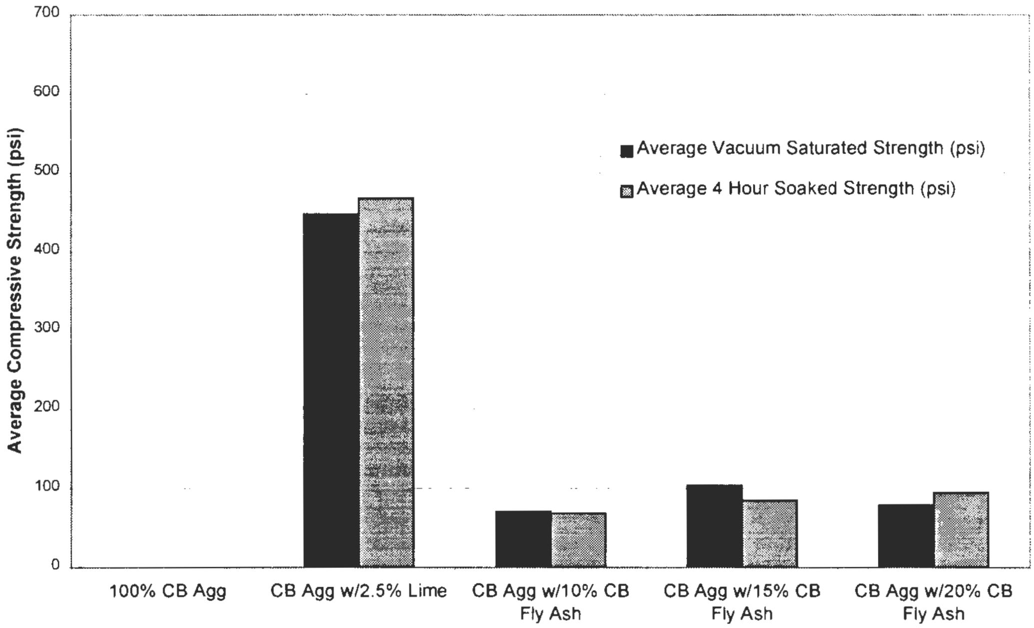

Figure 10. ASTM C 593 Compressive Strengths of Fly Ash and Lime Activated Reclaimed Council Bluffs Fly Ash Aggregate

aggregate is the most reactive of the reclaimed fly ash aggregates tested. The fly ash activated reclaimed ash aggregate strengths ranged from 40 psi to 55 psi. As with the freeze-thaw test results, 10%, 15%, and 20% Council Bluffs fly ash activated samples performed very similarly. This supports the idea that fly ash additive levels greater than 10% do not provide enough benefit to justify the additional cost and effort. The 2.5% lime activated reclaimed Council Bluffs reclaimed fly ash aggregate samples achieved vacuum-saturated and soaked compressive strengths of 450 to 470 psi, greater than the ASTM C 593 specified minimum of 400 psi. 2.5% lime activated Council Bluffs reclaimed fly ash aggregate can be expected to perform as a strong and durable base material.

Reclaimed Neal 3 Fly Ash Aggregate

Figure 11 shows the vacuum-saturated and 4 hour soaked compressive strengths of 100% reclaimed Neal 3 fly ash aggregate, and reclaimed fly ash aggregate stabilized by 2.5% lime and 10%, 15%, and 20% Neal 3 fly ash. The 100% reclaimed fly ash aggregate samples failed to remain intact during the vacuum-saturation and 4 hour soaking cures, so Figure 11 indicates compressive strengths of zero for this material. The fly ash activated reclaimed fly ash aggregate strengths were all roughly 30 psi to 55 psi. As with the freeze-thaw test results, 10%, 15%, and 20% fly ash activated reclaimed Neal 3 fly ash samples performed very similarly. Again, it appears that fly ash additive levels greater than 10% do not provide enough benefit to justify the additional cost and effort. The 2.5% lime activated reclaimed

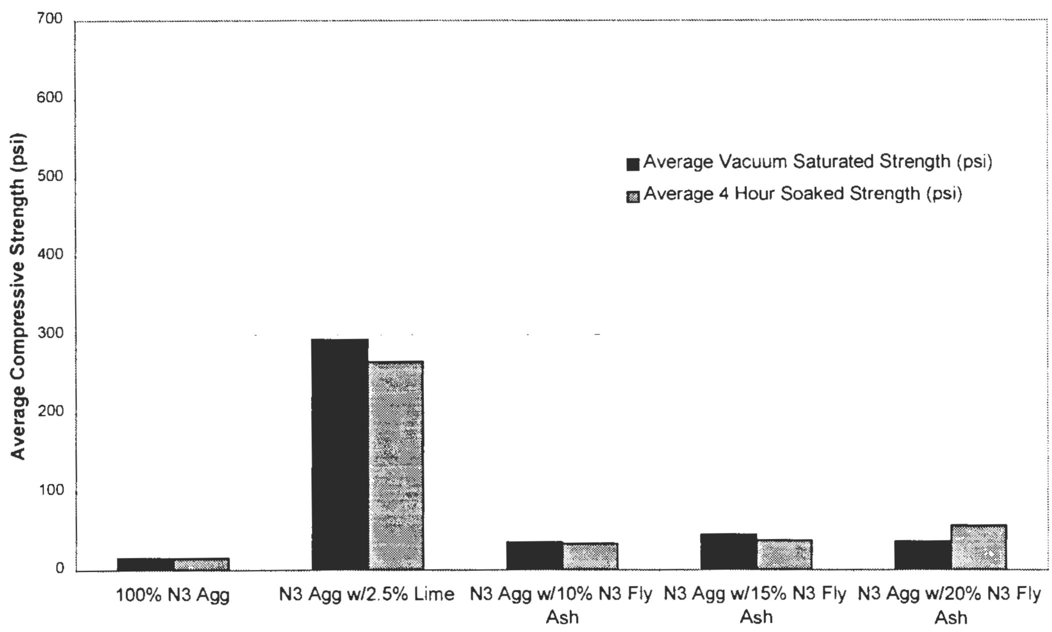

Figure 11. ASTM C 593 Compressive Strengths of Fly Ash and Lime Activated Reclaimed Neal 3 Fly Ash Aggregate

Neal 3 fly ash aggregate samples achieved vacuum-saturated and 4 hour soaked compressive strengths of 260 to 295 psi. As with the lime activated Ottumwa aggregate, these strengths are below the ASTM C 593 specified minimum of 400 psi, but they still represent significant strength increases for the low activator level.

Reclaimed Prairie Creek Fly Ash Aggregate

Figure 12 shows the vacuum-saturated and 4 hour soaked compressive strengths of 100% reclaimed Prairie Creek fly ash aggregate, and reclaimed fly ash aggregate stabilized by 2.5% lime and 10% Prairie Creek fly ash. The 100% Prairie Creek reclaimed fly ash aggregate samples remained intact during the vacuum-saturation cure, but they did not

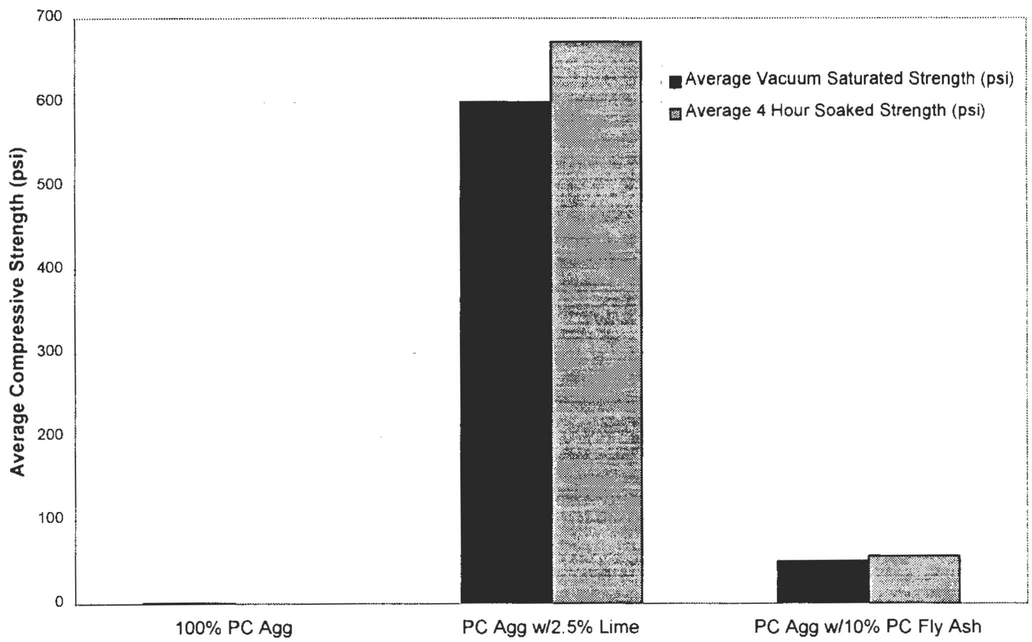

Figure 12. ASTM C 593 Compressive Strengths of Fly Ash and Lime Activated Reclaimed Prairie Creek Fly Ash Aggregate

survive the 4 hour soaking cure . The vacuum-saturated untreated samples achieved negligible compressive strengths of less than 1 psi. The 10% fly ash activated reclaimed fly ash aggregate strengths were roughly 50 psi to 60 psi. The 2.5% lime activated reclaimed Prairie Creek reclaimed fly ash aggregate samples achieved vacuum-saturated and 4 hour soaked compressive strengths of 600 psi to 670 psi, more than 1.5 times the ASTM C 593 specified minimum of 400 psi. These high strengths indicate that Prairie Creek aggregate benefits more from the 2.5% lime activator than the other three reclaimed fly ash aggregates. 2.5% lime activated Prairie Creek fly ash aggregate can be expected to perform as a strong and durable base material.

Correlation to Freeze-Thaw Durability Results

Figure 13 shows the correlation between freeze-thaw cycles survived and ASTM C 593 compressive strength for fly ash and lime activated samples. It is apparent from Figure 13 that there is good correlation between these two properties for both fly ash and lime activated reclaimed fly ash aggregate. An R^2 value of 0 would indicate no correlation between the two properties, and an R^2 value of 1 would indicate perfect correlation between the properties. The R^2 value of the best-fit line for the data points is 0.85, indicating a strong statistical correlation between freeze-thaw durability and C 593 compressive strength for the lime and fly ash activated reclaimed fly ash aggregates.

These results verify that ASTM C 593 vacuum-saturated compressive strength is a good predictor of the freeze-thaw durability of lime and fly ash activated reclaimed fly ash aggregate. ASTM C 593 vacuum-saturated compressive strength has also been shown to

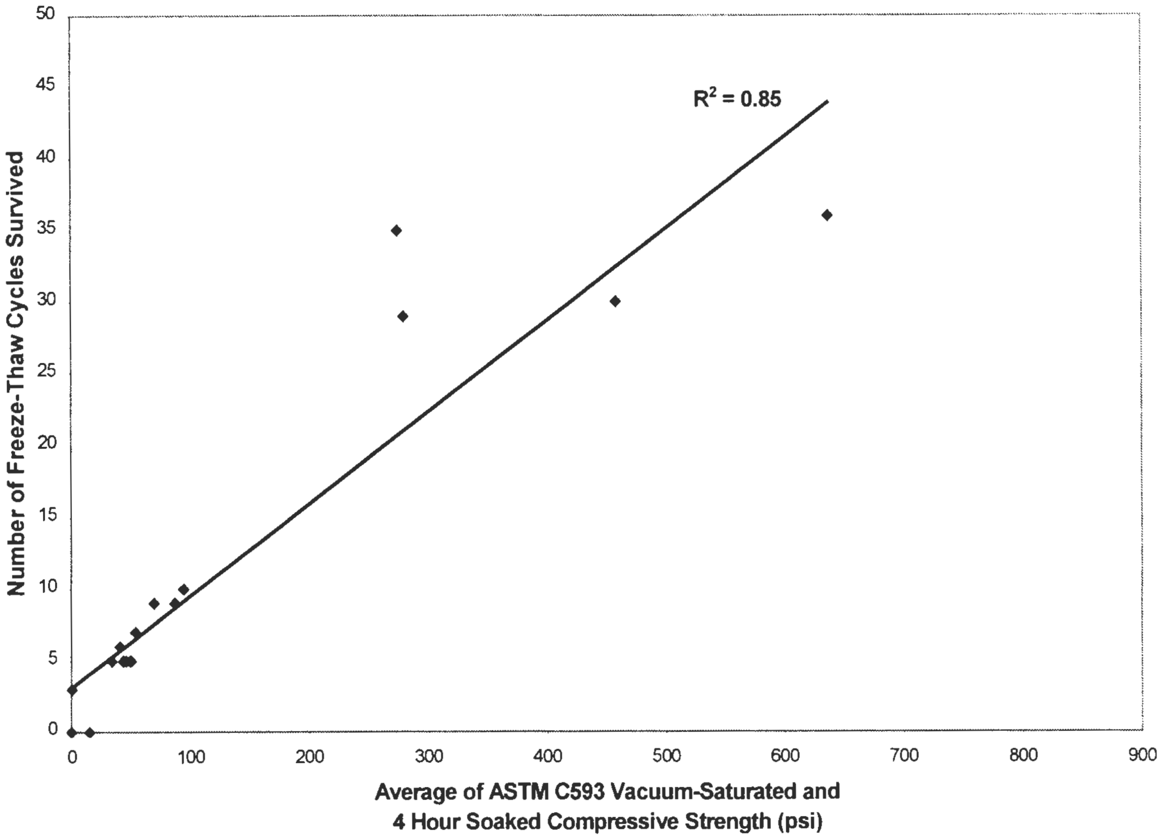

Figure 13. Correlation of Freeze-Thaw Durability to ASTM C 593 Compressive Strength

reliably predict the freeze-thaw durability of CKD activated reclaimed fly ash aggregate. The only material not exhibiting a strong correlation between vacuum-saturated compressive strength and freeze-thaw durability is AFBC activated reclaimed fly ash aggregate. The apparently poor freeze-thaw performance of the AFBC/reclaimed fly ash aggregate sections of the Ottumwa-Midland access road and the Sutherland Generating Station access road was not predicted by laboratory vacuum-saturated compressive strength tests. AFBC/reclaimed fly ash aggregate apparently possesses unique void structure properties that make it more susceptible to frost action than lime or CKD activated reclaimed ash aggregate. These void structure properties are apparently unaffected by vacuum saturation, so ASTM C 593 cannot be used to predict the freeze-thaw durability of AFBC activated reclaimed fly ash aggregate. An investigation of these void structure properties is beyond the scope of this research.

XI. RESULTS OF UNCONFINED COMPRESSIVE STRENGTH TESTS ON ACTIVATED RECLAIMED FLY ASH AGGREGATE

Figures 14, 15, 16, 17, 18, and 19 show the results of the average unconfined compressive strength results for each activator/reclaimed fly ash aggregate mixture. As discussed in the freeze-thaw durability and ASTM C 593 compressive strength results, the testing of AFBC and CKD as potential activators in future projects was discontinued. Therefore, the mixtures compared in Figure 14 were not included on Figure 15 because it is unlikely they will be used in any future field projects.

The AFBC and CKD activated reclaimed Ottumwa fly ash aggregate specimens were tested early in the research program for curing periods of up to approximately one year (336 days of curing) under sealed and humid curing conditions. The results of these tests verified that long-term strength gains were still occurring after one year of both curing conditions. These test results also showed little difference between the sealed cured and humid cured samples. Therefore, the tests on lime and fly ash activated aggregate samples only utilized sealed curing. The lime and fly ash activated reclaimed fly ash aggregate specimens compared on Figure 15 were tested over curing periods of up to two months (56 days).

Figure 15 shows that the lime/reclaimed fly ash aggregate mixtures exhibited higher unconfined compressive strengths than the fly ash/reclaimed fly ash aggregate mixtures. Figures 16, 17, 18, and 19 provide a detailed summary of the results of individual activator/reclaimed fly ash aggregate mixtures.

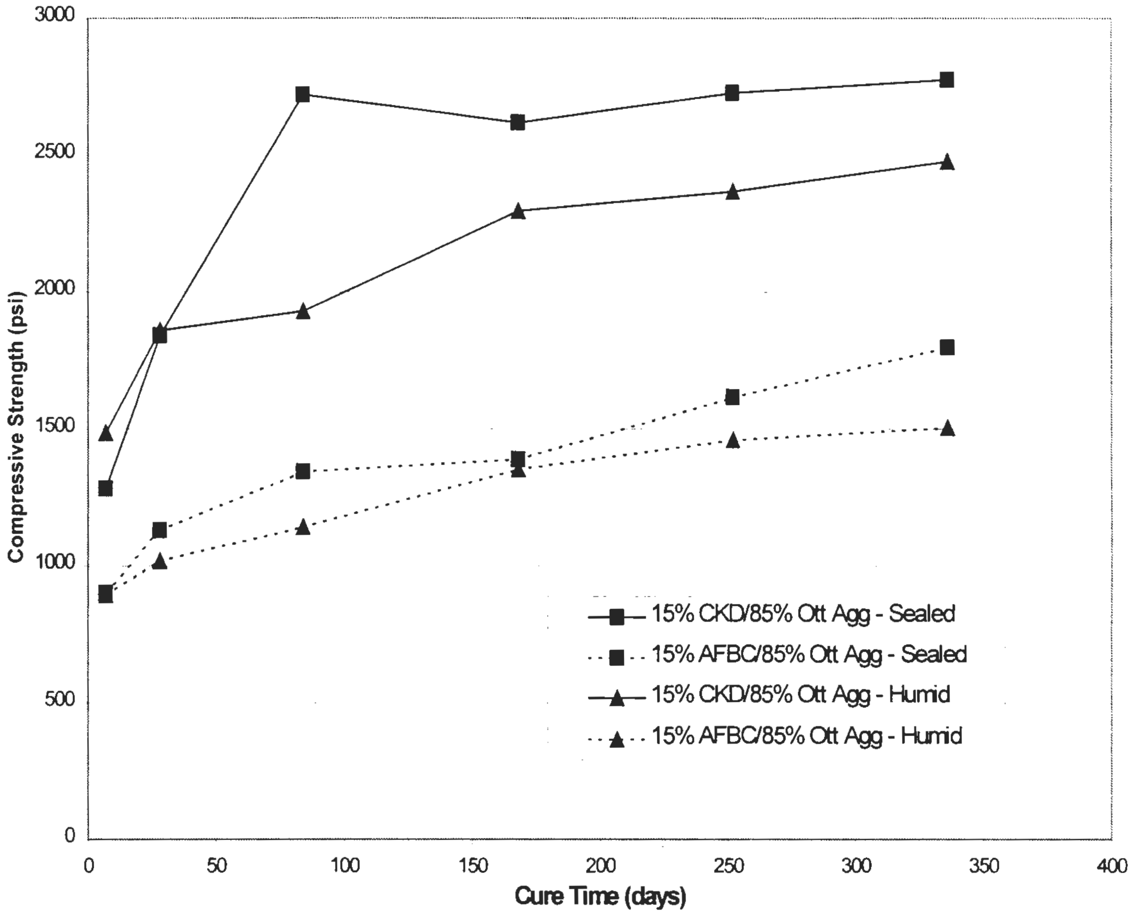

Figure 14. Long Term Unconfined Compressive Strengths of CKD and AFBC Activated Reclaimed Ottumwa Fly Ash Aggregate

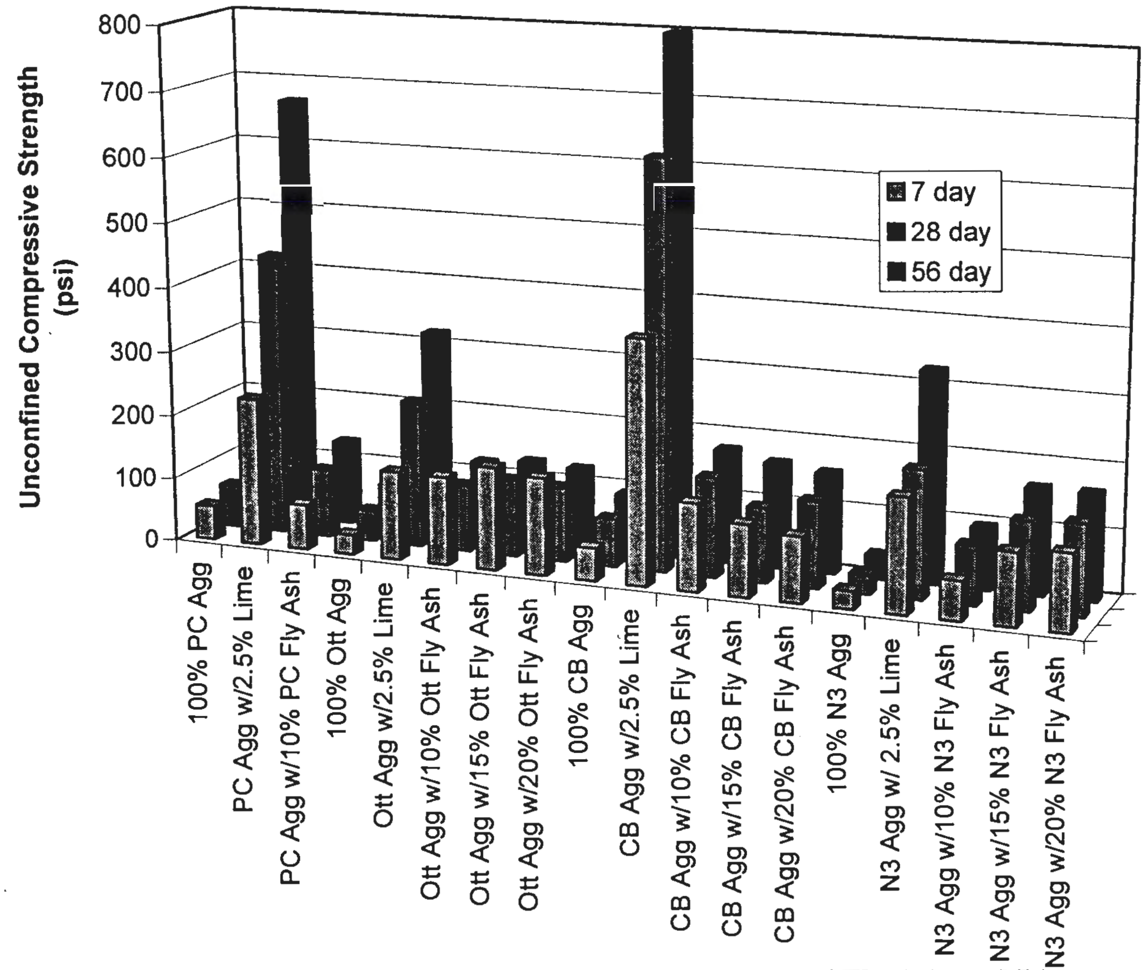

Figure 15. Unconfined Compressive Strengths of Fly Ash and Lime Activated Reclaimed Fly Ash Aggregate

Reclaimed Ottumwa Fly Ash Aggregate

Sealed cure and humid cure unconfined compressive strength results for 15% AFBC/85% reclaimed Ottumwa fly ash aggregate and 15%CKD/85% reclaimed Ottumwa fly ash aggregate are shown in Figure 14. From Figure 14, it can be seen that 15% CKD activated reclaimed Ottumwa fly ash aggregate samples reached compressive strengths of around 1300 psi to 1500 psi at 7 days and continued to gain strength until the end of testing at 336 days. The strength gain trend was still a steady gain at the end of testing, indicating that all of the strength gains were not completed at the end of 336 days. Figure 14 also shows that the 15% AFBC/85% reclaimed Ottumwa fly ash samples achieved compressive strengths of approximately 900 psi at 7 days and continued gaining strength until the end of testing at 336 days.

Figure 16 shows the unconfined compressive strengths results of 100% reclaimed Ottumwa fly ash aggregate as well as reclaimed fly ash aggregate activated with 2.5% lime and with 10%, 15%, and 20% Ottumwa fly ash. The 100% reclaimed fly ash aggregate samples had low strengths of less than 70 psi at 56 days, but they exhibited continued strength gains through the 56 day curing period. This indicates that the reaction of pozzolanic material in the aggregate is a source of strength gain.

The fly ash activated reclaimed fly ash aggregate strengths were roughly 100 psi at 7 days, dropped to around 80 psi at 28 days, and increased to around 100 psi again by 84 days. A possible cause of this strength drop is a mechanism wherein early reaction products that provided strength at 7 days had deteriorated somewhat by 28 days. The subsequent slow recovery of some of the strength can be attributed to long term pozzolanic reactions, which

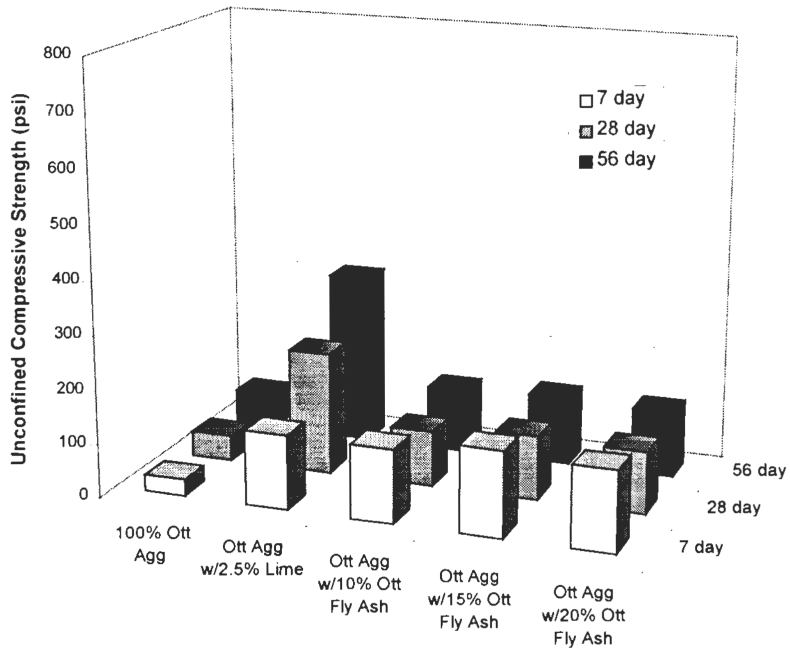

Figure 16. Unconfined Compressive Strengths of Fly Ash and Lime Activated Reclaimed Ottumwa Fly Ash Aggregate

probably cause a slow, continued strength increase as long as calcium and water are available to facilitate these reactions.

As in the freeze-thaw and ASTM C 593 test results, 10%, 15%, and 20% fly ash activated reclaimed Ottumwa fly ash samples performed very similarly. This result again supports the idea that fly ash additive levels greater than 10% do not provide sufficient benefit to justify the additional cost and effort. The 2.5% lime activated reclaimed Ottumwa fly ash samples achieved unconfined compressive strengths of around 100 psi at 7 days, 200 psi at 28 days, and over 300 psi at 56 days. This indicates that a significant strength increase can be gained by the addition of a small amount of lime activator.

Reclaimed Council Bluffs Fly Ash Aggregate

Figure 17 shows the unconfined compressive strengths results of 100% reclaimed Council Bluffs fly ash aggregate, and reclaimed fly ash aggregate stabilized by 2.5% lime and 10%, 15%, and 20% Council Bluffs fly ash. The 100% reclaimed fly ash aggregate samples had low strengths of less than 100 psi, but they exhibited continued strength gains through the 56 day curing period. This indicates that the reaction of pozzolanic material in the aggregate is a source of strength gain. The fly ash activated reclaimed fly ash aggregate strengths reached 100 psi to 140 psi at 7 days, increased to around 120 psi to 150 psi at 28 days, and show continued strength gains to approximately 155 to 175 psi by 56 days. As with the freeze-thaw and ASTM C 593 test results, 10%, 15%, and 20% fly ash activated reclaimed Council Bluffs fly ash samples performed very similarly. This result again

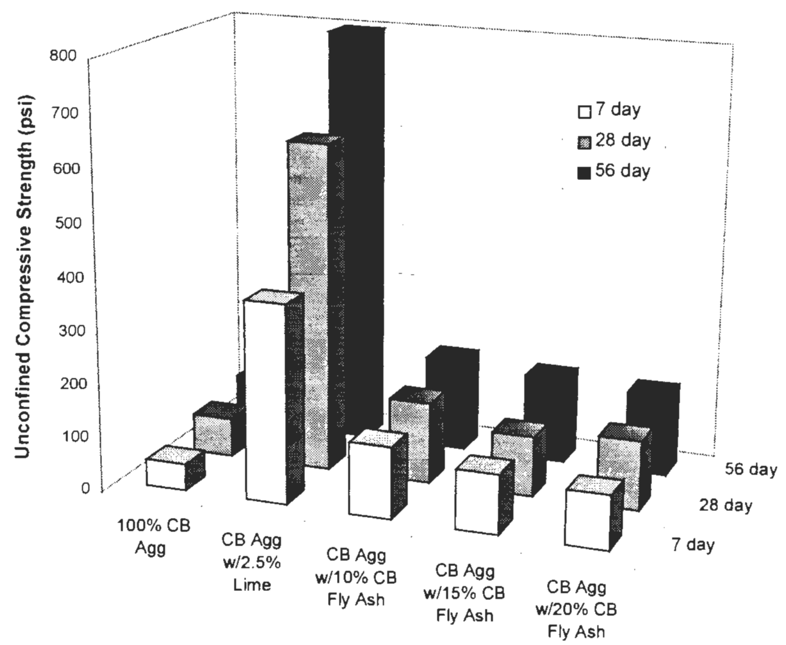

Figure 17. Unconfined Compressive Strengths of Fly Ash and Lime Activated Reclaimed Council Bluffs Fly Ash Aggregate

supports the idea that fly ash additive levels greater than 10% do not provide sufficient benefit to justify the additional cost and effort. The 2.5% lime activated reclaimed Council Bluffs fly ash aggregate samples achieved unconfined compressive strengths of around 375 psi at 7 days, 630 psi at 28 days, and nearly 800 psi at 56 days. This supports Barnes' (11) observation that Council Bluffs material is the most reactive aggregate and fly ash in the study.

Reclaimed Neal 3 Fly Ash Aggregate

Figure 18 shows the unconfined compressive strengths results of 100% reclaimed Neal 3 fly ash aggregate, and reclaimed fly ash aggregate stabilized by 2.5% lime and 10%, 15%, and 20% Neal 3 fly ash. The 100% reclaimed fly ash aggregate samples had low strengths of less than 40 psi and exhibited minimal strength gains through the 56 day curing period. This may indicate a lower amount of unreacted pozzolanic material in the Neal 3 aggregate than in the other three aggregates in the study. It is possible that the pozzolanic reactions stopped because nearly all of the free calcium or the unreacted pozzolans were used up in the fly ash hydration reactions that formed the aggregate.

The fly ash activated reclaimed ash aggregate strengths reached 60 psi to 120 psi at 7 days, increased to 90 psi to 140 psi at 28 days, and showed continued strength gains to approximately 95 to 160 psi by 56 days. Unlike the Ottumwa and Council Bluffs materials, 15%, and 20% fly ash activated reclaimed Neal 3 fly ash samples significantly outperformed 10% fly ash activated samples. This result may indicate that Neal 3 fly ash is less reactive

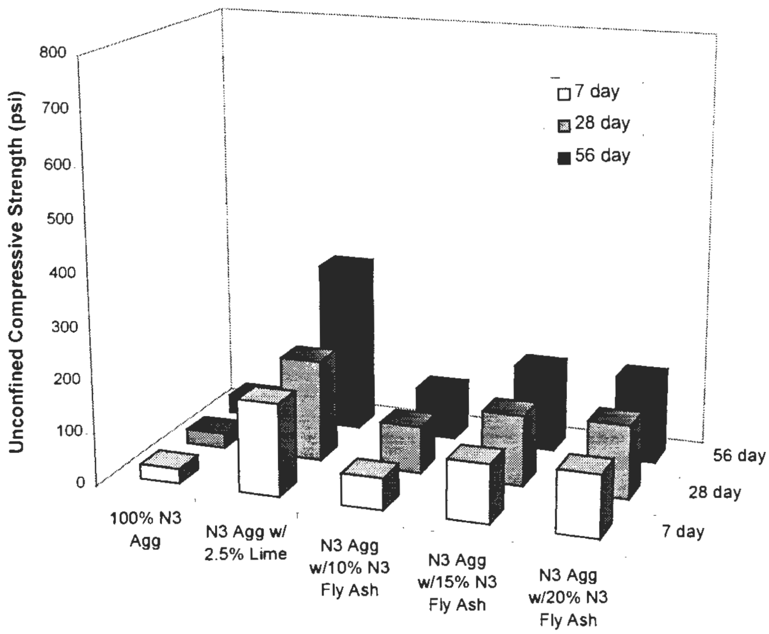

Figure 18. Unconfined Compressive Strengths of Fly Ash and Lime Activated Reclaimed Neal 3 Fly Ash Aggregate

than Ottumwa and Council Bluffs fly ash, so more ash activator is needed to provide calcium and pozzolanic material to increase mixture strength. The 2.5% lime activated reclaimed Neal 3 fly ash aggregate samples achieved unconfined compressive strengths of around 180 psi at 7 days, 200 psi at 28 days, and 325 psi at 56 days, again indicating that a significant strength increase can be gained by a small amount of lime activator.

Reclaimed Prairie Creek Fly Ash Aggregate

Figure 18 shows the unconfined compressive strengths results of 100% reclaimed Prairie Creek fly ash aggregate, and reclaimed ash aggregate stabilized by 2.5% lime and10% Prairie Creek fly ash. The 100% reclaimed ash aggregate samples had low strengths of less

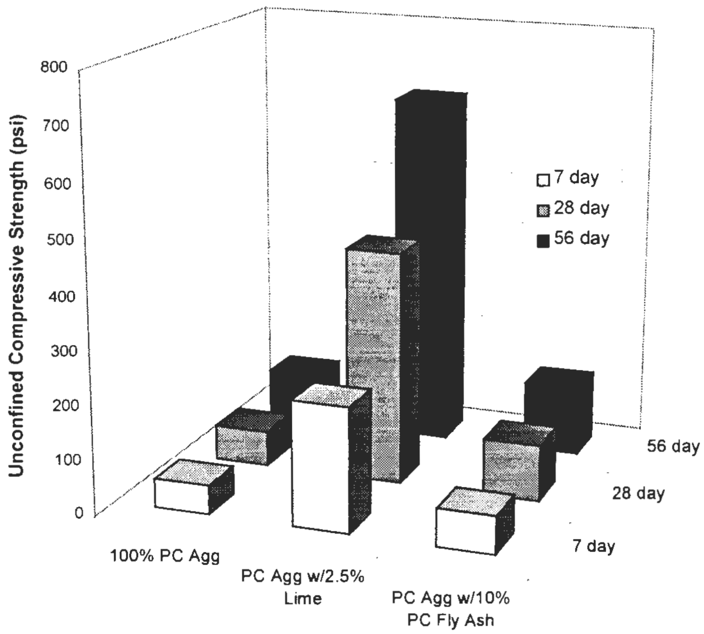

Figure 19. Unconfined Compressive Strengths of Fly Ash and Lime Activated Reclaimed Prairie Creek Fly Ash Aggregate

than 100 psi, but they exhibited continued strength gains through the 56 day curing period. This indicates that unreacted pozzolanic material in the aggregate may be a source of strength gain.

The 10% fly ash activated reclaimed ash aggregate strengths reached 70 psi at 7 days, increased to 105 psi at 28 days, and increased to 120 psi by 56 days. The 2.5% lime activated reclaimed Prairie Creek fly ash aggregate samples exhibited unconfined compressive strengths of 230 psi at 7 days, 440 psi at 28 days, and 670 psi at 56 days.

Summary

Overall, the unconfined compressive strength results appear to correlate very well with the freeze-thaw durability and ASTM C 593 test results. The main exception to the correlation is the high strength of the 15% AFBC activated reclaimed Ottumwa fly ash aggregate samples, which correlates well with the mixture's high ASTM C 593 compressive strength but contradicts the mixture's poor freeze-thaw durability test results.

The AFBC and CKD activated reclaimed ash aggregate mixtures showed steady, continued strength gain for curing periods of up to one year. Although the lime and fly ash activated samples were tested with a maximum of 56 days of curing, long term strength gains similar to those displayed by the AFBC and CKD activated aggregates can probably be expected from these materials. The pozzolanic reactions that provide continued strength gain can occur as long as unreacted pozzolanic material, calcium, and moisture are present to drive the cementation reactions.

Among the lime and fly ash activated mixtures being considered for future field use, the lime activated Council Bluffs and Prairie Creek aggregates reached the highest unconfined compressive strengths, followed by the lime activated Ottumwa and Neal 3 aggregates. The Council Bluffs and Prairie Creek materials were also the strongest fly ash activated aggregate mixtures.

XII. RESULTS OF VOLUMETRIC STABILITY TESTS ON ACTIVATED RECLAIMED FLY ASH AGGREGATE

Reclaimed Ottumwa Fly Ash Aggregate

Figure 20 shows the volume vs. time plot for 15% AFBC/85% reclaimed Ottumwa fly ash aggregate samples compacted at optimum moisture content. Figure 20 shows that very little volume change occurred in samples subjected to any of the three curing environments. These results support the theory that the deterioration in the AFBC section of the Ottumwa-Midland landfill access road was caused by a freeze-thaw durability problem and not by a volumetric stability problem.

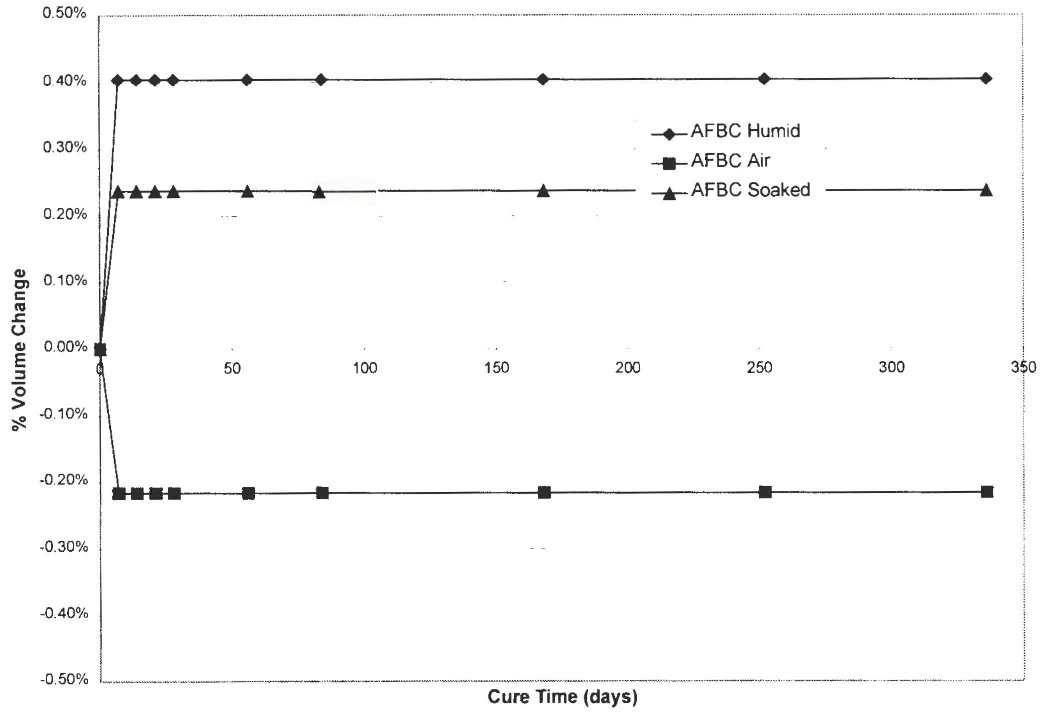

Figure 20. Volumetric Stability of AFBC Activated Reclaimed Ottumwa Fly Ash Aggregate Compacted at Optimum Moisture Content

Figure 21 shows the volume vs. time plot for 10% CKD/90% reclaimed Ottumwa fly ash aggregate samples compacted at optimum moisture content. It can be seen from Figure 21 that very little volume change occurred in samples subjected to any of the three curing environments. This result was expected due to the good field performance of the CKD section of the Ottumwa-Midland landfill access road.

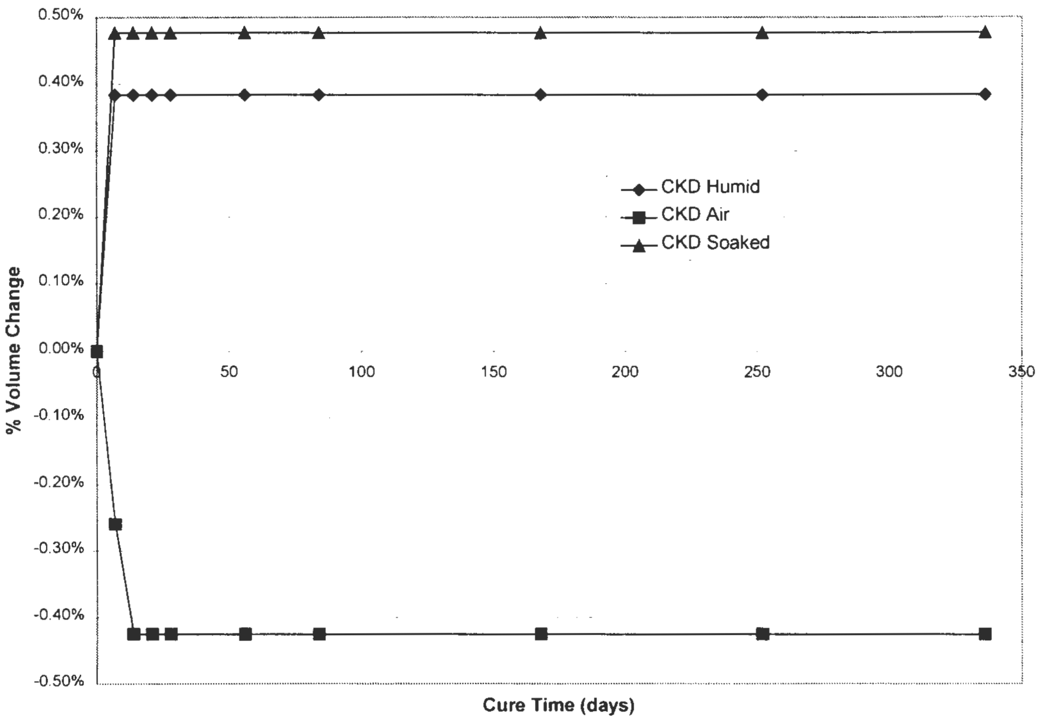

Figure 21. Volumetric Stability of CKD Activated Reclaimed Ottumwa Fly Ash Aggregate Compacted at Optimum Moisture Content

Figure 22 shows the volume vs. time plot for 15% AFBC/85% reclaimed Ottumwa fly ash aggregate samples compacted at 3% lower than optimum moisture content. It can be seen from Figure 22 that very little volume change occurred in samples subjected to any of the three curing environments. It appears that AFBC activated reclaimed fly ash aggregate that is compacted dry of optimum and later hydrated is not subject to volumetric instability. This result supports the idea that the deterioration of the AFBC section of the Sutherland power plant access road was caused by a freeze-thaw durability problem and not by a volumetric stability problem caused by inadequate compaction moisture and subsequent hydration.

Figure 23 shows the volume vs. time plot for 10% CKD/90% reclaimed Ottumwa fly ash aggregate samples compacted at optimum moisture content. Figure 23 shows that very little volume change occurred in samples subjected to any of the three curing environments. It appears that CKD activated reclaimed fly ash aggregate that is compacted dry of optimum

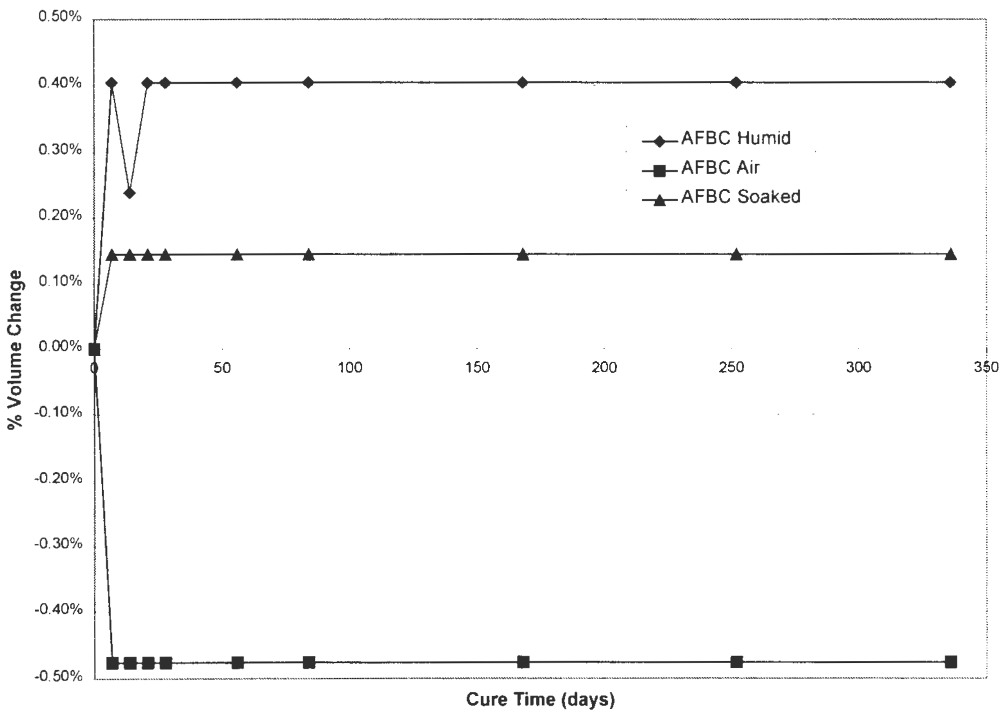

Figure 22. Volumetric Stability of AFBC Activated Reclaimed Ottumwa Fly Ash Aggregate Compacted Dry of Optimum Moisture Content

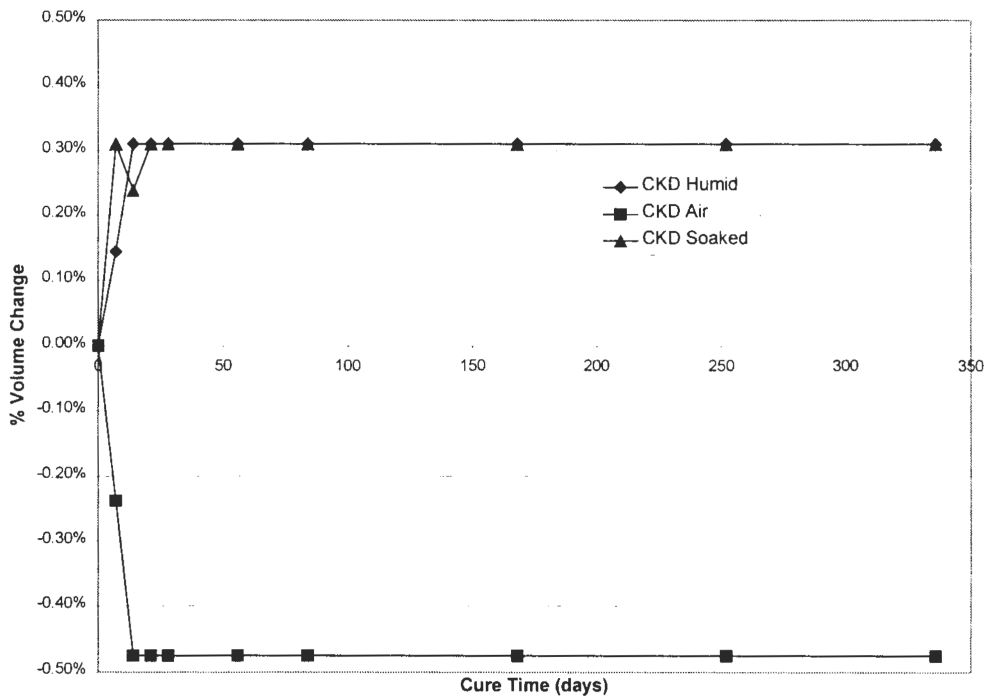

Figure 23. Volumetric Stability of CKD Activated Reclaimed Ottumwa Fly Ash Aggregate Compacted Dry of Optimum Moisture Content

moisture content and later hydrated is not subject to volumetric instability.

Ottumwa Fly Ash

The results of volumetric stability tests on Ottumwa fly ash cubes subjected to air, 100% humidity, and soaked curing conditions for 105 days are shown in Figure 24. Figure 24 shows that none of the Ottumwa fly ash samples deviated more than 0.5% from their original volumes. This indicates that Ottumwa fly ash/reclaimed Ottumwa fly ash aggregate mixtures should not have a volumetric stability problem.

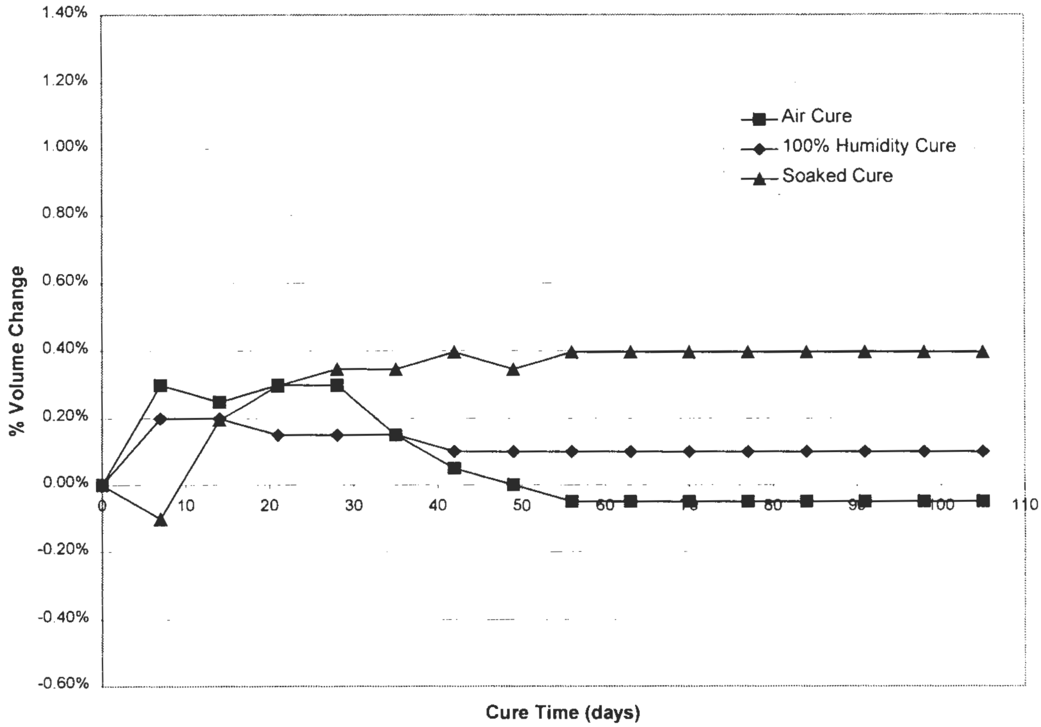

Figure 24. Volumetric Stability of Ottumwa Fly Ash

Council Bluffs Fly Ash

The results of volumetric stability tests on Council Bluffs fly ash cubes subjected to air, 100% humidity, and soaked curing conditions for 105 days are shown in Figure 25. Figure 25 shows that none of the Council Bluffs fly ash samples deviated more than 0.5% from their original volumes. This indicates that Council Bluffs fly ash/reclaimed Council Bluffs fly ash aggregate mixtures should not have a volumetric stability problem.

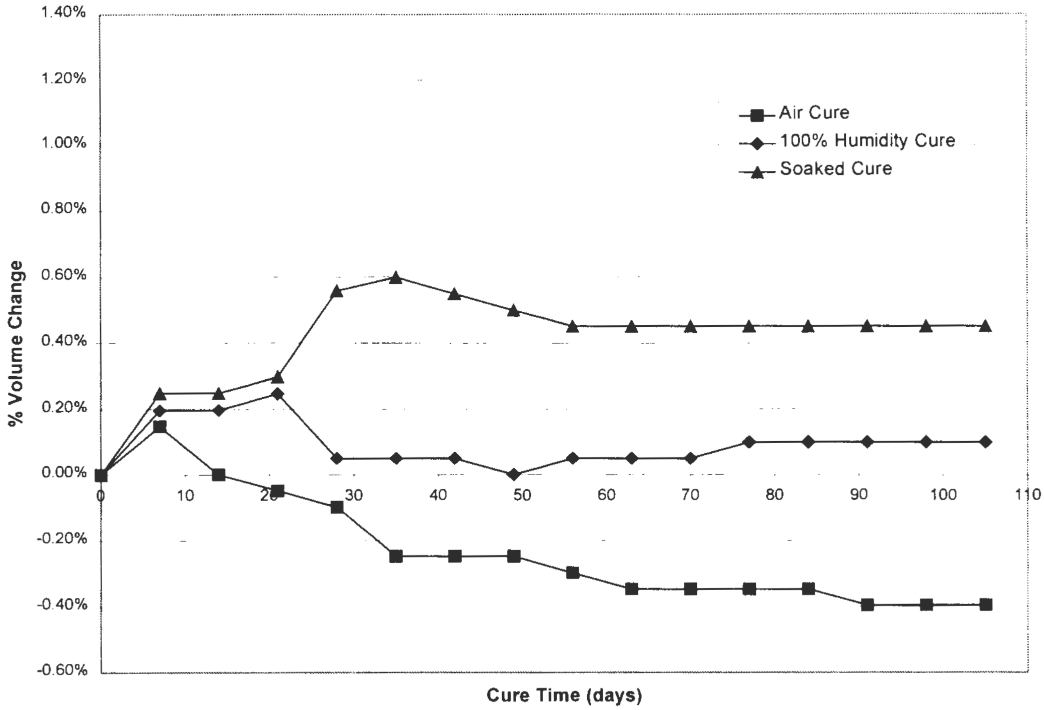

Figure 25. Volumetric Stability of Council Bluffs Fly Ash

Neal 3 Fly Ash

The results of volumetric stability tests on Neal 3 fly ash cubes subjected to air, 100% humidity, and soaked curing conditions for 105 days are shown in Figure 26. Figure 26 shows that none of the Neal 3 fly ash samples deviated more than 1.4% from their original volumes. Although this percent volume change is more than the change observed in Ottumwa and Council Bluffs fly ash specimens, it is still very minimal compared to the 50% or greater expansions often seen in hydrated raw AFBC ash. Since tests on 15% AFBC/85% reclaimed fly ash mixtures indicate that those mixtures are volumetrically stable, Neal 3 fly ash/reclaimed Neal 3 fly ash aggregate mixtures should not have a volumetric stability problem.

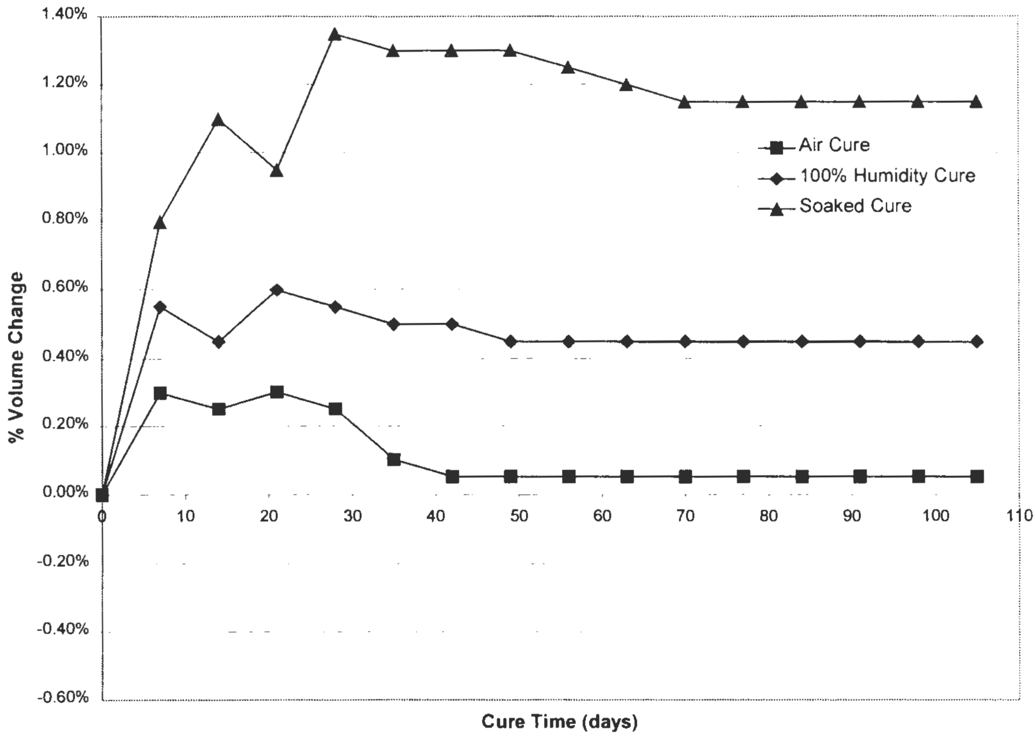

Figure 26. Volumetric Stability of Neal 3 Fly Ash

Prairie Creek Fly Ash

The results of volumetric stability tests on Prairie Creek fly ash cubes subjected to air, 100% humidity, and soaked curing conditions for 105 days are shown in Figure 27. Figure 27 shows that none of the Prairie Creek fly ash samples deviated more than 0.6% from their original volumes. This indicates that Prairie Creek fly ash/reclaimed Prairie Creek fly ash aggregate mixtures should not have a volumetric stability problem.

Summary

The results of the volumetric stability tests indicate that volumetric stability is not a problem with AFBC, CKD, lime, and fly ash activated reclaimed fly ash aggregate. The tests

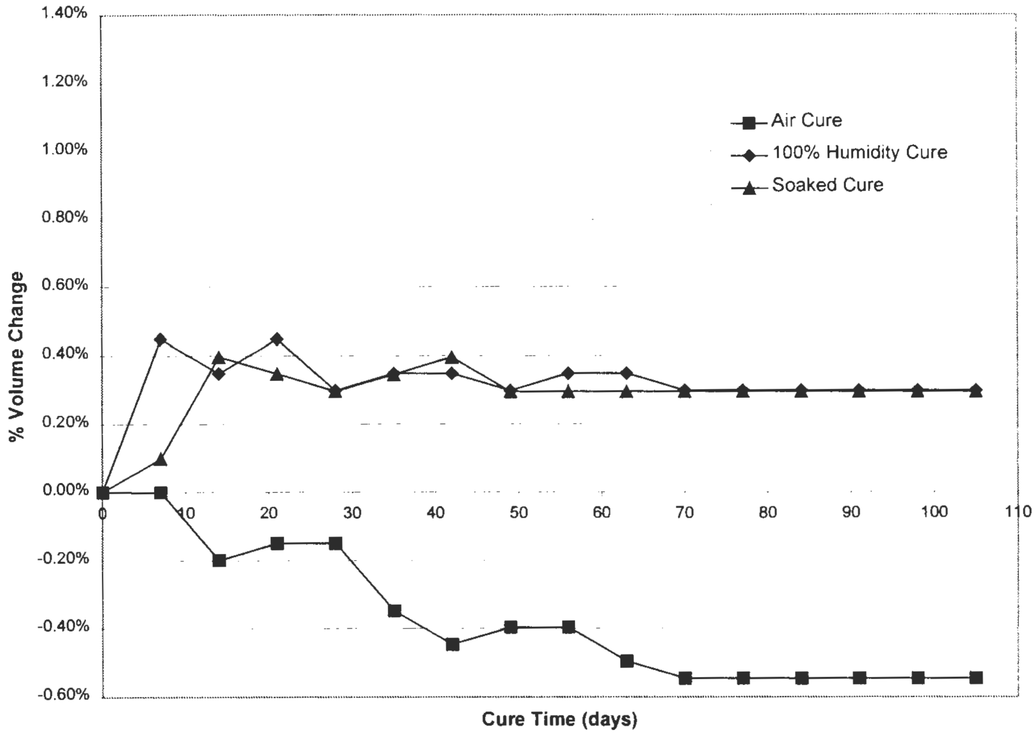

Figure 27. Volumetric Stability of Prairie Creek Fly Ash

showed no tendency for expansiveness in humid or soaked cured conditions as well as no tendency for excessive shrinkage in air cured conditions. The results of the unconfined compressive strength tests support this conclusion because if the materials were expansive, they would have lower long-term strengths as cracks formed and the samples deteriorated. Activated reclaimed fly ash aggregate mixtures showed strength gains rather than losses in long-term unconfined compressive strength with longer curing periods, indicating that the mixtures are volumetrically stable.

XIII. SUMMARY AND DISCUSSION OF RESULTS

The main consideration for the prediction of the durability, strength, and volumetric stability of activator/reclaimed fly ash aggregate mixtures is the manner in which they will perform in field applications. The results of freeze-thaw durability testing, ASTM C 593 vacuum-saturated compressive strength testing, and unconfined compressive strength testing indicate that the untreated materials act as a granular material, while the lime-treated material develops higher strengths associated with a pozzolanic base material. The use of CKD, which is highly effective as an activator, was discontinued due to lowered availability and environmental concerns. CKD can contain high levels of lead, and changes in the manufacture of Portland cement have rendered it nearly unavailable in Iowa.

Raw fly ash is somewhat effective as an activator, but fly ash/reclaimed fly ash aggregate mixtures break down when subjected to multiple freeze-thaw cycles. This may not be a large problem if high strengths are not required, because the base will probably function in a similar manner to a crushed stone base. This is evidenced by the good performance of the AFBC/reclaimed fly ash aggregate sections of the Ottumwa-Midland and Sutherland access roads. The surface courses of both roads remain intact and serviceable despite the deterioration of base into rough, angular aggregate-sized pieces. Although cores can no longer be extracted from these sections, aggregate interlock forces appear to provide adequate strength to the pavements.

The use of fly ash aggregate without an activator is the obvious choice for low cost applications where high strengths are not required. The addition of 2.5% lime by dry weight of reclaimed ash aggregate provides significant gains in strength and durability for all the reclaimed fly ash aggregate sources tested in this project. The use of fly ash as an activator is preferred by vendors of reclaimed fly ash aggregate because they already possess it and do not need to purchase it from another source. This would not be the case with lime. The effectiveness of fly ash as an activator for reclaimed fly ash aggregate is definite, but it is not nearly as pronounced as the effect of lime activator. The addition of fly ash activator definitely results in a strength and durability increase, but as Barnes (11) has indicated, magnitude of this strength gain is questionable and the fast setting tendency of fly ash may raise concerns for road base construction. The additive level of 10% fly ash by dry weight of aggregate was selected as optimum. This level reduces keeps the workability concerns to a minimum, and 15% and 20% fly ash addition rates did not provide significantly different strength or durability than 10% fly ash in any of the materials tested for this project.

XIV. CONCLUSIONS

The following conclusions relate to the specific application of the reclaimed fly ash aggregates and activators included in this project.

- All four reclaimed fly ash aggregates investigated for this project have potential for use as road base material.
- Of those activators being considered for future use with reclaimed fly ash aggregate, only lime provides sufficient durability against freeze-thaw damage.
- The use of fly ash as an activator, while somewhat effective, may create construction problems due to rapid hydration and setting characteristics.
- ASTM C 593 vacuum-saturated compressive strength is a useful predictor of freeze-thaw durability for lime, fly ash, and CKD activated reclaimed fly ash aggregate.
- ASTM C 593 vacuum-saturated compressive strength is not a predictor of freeze-thaw durability for AFBC activated reclaimed fly ash aggregate.
- The breakdown of the AFBC activated bases of the Sutherland and Ottumwa-Midland test roads shows that pavement performance is good even when the reclaimed fly ash aggregate base is no longer cemented together because the material continues to function as a Macadam base.
- All of the activators tested can be expected to continue to provide long-term strength gains as long as unreacted pozzolans, free calcium, and water are present to drive pozzolanic reactions. These gains may be a source of autogenous healing of cracks in bases constructed of activated reclaimed fly ash aggregate.

- None of the activator/reclaimed fly ash aggregate mixtures tested exhibited volumetric instability in soaked, 100% humidity, or air-cured conditions.

XV. RECOMMENDATIONS

Design Recommendations

The main application of activated reclaimed fly ash aggregate bases is in low-volume roads. The recent pavement thickness design guide by Bergeson and Barnes (14) provides a method for assigning layer coefficients to activated reclaimed fly ash aggregate bases for AASHTO pavement thickness design. Care should be taken to avoid excessively high design strengths for activated reclaimed fly ash bases, particularly with lime activator. It was noted by Barnes that flexible pavement bases with a high unconfined compressive strength (>800 psi) may cause reflective cracking in the asphalt surface layer (11). This could result in a shorter pavement life by allowing water to infiltrate and increase the severity of freeze-thaw attack on the base.

Construction Recommendations

The construction recommendations are the result of laboratory experience with the reclaimed fly ash aggregate, as well as field experience with the Sutherland and Ottumwa-Midland test roads. Barnes (11) covers several strength-related construction recommendations. The recommendations provided here focus on the durability aspects of activated reclaimed fly ash aggregate for use in road bases.

- The surface should be sealed after final compaction to maintain moisture during curing. An asphalt emulsion is recommended. This is essential for development of long-term strength and durability. Curing and strength development will continue for long time periods as long as moisture is available to drive the pozzolanic reactions.

- The base should be allowed to cure prior to placement of the surface layer. Unconfined compressive strength and CBR test results (11) indicate that the base may be strong enough in three days to support construction equipment without damage. Field trials are required to determine the exact time.
- A capillary break layer should be provided just below a fly ash activated reclaimed fly ash aggregate base. This layer may consist of four to six inches of crushed stone or a similar material. The purpose of this layer is to prevent excessive moisture from reaching the base, thereby preventing potential freeze-thaw damage by reducing the possibility of water infiltration into the pore structure of the base. This layer should not be necessary with a lime activated reclaimed fly ash aggregate base.

APPENDIX A
FREEZE-THAW DATA

10% CKD/90% Ottumwa Aggregate Freeze-Thaw Cylinders - Sheet 1

Sample #	Wt 0 day	Cure	Wt. Soak Day	Wt. 1st Day in freezer	Wt. after 1st freezer cycle	Wt. after 1st thawing cycle
1CKDft	1675.9	5 day wrap/2 day soak	1673.7	1693.5	1686.8	1697.8
2CKDft	1636.0	5 day wrap/2 day soak	1633.9	1657.6	1647.6	1661.6
3CKDft	1686.1	5 day wrap/2 day soak	1682.0	1703.9	1693.7	1709.1
4CKDft	1667.0	5 day wrap/2 day soak	1665.1	1689.6	1681.7	1695.8
5CKDft	1661.5	7 day wrap	-	1660.3	1650.3	1686.8
6CKDft	1697.5	7 day wrap	-	1692.1	1683.0	1716.4
7CKDft	1646.1	7 day wrap	-	1647.1	1639.2	1676.8
8CKDft	1694.2	7 day wrap	-	1695.0	1686.8	1717.5

Sample #	Wt. after 2nd freezer cycle	Wt. after 2nd thawing cycle	Wt. after 3rd 3-day freezer cycle	Wt. after 3rd thawing cycle	Wt. after 4th freezer cycle	Wt. after 4th thawing cycle
1CKDft	1688.1	1700.2	1692.0	1699.9	1691.5	1701.1
2CKDft	1651.7	1665.2	1656.1	1665.5	1658.5	1668.6
3CKDft	1699.0	1712.3	1705.4	1712.5	1703.1	1713.1
4CKDft	1686.0	1699.8	1690.0	1699.9	1690.8	1700.6
5CKDft	1676.3	1689.5	1677.6	1691.0	1683.0	1693.8
6CKDft	1706.9	1718.4	1707.7	1719.6	1710.0	1722.2
7CKDft	1668.4	1681.8	1670.4	1682.9	1675.6	1686.1
8CKDft	1708.2	1720.6	1708.9	1722.0	1714.5	1723.7

Sample #	Wt. after 5th freezer cycle	Wt. after 5th thawing cycle	Wt. after 6th freezer cycle	Wt. after 6th thawing cycle	Wt. after 7th freezer cycle	Wt. after 7th thawing cycle
1CKDft	1693.8	1702.0	1695.9	1710.6	1701.5	1710.5
2CKDft	1662.1	1668.4	1660.3	1678.1	1668.2	1678.4
3CKDft	1705.3	1713.9	1707.7	1723.7	1715.0	1722.8
4CKDft	1691.6	1700.3	1693.3	1711.0	1703.0	1711.2
5CKDft	1688.4	1694.1	1685.2	1703.5	1696.7	1704.6
6CKDft	1712.7	1722.7	1712.7	1732.7	1725.4	1732.4
7CKDft	1676.6	1686.7	1677.7	1697.5	1688.5	1696.4
8CKDft	1715.4	1724.7	1716.0	1735.2	1726.9	1733.8

10% CKD/90% Ottumwa Aggregate Freeze-Thaw Cylinders - Sheet 2

Sample #	Wt. after 8th freezer cycle	Wt. after 8th thawing cycle	Wt. after 9th freezer cycle	Wt. after 9th thawing cycle	Wt. after 10th freezer cycle	Wt. after 10th thawing cycle
1CKDft	1701.5	1709.9	1700.8	1710.3	1703.2	1709.9
2CKDft	1667.5	1677.7	1667.2	1677.8	1668.6	1678.0
3CKDft	1715.3	1722.5	1712.8	1723.6	1716.4	1723.1
4CKDft	1702.6	1711.7	1701.8	1712.3	1703.1	1711.1
5CKDft	1697.4	1703.8	1694.3	1703.8	1696.4	1703.0
6CKDft	1725.6	1732.4	1724.0	1733.2	1725.5	1732.8
7CKDft	1686.0	1695.5	1686.4	1695.7	1685.7	1695.9
8CKDft	1725.7	1734.2	1726.7	1734.4	1726.9	1734.0

Sample #	Wt. after 11th freezer cycle	Wt. after 11th thawing cycle	Wt. after 12th freezer cycle	Wt. after 12th thawing cycle	Wt. after 13th freezer cycle	Wt. after 13th thawing cycle
1CKDft	1702.3	1710.1	1700.7	1710.4	1702.6	1710.2
2CKDft	1670.0	1678.4	1669.0	1678.8	1670.2	1678.9
3CKDft	1716.0	1723.1	1716.0	1724.1	1715.2	1723.7
4CKDft	1704.9	171.4	1703.9	1712.6	1705.9	1704.3
5CKDft	1698.6	1704.0	1723.5	1734.3	Removed for use as a	demonstration sample
6CKDft	1724.7	1732.7	1695.1	1704.0	1728.2	1733.9
7CKDft	1688.2	1693.9	1684.7	1692.3	1682.2	1687.9
8CKDft	1725.9	1733.9	1725.0	1735.1	1729.6	1734.7

Sample #	Wt. after 14th freezer cycle	Wt. after 14th thawing cycle	Wt. after 15th freezer cycle	Wt. after 15th thawing cycle	Wt. after 16th freezer cycle	Wt. after 16th thawing cycle
1CKDft	1704	1711.7	1705.6	1712.0	1704.3	1711.7
2CKDft	1669.8	1681.0	1672.1	1680.7	1671.1	1681.3
3CKDft	1715.9	1725.7	1717.5	1725.4	1717.9	1725.7
4CKDft	1695.9	1703.3	1693.3	1700.1	1691.2	1695.6
5CKDft	-	-	-	-	-	-
6CKDft	1725.1	1734.4	1727.5	1734.8	1725.7	1734.6
7CKDft	1677.1	1684.3	1674.0	1682.4	1674.3	1671.9
8CKDft	1727.2	1735.4	1728.4	1735.6	1729.3	1735.7

10% CKD/90% Ottumwa Aggregate Freeze-Thaw Cylinders - Sheet 3

Sample #	Wt. after 17th freezer cycle	Wt. after 17th thawing cycle	Wt. after 18th freezer cycle	Wt. after 18th thawing cycle	Wt. after 19th freezer cycle	Wt. after 19th thawing cycle
1CKDft	1704.0	1711.7	1704.8	1712.2	1705.2	1713.2
2CKDft	1672.2	1681.2	1672.0	1680.1	1670.2	1680.3
3CKDft	1716.9	1724.5	1715.5	1725.0	1717.0	1725.8
4CKDft	1687.7	1687.9	1675.7	1682.2	1673.7	1675.9
5CKDft	-	-	-	-	-	-
6CKDft	1726.6	1735.0	1726.0	1735.4	1726.7	1734.7
7CKDft	1665.7	1667.5	1656.7	1624.1	1613.5	1608.9
8CKDft	1728.5	1735.5	1729.1	1736.7	1730.3	1736.3

Sample #	Wt. after 20th freezer cycle	Wt. after 20th thawing cycle	Wt. after 21st freezer cycle	Wt. after 21st thawing cycle	Wt. after 22nd freezer cycle	Wt. after 22nd thawing cycle
1CKDft	1707.8	1713.1	1706.9	1713.0	1707.0	1713.4
2CKDft	1672.7	1681.3	1671.6	1667.3	1657.8	1643.5
3CKDft	1719.4	1726.9	1718.8	1727.2	1720.2	1728.1
4CKDft	1668.3	1657.1	1649.5	1632.3	1620.3	1602.5
5CKDft	-	-	-	-	-	-
6CKDft	1727.4	1735.4	1727.5	1735.8	1727.4	1736.5
7CKDft	1595.8	1592.6	1584.6	1560.2	1548.0	1548.8
8CKDft	1729.6	1736.9	1730.0	1737.3	1731.2	1737.9

Sample #	Wt. after 23rd freezer cycle	Wt. after 23rd thawing cycle	Wt. after 24th freezer cycle	Wt. after 24th thawing cycle	Wt. after 25th freezer cycle	Wt. after 25th thawing cycle
1CKDft	1707.3	1713.5	1707.7	1714.1	1707.7	1715.3
2CKDft	1632.6	1610.3	1600.0	1569.2	1560.0	1554.1
3CKDft	1720	1728.2	1721.1	1723.8	1715.3	1723.2
4CKDft	1589.5	1524.6	1515.8	1518.8	1507.8	1512.7
5CKDft	-	-	-	-	-	-
6CKDft	1731.3	1737.0	1730.4	1736.1	1728.9	1736.3
7CKDft	1539.5	1527.4	1517.9	1477.4	1467.7	1477.5
8CKDft	1733.2	1738.3	1732.6	1738.7	1732.6	1739.3

10% CKD/90% Ottumwa Aggregate Freeze-Thaw Cylinders - Sheet 4

Sample #	Wt. after 26th freezer cycle	Wt. after 26th thawing cycle	Wt. after 27th freezer cycle	Wt. after 27th thawing cycle	Wt. after 28th freezer cycle	Wt. after 28th thawing cycle
1CKDft	1709.7	1716.2	1708.2	1716.5	1711.7	1715.8
2CKDft	1545.5	1547.8	1537.1	1533.8	1527.6	1501.7
3CKDft	1715.1	1717.5	1710.8	1712.1	1705.9	1693.9
4CKDft	1502.1	1499.8	1484.5	1498.6	1485.4	1462.3
5CKDft	-	-	-	-	-	-
6CKDft	1730.2	1735.8	1729.1	1734.4	1731.6	1728.5
7CKDft	1467.9	1466.3	1458.7	1418.9	1411.0	1412.9
8CKDft	1732.6	1740.1	1734.9	1741.2	1737.4	1741.0

Sample #	Wt. after 29th freezer cycle	Wt. after 29th thawing cycle	Wt. after 30th freezer cycle	Wt. after 30th thawing cycle	Wt. after 31st freezer cycle	Wt. after 31st thawing cycle
1CKDft	1709.3	1717.3	1714.6	1705.8	1702.1	1671.7
2CKDft	1494.3	1480.8	1473.7	1467.6	1460.7	1427.2
3CKDft	1686.3	1671.7	1666.5	1665.9	1660.2	1616.9
4CKDft	1452.6	1443.9	1434.6	1421.4	1415.1	1404.6
5CKDft	-	-	-	-	-	-
6CKDft	1735.1	1714.0	1711.5	1699.5	1695.1	1680.1
7CKDft	1405.6	1387.2	1379.9	1374.5	1367.0	1351.0
8CKDft	1719.8	1736.7	1734.1	1733.0	1729.8	1712.0

Sample #	Wt. after 32nd freezer cycle	Wt. after 32nd thawing cycle	Wt. after 33rd freezer cycle	Wt. after 33rd thawing cycle	Wt. after 34th freezer cycle	Wt. after 34th thawing cycle
1CKDft	1666.9	1659.6	1654.5	1632.5	1626.3	1619.2
2CKDft	1420.1	1397.7	1390.9	1360.6	1352.8	1337.9
3CKDft	1611.2	1587.5	1581.5	1543.7	1534.4	1523.4
4CKDft	1396.8	1385.9	1379.1	1346.6	1338.2	1330.5
5CKDft	-	-	-	-	-	-
6CKDft	1675.1	1652.2	1645.9	1631.3	1624.9	1616.0
7CKDft	1343.7	1341.2	1334.2	1337.7	1329.8	1330.5
8CKDft	1708.7	1698.9	1695.6	1682.5	1677.7	1633.1

10% CKD/90% Ottumwa Aggregate Freeze-Thaw Cylinders - Sheet 5

Sample #	Wt. after 35th freezer cycle	Wt. after 35th thawing cycle	Wt. after 36th freezer cycle	Wt. after 36th thawing cycle	Wt. after 37th freezer cycle	Wt. after 37th thawing cycle
1CKDft	1612.7	1603.2	1597.0	1602.4	1596.0	1598.2
2CKDft	1330.2	1337.0	1329.4	1331.1	1323.0	1330.6
3CKDft	1514.6	1503.5	1496.2	1494.3	1487.0	1493.2
4CKDft	1321.3	1320.7	1312.2	1315.6	1308.1	1309.2
5CKDft	-	-	-	-	-	-
6CKDft	1608.6	1609.6	1602.3	1608.0	1600.5	1606.3
7CKDft	1322.9	1320.2	1311.6	1319.2	1310.7	1316.2
8CKDft	1626.3	1632.4	1627.3	1632.2	1625.5	1631.8

Sample #	Wt. after 38th freezer cycle	Wt. after 38th thawing cycle	Wt. after 39th freezer cycle	Wt. after 39th thawing cycle	Wt. after 40th freezer cycle	Wt. after 40th thawing cycle
1CKDft	1588.5	1595.9	1588.6	1589.1	1582.3	1578.8
2CKDft	1322.5	1320.2	1312.6	1312.5	1304.8	1300.8
3CKDft	1483.0	1491.7	1483.2	1484.0	1476.3	1479.5
4CKDft	1303.3	1310.2	1302.6	1297.6	1290.6	1287.1
5CKDft	-	-	-	-	-	-
6CKDft	1599.2	1607.2	1599.8	1605.9	1598.9	1606.4
7CKDft	1307.6	1312.3	1303.6	1307.3	1299.9	1303.3
8CKDft	1623.5	1631.2	1624.8	1629.9	1623.4	1615.5

Sample #	Wt. after 41st freezer cycle	Wt. after 41st thawing cycle	Wt. after 42nd freezer cycle	Wt. after 42nd thawing cycle	Wt. after 43rd freezer cycle	Wt. after 43rd thawing cycle
1CKDft	1571.0	1575.3	1568.5	1576.0	1568.7	1574.0
2CKDft	1292.9	1300.0	1293.5	1294.1	1287.5	1294.3
3CKDft	1471.6	1479.6	1471.4	1479.6	1472.6	1480.9
4CKDft	1280.0	1285.4	1278.1	1286.3	1280.2	1284.9
5CKDft	-	-	-	-	-	-
6CKDft	1598.9	1607.3	1601.2	1606.2	1599.5	1596.9
7CKDft	1294.8	1303.6	1297.0	1303.0	1295.5	1302.7
8CKDft	1607.5	1615.2	1609.0	1613.9	1607.8	1614.5

10% CKD/90% Ottumwa Aggregate Freeze-Thaw Cylinders - Sheet 6

Sample #	Wt. after 44th freezer cycle	Wt. after 44th thawing cycle	Wt. after 45th freezer cycle	Wt. after 45th thawing cycle	Wt. after 46th freezer cycle	Wt. after 46th thawing cycle
1CKDft	1566.6	1573.6	1566.6	1575.1	1567.9	1575.7
2CKDft	1287.3	1294.1	1287.3	1291.0	1283.6	1290.6
3CKDft	1473.0	1480.8	1473.0	1481.5	1474.3	1482.9
4CKDft	1278.7	1283.9	1277.3	1278.6	1271.8	1271.1
5CKDft	-	-	-	-	-	-
6CKDft	1589.5	1594.6	1587.3	1595.3	1589.1	1596.9
7CKDft	1294.4	1288.8	1281.2	1283.5	1276.3	1275.4
8CKDft	1607.3	1614.4	1607.7	1615.1	1609.4	1616.5

Sample #	Wt. after 47th freezer cycle	Wt. after 47th thawing cycle	Wt. after 48th freezer cycle	Wt. after 48th thawing cycle	Wt. after 49th freezer cycle	Wt. after 49th thawing cycle
1CKDft	1568.9	1574.8	1566.8	1573.8	1567.2	1574.7
2CKDft	1283.9	1283.9	1276.8	1281.8	1275.5	1280.4
3CKDft	1475.6	1480.0	1471.7	1480.7	1472.3	1480.6
4CKDft	1264.2	1258.6	1250.2	1256.6	1248.1	1256.4
5CKDft	-	-	-	-	-	-
6CKDft	1590.0	1595.9	1588.5	1594.9	1587.9	1590.9
7CKDft	1268.0	1227.6	1219.3	1197.8	1190.0	1194.5
8CKDft	1609.8	1614.6	1608.2	1614.6	1609.0	1614.9

Sample #	Wt. after 50th freezer cycle	Wt. after 50th thawing cycle	Wt. after 51st freezer cycle	Wt. after 51st thawing cycle	Wt. after 52nd freezer cycle	Wt. after 52nd thawing cycle
1CKDft	1566.6	1573.5	1566.5	1574.1	1567.2	1575.4
2CKDft	1272.6	1278.9	1271.5	1278.4	1272.3	1276.1
3CKDft	1471.5	1480.5	1473.5	1481.4	1473.6	1481.4
4CKDft	1248.7	1244.5	1237.9	1245.4	1238.5	1242.2
5CKDft	-	-	-	-	-	-
6CKDft	1584.5	1591.4	1584.8	1592.4	1584.8	1592.5
7CKDft	1187.1	1188.6	1181.0	1172.4	1164.9	1172.4
8CKDft	1608.5	1614.7	1607.7	1599.5	1591.6	1599.3

10% CKD/90% Ottumwa Aggregate Freeze-Thaw Cylinders - Sheet 7

Sample #	Wt. after 53rd freezer cycle	Wt. after 53rd thawing cycle	Wt. after 54th freezer cycle	Wt. after 54th thawing cycle	Wt. after 55th freezer cycle	Wt. after 55th thawing cycle
1CKDft	1567.9	1575.2	1567.7	1575.8	1568.5	1579.3
2CKDft	1269.0	1265.5	1257.6	1257.2	1249.7	1260.2
3CKDft	1473.7	1482.1	1473.6	1481.0	1473.0	1486.4
4CKDft	1234.9	1240.6	1233.6	1224.5	1217.4	1227.7
5CKDft	-	-	-	-	-	-
6CKDft	1585.9	1593.1	1586.0	1590.4	1583.3	1595.4
7CKDft	1165.4	1172.1	1163.9	1162.8	1155.1	1160.3
8CKDft	1592.2	1587.4	1579.4	1586.2	1578.9	1572.3

Sample #	Wt. after 56th freezer cycle	Wt. after 56th thawing cycle	Wt. after 57th freezer cycle	Wt. after 57th thawing cycle	Wt. after 58th freezer cycle	Wt. after 58th thawing cycle
1CKDft	1572.3	1572.7	1565.2	1571.7	1563.2	1567.3
2CKDft	1253.2	1239.7	1232.0	1237.9	1231.1	1224.6
3CKDft	1479.1	1486.7	1478.0	1482.1	1473.4	1482.6
4CKDft	1220.5	1228.0	1220.4	1215.0	1203.8	1200.4
5CKDft	-	-	-	-	-	-
6CKDft	1588.1	1592.1	1584.5	1589.7	1581.6	1589.5
7CKDft	1153.2	1124.1	1116.7	1120.0	1112.8	1121.4
8CKDft	1564.7	1572.6	1564.1	1569.4	1561.3	1569.4

Sample #	Wt. after 59th freezer cycle	Wt. after 59th thawing cycle
1CKDft	1559.3	1561.7
2CKDft	1217.3	1210.8
3CKDft	1474.9	1483.2
4CKDft	1193.1	1194.0
5CKDft	-	-
6CKDft	1582.4	1571.7
7CKDft	1114.1	1120.2
8CKDft	1562.0	1566.8

15% AFBC/85% Ottumwa Aggregate Freeze-Thaw Cylinders - Sheet 1

Sample #	Wt 0 day	Cure	Wt. Soak Day	Wt. 1st Day in freezer	Wt. after 1st freezer cycle	Wt. after 1st thawing cycle
1AFBCft	1588.9	5 day wrap/2 day soak	1586.5	1641.5	1630.0	1653.0
2AFBCft	1602.6	5 day wrap/2 day soak	1599.6	1646.8	1632.5	1655.0
3AFBCft	1567.9	5 day wrap/2 day soak	1565.4	1615.9	1603.4	1624.0
4AFBCft	1555.7	5 day wrap/2 day soak	1552.6	1618.1	1598.1	1623.0
5AFBCft	1572.9	7 day wrap	-	1568.7	1559.1	1632.5
6AFBCft	1630.1	7 day wrap	-	1626.9	1616.9	1682.5
7AFBCft	1593.2	7 day wrap	-	1590.2	1579.8	1652.8
8AFBCft	1572.7	7 day wrap	-	1570.3	1560.3	1629.0

Sample #	Wt. after 2nd freezer cycle	Wt. after 2nd thawing cycle	Wt. after 3rd 3-day freezer cycle	Wt. after 3rd thawing cycle	Wt. after 4th freezer cycle	Wt. after 4th thawing cycle
1AFBCft	1638.7	1654.6	1637.9	1667.2	1656.4	1608.2
2AFBCft	1644.6	1655.2	1642.2	1673.1	1648.6	1670.6
3AFBCft	1614.1	1623.2	1609.0	1642.8	1627.8	1638.1
4AFBCft	1608.1	1620.3	1602.2	1637.6	1616.5	1604.4
5AFBCft	1622.1	1639.0	1628.2	1657.6	1637.5	1647.2
6AFBCft	1673.2	1691.1	1679.3	1706.8	1693.4	1711.2
7AFBCft	1640.9	1660.1	1645.4	1678.8	1661.9	1674.4
8AFBCft	1618.1	1635.5	1623.3	1655.7	1642.3	1662.5

Sample #	Wt. after 5th freezer cycle	Wt. after 5th thawing cycle	Wt. after 6th freezer cycle	Wt. after 6th thawing cycle	Wt. after 7th freezer cycle	Wt. after 7th thawing cycle
1AFBCft	1586.1	1518.0	1498.6	1243.7	1228.2	1065.7
2AFBCft	1654.9	1660.6	1644.9	1542.0	1526.4	1424.7
3AFBCft	1620.4	1617.2	1600.5	1291.0	1278.0	1195.8
4AFBCft	1587.0	1357.2	1337.4	1001.2	993.0	857.1
5AFBCft	1623.1	1575.4	1557.0	1357.2	1345.5	1134.6
6AFBCft	1688.5	1563.5	1546.4	1262.1	1251.1	1093.6
7AFBCft	1651.5	1533.2	1512.4	1269.5	1255.4	998.0
8AFBCft	1642.8	1555.7	1525.5	1167.2	1155.6	984.1

15% AFBC/85% Ottumwa Aggregate Freeze-Thaw Cylinders - Sheet 2

Sample #	Wt. after 8th freezer cycle	Wt. after 8th thawing cycle	Wt. after 9th freezer cycle
1AFBCft	1050.4	866.4	855.7
2AFBCft	1407.9	1244.4	1229.9
3AFBCft	1182.2	818.7	649.9
4AFBCft	846.7	657.8	807.0
5AFBCft	973.7	771.8	762.2
6AFBCft	988.1	831.5	821.5
7AFBCft	1079.1	685.8	675.4
8AFBCft	1123.3	948.1	937.3

100% Ottumwa Aggregate Freeze-Thaw Cylinders - Sheet 1

Sample #	Wt 0 day	Cure	Wt. 1st Day in freezer	Wt. after 1st freezer cycle
1Ot100	1565.2	7 day wrap	1554.9	1537.8
2Ot100	1574.6	7 day wrap	1566.3	1548.2
3Ot100	1567.7	7 day wrap	1559.8	1542.6
4Ot100	1571.9	7 day wrap	1566.5	1551.0

Ottumwa Fly Ash Activated Ottumwa Aggregate Freeze-Thaw Cylinders - Sheet 1

Sample #	Wt 0 day	Cure	Activator	Wt. 1st Day in freezer	Wt. after 1st freezer cycle	Wt. after 1st thawing cycle
1Ofa10	1630.4	7 day sealed	10% Ott. Fly Ash	1629.6	1616.5	1675.5
2Ofa10	1617.2	7 day sealed	10% Ott. Fly Ash	1614.0	1603.1	1663.5
3Ofa10	1626.2	7 day sealed	10% Ott. Fly Ash	1622.8	1608.6	1645.0
4Ofa10	1622.2	7 day sealed	10% Ott. Fly Ash	1620.9	1609.4	1666.5
1Ofa15	1613.3	7 day sealed	15% Ott. Fly Ash	1611.1	1604.1	1670.9
2Ofa15	1610.5	7 day sealed	15% Ott. Fly Ash	1605.1	1595.2	1663.2
3Ofa15	1595.3	7 day sealed	15% Ott. Fly Ash	1591.6	1580.6	1654.8
4Ofa15	1630.3	7 day sealed	15% Ott. Fly Ash	1627.5	1614.8	1680.3
1Ofa20	1584.0	7 day sealed	20% Ott. Fly Ash	1576.2	1564.3	1648.4
2Ofa20	1582.1	7 day sealed	20% Ott. Fly Ash	1579.2	1567.3	1649.0
3Ofa20	1567.6	7 day sealed	20% Ott. Fly Ash	1562.2	1548.7	1638.7
4Ofa20	1600.0	7 day sealed	20% Ott. Fly Ash	1594.8	1580.6	1662.0

Sample #	Wt. after 2nd freezer cycle	Wt. after 2nd thawing cycle	Wt. after 3rd freezer cycle	Wt. after 3rd thawing cycle	Wt. after 4th freezer cycle	Wt. after 4th thawing cycle
1Ofa10	1666.9	1496.0	1488.0	1232.6	1219.8	1102.2
2Ofa10	1651.6	1432.3	1418.6	1010.2	998.1	828.8
3Ofa10	1632.8	1360.5	1351.4	997.3	982.5	793.0
4Ofa10	1656.0	1303.7	1292.6	1010.2	996.1	849.2
1Ofa15	1666.5	1352.6	1341.6	1068.1	1058.3	901.1
2Ofa15	1649.7	1328.7	1320.6	1089.2	1076.3	779.8
3Ofa15	1644.3	1152.1	1142.5	852.4	841.0	727.6
4Ofa15	1669.0	1307.0	1295.7	1114.3	1104.4	879.4
1Ofa20	1636.4	1290.5	1278.6	955.6	943.7	800.0
2Ofa20	1635.5	1334.0	1319.6	967.2	954.5	806.4
3Ofa20	1624.0	1248.2	1237.5	960.8	948.8	786.3
4Ofa20	1651.5	1447.2	1433.4	1126.5	1115.8	1011.2

Ottumwa Fly Ash Activated Ottumwa Aggregate Freeze-Thaw Cylinders - Sheet 2

Sample #	Wt. after 5th freezer cycle	Wt. after 5th thawing cycle	Wt. after 6th freezer cycle
1Ofa10	1094.5	928.1	920.5
2Ofa10	820.8	681.9	678.1
3Ofa10	784.6	635.4	632.2
4Ofa10	842.3	714.1	712.2
1Ofa15	894.6		
2Ofa15	776.4		
3Ofa15	724.7		
4Ofa15	874.8		
1Ofa20	793.2	657.2	652.6
2Ofa20	798.7	657.2	653.8
3Ofa20	778.6	636.8	634.3
4Ofa20	950.2	804.4	799.0

2.5% CKD & Lime Activated Ottuwma Aggregate Freeze-Thaw Cylinders - Sheet 1

Sample #	Wt 0 day	Cure	Activator	Wt. 1st Day in freezer	Wt. after 1st freezer cycle	Wt. after 1st thawing cycle
1Olm2.5	1692.9	7 day sealed	2.5% Lime	1692.9	1682.3	1712.6
2Olm2.5	1662.7	7 day sealed	2.5% Lime	1662.7	1653.2	1695.3
3Olm2.5	1688.3	7 day sealed	2.5% Lime	1688.2	1678.3	1709.6
4Olm2.5	1642.3	7 day sealed	2.5% Lime	1642.0	1631.7	1684.1
1Ockd2.5	1678.0	7 day sealed	2.5% CKD	1677.3	1664.7	1701.6
2Ockd2.5	1704.1	7 day sealed	2.5% CKD	1704.1	1693.0	1715.0
3Ockd2.5	1686.7	7 day sealed	2.5% CKD	1686.2	1675.5	1705.9
4Ockd2.5	1689.5	7 day sealed	2.5% CKD	1688.8	1678.7	1702.1

Sample #	Wt. after 2nd freezer cycle	Wt. after 2nd thawing cycle	Wt. after 3rd freezer cycle	Wt. after 3rd thawing cycle	Wt. after 4th freezer cycle	Wt. after 4th thawing cycle
1Olm2.5	1702.7	1712.1	1704.7	1706.8	1699.3	1701.3
2Olm2.5	1686.4	1695.7	1684.7	1674.2	1664.2	1654.5
3Olm2.5	1702.4	1711.6	1703.3	1704.6	1693.2	1694.5
4Olm2.5	1674.6	1681.4	1671.5	1648.1	1639.0	1584.1
1Ockd2.5	1694.5	1690.5	1679.3	1608.0	1597.4	1577.8
2Ockd2.5	1706.4	1708.1	1701.6	1690.2	1683.7	1674.4
3Ockd2.5	1700.3	1693.1	1684.6	1635.2	1622.2	1596.2
4Ockd2.5	1697.1	1688.4	1684.2	1658.3	1649.9	1614.6

Sample #	Wt. after 5th freezer cycle	Wt. after 5th thawing cycle	Wt. after 6th freezer cycle	Wt. after 6th thawing cycle	Wt. after 7th freezer cycle	Wt. after 7th thawing cycle
1Olm2.5	1694.1	1695.8	1690.1	1693.0	1680.2	1688.3
2Olm2.5	1645.8	1641.7	1633.2	1628.3	1614.5	1615.7
3Olm2.5	1688.3	1692.2	1682.6	1678.1	1665.8	1674.1
4Olm2.5	1567.8	1527.2	1519.8	1472.8	1462.1	1458.3
1Ockd2.5	1586.2	1520.3	1516.2	1451.0	1447.3	1405.0
2Ockd2.5	1680.9	1643.8	1640.2	1632.9	1631.1	1624.4
3Ockd2.5	1603.6	1585.6	1582.6	1572.2	1570.3	1563.7
4Ockd2.5	1624.5	1606.5	1602.8	1596.7	1594.2	1586.8

2.5% CKD & Lime Activated Ottuwma Aggregate Freeze-Thaw Cylinders - Sheet 2

Sample #	Wt. after 8th freezer cycle	Wt. after 8th thawing cycle	Wt. after 9th freezer cycle	Wt. after 9th thawing cycle	Wt. after 10th freezer cycle	Wt. after 10th thawing cycle
1Olm2.5	1679.3	1684.9	1680.2	1680.0	1673.5	1677.1
2Olm2.5	1604.9	1601.4	1596.1	1595.9	1585.4	1575.3
3Olm2.5	1663.8	1664.9	1662.5	1665.2	1652.4	1643.1
4Olm2.5	1448.2	1434.5	1428.3	1421.0	1411.4	1386.0
1Ockd2.5	1401.9	1384.4	1379.5	1356.2	1350.3	1340.9
2Ockd2.5	1619.4	1611.9	1605.2	1588.7	1584.5	1585.7
3Ockd2.5	1559.2	1554.7	1549.3	1539.0	1533.6	1502.3
4Ockd2.5	1579.8	1564.5	1560.8	1558.7	1553.6	1516.8

Sample #	Wt. after 11th freezer cycle	Wt. after 11th thawing cycle	Wt. after 12th freezer cycle	Wt. after 12th thawing cycle	Wt. after 13th freezer cycle	Wt. after 13th thawing cycle
1Olm2.5	1672.8	1659.1	1653.0	1634.7	1626.8	1619.0
2Olm2.5	1569.8	1556.7	1551.6	1484.9	1477.9	1434.8
3Olm2.5	1638.8	1629.1	1624.6	1620.3	1615.8	1596.0
4Olm2.5	1379.0	1366.4	1358.4	1300.3	1291.8	1226.1
1Ockd2.5	1334.7	1300.5	1292.4	1280.3	1270.6	1259.9
2Ockd2.5	1580.6	1576.9	1571.3	1572.3	1564.6	1561.2
3Ockd2.5	1496.2	1465.5	1460.5	1430.1	1424.3	1422.7
4Ockd2.5	1511.2	1496.4	1490.8	1476.6	1466.8	1460.0

Sample #	Wt. after 14th freezer cycle	Wt. after 14th thawing cycle	Wt. after 15th freezer cycle	Wt. after 15th thawing cycle	Wt. after 16th freezer cycle	Wt. after 16th thawing cycle
1Olm2.5	1612.2	1594.6	1587.3	1539.3	1530.9	1519.7
2Olm2.5	1426.0	1343.8	1334.8	1309.2	1298.2	1282.1
3Olm2.5	1588.6	1560.4	1554.8	1537.2	1528.2	1514.5
4Olm2.5	1215.7	1166.1	1155.3	1126.0	1117.3	1090.0
1Ockd2.5	1252.4	1232.1	1223.1	1209.6	1201.3	1198.2
2Ockd2.5	1554.2	1556.8	1550.9	1550.9	1542.5	1543.0
3Ockd2.5	1415.7	1411.9	1403.5	1403.9	1395.9	1394.7
4Ockd2.5	1451.8	1424.9	1416.7	1408.6	1399.6	1401.8

2.5% CKD & Lime Activated Ottuwma Aggregate Freeze-Thaw Cylinders - Sheet 3

Sample #	Wt. after 17th freezer cycle	Wt. after 17th thawing cycle	Wt. after 18th freezer cycle	Wt. after 18th thawing cycle	Wt. after 19th freezer cycle	Wt. after 19th thawing cycle
1Olm2.5	1510.8	1481.1	1471.1	1468.2	1458.5	1445.8
2Olm2.5	1273.2	1236.4	1226.0	1231.0	1222.2	1214.7
3Olm2.5	1504.5	1472.1	1463.6	1443.5	1434.3	1424.0
4Olm2.5	1080.9	1053.2	1044.4	1036.4	1027.8	1027.6
1Ockd2.5	1191.3	1192.5	1184.3	1188.6	1180.4	1169.8
2Ockd2.5	1534.3	1538.9	1530.1	1535.8	1529.6	1535.1
3Ockd2.5	1386.6	1382.0	1372.3	1360.6	1353.3	1342.8
4Ockd2.5	1393.3	1385.3	1377.3	1375.7	1363.0	1371.7

Sample #	Wt. after 20th freezer cycle	Wt. after 20th thawing cycle	Wt. after 21st freezer cycle	Wt. after 21st thawing cycle	Wt. after 22nd freezer cycle	Wt. after 22nd thawing cycle
1Olm2.5	1435.2	1426.8	1415.0	1417.4	1407.3	1414.9
2Olm2.5	1205.0	1199.0	1188.9	1179.3	1169.1	1169.5
3Olm2.5	1413.9	1398.0	1386.5	1379.2	1369.3	1354.5
4Olm2.5	1019.9	978.5	969.7	949.0	941.5	941.6
1Ockd2.5	1162.0	1158.5	1150.2	1155.3	1146.0	1153.8
2Ockd2.5	1528.0	1527.0	1519.5	1528.3	1520.5	1529.5
3Ockd2.5	1335.2	1328.3	1321.3	1321.0	1313.9	1309.8
4Ockd2.5	1363.6	1369.1	1361.3	1365.1	1356.1	1365.9

Sample #	Wt. after 23rd freezer cycle	Wt. after 23rd thawing cycle	Wt. after 24th freezer cycle	Wt. after 24th thawing cycle	Wt. after 25th freezer cycle	Wt. after 25th thawing cycle
1Olm2.5	1403.6	1397.0	1387.1	1386.5	1376.7	1376.2
2Olm2.5	1159.7	1161.0	1151.3	1149.1	1138.8	1144.1
3Olm2.5	1344.2	1335.5	1325.1	1318.0	1306.2	1296.2
4Olm2.5	933.4	939.0	931.0	922.8	913.9	909.0
1Ockd2.5	1146.1	1127.7	1119.4	1087.8	1079.0	1085.9
2Ockd2.5	1522.6	1522.0	1514.9	1521.9	1513.0	1516.8
3Ockd2.5	1303.2	1297.5	1289.1	1283.7	1276.9	1277.7
4Ockd2.5	1359.0	1356.6	1349.3	1355.2	1346.0	1353.3

2.5% CKD & Lime Activated Ottuwma Aggregate Freeze-Thaw Cylinders - Sheet 4

Sample #	Wt. after 26th freezer cycle	Wt. after 26th thawing cycle	Wt. after 27th freezer cycle	Wt. after 27th thawing cycle	Wt. after 28th freezer cycle	Wt. after 28th thawing cycle
1Olm2.5	1366.5	1368.6	1358.7	1364.7	1354.6	1361.7
2Olm2.5	1135.7	1136.1	1127.3	1107.9	1098.0	1099.6
3Olm2.5	1286.7	1272.0	1262.1	1257.5	1247.0	1251.1
4Olm2.5	900.5	904.0	896.8	887.3	879.6	868.6
1Ockd2.5	1078.8	1078.5	1071.1	1080.0	1071.3	1070.3
2Ockd2.5	1510.5	1517.1	1510.5	1513.3	1504.5	1512.6
3Ockd2.5	1268.1	1263.0	1252.8	1257.9	1249.7	1247.6
4Ockd2.5	1345.8	1347.2	1339.9	1348.2	1339.3	1340.5

Sample #	Wt. after 29th freezer cycle	Wt. after 29th thawing cycle	Wt. after 30th freezer cycle	Wt. after 30th thawing cycle	Wt. after 31st freezer cycle	Wt. after 31st thawing cycle
1Olm2.5	1350.3	1353.6	1341.8	1346.5	1335.8	1342.0
2Olm2.5	1091.1	1092.7	1083.9	1088.1	1079.0	1078.6
3Olm2.5	1240.8	1246.9	1235.8	1240.2	1229.0	1235.9
4Olm2.5	860.6	855.0	847.7	839.3	831.7	832.0
1Ockd2.5	1062.5	1070.2	1061.6	1068.6	1061.5	1065.3
2Ockd2.5	1504.4	1509.3	1502.9	1497.9	1490.7	1492.7
3Ockd2.5	1240.0	1245.1	1237.3	1229.0	1221.3	1208.1
4Ockd2.5	1333.1	1337.3	1329.7	1336.6	1327.8	1326.2

Sample #	Wt. after 32nd freezer cycle	Wt. after 32nd thawing cycle	Wt. after 33rd freezer cycle	Wt. after 33rd thawing cycle	Wt. after 34th freezer cycle	Wt. after 34th thawing cycle
1Olm2.5	1332.4	1334.0	1324.8	1330.0	1319.6	1326.0
2Olm2.5	1069.5	1057.1	1048.2	1028.1	1020.0	1022.8
3Olm2.5	1225.5	1221.6	1212.7	1208.1	1198.3	1188.0
4Olm2.5	823.9	789.5	780.4	774.0	767.5	761.3
1Ockd2.5	1058.2	1059.9	1052.0	1056.2	1048.8	1051.7
2Ockd2.5	1485.0	1493.3	1487.9	1491.7	1482.8	1484.5
3Ockd2.5	1199.8	1206.7	1198.0	1201.0	1193.0	1182.0
4Ockd2.5	1316.7	1318.5	1310.9	1313.6	1303.8	1304.4

2.5% CKD & Lime Activated Ottuwma Aggregate Freeze-Thaw Cylinders - Sheet 5

Sample #	Wt. after 35th freezer cycle	Wt. after 35th thawing cycle
1Olm2.5	1316.2	1317.6
2Olm2.5	1014.2	1018.3
3Olm2.5	1180.6	1176.8
4Olm2.5	756.1	749.7
1Ockd2.5	1045.5	1042.2
2Ockd2.5	1478.9	1473.9
3Ockd2.5	1175.4	1174.9
4Ockd2.5	1297.1	1301.3

100% Council Bluffs Aggregate Freeze-Thaw Cylinders - Sheet 1

Sample #	Wt 0 day	Cure	Wt. 1st Day in freezer	Wt. after 1st freezer cycle
1CB100	1548.5	7 day sealed	1533.9	1517.7
2CB100	1532.5	7 day sealed	1527.5	1511.5
3CB100	1541.5	7 day sealed	1526.9	1508.4
4CB100	1551.3	7 day sealed	1545.7	1524.0

Council Bluffs Fly Ash Activated Council Bluffs Aggregate Freeze-Thaw Cylinders - Sheet 1

Sample #	Wt 0 day	Cure	Additive	Wt. 1st Day in freezer	Wt. after 1st freezer cycle	Wt. after 1st thawing cycle
1CBfa10	1608.9	7 day sealed	10% CB Fly Ash	1606.7	1593.8	1629.7
2CBfa10	1585.5	7 day sealed	10% CB Fly Ash	1583.1	1567.2	1606.2
3CBfa10	1575.8	7 day sealed	10% CB Fly Ash	1572.3	1555.8	1600.0
4CBfa10	1647.9	7 day sealed	10% CB Fly Ash	1646.9	1632.2	1664.3
1CBfa15	1565.4	7 day sealed	15% CB Fly Ash	1563.7	1546.4	1600.9
2CBfa15	1582.2	7 day sealed	15% CB Fly Ash	1580.3	1568.1	1615.3
3CBfa15	1567.9	7 day sealed	15% CB Fly Ash	1564.0	1551.2	1603.6
4CBfa15	1539.0	7 day sealed	15% CB Fly Ash	1535.1	1523.1	1580.1
1CBfa20	1513.1	7 day sealed	20% CB Fly Ash	1507.7	1494.7	1572.4
2CBfa20	1448.5	7 day sealed	20% CB Fly Ash	1441.5	1433.0	1508.8
3CBfa20	1490.1	7 day sealed	20% CB Fly Ash	1486.9	1474.0	1548.9
4CBfa20	1467.8	7 day sealed	20% CB Fly Ash	1458.1	1446.0	1527.7

Sample #	Wt. after 2nd freezer cycle	Wt. after 2nd thawing cycle	Wt. after 3rd freezer cycle	Wt. after 3rd thawing cycle	Wt. after 4th freezer cycle	Wt. after 4th thawing cycle
1CBfa10	1620.5	1550.0	1544.1	1340.2	1327.3	1230.5
2CBfa10	1594.1	1491.4	1481.5	1279.6	1268.7	1092.1
3CBfa10	1590.9	1409.5	1403.8	1212.8	1196.9	1037.5
4CBfa10	1653.3	1609.6	1604.0	1532.0	1515.8	1413.4
1CBfa15	1594.8	1445.7	1439.9	1329.9	1320.1	1236.5
2CBfa15	1610.2	1530.9	1523.1	1442.6	1430.9	1348.2
3CBfa15	1594.0	1514.8	1507.9	1457.3	1445.7	1402.6
4CBfa15	1570.4	1463.5	1454.9	1400.0	1385.9	1328.7
1CBfa20	1563.0	1454.6	1445.2	1346.7	1335.3	1240.7
2CBfa20	1497.6	1354.8	1341.9	1158.6	1149.8	1080.5
3CBfa20	1536.5	1401.9	1390.0	1236.9	1224.2	1154.4
4CBfa20	1516.4	1279.8	1269.2	1077.5	1068.4	931.9

Council Bluffs Fly Ash Activated Council Bluffs Aggregate Freeze-Thaw Cylinders - Sheet 2

Sample #	Wt. after 5th freezer cycle	Wt. after 5th thawing cycle	Wt. after 6th freezer cycle	Wt. after 6th thawing cycle	Wt. after 7th freezer cycle	Wt. after 7th thawing cycle
1CBfa10	1219.3	1127.4	1119.0	1074.5	1065.9	1011.4
2CBfa10	1082.5	1028.1	1020.7	989.5	981.7	888.7
3CBfa10	1027.7	870.9	863.4	800.0	793.5	660.2
4CBfa10	1401.9	1354.8	1347.7	1274.8	1265.6	1183.7
1CBfa15	1227.2	1208.3	1196.7	1112.5	1102.8	1039.2
2CBfa15	1343.5	1330.3	1310.0	1287.1	1280.7	1201.7
3CBfa15	1397.5	1357.1	1345.5	1292.4	1283.9	1221.0
4CBfa15	1322.3	1306.1	1295.1	1228.7	1221.3	1147.9
1CBfa20	1232.6	1162.4	1150.1	1079.0	1070.7	1034.7
2CBfa20	1073.1	961.3	943.1	833.3	826.5	732.9
3CBfa20	1147.3	1057.4	1049.0	980.0	971.6	866.7
4CBfa20	925.6	808.9	798.4	675.8	670.1	574.4

Sample #	Wt. after 8th freezer cycle	Wt. after 8th thawing cycle	Wt. after 9th freezer cycle	Wt. after 9th thawing cycle	Wt. after 10th freezer cycle	Wt. after 10th thawing cycle
1CBfa10	1003.3	903.5	896.5	853.7		
2CBfa10	882.3	740.2	733.1	669.9		
3CBfa10	654.8	554.6	549.2	492.4		
4CBfa10	1174.5	1112.5	1102.9	1029.3		
1CBfa15	1032.0	938.2	934.0	854.8	849.5	755.1
2CBfa15	1194.5	1099.2	1095.3	978.2	973.1	802.4
3CBfa15	1211.5	1100.0	1093.2	964.5	957.6	784.1
4CBfa15	1141.0	1029.8	1025.1	952.4	944.7	763.2
1CBfa20	1025.6	994.9	987.3	954.0		
2CBfa20	725.4	664.8	658.4	606.4		
3CBfa20	858.2	790.2	783.8	686.3		
4CBfa20	568.4	518.4	513.6	432.8		

2.5% Lime/97.5% Council Bluffs Aggregate Freeze-Thaw Cylinders - Sheet 1

Sample #	Wt 0 day	Cure	Additive	Wt. 1st day in freezer	Wt. after 1st freezer cycle	Wt. after 1st thawing cycle
1CBlm2.5	1612.9	7 day sealed	2.5% Lime	1611.6	1598.1	1640.5
2CBlm2.5	1546.9	7 day sealed	2.5% Lime	1544.4	1533.9	1614.3
3CBlm2.5	1571.2	7 day sealed	2.5% Lime	1570.0	1558.4	1624.8
4CBlm2.5	1587.7	7 day sealed	2.5% Lime	1586.5	1577.0	1629.3

Sample #	Wt. after 2nd freezer cycle	Wt. after 2nd thawing cycle	Wt. after 3rd freezer cycle	Wt. after 3rd thawing cycle	Wt. after 4th freezer cycle	Wt. after 4th thawing cycle
1CBlm2.5	1631.8	1641.3	1636.5	1640.8	1630.8	1637.0
2CBlm2.5	1607.8	1611.9	1606.9	1606.5	1596.5	1595.5
3CBlm2.5	1615.4	1622.2	1619.7	1620.3	1610.6	1611.6
4CBlm2.5	1623.1	1628.5	1625.9	1626.7	1618.8	1617.9

Sample #	Wt. after 5th freezer cycle	Wt. after 5th thawing cycle	Wt. after 6th freezer cycle	Wt. after 6th thawing cycle	Wt. after 7th freezer cycle	Wt. after 7th thawing cycle
1CBlm2.5	1630.4	1635.8	1629.6	1633.3	1629.5	1632.1
2CBlm2.5	1589.3	1591.8	1588.0	1585.1	1579.2	1579.7
3CBlm2.5	1605.4	1609.8	1601.6	1605.9	1601.2	1600.3
4CBlm2.5	1612.5	1615.6	1607.8	1612.2	1607.3	1609.1

Sample #	Wt. after 8th freezer cycle	Wt. after 8th thawing cycle	Wt. after 9th freezer cycle	Wt. after 9th thawing cycle	Wt. after 10th freezer cycle	Wt. after 10th thawing cycle
1CBlm2.5	1627.0	1628.2	1624.1	1625.6	1620.8	1620.4
2CBlm2.5	1568.9	1567.7	1560.6	1537.1	1528.3	1522.0
3CBlm2.5	1594.8	1589.7	1581.1	1577.4	1569.6	1512.9
4CBlm2.5	1602.5	1604.8	1598.7	1596.2	1587.7	1580.5

2.5% Lime/97.5% Council Bluffs Aggregate Freeze-Thaw Cylinders - Sheet 2

Sample #	Wt. after 11th freezer cycle	Wt. after 11th thawing cycle	Wt. after 12th freezer cycle	Wt. after 12th thawing cycle	Wt. after 13th freezer cycle	Wt. after 13th thawing cycle
1CBlm2.5	1613.9	1617.8	1610.3	1613.8	1608.4	1610.2
2CBlm2.5	1511.9	1499.5	1486.1	1456.8	1446.3	1378.9
3CBlm2.5	1501.8	1504.1	1494.9	1497.3	1488.9	1478.0
4CBlm2.5	1569.9	1565.4	1553.3	1554.5	1547.1	1535.3

Sample #	Wt. after 14th freezer cycle	Wt. after 14th thawing cycle	Wt. after 15th freezer cycle	Wt. after 15th thawing cycle	Wt. after 16th freezer cycle	Wt. after 16th thawing cycle
1CBlm2.5	1602.1	1600.3	1593.1	1594.4	1585.4	1590.7
2CBlm2.5	1368.7	1313.7	1303.8	1274.0	1264.3	1193.0
3CBlm2.5	1468.4	1449.8	1440.7	1412.6	1402.9	1396.0
4CBlm2.5	1527.2	1521.2	1513.3	1500.9	1491.0	1439.8

Sample #	Wt. after 17th freezer cycle	Wt. after 17th thawing cycle	Wt. after 18th freezer cycle	Wt. after 18th thawing cycle	Wt. after 19th freezer cycle	Wt. after 19th thawing cycle
1CBlm2.5	1582.9	1566.3	1559.7	1547.1	1538.3	1539.9
2CBlm2.5	1183.3	1139.4	1130.3	1098.7	1090.6	1091.2
3CBlm2.5	1388.0	1355.2	1345.8	1326.1	1317.1	1290.5
4CBlm2.5	1431.3	1410.5	1401.1	1362.1	1351.2	1346.9

Sample #	Wt. after 20th freezer cycle	Wt. after 20th thawing cycle	Wt. after 21st freezer cycle	Wt. after 21st thawing cycle	Wt. after 22nd freezer cycle	Wt. after 22nd thawing cycle
1CBlm2.5	1530.9	1536.3	1527.0	1493.5	1484.4	1419.6
2CBlm2.5	1081.6	1085.1	1076.6	1065.9	1057.0	1042.7
3CBlm2.5	1268.5	1266.1	1258.2	1224.0	1214.3	1185.1
4CBlm2.5	1336.2	1300.5	1292.5	1273.7	1264.7	1258.8

2.5% Lime/97.5% Council Bluffs Aggregate Freeze-Thaw Cylinders - Sheet 3

Sample #	Wt. after 23rd freezer cycle	Wt. after 23rd thawing cycle	Wt. after 24th freezer cycle	Wt. after 24th thawing cycle	Wt. after 25th freezer cycle	Wt. after 25th thawing cycle
1CBlm2.5	1411.2	1402.7	1392.0	1390.7	1380.9	1382.5
2CBlm2.5	1033.4	1019.3	1009.9	1008.8	999.6	960.2
3CBlm2.5	1174.7	1167.6	1157.1	1147.3	1137.4	1124.4
4CBlm2.5	1249.9	1219.4	1208.3	1154.9	1146.1	1138.3

Sample #	Wt. after 26th freezer cycle	Wt. after 26th thawing cycle	Wt. after 27th freezer cycle	Wt. after 27th thawing cycle	Wt. after 28th freezer cycle	Wt. after 28th thawing cycle
1CBlm2.5	1371.5	1351.0	1341.1	1336.9	1327.0	1330.7
2CBlm2.5	950.6	946.3	937.7	937.1	929.1	922.0
3CBlm2.5	1114.0	1099.8	1091.7	1077.7	1069.9	1054.4
4CBlm2.5	1129.1	1115.1	1102.4	1052.0	1043.3	1025.2

Sample #	Wt. after 29th freezer cycle	Wt. after 29th thawing cycle	Wt. after 30th freezer cycle	Wt. after 30th thawing cycle
1CBlm2.5	1321.1	1302.2	1293.3	1261.5
2CBlm2.5	914.0	901.7	893.9	884.5
3CBlm2.5	1045.1	987.4	979.3	966.1
4CBlm2.5	1018.2	1014.7	1006.1	998.1

100% Neal 3 Aggregate Freeze-Thaw Cylinders - Sheet 1

Sample #	Wt 0 day	Cure	Wt. 1st Day in freezer	Wt. after 1st freezer cycle
1N3 100	1594.6	7 day sealed	1533.9	1517.7
2N3 100	1591.1	7 day sealed	1527.5	1511.5
3N3 100	1594.3	7 day sealed	1526.9	1508.4
4N3 100	1590.8	7 day sealed	1545.7	1524.0

Neal 3 Fly Ash Activated Neal 3 Aggregate Freeze-Thaw Cylinders - Sheet 1

Sample #	Wt 0 day	Cure	Activator	Wt. 1st day in freezer	Wt. after 1st freezer cycle	Wt. after 1st thawing cycle
1N3fa10	1433.7	7 day sealed	10% Neal 3 Fly Ash	1426.1	1411.0	1447.1
2N3fa10	1456.8	7 day sealed	10% Neal 3 Fly Ash	1454.8	1438.3	1487.2
3N3fa10	1431.5	7 day sealed	10% Neal 3 Fly Ash	1428.2	1416.9	1457.2
4N3fa10	1438.0	7 day sealed	10% Neal 3 Fly Ash	1429.2	1412.8	1462.4
1N3fa15	1429.2	7 day sealed	15% Neal 3 Fly Ash	1426.4	1415.5	1464.5
2N3fa15	1434.9	7 day sealed	15% Neal 3 Fly Ash	1428.8	1420.4	1461.8
3N3fa15	1453.9	7 day sealed	15% Neal 3 Fly Ash	1449.0	1440.1	1482.3
4N3fa15	1474.4	7 day sealed	15% Neal 3 Fly Ash	1471.6	1462.5	1510.7
1N3fa20	1427.3	7 day sealed	20% Neal 3 Fly Ash	1425.7	1415.6	1487.7
2N3fa20	1397.8	7 day sealed	20% Neal 3 Fly Ash	1388.7	1372.5	1437.4
3N3fa20	1415.3	7 day sealed	20% Neal 3 Fly Ash	1399.6	1384.6	1449.2
4N3fa20	1419.1	7 day sealed	20% Neal 3 Fly Ash	1414.2	1404.3	1462.2

Sample #	Wt. after 2nd freezer cycle	Wt. after 2nd thawing cycle	Wt. after 3rd freezer cycle	Wt. after 3rd thawing cycle	Wt. after 4th freezer cycle	Wt. after 4th thawing cycle
1N3fa10	1439.4	1259.1	1250.0	959.6	952.9	787.0
2N3fa10	1484.0	1343.3	1332.4	1078.0	1070.4	878.7
3N3fa10	1447.2	1228.5	1223.3	1006.8	999.0	834.7
4N3fa10	1454.7	1232.2	1225.7	979.9	974.9	815.1
1N3fa15	1450.6	1225.2	1218.6	969.7	964.5	864.0
2N3fa15	1451.2	1312.9	1305.7	1152.6	1146.4	967.2
3N3fa15	1474.2	1295.2	1289.3	1183.0	1177.1	1057.2
4N3fa15	1501.4	1350.5	1343.5	1235.3	1228.8	1095.0
1N3fa20	1483.9	1139.8	1135.9	964.4	958.4	731.5
2N3fa20	1432.0	1083.0	1074.7	868.4	859.3	729.3
3N3fa20	1443.9	1092.9	1088.8	786.3	780.6	653.7
4N3fa20	1456.2	1203.1	1199.1	913.6	907.4	724.0

Neal 3 Fly Ash Activated Neal 3 Aggregate Freeze-Thaw Cylinders - Sheet 2

Sample #	Wt. after 5th freezer cycle	Wt. after 5th thawing cycle	Wt. after 6th freezer cycle	Wt. after 6th thawing cycle
1N3fa10	777.1	653.1		
2N3fa10	870.6	788.4		
3N3fa10	826.2	719.1		
4N3fa10	807.7	691.2		
1N3fa15	855.5	756.1	750.6	645.9
2N3fa15	957.2	900.0	892.3	796.2
3N3fa15	1045.7	911.3	903.9	771.3
4N3fa15	1084.4	1002.3	993.4	917.0
1N3fa20	724.7	624.6		
2N3fa20	719.7	621.4		
3N3fa20	647.7	550.1		
4N3fa20	718.2	567.6		

2.5% Lime/97.5% Neal 3 Aggregate Freeze-Thaw Cylinders - Sheet 1

Sample #	Wt 0 day	Cure	Additive	Wt. 1st day in freezer	Wt. after 1st freezer cycle	Wt. after 1st thawing cycle
1N3lm2.5	1452.6	7 day sealed	2.5% Lime	1452.3	1439.3	1492.3
2N3lm2.5	1470.6	7 day sealed	2.5% Lime	1468.6	1457.1	1500.1
3N3lm2.5	1464.4	7 day sealed	2.5% Lime	1463.1	1454.6	1497.2
4N3lm2.5	1457.7	7 day sealed	2.5% Lime	1456.5	1445.7	1489.4

Sample #	Wt. after 2nd freezer cycle	Wt. after 2nd thawing cycle	Wt. after 3rd freezer cycle	Wt. after 3rd thawing cycle	Wt. after 4th freezer cycle	Wt. after 4th thawing cycle
1N3lm2.5	1491.0	1493.3	1490.2	1471.5	1464.6	1462.9
2N3lm2.5	1496.4	1500.7	1497.4	1485.9	1477.4	1478.5
3N3lm2.5	1494.5	1498.1	1494.6	1484.7	1473.9	1475.0
4N3lm2.5	1486.5	1490.5	1485.6	1474.9	1468.3	1468.4

Sample #	Wt. after 5th freezer cycle	Wt. after 5th thawing cycle	Wt. after 6th freezer cycle	Wt. after 6th thawing cycle	Wt. after 7th freezer cycle	Wt. after 7th thawing cycle
1N3lm2.5	1457.6	1446.3	1441.7	1431.6	1422.6	1396.9
2N3lm2.5	1472.7	1466.2	1459.6	1460.5	1450.7	1451.6
3N3lm2.5	1468.6	1458.4	1452.0	1448.5	1440.6	1426.2
4N3lm2.5	1462.5	1449.6	1443.7	1435.5	1429.2	1418.9

Sample #	Wt. after 8th freezer cycle	Wt. after 8th thawing cycle	Wt. after 9th freezer cycle	Wt. after 9th thawing cycle	Wt. after 10th freezer cycle	Wt. after 10th thawing cycle
1N3lm2.5	1390.5	1378.9	1372.3	1352.4	1343.1	1287.0
2N3lm2.5	1442.9	1436.9	1430.5	1422.6	1417.0	1380.3
3N3lm2.5	1417.9	1408.6	1398.6	1387.9	1377.5	1349.7
4N3lm2.5	1410.9	1386.5	1380.6	1363.6	1354.7	1322.4

2.5% Lime/97.5% Neal 3 Aggregate Freeze-Thaw Cylinders - Sheet 2

Sample #	Wt. after 11th freezer cycle	Wt. after 11th thawing cycle	Wt. after 12th freezer cycle	Wt. after 12th thawing cycle	Wt. after 13th freezer cycle	Wt. after 13th thawing cycle
1N3lm2.5	1273.9	1232.4	1224.3	1188.7	1179.4	1161.7
2N3lm2.5	1371.1	1339.7	1331.3	1286.6	1276.2	1254.5
3N3lm2.5	1335.2	1321.9	1296.4	1276.9	1264.1	1249.8
4N3lm2.5	1310.7	1292.3	1282.6	1254.3	1245.2	1207.5

Sample #	Wt. after 14th freezer cycle	Wt. after 14th thawing cycle	Wt. after 15th freezer cycle	Wt. after 15th thawing cycle	Wt. after 16th freezer cycle	Wt. after 16th thawing cycle
1N3lm2.5	1150.3	1125.4	1113.3	1095.5	1085.4	1078.1
2N3lm2.5	1241.6	1225.6	1213.3	1209.3	1198.8	1173.2
3N3lm2.5	1227.6	1210.8	1192.4	1180.1	1168.5	1141.2
4N3lm2.5	1198.2	1168.7	1157.8	1111.2	1099.5	1066.4

Sample #	Wt. after 17th freezer cycle	Wt. after 17th thawing cycle	Wt. after 18th freezer cycle	Wt. after 18th thawing cycle	Wt. after 19th freezer cycle	Wt. after 19th thawing cycle
1N3lm2.5	1065.0	1044.3	1027.5	1019.8	1010.6	998.3
2N3lm2.5	1162.9	1132.7	1122.3	1121.0	1109.4	1086.5
3N3lm2.5	1130.5	1121.4	1108.2	1094.6	1085.9	1072.1
4N3lm2.5	1056.5	1023.4	1013.3	999.6	989.7	949.8

Sample #	Wt. after 20th freezer cycle	Wt. after 20th thawing cycle	Wt. after 21st freezer cycle	Wt. after 21st thawing cycle	Wt. after 22nd freezer cycle	Wt. after 22nd thawing cycle
1N3lm2.5	977.6	958.6	937.2	929.5	925.3	911.8
2N3lm2.5	1075.5	1068.5	1056.6	1056.7	1045.5	1038.7
3N3lm2.5	1058.7	1047.0	1032.4	1020.1	1009.3	997.2
4N3lm2.5	937.5	919.1	908.2	904.0	894.4	887.7

Sample #	Wt. after 23rd freezer cycle	Wt. after 23rd thawing cycle	Wt. after 24th freezer cycle	Wt. after 24th thawing cycle	Wt. after 25th freezer cycle	Wt. after 25th thawing cycle
158	900.3	887.6	870.5	861.1	847.2	836.7
159	1027.8	1010.4	998.6	995.7	984.0	985.5
160	976.3	964.2	953.0	944.8	928.3	921.4
161	877.7	806.1	797.9	780.6	771.6	771.2

2.5% Lime/97.5% Neal 3 Aggregate Freeze-Thaw Cylinders - Sheet 3

Sample #	Wt. after 26th freezer cycle	Wt. after 26th thawing cycle	Wt. after 27th freezer cycle	Wt. after 27th thawing cycle	Wt. after 28th freezer cycle	Wt. after 28th thawing cycle
1N3lm2.5	821.3	808.4	794.6	781.2	765.8	750.7
2N3lm2.5	974.4	978.7	968.5	969.7	960.5	954.5
3N3lm2.5	911.7	894.7	881.2	867.0	848.6	837.2
4N3lm2.5	762.7	761.2	752.7	751.4	743.7	735.0

Sample #	Wt. after 29th freezer cycle	Wt. after 29th thawing cycle
1N3lm2.5	738.0	725.4
2N3lm2.5	944.3	933.3
3N3lm2.5	821.9	804.6
4N3lm2.5	727.0	724.1

100% Prairie Creek Aggregate Freeze-Thaw Cylinders - Sheet 1

Sample #	Wt 0 day	Cure	Wt. 1st Day in freezer	Wt. after 1st freezer cycle	Wt. after 1st thawing cycle	Wt. after 2nd freezer cycle
1PC100	1524.4	7 day sealed	1519.1	1504.1	1524.8	1511.9
2PC100	1523.4	7 day sealed	1514.4	1505.7	1522.9	1508.7
3PC100	1534.8	7 day sealed	1523.3	1514.4	1513.4	1498.2
4PC100	1551.7	7 day sealed	1542.6	1532.0	1527.8	1516.8

Sample #	Wt. after 2nd thawing cycle	Wt. after 3rd 3-day freezer cycle	Wt. after 3rd thawing cycle
1PC100	755.5	747.2	442.7
2PC100	817.5	807.5	310.9
3PC100	810.5	802.9	332.7
4PC100	818.9	810.5	468.2

Fly Ash Activated Prairie Creek Aggregate Freeze-Thaw Cylinders - Sheet 1

Sample #	Wt 0 day	Cure	Activator	Wt. 1st day in freezer	Wt. after 1st freezer cycle	Wt. after 1st thawing cycle
1PC100	1600.1	7 day sealed	10% Prairie Creek Fly Ash	1597.1	1587.5	1653.1
2PC100	1618.3	7 day sealed	10% Prairie Creek Fly Ash	1616.2	1608.4	1661.9
3PC100	1584.4	7 day sealed	10% Prairie Creek Fly Ash	1577.7	1569.4	1639.3
4PC100	1626.8	7 day sealed	10% Prairie Creek Fly Ash	1625.8	1619.2	1670.0

Sample #	Wt. after 2nd freezer cycle	Wt. after 2nd thawing cycle	Wt. after 3rd freezer cycle	Wt. after 3rd thawing cycle	Wt. after 4th freezer cycle	Wt. after 4th thawing cycle
1PC100	1645.1	1425.8	1413.1	1169.8	1164.8	1024.1
2PC100	1653.5	1515.5	1505.4	1242.8	1237.3	1142.6
3PC100	1628.6	1416.5	1401.1	1142.4	1136.8	952.8
4PC100	1657.6	1564.5	1554.1	1330.5	1325.1	1247.6

Sample #	Wt. after 5th freezer cycle	Wt. after 5th thawing cycle	Wt. after 6th freezer cycle	Wt. after 6th thawing cycle	Wt. after 7th freezer cycle	Wt. after 7th thawing cycle
1PC100	1013.5	838.0	830.1	776.7	770.2	719.8
2PC100	1134.1	987.0	977.0	910.9	902.6	805.4
3PC100	944.8	833.9	826.5	724.1	716.7	659.8
4PC100	1237.5	1102.5	1093.3	981.3	972.7	933.8

2.5% CKD and Lime Activator Prairie Aggregate Freeze-Thaw Cylinders - Sheet 1

Sample #	Wt 0 day	Cure	Activator	Wt. 1st Day in freezer	Wt. after 1st freezer cycle	Wt. after 1st thawing cycle
1PClm2.5	1680.0	7 day wrap	2.5% Lime	1679.9	1666.3	1700.3
2PClm2.5	1652.1	7 day wrap	2.5% Lime	1652.0	1640.3	1686.4
3PClm2.5	1659.9	7 day wrap	2.5% Lime	1659.7	1649.0	1687.7
4PClm2.5	1623.2	7 day wrap	2.5% Lime	1621.3	1609.4	1668.2
1PCckd2.5	1701.0	7 day wrap	2.5% CKD	1700.7	1688.5	1713.4
2PCckd2.5	1681.6	7 day wrap	2.5% CKD	1681.6	1671.1	1702.7
3PCckd2.5	1694.2	7 day wrap	2.5% CKD	1694.2	1680.6	1707.9
4PCckd2.5	1709.3	7 day wrap	2.5% CKD	1709.1	1697.2	1723.2

Sample #	Wt. after 2nd freezer cycle	Wt. after 2nd thawing cycle	Wt. after 3rd freezer cycle	Wt. after 3rd thawing cycle	Wt. after 4th freezer cycle	Wt. after 4th thawing cycle
1PClm2.5	1691.0	1703.6	1694.2	1699.9	1684.9	1699.5
2PClm2.5	1676.5	1691.3	1683.4	1687.0	1671.8	1685.7
3PClm2.5	1680.6	1692.3	1685.1	1688.0	1674.4	1678.0
4PClm2.5	1661.5	1669.5	1661.8	1636.3	1621.9	1618.3
1PCckd2.5	1706.5	1713.5	1706.8	1710.0	1703.2	1708.0
2PCckd2.5	1696.3	1705.1	1697.3	1698.0	1690.3	1692.3
3PCckd2.5	1699.4	1708.3	1701.2	1704.9	1698.2	1701.3
4PCckd2.5	1716.6	1723.6	1717.7	1720.2	1712.9	1717.7

Sample #	Wt. after 5th freezer cycle	Wt. after 5th thawing cycle	Wt. after 6th freezer cycle	Wt. after 6th thawing cycle	Wt. after 7th freezer cycle	Wt. after 7th thawing cycle
1PClm2.5	1692.7	1700.2	1687.2	1700.6	1691.0	1700.3
2PClm2.5	1673.2	1686.3	1673.4	1687.7	1676.4	1687.0
3PClm2.5	1666.8	1668.7	1657.8	1661.5	1651.9	1665.3
4PClm2.5	1605.1	1595.0	1581.7	1581.4	1569.6	1567.9
1PCckd2.5	1700.6	1707.0	1698.7	1706.1	1697.5	1706.3
2PCckd2.5	1682.4	1688.1	1679.1	1685.4	1676.1	1679.6
3PCckd2.5	1696.8	1701.5	1694.1	1699.3	1688.8	1694.9
4PCckd2.5	1707.4	1717.2	1708.0	1716.4	1707.4	1713.8

2.5% CKD and Lime Activator Prairie Aggregate Freeze-Thaw Cylinders - Sheet 2

Sample #	Wt. after 8th freezer cycle	Wt. after 8th thawing cycle	Wt. after 9th freezer cycle	Wt. after 9th thawing cycle	Wt. after 10th freezer cycle	Wt. after 10th thawing cycle
1PClm2.5	1689.3	1701.1	1696.7	1704.7	1694.5	1703.9
2PClm2.5	1674.5	1686.4	1680.6	1690.7	1679.9	1660.5
3PClm2.5	1650.1	1648.9	1645.3	1643.1	1632.8	1640.4
4PClm2.5	1556.4	1546.4	1541.5	1521.9	1512.5	1514.3
1PCckd2.5	1697.1	1704.8	1700.8	1706.5	1694.9	1705.7
2PCckd2.5	1666.4	1676.1	1667.7	1675.2	1665.7	1672.0
3PCckd2.5	1684.2	1691.7	1688.4	1692.8	1683.5	1689.5
4PCckd2.5	1703.3	1712.6	1707.6	1714.4	1706.1	1712.1

Sample #	Wt. after 11th freezer cycle	Wt. after 11th thawing cycle	Wt. after 12th freezer cycle	Wt. after 12th thawing cycle	Wt. after 13th freezer cycle	Wt. after 13th thawing cycle
1PClm2.5	1700.6	1705.8	1696.0	1706.7	1703.4	1701.6
2PClm2.5	1657.2	1595.4	1584.6	1570.7	1566.0	1533.7
3PClm2.5	1636.0	1613.2	1602.7	1580.0	1576.1	1573.2
4PClm2.5	1507.7	1512.4	1502.3	1484.2	1478.7	1316.4
1PCckd2.5	1704.1	1706.2	1696.2	1707.1	1703.2	1706.8
2PCckd2.5	1668.8	1671.1	1661.3	1666.7	1665.7	1665.0
3PCckd2.5	1686.6	1688.7	1678.3	1687.6	1683.0	1687.6
4PCckd2.5	1709.3	1713.0	1703.9	1713.0	1708.9	1714.1

Sample #	Wt. after 14th freezer cycle	Wt. after 14th thawing cycle	Wt. after 15th freezer cycle	Wt. after 15th thawing cycle	Wt. after 16th freezer cycle	Wt. after 16th thawing cycle
1PClm2.5	1696.4	1678.7	1674.4	1669.9	1665.8	1546.3
2PClm2.5	1526.1	1495.5	1489.1	1428.3	1423.8	1341.9
3PClm2.5	1566.9	1530.2	1527.2	1481.5	1475.1	1339.0
4PClm2.5	1310.6	1261.7	1255.2	1132.9	1125.6	1033.0
1PCckd2.5	1702.6	1708.5	1704.8	1707.7	1705.8	1703.4
2PCckd2.5	1658.9	1663.9	1658.4	1655.8	1650.1	1635.9
3PCckd2.5	1682.3	1682.3	1680.4	1679.9	1677.3	1670.1
4PCckd2.5	1709.2	1711.7	1707.1	1710.6	1705.0	1703.8

2.5% CKD and Lime Activator Prairie Aggregate Freeze-Thaw Cylinders - Sheet 3

Sample #	Wt. after 17th freezer cycle	Wt. after 17th thawing cycle	Wt. after 18th freezer cycle	Wt. after 18th thawing cycle	Wt. after 19th freezer cycle	Wt. after 19th thawing cycle
1PClm2.5	1538.7	1481.7	1472.6	1466.4	1457.9	1450.6
2PClm2.5	1333.6	1194.0	1184.6	1163.9	1156.2	1161.2
3PClm2.5	1330.1	1302.9	1293.9	1303.0	1294.2	1276.3
4PClm2.5	1025.7	995.0	988.1	921.9	915.7	885.7
1PCckd2.5	1699.0	1692.0	1687.8	1684.7	1680.7	1680.8
2PCckd2.5	1629.6	1554.8	1546.2	1504.5	1498.9	1479.7
3PCckd2.5	1663.6	1664.6	1657.3	1657.3	1650.0	1628.4
4PCckd2.5	1697.4	1675.4	1665.5	1671.2	1664.6	1652.2

Sample #	Wt. after 20th freezer cycle	Wt. after 20th thawing cycle	Wt. after 21st freezer cycle	Wt. after 21st thawing cycle	Wt. after 22nd freezer cycle	Wt. after 22nd thawing cycle
1PClm2.5	1442.0	1440.0	1430.2	1422.9	1413.2	1408.0
2PClm2.5	1152.4	1119.6	1111.0	1005.6	998.8	997.5
3PClm2.5	1268.6	1258.8	1249.5	1249.1	1241.8	1209.7
4PClm2.5	879.1	871.9	864.3	860.8	855.0	850.1
1PCckd2.5	1676.0	1677.7	1671.7	1671.1	1666.4	1669.1
2PCckd2.5	1471.4	1474.0	1465.4	1469.2	1462.8	1462.9
3PCckd2.5	1621.2	1628.4	1621.1	1622.5	1616.8	1614.8
4PCckd2.5	1645.9	1647.4	1640.5	1644.6	1639.9	1622.5

Sample #	Wt. after 23rd freezer cycle	Wt. after 23rd thawing cycle	Wt. after 24th freezer cycle	Wt. after 24th thawing cycle	Wt. after 25th freezer cycle	Wt. after 25th thawing cycle
1PClm2.5	1398.2	1375.1	1366.0	1370.6	1358.7	1368.7
2PClm2.5	988.8	994.4	986.4	985.0	975.8	965.4
3PClm2.5	1199.9	1188.3	1179.2	1169.7	1159.6	1163.8
4PClm2.5	842.9	847.6	840.6	816.8	809.1	809.9
1PCckd2.5	1663.0	1670.0	1663.0	1666.7	1659.9	1662.0
2PCckd2.5	1545.8	1465.1	1457.5	1459.9	1450.6	1450.3
3PCckd2.5	1608.7	1605.0	1597.3	1584.1	1575.8	1558.7
4PCckd2.5	1616.2	1618.5	1611.7	1590.5	1580.6	1567.8

2.5% CKD and Lime Activator Prairie Aggregate Freeze-Thaw Cylinders - Sheet 4

Sample #	Wt. after 26th freezer cycle	Wt. after 26th thawing cycle	Wt. after 27th freezer cycle	Wt. after 27th thawing cycle	Wt. after 28th freezer cycle	Wt. after 28th thawing cycle
1PClm2.5	1358.9	1365.8	1355.7	1366.6	1357.1	1358.3
2PClm2.5	958.6	964.7	957.3	962.7	955.6	963.2
3PClm2.5	1153.0	1156.9	1147.7	1154.0	1146.1	1154.5
4PClm2.5	802.9	808.9	803.7	802.0	795.3	794.1
1PCckd2.5	1656.2	1649.3	1640.6	1620.4	1613.6	1607.8
2PCckd2.5	1440.4	1440.3	1433.0	1401.0	1392.3	1400.7
3PCckd2.5	1552.5	1519.5	1512.4	1511.8	1505.7	1504.7
4PCckd2.5	1560.1	1534.7	1528.0	1517.3	1511.5	1501.0

Sample #	Wt. after 29th freezer cycle	Wt. after 29th thawing cycle	Wt. after 30th freezer cycle	Wt. after 30th thawing cycle	Wt. after 31st freezer cycle	Wt. after 31st thawing cycle
1PClm2.5	1347.6	1338.0	1328.3	1337.9	1328.2	1334.5
2PClm2.5	954.8	958.4	949.7	954.5	946.6	953.2
3PClm2.5	1146.0	1153.1	1144.2	1128.8	1119.4	1123.3
4PClm2.5	787.2	788.9	781.7	777.9	771.4	768.9
1PCckd2.5	1599.3	1593.4	1584.8	1577.8	1569.7	1551.9
2PCckd2.5	1393.0	1361.7	1353.6	1354.1	1346.6	1320.1
3PCckd2.5	1496.0	1491.8	1484.8	1470.0	1462.1	1460.0
4PCckd2.5	1492.8	1455.7	1447.9	1421.1	1414.5	1406.5

Sample #	Wt. after 32nd freezer cycle	Wt. after 32nd thawing cycle	Wt. after 33rd freezer cycle	Wt. after 33rd thawing cycle	Wt. after 34th freezer cycle	Wt. after 34th thawing cycle
1PClm2.5	1324.7	1338.6	1329.9	1338.9	1328.5	1336.0
2PClm2.5	945.6	945.9	938.5	945.4	938.2	907.9
3PClm2.5	1114.2	1107.2	1098.9	1037.4	1030.6	1028.3
4PClm2.5	762.5	757.2	751.3	748.6	743.0	731.3
1PCckd2.5	1542.5	1553.0	1545.7	1547.5	1542.0	1533.8
2PCckd2.5	1309.7	1273.4	1265.1	1249.6	1242.1	1239.8
3PCckd2.5	1451.2	1447.0	1438.0	1416.0	1407.5	1407.0
4PCckd2.5	1399.2	1395.3	1386.8	1376.3	1359.4	1365.7

2.5% CKD and Lime Activator Prairie Aggregate Freeze-Thaw Cylinders - Sheet 5

Sample #	Wt. after 35th freezer cycle	Wt. after 35th thawing cycle	Wt. after 36th freezer cycle	Wt. after 36th thawing cycle
1PClm2.5	1326.6	1329.1	1322.8	1289.0
2PClm2.5	900.7	900.5	894.6	881.4
3PClm2.5	1020.9	997.4	990.6	978.1
4PClm2.5	725.1	701.6	696.6	688.5
1PCckd2.5	1525.6	1512.1	1504.6	1479.6
2PCckd2.5	1231.5	1235.1	1227.3	1212.3
3PCckd2.5	1398.4	1348.5	1343.0	1343.4
4PCckd2.5	1358.0	1360.3	1352.8	1329.0

APPENDIX B
ASTM C 593 COMPRESSIVE STRENGTH DATA

ASTM C593 Test on 10% CKD/90% Ottumwa Aggregate cylinders

7/31/96

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1OTckd10-593	Vac. Sat.	1701.1	1691.7	25160	2003
2OTckd10-593	Vac. Sat.	16575.4	1666.7	21550	1716
3OTckd10-593	Vac. Sat.	1691.4	1680.3	25560	2035
4OTckd10-593	4 hr. Soak	1710.8	1699.5	22170	1765
5OTckd10-593	4 hr. Soak	1674.1	1665.8	21730	1730
6Ockd10-593	4 hr. Soak	1693.1	1681.3	23780	1893

Average Soak Load = 22,560 lb 1796 psi

Average V.S. Load = 24,090 lb 1918 psi

ASTM C593 Test on 15% AFBC/85% Ottumwa Aggregate cylinders

8/8/96

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1OTafbc15-593	Vac. Sat.	1680.0	1670.3	13880	1105
2OTafbc15-593	Vac. Sat.	1688.0	1678.3	15790	1257
3OTafbc15-593	Vac. Sat.	1667.1	1660.9	14100	1123
4OTafbc15-593	4 hr. Soak	1667.9	1662.5	13870	1104
5OTafbc15-593	4 hr. Soak	1700.6	1688.8	15320	1220
6OTafbc15-593	4 hr. Soak	1693.4	1686.0	14570	1160

Average Soak Load = 14,587 lb 1161 psi

Average V.S. Load = 14,590 lb 1162 psi

ASTM C593 Test on 100% Ottumwa Aggregate cylinders

6/6/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1OT100-593	4 hr. Soak	1717.8	1714.9	0	0
2OT100-593	4 hr. Soak	1723.6	1714.9	150	12
3OT100-593	4 hr. Soak	1703.7	1699.7	0	0
4OT100-593	Vac. Sat.	1718.0	1711.8	0	0
5OT100-593	Vac. Sat.	1722.7	1717.5	0	0
6OT100-593	Vac. Sat.	1714.3	1709.9	0	0

5 of 6 samples fell apart before testing. #1 & 3 fell apart during soaking.
#4, 5, & 6 fell apart during saturation.

Average Soak Load = 4 lb 0 psi

Average V.S. Load = 0 lb 0 psi

ASTM C593 Test - 2.5% Lime/97.5% Ottumwa Aggregate cylinders

6/19/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1OTlm2.5-593	4 hr. Soak	1677.2	1675.0	4040	322
2OTlm2.5-593	4 hr. Soak	1699.1	1696.6	4540	361
3OTlm2.5-593	4 hr. Soak	1630.6	1627.6	2070	165
4OTlm2.5-593	Vac. Sat.	1646.1	1639.8	3070	244
5OTlm2.5-593	Vac. Sat.	1657.4	1653.8	3150	251
6OTlm2.5-593	Vac. Sat.	1683.4	1680.2	3760	299

Average Soak Load = 3550 lb 283 psi

Average V.S. Load = 3327 lb 265 psi

ASTM C593 Test - 2.5% CKD/97.5% Ottumwa Aggregate cylinders

7/1/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1OTckd2.5-593	Vac. Sat.	1712.9	1709.0	2480	197
2OTckd2.5-593	Vac. Sat.	1708.3	1704.0	2450	195
3OTckd2.5-593	Vac. Sat.	1691.5	1688.3	2660	212
4OTckd2.5-593	4 hr. Soak	1700.8	1697.3	2670	213
5OTckd2.5-593	4 hr. Soak	1704.7	1700.4	2970	236
6OTckd2.5-593	4 hr. Soak	1694.9	1689.6	2780	221

Average Soak Load = 2807 lb 223 psi

Average V.S. Load = 2530 lb 201 psi

ASTM C593 Test - 10% Ottumwa Fly Ash/90% Ottumwa Aggregate cylinders

7/2/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1OTfa10-593	Vac. Sat.	1610.9	1603.7	430	34
2OTfa10-593	Vac. Sat.	1634.6	1630.9	700	56
3OTfa10-593	Vac. Sat.	1619.0	1614.7	450	36
4OTfa10-593	4 hr. Soak	1635.6	1629.6	710	57
5OTfa10-593	4 hr. Soak	1596.7	1591.3	545	43
6OTfa10-593	4 hr. Soak	1612.3	1600.3	460	37

Average Soak Load = 572 lb 45 psi

Average V.S. Load = 527 lb 42 psi

ASTM C593 Test - 15% Ottumwa Fly Ash/85% Ottumwa Aggregate cylinders

7/10/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1OTfa15-593	Vac. Sat.	1612.0	1608.8	780	62
2OTfa15-593	Vac. Sat.	1616.8	1611.9	625	50
3OTfa15-593	Vac. Sat.	1603.0	1599.0	550	44
4OTfa15-593	4 hr. Soak	1609.0	1603.4	720	57
5OTfa15-593	4 hr. Soak	1631.4	1627.3	640	51
6OTfa15-593	4 hr. Soak	1619.8	1614.7	425	34

Average Soak Load = 595 lb 47 psi

Average V.S. Load = 652 lb 52 psi

ASTM C593 Test - 20% Ottumwa Fly Ash/80% Ottumwa Aggregate cylinders

7/15/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1OTfa20-593	Vac. Sat.	1563.8	1555.6	780	62
2OTfa20-593	Vac. Sat.	1574.8	1566.3	560	45
3OTfa20-593	Vac. Sat.	1599.4	1592.4	730	58
4OTfa20-593	4 hr. Soak	1556.1	1540.3	420	33
5OTfa20-593	4 hr. Soak	1564.2	1554.2	440	35
6OTfa20-593	4 hr. Soak	1607.2	1604.0	830	66

Average Soak Load = 563 lb 45 psi

Average V.S. Load = 690 lb 55 psi

ASTM C593 Test on 100% Council Bluffs Aggregate cylinders

5/22/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1CB100-593	4 hr. Soak	1523.0	1508.0	0	0
2CB100-593	4 hr. Soak	1532.5	1523.3	0	0
3CB100-593	4 hr. Soak	1545.7	1538.2	0	0
4CB100-593	Vac. Sat.	1553.6	1540.2	0	0
5CB100-593	Vac. Sat.	1548.4	1528.1	0	0
6CB100-593	Vac. Sat.	1547.9	1541.1	0	0

All 6 samples fell apart before testing. #1, 2, & 3 fell apart during soaking.
#4, 5, & 6 fell apart during saturation.

Average Soak Load = 0 lb 0 psi

Average V.S. Load = 0 lb 0 psi

ASTM C593 Test - 10% Council Bluffs Ash/90% CB Aggregate cylinders

7/16/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1CBfa10-593	Vac. Sat.	1614.4	1611.3	960	76
2CBfa10-593	Vac. Sat.	1623.4	1619.8	810	64
3CBfa10-593	Vac. Sat.	1591.6	1585.8	920	73
4CBfa10-593	4 hr. Soak	1585.7	1580.0	780	62
5CBfa10-593	4 hr. Soak	1607.4	1601.7	880	70
6CBfa10-593	4 hr. Soak	1596.0	1589.6	900	72

Average Soak Load = 853 lb 68 psi

Average V.S. Load = 897 lb 71 psi

ASTM C593 Test - 15% Council Bluffs Ash/85% CB Aggregate cylinders

7/24/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1CBfa15-593	Vac. Sat.	1538.4	1532.7	970	77
2CBfa15-593	Vac. Sat.	1599.8	1596.5	1680	134
3CBfa15-593	Vac. Sat.	1556.4	1553.0	1280	102
4CBfa15-593	4 hr. Soak	1571.1	1564.3	1000	80
5CBfa15-593	4 hr. Soak	1550.1	1545.1	1170	93
6CBfa15-593	4 hr. Soak	1557.9	1553.6	1040	83

Average Soak Load = 1070 lb 85 psi

Average V.S. Load = 1310 lb 104 psi

ASTM C593 Test - 20% Council Bluffs Fly Ash/80% CB Aggregate cylinders

7/24/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1CBfa20-593	Vac. Sat.	1516.6	1511.3	1210	96
2CBfa20-593	Vac. Sat.	1497.4	1483.0	900	72
3CBfa20-593	Vac. Sat.	1501.9	1492.0	850	68
4CBfa20-593	4 hr. Soak	1524.4	1517.6	1800	143
5CBfa20-593	4 hr. Soak	1463.1	1448.4	880	70
6CBfa20-593	4 hr. Soak	1507.5	1497.5	910	72

Average Soak Load = 1197 lb 95 psi

Average V.S. Load = 987 lb 79 psi

ASTM C593 Test - 2.5% Lime/97.5% Council Bluffs Aggregate cylinders

8/7/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1CBlm2.5-593	Vac. Sat.	1549.2	1545.7	5160	411
2CBlm2.5-593	Vac. Sat.	1603.4	1598.1	5620	447
3CBlm2.5-593	Vac. Sat.	1586.9	1582.5	6100	486
4CBlm2.5-593	4 hr. Soak	1622.6	1619.3	6480	516
5CBlm2.5-593	4 hr. Soak	1542.4	1538.1	4420	352
6CBlm2.5-593	4 hr. Soak	1595.4	1591.6	6740	537

Average Soak Load = 5880 lb 468 psi

Average V.S. Load = 5627 lb 448 psi

ASTM C593 Test on 100% Neal 3 Aggregate cylinders

5/22/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1N3-100-593	4 hr. Soak	1590.2	1583.4	0	0
2N3-100-593	4 hr. Soak	1568.4	1557.2	205	16
3N3-100-593	4 hr. Soak	1596.6	1590.3	175	14
4N3-100-593	Vac. Sat.	1604.6	1595.1	0	0
5N3-100-593	Vac. Sat.	1584.7	1579.1	180	14
6N3-100-593	Vac. Sat.	1593.9	1583.7	200	16

All 4 samples were tested uncapped. #1 Broke during handling; #4 broke during attempted capping

Average Soak Load = 190 lb 15 psi

Average V.S. Load = 190 lb 15 psi

ASTM C593 Test - 10% Neal 3 Ash/90% Neal 3 Aggregate cylinders

7/29/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1N3fa10-593	Vac. Sat.	1444.8	1440.9	440	35
2N3fa10-593	Vac. Sat.	1454.0	1448.7	540	43
3N3fa10-593	Vac. Sat.	1444.4	1438.0	350	28
4N3fa10-593	4 hr. Soak	1446.7	1438.1	480	38
5N3fa10-593	4 hr. Soak	1422.9	1417.8	300	24
6N3fa10-593	4 hr. Soak	1464.0	1459.5	470	37

Average Soak Load = 417 lb 33 psi

Average V.S. Load = 443 lb 35 psi

ASTM C593 Test - 15% Neal 3 Ash/85% Neal 3 Aggregate cylinders

7/29/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1N3fa15-593	Vac. Sat.	1452.1	1444.4	540	43
2N3fa15-593	Vac. Sat.	1429.5	1425.5	540	43
3N3fa15-593	Vac. Sat.	1458.8	1452.6	630	50
4N3fa15-593	4 hr. Soak	1437.5	1434.2	390	31
5N3fa15-593	4 hr. Soak	1441.9	1436.1	500	40
6N3fa15-593	4 hr. Soak	1449.0	1441.2	510	41

Average Soak Load = 467 lb 37 psi

Average V.S. Load = 570 lb 45 psi

ASTM C593 Test - 20% Neal 3 Fly Ash/80% Neal 3 Aggregate cylinders

7/30/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1N3fa20-593	Vac. Sat.	1428.3	1420.2	450	36
2N3fa20-593	Vac. Sat.	1422.4	1412.3	490	39
3N3fa20-593	Vac. Sat.	1394.0	1388.0	430	34
4N3fa20-593	4 hr. Soak	1422.1	1412.7	670	53
5N3fa20-593	4 hr. Soak	1413.8	1406.0	630	50
6N3fa20-593	4 hr. Soak	1427.7	1423.0	810	64

Average Soak Load = 703 lb 56 psi

Average V.S. Load = 457 lb 36 psi

ASTM C593 Test - 2.5% Lime/97.5% Neal 3 Aggregate cylinders

8/13/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1N3lm2.5-593	Vac. Sat.	1460.8	1458.3	3720	296
2N3lm2.5-593	Vac. Sat.	1482.5	1480.4	3800	303
3N3lm2.5-593	Vac. Sat.	1438.3	1435.4	3580	285
4N3lm2.5-593	4 hr. Soak	1446.5	1444.6	3390	270
5N3lm2.5-593	4 hr. Soak	1468.4	1466.2	3330	265
6N3lm2.5-593	4 hr. Soak	1445.7	1443.4	3280	261

Average Soak Load = 3333 lb 265 psi

Average V.S. Load = 3700 lb 294 psi

ASTM C593 Test on 100% Prairie Creek Aggregate cylinders

6/6/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1PC100-593	4 hr. Soak	1687.0	1683.5	0	0
2PC100-593	4 hr. Soak	1677.4	1673.9	0	0
3PC100-593	4 hr. Soak	1654.4	1641.8	0	0
4PC100-593	Vac. Sat.	1667.3	1663.0	180	14
5PC100-593	Vac. Sat.	1669.3	1666.7	130	10
6PC100-593	Vac. Sat.	1664.7	1661.1	140	11

3 samples fell apart before testing. #1, 2, & 3 fell apart during soaking.

Average Soak Load = 0 lb 0 psi

Average V.S. Load = 12 lb 1 psi

ASTM C593 Test - 10% Prairie Creek Ash/90% PC Aggregate cylinders

7/31/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1PCfa10-593	Vac. Sat.	1602.6	1597.0	540	43
2PCfa10-593	Vac. Sat.	1617.0	1612.7	740	59
3PCfa10-593	Vac. Sat.	1627.7	1622.7	660	53
4PCfa10-593	4 hr. Soak	1577.2	1573.2	420	33
5PCfa10-593	4 hr. Soak	1625.2	1619.2	690	55
6PCfa10-593	4 hr. Soak	1634.5	1631.8	1030	82

Average Soak Load = 713 lb 57 psi

Average V.S. Load = 647 lb 51 psi

ASTM C593 Test - 2.5% Lime/97.5% Prairie Creek Aggregate cylinders

6/18/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1PCIm2.5-593	4 hr. Soak	1673.8	1670.9	9080	723
2PCIm2.5-593	4 hr. Soak	1663.6	1661.7	7500	597
3PCIm2.5-593	4 hr. Soak	1628.8	1626.3	8760	697
4PCIm2.5-593	Vac. Sat.	1664.1	1662.0	7600	605
5PCIm2.5-593	Vac. Sat.	1675.0	1672.0	8240	656
6PCIm2.5-593	Vac. Sat.	1649.3	1647.2	6800	541

Average Soak Load = 8447 lb 672 psi

Average V.S. Load = 7547 lb 601 psi

ASTM C593 Test - 2.5% CKD/97.5% Prairie Creek Aggregate cylinders

6/18/97

Sample #	Cure	Wt. 0 day (g)	Wt. 7 day (g)	Load (lb)	Stress (psi)
1PCckd2.5-593	4 hr. Soak	1683.5	1680.2	3440	274
2PCckd2.5-593	4 hr. Soak	1693.5	1691.3	4270	340
3PCckd2.5-593	4 hr. Soak	1669.0	1666.5	3660	291
4PCckd2.5-593	Vac. Sat.	1689.1	1685.9	3670	292
5PCckd2.5-593	Vac. Sat.	1694.5	1691.8	3130	249
6PCckd2.5-593	Vac. Sat.	1687.1	1684.0	2635	210

Average Soak Load =	3790 lb	302 psi
Average V.S. Load =	3145 lb	250 psi

APPENDIX C
UNCONFINED COMPRESSIVE STRENGTH DATA

Long Term Strength Gain Samples - 15% CKD/85% Ottumwa Aggregate
Sealed Cure (Made 11/20/95)

Sample #	Type	Cure Time	Break Day	Wt. 0 day	Wt. Brk Day	Load (lb)	Stress (psi)	
1Clt	15% CKD	7 days	11/27/95	1676.8	1668.3	17,040	1357	Avg. of 3
2Clt	15% CKD	7 days	11/27/95	1628.7	1619.7	13,540	1078	1280 psi
3Clt	15% CKD	7 days	11/27/95	1671.0	1661.9	17,660	1406	
4Clt	15% CKD	28 days	12/18/95	1659.2	1646.9	20,540	1635	Avg. of 3
5Clt	15% CKD	28 days	12/18/95	1634.5	1626.0	18,680	1487	1841 psi
6Clt	15% CKD	28 days	12/18/95	1711.1	1696.6	30,140	2400	
7Clt	15% CKD	84 days	2/12/96	1664.8	1651.7	33,430	2662	Avg. of 3
8Clt	15% CKD	84 days	2/12/96	1680.7	1663.5	35,200	2803	2722 psi
9Clt	15% CKD	84 days	2/12/96	1672.3	1655.9	33,950	2703	
10Clt	15% CKD	168 days	5/6/96	1706.9	1683.5	35,570	2832	Avg. of 3
11Clt	15% CKD	168 days	5/6/96	1665.2	1646.8	32,690	2603	2618 psi
12Clt	15% CKD	168 days	5/6/96	1640.6	1620.7	30,380	2419	
13Clt	15% CKD	252 days	7/29/96	1706.3	1684.0	44,220	3521	Avg. of 3
14Clt	15% CKD	252 days	7/29/96	1650.1	1631.1	20,010	1593	2729 psi
15Clt	15% CKD	252 days	7/29/96	1690.6	1662.8	38,600	3073	
16Clt	15% CKD	336 days	10/21/96	1683.3	1644.4	38,790	3088	Avg. of 3
17Clt	15% CKD	336 days	10/21/96	1673.8	1662.2	36,420	2900	2777 psi
18Clt	15% CKD	336 days	10/21/96	1699.1	1670.1	29,410	2342	

Long Term Strength Gain Samples - 15% AFBC/85% Ottumwa Aggregate
Sealed Cure (Made 11/21/95)

Sample #	Type	Cure Time	Break Day	Wt. 0 day	Wt. Brk Day	Load (lb)	Stress (psi)	
1Alt	15% AFBC	7 days	11/28/95	1712.1	1705.2	12,270	977	Avg. of 3
2Alt	15% AFBC	7 days	11/28/95	1632.8	1624.5	10,180	811	902 psi
3Alt	15% AFBC	7 days	11/28/95	1666.2	1658.1	11,550	920	
4Alt	15% AFBC	28 days	12/19/95	1625.4	1619.2	12,040	959	Avg. of 3
5Alt	15% AFBC	28 days	12/19/95	1673.3	1665.1	14,230	1133	1129 psi
6Alt	15% AFBC	28 days	12/19/95	1697.2	1688.2	16,260	1295	
7Alt	15% AFBC	84 days	2/13/96	1670.3	1655.7	19,560	1557	Avg. of 3
8Alt	15% AFBC	84 days	2/13/96	1651.3	1634.7	14,750	1174	1341 psi
9Alt	15% AFBC	84 days	2/13/96	1662.9	1643.5	16,220	1291	
10Alt	15% AFBC	168 days	5/7/96	1706.8	1687.3	19,730	1571	Avg. of 3
11Alt	15% AFBC	168 days	5/7/96	1638.4	1625.1	13,960	1111	1387 psi
12Alt	15% AFBC	168 days	5/7/96	1671.6	1650.9	18,580	1479	
13Alt	15% AFBC	252 days	7/30/96	1682.1	1656.8	20,900	1664	Avg. of 3
14Alt	15% AFBC	252 days	7/30/96	1651.2	1623.9	19,650	1564	1615 psi
15Alt	15% AFBC	252 days	7/30/96	1727.9	1708.8	20,320	1618	
16Alt	15% AFBC	336 days	10/22/96	1671.8	1648.3	19,750	1572	Avg. of 3
17Alt	15% AFBC	336 days	10/22/96	1668	1644.1	24,250	1931	1797 psi
18Alt	15% AFBC	336 days	10/22/96	1682.2	1660.2	23,720	1889	

Long Term Strength Gain Samples - 15% CKD/85% Ottumwa Aggregate
Humid Cure (Made 6/12/96)

Sample #	Type	Cure Time	Break Day	Wt. 0 day	Wt. Brk Day	Load (lb)	Stress (psi)	
1Clt-h	15% CKD	7 days	6/26/96	1634.4	1674.3	17,500	1393	Avg. of 3
2Clt-h	15% CKD	7 days	6/26/96	1673.9	1701.9	20,630	1642	1486 psi
3Clt-h	15% CKD	7 days	6/26/96	1695.9	1734.3	17,890	1424	
4Clt-h	15% CKD	28 days	7/17/96	1619.8	1682.5	18,490	1471	Avg. of 3
5Clt-h	15% CKD	28 days	7/17/96	1684.4	1720.6	25,580	2036	1859 psi
6Clt-h	15% CKD	28 days	7/17/96	1726.4	1765.0	26,010	2070	
7Clt-h	15% CKD	84 days	9/11/96	1653.2	1713.0	23,140	1841	Avg. of 3
8Clt-h	15% CKD	84 days	9/11/96	1677.4	1725.8	26,130	2079	1929 psi
9Clt-h	15% CKD	84 days	9/11/96	1686.2	1749.2	23,470	1868	
10Clt-h	15% CKD	168 days	12/4/96	1670.4	1724.7	31,740	2526	Avg. of 3
11Clt-h	15% CKD	168 days	12/4/96	1644.5	1715.4	21,090	1678	2295 psi
12Clt-h	15% CKD	168 days	12/4/96	1701.2	1740.0	33,700	2682	
13Clt-h	15% CKD	252 days	2/26/97	1674.1	1732.6	32,100	2554	Avg. of 3
14Clt-h	15% CKD	252 days	2/26/97	1693.2	1766.9	30,100	2395	2366 psi
15Clt-h	15% CKD	252 days	2/26/97	1681.5	1750.2	27,000	2149	
16Clt-h	15% CKD	336 days	5/28/97	1694.1	1746.9	36,750	2924	Avg. of 3
17Clt-h	15% CKD	336 days	5/28/97	1674.0	1749.0	28,700	2284	2476 psi
18Clt-h	15% CKD	336 days	5/28/97	1692.6	1765.2	27,900	2220	

Long Term Strength Gain Samples - 15% AFBC/85% Ottuwma Aggregate
Humid Cure (Made 6/13/96)

Sample #	Type	Cure Time	Break Day	Wt. 0 day	Wt. Brk Day	Load (lb)	Stress (psi)	
1A lt-h	15% AFBC	7 days	7/3/96	1672.5	1707.0	13,120	1044	Avg. of 3
2A lt-h	15% AFBC	7 days	7/3/96	1577.3	1631.4	10,190	811	896 psi
3A lt-h	15% AFBC	7 days	7/3/96	1609.3	1644.8	10,470	833	
4A lt-h	15% AFBC	28 days	7/25/96	1678.4	1720.7	14,680	1168	Avg. of 3
5A lt-h	15% AFBC	28 days	7/25/96	1562.4	1627.9	10,370	825	1036 psi
6A lt-h	15% AFBC	28 days	7/25/96	1616.7	1669.9	13,300	1058	
7A lt-h	15% AFBC	84 days	9/19/96	1629.6	1693.7	14,020	1116	Avg. of 3
8A lt-h	15% AFBC	84 days	9/19/96	1593.6	1655.1	15,330	1220	1119 psi
9A lt-h	15% AFBC	84 days	9/19/96	1645.2	1692.8	12,850	1023	
10A lt-h	15% AFBC	168 days	12/12/96	1638.8	1709.4	17,110	1362	Avg. of 3
11A lt-h	15% AFBC	168 days	12/12/96	1607.6	1664.1	16,160	1286	1350 psi
12A lt-h	15% AFBC	168 days	12/12/96	1628.2	1695.8	17,610	1401	
13A lt-h	15% AFBC	252 days	3/6/97	1637.9	1713.2	18,600	1480	Avg. of 3
14A lt-h	15% AFBC	252 days	3/6/97	1629.4	1706.3	18,100	1440	1459 psi
15A lt-h	15% AFBC	252 days	3/6/97	1632.2	1709.4	18,300	1456	
16A lt-h	15% AFBC	336 days	6/5/97	1622.6	1689.1	19,000	1512	Avg. of 3
17A lt-h	15% AFBC	336 days	6/5/97	1635.9	1710.9	19,420	1545	1504 psi
18A lt-h	15% AFBC	336 days	6/5/97	1618.5	1687.4	18,280	1455	

Strength Gain Tests - 7, 28, & 56 Day Sealed Cure - Sheet 1

Sample Type	Sample #	Cure Time	Break Date	Wt. 0 Day (g)	Wt. Break Day (g)	Load (lb)	Stress (psi)	Avg. Stress (psi)
100% PC Aggregate	1PC100s	7 days	8/5/97	1637.4	1635.3	475	38	
100% PC Aggregate	2PC100s	7 days	8/5/97	1661.7	1660.4	790	63	54
100% PC Aggregate	3PC100s	7 days	8/5/97	1622.1	1620.8	780	62	
100% PC Aggregate	4PC100s	28 days	8/26/97	1647.8	1643.5	800	64	
100% PC Aggregate	5PC100s	28 days	8/26/97	1618.3	1613.0	890	71	66
100% PC Aggregate	6PC100s	28 days	8/26/97	1618.4	1616.5	810	64	
100% PC Aggregate	7PC100s	56 days	9/23/97	1638.0	1635.2	1170	93	
100% PC Aggregate	8PC100s	56 days	9/23/97	1618.5	1614.5	1290	103	95
100% PC Aggregate	9PC100s	56 days	9/23/97	1622.3	1618.9	1120	89	
2.5% Lime/97.5% PC Agg	1PClm-s	7 days	8/5/97	1601.9	1599.7	3000	239	
2.5% Lime/97.5% PC Agg	2PClm-s	7 days	8/5/97	1598.7	1597.5	2960	236	231
2.5% Lime/97.5% PC Agg	3PClm-s	7 days	8/5/97	1602.8	1601.2	2740	218	
2.5% Lime/97.5% PC Agg	4PClm-s	28 days	8/26/97	1583.0	1581.4	5320	423	
2.5% Lime/97.5% PC Agg	5PClm-s	28 days	8/26/97	1582.9	1581.3	5240	417	438
2.5% Lime/97.5% PC Agg	6PClm-s	28 days	8/26/97	1613.5	1612.2	5960	474	
2.5% Lime/97.5% PC Agg	7PClm-s	56 days	9/23/97	1625.4	1622.8	10080	802	
2.5% Lime/97.5% PC Agg	8PClm-s	56 days	9/23/97	1591.4	1589.0	7500	597	667
2.5% Lime/97.5% PC Agg	9PClm-s	56 days	9/23/97	1567.6	1561.5	7560	602	
10% PC Fly Ash/90% PC Agg	1PCfa10s	7 days	8/11/97	1584.6	1582.3	910	72	
10% PC Fly Ash/90% PC Agg	2PCfa10s	7 days	8/11/97	1599.7	1596.9	970	77	71
10% PC Fly Ash/90% PC Agg	3PCfa10s	7 days	8/11/97	1590.2	1586.6	810	64	
10% PC Fly Ash/90% PC Agg	4PCfa10s	28 days	9/1/97	1633.9	1631.0	1470	117	
10% PC Fly Ash/90% PC Agg	5PCfa10s	28 days	9/1/97	1581.6	1578.0	1180	94	106
10% PC Fly Ash/90% PC Agg	6PCfa10s	28 days	9/1/97	1616.9	1614.0	1330	106	
10% PC Fly Ash/90% PC Agg	7PCfa10s	56 days	9/29/97	1583.7	1577.7	1570	125	
10% PC Fly Ash/90% PC Agg	8PCfa10s	56 days	9/29/97	1624.4	1619.4	1580	126	131
10% PC Fly Ash/90% PC Agg	9PCfa10s	56 days	9/29/97	1596.8	1593.5	1790	142	

Strength Gain Tests - 7, 28, & 56 Day Sealed Cure - Sheet 2

Sample Type	Sample #	Cure Time	Break Date	Wt. 0 Day (g)	Wt. Break Day (g)	Load (lb)	Stress (psi)	Avg. Stress (psi)
100% Ottumwa Agg	1OT100s	7 days	8/11/97	1701.1	1700.2	320	25	
100% Ottumwa Agg	2OT100s	7 days	8/11/97	1681.9	1681.1	450	36	31
100% Ottumwa Agg	3OT100s	7 days	8/11/97	1703.5	1702.3	390	31	
100% Ottumwa Agg	4OT100s	28 days	9/1/97	1701.2	1699.0	630	50	
100% Ottumwa Agg	5OT100s	28 days	9/1/97	1698.4	1695.8	520	41	48
100% Ottumwa Agg	6OT100s	28 days	9/1/97	1687.6	1685.5	670	53	
100% Ottumwa Agg	7OT100s	56 days	9/29/97	1682.2	1678.7	860	68	
100% Ottumwa Agg	8OT100s	56 days	9/29/97	1681.8	1677.9	930	74	68
100% Ottumwa Agg	9OT100s	56 days	9/29/97	1692.3	1688.4	780	62	
100% Coucil Bluffs Agg	1CB100s	7 days	8/14/97	1625.9	1625.8	620	49	
100% Coucil Bluffs Agg	2CB100s	7 days	8/14/97	1602.4	1601.9	680	54	51
100% Coucil Bluffs Agg	3CB100s	7 days	8/14/97	1610.4	1610.0	630	50	
100% Coucil Bluffs Agg	4CB100s	28 days	9/4/97	1603.3	1602.2	870	69	
100% Coucil Bluffs Agg	5CB100s	28 days	9/4/97	1605.1	1603.8	940	75	75
100% Coucil Bluffs Agg	6CB100s	28 days	9/4/97	1612.4	1609.8	1010	80	
100% Coucil Bluffs Agg	7CB100s	56 days	10/2/97	1620.2	1614.7	1090	87	
100% Coucil Bluffs Agg	8CB100s	56 days	10/2/97	1612.8	1609.2	1220	97	91
100% Coucil Bluffs Agg	9CB100s	56 days	10/2/97	1612.7	1609.3	1120	89	
100% Neal 3 Agg	1N3-100s	7 days	8/13/97	1451.1	1449.1	380	30	
100% Neal 3 Agg	2N3-100s	7 days	8/13/97	1431.4	1425.7	290	23	28
100% Neal 3 Agg	3N3-100s	7 days	8/13/97	1461.7	1459.4	370	29	
100% Neal 3 Agg	4N3-100s	28 days	9/3/97	1435.1	1432.0	360	29	
100% Neal 3 Agg	5N3-100s	28 days	9/3/97	1458.6	1456.9	340	27	30
100% Neal 3 Agg	6N3-100s	28 days	9/3/97	1454.3	1451.4	430	34	
100% Neal 3 Agg	7N3-100s	56 days	10/1/97	1451.6	1447.9	460	37	
100% Neal 3 Agg	8N3-100s	56 days	10/1/97	1472.9	1468.8	470	37	37
100% Neal 3 Agg	9N3-100s	56 days	10/1/97	1449.1	1444.0	480	38	

Strength Gain Tests - 7, 28, & 56 Day Sealed Cure - Sheet 3

Sample Type	Sample #	Cure Time	Break Date	Wt. 0 Day (g)	Wt. Break Day (g)	Load (lb)	Stress (psi)	Avg. Stress (psi)
2.5% Lime/ 97.5% Ott Agg	1OTlm-s	7 days	8/12/97	1618.5	1616.9	1600	127	138
2.5% Lime/ 97.5% Ott Agg	2OTlm-s	7 days	8/12/97	1679.7	1679.1	1850	147	
2.5% Lime/ 97.5% Ott Agg	3OTlm-s	7 days	8/12/97	1656.6	1655.0	1740	138	
2.5% Lime/ 97.5% Ott Agg	4OTlm-s	28 days	9/2/97	1697.3	1696.0	3160	251	228
2.5% Lime/ 97.5% Ott Agg	5OTlm-s	28 days	9/2/97	1639.2	1637.5	2810	224	
2.5% Lime/ 97.5% Ott Agg	6OTlm-s	28 days	9/2/97	1619.3	1617.2	2610	208	
2.5% Lime/ 97.5% Ott Agg	7OTlm-s	56 days	9/30/97	1662.5	1659.7	4200	334	319
2.5% Lime/ 97.5% Ott Agg	8OTlm-s	56 days	9/30/97	1663.9	1660.7	4210	335	
2.5% Lime/ 97.5% Ott Agg	9OTlm-s	56 days	9/30/97	1629.2	1626.3	3620	288	
2.5% Lime/ 97.5% CB Agg	1CBlm-s	7 days	8/20/97	1583.9	1583.3	4840	385	376
2.5% Lime/ 97.5% CB Agg	2CBlm-s	7 days	8/20/97	1547.8	1546.1	4100	326	
2.5% Lime/ 97.5% CB Agg	3CBlm-s	7 days	8/20/97	1600.0	1599.7	5240	417	
2.5% Lime/ 97.5% CB Agg	4CBlm-s	28 days	9/10/97	1600.7	1599.3	9280	738	628
2.5% Lime/ 97.5% CB Agg	5CBlm-s	28 days	9/10/97	1555.8	1554.4	7340	584	
2.5% Lime/ 97.5% CB Agg	6CBlm-s	28 days	9/10/97	1550.5	1548.8	7040	560	
2.5% Lime/ 97.5% CB Agg	7CBlm-s	56 days	10/8/97	1578.1	1575.0	8640	688	798
2.5% Lime/ 97.5% CB Agg	8CBlm-s	56 days	10/8/97	1575.7	1573.2	10500	836	
2.5% Lime/ 97.5% CB Agg	9CBlm-s	56 days	10/8/97	1593.3	1588.4	10960	872	
2.5% Lime/ 97.5% Neal 3 Agg	1N3lm-s	7 days	8/13/97	1443.6	1443.1	2170	173	177
2.5% Lime/ 97.5% Neal 3 Agg	2N3lm-s	7 days	8/13/97	1459.4	1459.3	2190	174	
2.5% Lime/ 97.5% Neal 3 Agg	3N3lm-s	7 days	8/13/97	1472.4	1472.4	2320	185	
2.5% Lime/ 97.5% Neal 3 Agg	4N3lm-s	28 days	9/3/97	1450.0	1448.6	2340	186	197
2.5% Lime/ 97.5% Neal 3 Agg	5N3lm-s	28 days	9/3/97	1469.4	1468.4	2720	216	
2.5% Lime/ 97.5% Neal 3 Agg	6N3lm-s	28 days	9/3/97	1430.6	1428.1	2380	189	
2.5% Lime/ 97.5% Neal 3 Agg	7N3lm-s	56 days	10/1/97	1453.3	1450.8	4100	326	325
2.5% Lime/ 97.5% Neal 3 Agg	8N3lm-s	56 days	10/1/97	1448.0	1445.4	4230	337	
2.5% Lime/ 97.5% Neal 3 Agg	9N3lm-s	56 days	10/1/97	1465.3	1462.1	3930	313	

Strength Gain Tests - 7, 28, & 56 Day Sealed Cure - Sheet 4

Sample Type	Sample #	Cure Time	Break Date	Wt. 0 Day (g)	Wt. Break Day (g)	Load (lb)	Stress (psi)	Avg. Stress (psi)
10% Ott Fly Ash/90% Ott Agg	1OTfa10s	7 days	8/12/97	1620.6	1620.0	1600	127	
10% Ott Fly Ash/90% Ott Agg	2OTfa10s	7 days	8/12/97	1609.3	1608.3	1790	142	137
10% Ott Fly Ash/90% Ott Agg	3OTfa10s	7 days	8/12/97	1612.3	1610.4	1790	142	
10% Ott Fly Ash/90% Ott Agg	4OTfa10s	28 days	9/2/97	1605.2	1602.4	1420	113	
10% Ott Fly Ash/90% Ott Agg	5OTfa10s	28 days	9/2/97	1617.5	1615.1	1300	103	104
10% Ott Fly Ash/90% Ott Agg	6OTfa10s	28 days	9/2/97	1620.9	1619.1	1200	95	
10% Ott Fly Ash/90% Ott Agg	7OTfa10s	56 days	9/30/97	1600.0	1594.6	1410	112	
10% Ott Fly Ash/90% Ott Agg	8OTfa10s	56 days	9/30/97	1603.9	1601.1	1560	124	120
10% Ott Fly Ash/90% Ott Agg	9OTfa10s	56 days	9/30/97	1648.3	1645.9	1570	125	
15% Ott Fly Ash/85% Ott Agg	1OTfa15s	7 days	8/14/97	1599.7	1597.7	2100	167	
15% Ott Fly Ash/85% Ott Agg	2OTfa15s	7 days	8/14/97	1620.1	1619.2	2080	166	160
15% Ott Fly Ash/85% Ott Agg	3OTfa15s	7 days	8/14/97	1586.4	1583.5	1870	149	
15% Ott Fly Ash/85% Ott Agg	4OTfa15s	28 days	9/4/97	1613.3	1610.6	1500	119	
15% Ott Fly Ash/85% Ott Agg	5OTfa15s	28 days	9/4/97	1598.3	1595.2	1320	105	120
15% Ott Fly Ash/85% Ott Agg	6OTfa15s	28 days	9/4/97	1615.2	1612.2	1720	137	
15% Ott Fly Ash/85% Ott Agg	7OTfa15s	56 days	10/2/97	1602.5	1597.5	1550	123	
15% Ott Fly Ash/85% Ott Agg	8OTfa15s	56 days	10/2/97	1603.8	1599.3	1790	142	128
15% Ott Fly Ash/85% Ott Agg	9OTfa15s	56 days	10/2/97	1633.7	1627.6	1490	119	
20% Ott Fly Ash/80% Ott Agg	1OTfa20s	7 days	8/14/97	1554.8	1550.6	1560	124	
20% Ott Fly Ash/80% Ott Agg	2OTfa20s	7 days	8/14/97	1580.7	1579.5	2050	163	151
20% Ott Fly Ash/80% Ott Agg	3OTfa20s	7 days	8/14/97	1580.6	1578.0	2090	166	
20% Ott Fly Ash/80% Ott Agg	4OTfa20s	28 days	9/4/97	1588.2	1583.6	1550	123	
20% Ott Fly Ash/80% Ott Agg	5OTfa20s	28 days	9/4/97	1581.4	1579.2	1510	120	116
20% Ott Fly Ash/80% Ott Agg	6OTfa20s	28 days	9/4/97	1567.8	1563.0	1300	103	
20% Ott Fly Ash/80% Ott Agg	7OTfa20s	56 days	10/2/97	1568.5	1564.1	1530	122	
20% Ott Fly Ash/80% Ott Agg	8OTfa20s	56 days	10/2/97	1583.2	1579.3	1730	138	124
20% Ott Fly Ash/80% Ott Agg	9OTfa20s	56 days	10/2/97	1570.5	1565.8	1430	114	

Strength Gain Tests - 7, 28, & 56 Day Sealed Cure - Sheet 5

Sample Type	Sample #	Cure Time	Break Date	Wt. 0 Day (g)	Wt. Break Day (g)	Load (lb)	Stress (psi)	Avg. Stress (psi)
10% CB Fly Ash/90% CB Agg	1CBfa10s	7 days	8/15/97	1574.6	1573.8	2060	164	
10% CB Fly Ash/90% CB Agg	2CBfa10s	7 days	8/15/97	1510.0	1507.1	1570	125	136
10% CB Fly Ash/90% CB Agg	3CBfa10s	7 days	8/15/97	1557.7	1554.8	1490	119	
10% CB Fly Ash/90% CB Agg	4CBfa10s	28 days	9/5/97	1559.8	1556.4	2200	175	
10% CB Fly Ash/90% CB Agg	5CBfa10s	28 days	9/5/97	1526.5	1523.9	1610	128	154
10% CB Fly Ash/90% CB Agg	6CBfa10s	28 days	9/5/97	1540.1	1537.1	2000	159	
10% CB Fly Ash/90% CB Agg	7CBfa10s	56 days	10/3/97	1570.2	1566.5	2130	170	
10% CB Fly Ash/90% CB Agg	8CBfa10s	56 days	10/3/97	1592.2	1588.9	2710	216	176
10% CB Fly Ash/90% CB Agg	9CBfa10s	56 days	10/3/97	1522.6	1517.6	1810	144	
15% CB Fly Ash/85% CB Agg	1CBfa15s	7 days	8/19/97	1471.2	1467.2	1330	106	
15% CB Fly Ash/85% CB Agg	2CBfa15s	7 days	8/19/97	1530.4	1529.1	1660	132	112
15% CB Fly Ash/85% CB Agg	3CBfa15s	7 days	8/19/97	1483.6	1482.2	1220	97	
15% CB Fly Ash/85% CB Agg	4CBfa15s	28 days	9/9/97	1484.2	1479.8	1480	118	
15% CB Fly Ash/85% CB Agg	5CBfa15s	28 days	9/9/97	1496.6	1486.6	1400	111	116
15% CB Fly Ash/85% CB Agg	6CBfa15s	28 days	9/9/97	1491.7	1487.1	1510	120	
15% CB Fly Ash/85% CB Agg	7CBfa15s	56 days	10/7/97	1523.6	1519.8	2470	197	
15% CB Fly Ash/85% CB Agg	8CBfa15s	56 days	10/7/97	1523.0	1518.4	2060	164	163
15% CB Fly Ash/85% CB Agg	9CBfa15s	56 days	10/7/97	1505.2	1497.4	1620	129	
20% CB Fly Ash/80% CB Agg	1CBfa20s	7 days	8/20/97	1489.2	1482.7	1240	99	
20% CB Fly Ash/80% CB Agg	2CBfa20s	7 days	8/20/97	1447.2	1436.9	1100	88	102
20% CB Fly Ash/80% CB Agg	3CBfa20s	7 days	8/20/97	1504.5	1500.4	1520	121	
20% CB Fly Ash/80% CB Agg	4CBfa20s	28 days	9/10/97	1485.5	1478.1	1910	152	
20% CB Fly Ash/80% CB Agg	5CBfa20s	28 days	9/10/97	1461.1	1452.1	1370	109	134
20% CB Fly Ash/80% CB Agg	6CBfa20s	28 days	9/10/97	1484.0	1478.9	1760	140	
20% CB Fly Ash/80% CB Agg	7CBfa20s	56 days	10/8/97	1498.9	1488.8	1590	127	
20% CB Fly Ash/80% CB Agg	8CBfa20s	56 days	10/8/97	1507.9	1498.4	2320	185	155
20% CB Fly Ash/80% CB Agg	9CBfa20s	56 days	10/8/97	1480.2	1473.6	1940	154	

Strength Gain Tests - 7, 28, & 56 Day Sealed Cure - Sheet 6

Sample Type	Sample #	Cure Time	Break Date	Wt. 0 Day (g)	Wt. Break Day (g)	Load (lb)	Stress (psi)	Avg. Stress (psi)
10% N3 Fly Ash/90% N3 Agg	1N3fa10s	7 days	8/29/97	1666.4	1663.9	800	64	
10% N3 Fly Ash/90% N3 Agg	2N3fa10s	7 days	8/29/97	1649.3	1648.4	860	68	61
10% N3 Fly Ash/90% N3 Agg	3N3fa10s	7 days	8/29/97	1676.2	1675.2	640	51	
10% N3 Fly Ash/90% N3 Agg	4N3fa10s	28 days	9/19/97	1659.3	1656.2	1220	97	
10% N3 Fly Ash/90% N3 Agg	5N3fa10s	28 days	9/19/97	1649.2	1647.4	1180	94	91
10% N3 Fly Ash/90% N3 Agg	6N3fa10s	28 days	9/19/97	1666.5	1664.6	1040	83	
10% N3 Fly Ash/90% N3 Agg	7N3fa10s	56 days	10/17/97	1658.8	1655.2	1120	89	
10% N3 Fly Ash/90% N3 Agg	8N3fa10s	56 days	10/17/97	1668.0	1662.7	1050	84	96
10% N3 Fly Ash/90% N3 Agg	9N3fa10s	56 days	10/17/97	1668.4	1664.6	1440	115	
15% N3 Fly Ash/85% N3 Agg	1N3fa15s	7 days	9/3/97	1599.4	1597.8	1510	120	
15% N3 Fly Ash/85% N3 Agg	2N3fa15s	7 days	9/3/97	1608.7	1607.6	1080	86	112
15% N3 Fly Ash/85% N3 Agg	3N3fa15s	7 days	9/3/97	1660.4	1659.6	1620	129	
15% N3 Fly Ash/85% N3 Agg	4N3fa15s	28 days	9/24/97	1625.9	1624.1	1800	143	
15% N3 Fly Ash/85% N3 Agg	5N3fa15s	28 days	9/24/97	1656.5	1654.9	1640	131	136
15% N3 Fly Ash/85% N3 Agg	6N3fa15s	28 days	9/24/97	1618.0	1616.0	1670	133	
15% N3 Fly Ash/85% N3 Agg	7N3fa15s	56 days	10/22/97	1645.0	1641.5	2120	169	
15% N3 Fly Ash/85% N3 Agg	8N3fa15s	56 days	10/22/97	1663.9	1660.4	1960	156	163
15% N3 Fly Ash/85% N3 Agg	9N3fa15s	56 days	10/22/97	1624.8	1620.6	2050	163	
20% N3 Fly Ash/80% N3 Agg	1N3fa20s	7 days	9/11/97	1560.2	1558.6	1700	135	
20% N3 Fly Ash/80% N3 Agg	2N3fa20s	7 days	9/11/97	1539.0	1522.8	1400	111	119
20% N3 Fly Ash/80% N3 Agg	3N3fa20s	7 days	9/11/97	1554.8	1544.6	1370	109	
20% N3 Fly Ash/80% N3 Agg	4N3fa20s	28 days	10/2/97	1545.4	1534.4	1810	144	
20% N3 Fly Ash/80% N3 Agg	5N3fa20s	28 days	10/2/97	1556.4	1543.8	1630	130	141
20% N3 Fly Ash/80% N3 Agg	6N3fa20s	28 days	10/2/97	1563.1	1553.5	1860	148	
20% N3 Fly Ash/80% N3 Agg	7N3fa20s	56 days	10/30/97	1565.8	1560.1	1960	156	
20% N3 Fly Ash/80% N3 Agg	8N3fa20s	56 days	10/30/97	1569.3	1552.3	2350	187	163
20% N3 Fly Ash/80% N3 Agg	9N3fa20s	56 days	10/30/97	1550.8	1525.8	1820	145	

APPENDIX D
VOLUMETRIC STABILITY DATA

Volumetric Stability Measurements - Optimum Moisture Compacted Cylinders

15% AFBC/85% Reclaimed Ottumwa Fly Ash Aggregate Cylinders
336 day Air Cure samples

	0 Day			7 Day			14 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
1AIRafbc	4.61	4.00	57.93	4.60	4.00	57.81	4.60	4.00	57.81
2AIRafbc	4.62	4.01	58.35	4.61	4.01	58.22	4.61	4.01	58.22
3AIRafbc	4.61	4.01	58.22	4.60	4.01	58.09	4.60	4.01	58.09

	21 Day			28 Day			56 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
1AIRafbc	4.60	4.00	57.81	4.60	4.00	57.81	4.60	4.00	57.81
2AIRafbc	4.61	4.01	58.22	4.61	4.01	58.22	4.61	4.01	58.22
3AIRafbc	4.60	4.01	58.09	4.60	4.01	58.09	4.60	4.01	58.09

	84 Day			168 Day			252 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
1AIRafbc	4.60	4.00	57.81	4.60	4.00	57.81	4.60	4.00	57.81
2AIRafbc	4.61	4.01	58.22	4.61	4.01	58.22	4.61	4.01	58.22
3AIRafbc	4.60	4.01	58.09	4.60	4.01	58.09	4.60	4.01	58.09

	336 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)
1AIRafbc	4.60	4.00	57.81
2AIRafbc	4.61	4.01	58.22
3AIRafbc	4.60	4.01	58.09

Volumetric Stability Measurements - Optimum Moisture Compacted Cylinders

15% AFBC/85% Reclaimed Ottumwa Fly Ash Aggregate Cylinders
336 day Soaked Cure samples

	0 Day			7 Day			14 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
1SOAKafbc	4.61	4.02	58.51	4.61	4.02	58.51	4.61	4.02	58.51
2SOAKafbc	4.62	4.02	58.64	4.63	4.02	58.77	4.63	4.02	58.77
3SOAKafbc	4.61	4.01	58.22	4.61	4.02	58.51	4.61	4.02	58.51

	21 Day			28 Day			56 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
1SOAKafbc	4.61	4.02	58.51	4.61	4.02	58.51	4.61	4.02	58.51
2SOAKafbc	4.63	4.02	58.77	4.63	4.02	58.77	4.63	4.02	58.77
3SOAKafbc	4.61	4.02	58.51	4.61	4.02	58.51	4.61	4.02	58.51

	84 Day			168 Day			252 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
1SOAKafbc	4.61	4.02	58.51	4.61	4.02	58.51	4.61	4.02	58.51
2SOAKafbc	4.63	4.02	58.77	4.63	4.02	58.77	4.63	4.02	58.77
3SOAKafbc	4.61	4.02	58.51	4.61	4.02	58.51	4.61	4.02	58.51

	336 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)
1SOAKafbc	4.61	4.02	58.51
2SOAKafbc	4.63	4.02	58.77
3SOAKafbc	4.61	4.02	58.51

Volumetric Stability Measurements - Optimum Moisture Compacted Cylinders

15% AFBC/85% Reclaimed Ottumwa Fly Ash Aggregate Cylinders
336 day Humid Cure samples

	0 Day			7 Day			14 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
1HUMafbc	4.62	4.01	58.35	4.62	4.02	58.64	4.62	4.02	58.64
2HUMafbc	4.61	4.02	58.51	4.62	4.02	58.64	4.62	4.02	58.64
3HUMafbc	4.61	4.01	58.22	4.61	4.02	58.51	4.61	4.02	58.51

	21 Day			28 Day			56 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
1HUMafbc	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.02	58.64
2HUMafbc	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.02	58.64
3HUMafbc	4.61	4.02	58.51	4.61	4.02	58.51	4.61	4.02	58.51

	84 Day			168 Day			252 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
1HUMafbc	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.02	58.64
2HUMafbc	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.02	58.64
3HUMafbc	4.61	4.02	58.51	4.61	4.02	58.51	4.61	4.02	58.51

	336 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)
1HUMafbc	4.62	4.02	58.64
2HUMafbc	4.62	4.02	58.64
3HUMafbc	4.61	4.02	58.51

Volumetric Stability Measurements - Optimum Moisture Compacted Cylinders

10% CKD/90% Reclaimed Ottumwa Fly Ash Aggregate Cylinders
336 day Air Cure samples

	0 Day			7 Day			14 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
1AIRckd	4.62	4.02	58.64	4.62	4.01	58.35	4.62	4.01	58.35
2AIRckd	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.01	58.35
3AIRckd	4.61	4.02	58.51	4.62	4.01	58.35	4.62	4.01	58.35

	21 Day			28 Day			56 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
1AIRckd	4.62	4.01	58.35	4.62	4.01	58.35	4.62	4.01	58.35
2AIRckd	4.62	4.01	58.35	4.62	4.01	58.35	4.62	4.01	58.35
3AIRckd	4.62	4.01	58.35	4.62	4.01	58.35	4.62	4.01	58.35

	84 Day			168 Day			252 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
1AIRckd	4.62	4.01	58.35	4.62	4.01	58.35	4.62	4.01	58.35
2AIRckd	4.62	4.01	58.35	4.62	4.01	58.35	4.62	4.01	58.35
3AIRckd	4.62	4.01	58.35	4.62	4.01	58.35	4.62	4.01	58.35

	336 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)
1AIRckd	4.62	4.01	58.35
2AIRckd	4.62	4.01	58.35
3AIRckd	4.62	4.01	58.35

Volumetric Stability Measurements - Optimum Moisture Compacted Cylinders

10% CKD/90% Reclaimed Ottumwa Fly Ash Aggregate Cylinders
336 day Soaked Cure samples

	0 Day			7 Day			14 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
1SOAKckd	4.62	4.02	58.64	4.63	4.02	58.77	4.63	4.02	58.77
2SOAKckd	4.62	4.02	58.64	4.62	4.03	58.93	4.62	4.03	58.93
3SOAKckd	4.62	4.01	58.35	4.63	4.02	58.77	4.63	4.02	58.77

	21 Day			28 Day			56 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
1SOAKckd	4.63	4.02	58.77	4.63	4.02	58.77	4.63	4.02	58.77
2SOAKckd	4.62	4.03	58.93	4.62	4.03	58.93	4.62	4.03	58.93
3SOAKckd	4.63	4.02	58.77	4.63	4.02	58.77	4.63	4.02	58.77

	84 Day			168 Day			252 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
1SOAKckd	4.63	4.02	58.77	4.63	4.02	58.77	4.63	4.02	58.77
2SOAKckd	4.62	4.03	58.93	4.62	4.03	58.93	4.62	4.03	58.93
3SOAKckd	4.63	4.02	58.77	4.63	4.02	58.77	4.63	4.02	58.77

	336 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)
1SOAKckd	4.63	4.02	58.77
2SOAKckd	4.62	4.03	58.93
3SOAKckd	4.63	4.02	58.77

Volumetric Stability Measurements - Optimum Moisture Compacted Cylinders

10% CKD/90% Reclaimed Ottumwa Fly Ash Aggregate Cylinders
336 day Humid Cure samples

	0 Day			7 Day			14 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
1HUMckd	4.60	4.02	58.38	4.62	4.02	58.64	4.62	4.02	58.64
2HUMckd	4.62	4.02	58.64	4.62	4.03	58.93	4.62	4.03	58.93
3HUMckd	4.61	4.02	58.51	4.62	4.02	58.64	4.62	4.02	58.64

	21 Day			28 Day			56 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
1HUMckd	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.02	58.64
2HUMckd	4.62	4.03	58.93	4.62	4.03	58.93	4.62	4.03	58.93
3HUMckd	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.02	58.64

	84 Day			168 Day			252 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
1HUMckd	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.02	58.64
2HUMckd	4.62	4.03	58.93	4.62	4.03	58.93	4.62	4.03	58.93
3HUMckd	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.02	58.64

	336 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)
1HUMckd	4.62	4.02	58.64
2HUMckd	4.62	4.03	58.93
3HUMckd	4.62	4.02	58.64

Volumetric Stability Measurements - Dry Compacted Cylinders

15% AFBC/85% Reclaimed Ottumwa Fly Ash Aggregate Cylinders
336 day Air Cure samples

	0 Day			7 Day			14 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
4AIRafbc	4.62	4.01	58.35	4.61	4.00	57.93	4.61	4.00	57.93
5AIRafbc	4.61	4.02	58.51	4.61	4.01	58.22	4.61	4.01	58.22
6AIRafbc	4.61	4.01	58.22	4.60	4.01	58.09	4.60	4.01	58.09

	21 Day			28 Day			56 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
4AIRafbc	4.61	4.00	57.93	4.61	4.00	57.93	4.61	4.00	57.93
5AIRafbc	4.61	4.01	58.22	4.61	4.01	58.22	4.61	4.01	58.22
6AIRafbc	4.60	4.01	58.09	4.60	4.01	58.09	4.60	4.01	58.09

	84 Day			168 Day			252 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
4AIRafbc	4.61	4.00	57.93	4.61	4.00	57.93	4.61	4.00	57.93
5AIRafbc	4.61	4.01	58.22	4.61	4.01	58.22	4.61	4.01	58.22
6AIRafbc	4.60	4.01	58.09	4.60	4.01	58.09	4.60	4.01	58.09

	336 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)
4AIRafbc	4.61	4.00	57.93
5AIRafbc	4.61	4.01	58.22
6AIRafbc	4.60	4.01	58.09

Volumetric Stability Measurements - Dry Compacted Cylinders

15% AFBC/85% Reclaimed Ottumwa Fly Ash Aggregate Cylinders
336 day Soaked Cure samples

	0 Day			7 Day			14 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
4SOAKafbc	4.61	4.02	58.51	4.61	4.02	58.51	4.61	4.02	58.51
5SOAKafbc	4.63	4.02	58.77	4.64	4.02	58.89	4.64	4.02	58.89
6SOAKafbc	4.61	4.01	58.22	4.62	4.01	58.35	4.62	4.01	58.35

	21 Day			28 Day			56 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
4SOAKafbc	4.61	4.02	58.51	4.61	4.02	58.51	4.61	4.02	58.51
5SOAKafbc	4.64	4.02	58.89	4.64	4.02	58.89	4.64	4.02	58.89
6SOAKafbc	4.62	4.01	58.35	4.62	4.01	58.35	4.62	4.01	58.35

	84 Day			168 Day			252 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
4SOAKafbc	4.61	4.02	58.51	4.61	4.02	58.51	4.61	4.02	58.51
5SOAKafbc	4.64	4.02	58.89	4.64	4.02	58.89	4.64	4.02	58.89
6SOAKafbc	4.62	4.01	58.35	4.62	4.01	58.35	4.62	4.01	58.35

	336 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)
4SOAKafbc	4.61	4.02	58.51
5SOAKafbc	4.64	4.02	58.89
6SOAKafbc	4.62	4.01	58.35

Volumetric Stability Measurements - Dry Compacted Cylinders

15% AFBC/85% Reclaimed Ottumwa Fly Ash Aggregate Cylinders
336 day Humid Cure samples

	0 Day			7 Day			14 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
4HUMafbc	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.02	58.64
5HUMafbc	4.61	4.01	58.22	4.62	4.02	58.64	4.62	4.01	58.35
6HUMafbc	4.61	4.01	58.22	4.61	4.02	58.51	4.61	4.02	58.51

	21 Day			28 Day			56 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
4HUMafbc	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.02	58.64
5HUMafbc	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.02	58.64
6HUMafbc	4.61	4.02	58.51	4.61	4.02	58.51	4.61	4.02	58.51

	84 Day			168 Day			252 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
4HUMafbc	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.02	58.64
5HUMafbc	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.02	58.64
6HUMafbc	4.61	4.02	58.51	4.61	4.02	58.51	4.61	4.02	58.51

	336 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)
4HUMafbc	4.62	4.02	58.64
5HUMafbc	4.62	4.02	58.64
6HUMafbc	4.61	4.02	58.51

Volumetric Stability Measurements - Dry Compacted Cylinders

10% CKD/90% Reclaimed Ottumwa Fly Ash Aggregate Cylinders
336 day Air Cure samples

	0 Day			7 Day			14 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
4AIRckd	4.62	4.02	58.64	4.62	4.01	58.35	4.62	4.01	58.35
5AIRckd	4.62	4.02	58.64	4.62	4.02	58.64	4.61	4.01	58.22
6AIRckd	4.63	4.01	58.47	4.62	4.01	58.35	4.62	4.01	58.35

	21 Day			28 Day			56 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
4AIRckd	4.62	4.01	58.35	4.62	4.01	58.35	4.62	4.01	58.35
5AIRckd	4.61	4.01	58.22	4.61	4.01	58.22	4.61	4.01	58.22
6AIRckd	4.62	4.01	58.35	4.62	4.01	58.35	4.62	4.01	58.35

	84 Day			168 Day			252 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
4AIRckd	4.62	4.01	58.35	4.62	4.01	58.35	4.62	4.01	58.35
5AIRckd	4.61	4.01	58.22	4.61	4.01	58.22	4.61	4.01	58.22
6AIRckd	4.62	4.01	58.35	4.62	4.01	58.35	4.62	4.01	58.35

	336 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)
4AIRckd	4.62	4.01	58.35
5AIRckd	4.61	4.01	58.22
6AIRckd	4.62	4.01	58.35

Volumetric Stability Measurements - Dry Compacted Cylinders

10% CKD/90% Reclaimed Ottumwa Fly Ash Aggregate Cylinders
336 day Soaked Cure samples

	0 Day			7 Day			14 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
4SOAKckd	4.62	4.02	58.64	4.63	4.02	58.77	4.62	4.02	58.64
5SOAKckd	4.61	4.02	58.51	4.62	4.02	58.64	4.62	4.02	58.64
6SOAKckd	4.63	4.01	58.47	4.63	4.02	58.77	4.63	4.02	58.77

	21 Day			28 Day			56 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
4SOAKckd	4.63	4.02	58.77	4.63	4.02	58.77	4.63	4.02	58.77
5SOAKckd	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.02	58.64
6SOAKckd	4.63	4.02	58.77	4.63	4.02	58.77	4.63	4.02	58.77

	84 Day			168 Day			252 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
4SOAKckd	4.63	4.02	58.77	4.63	4.02	58.77	4.63	4.02	58.77
5SOAKckd	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.02	58.64
6SOAKckd	4.63	4.02	58.77	4.63	4.02	58.77	4.63	4.02	58.77

	336 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)
4SOAKckd	4.63	4.02	58.77
5SOAKckd	4.62	4.02	58.64
6SOAKckd	4.63	4.02	58.77

Volumetric Stability Measurements - Dry Compacted Cylinders

10% CKD/90% Reclaimed Ottumwa Fly Ash Aggregate Cylinders
336 day Humid Cure samples

	0 Day			7 Day			14 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
4HUMckd	4.62	4.02	58.64	4.63	4.02	58.77	4.63	4.02	58.77
5HUMckd	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.02	58.64
6HUMckd	4.62	4.01	58.35	4.63	4.01	58.47	4.63	4.02	58.77

	21 Day			28 Day			56 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
4HUMckd	4.63	4.02	58.77	4.63	4.02	58.77	4.63	4.02	58.77
5HUMckd	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.02	58.64
6HUMckd	4.63	4.02	58.77	4.63	4.02	58.77	4.63	4.02	58.77

	84 Day			168 Day			252 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)	Height (in)	Diameter (in)	Volume (in^3)
4HUMckd	4.63	4.02	58.77	4.63	4.02	58.77	4.63	4.02	58.77
5HUMckd	4.62	4.02	58.64	4.62	4.02	58.64	4.62	4.02	58.64
6HUMckd	4.63	4.02	58.77	4.63	4.02	58.77	4.63	4.02	58.77

	336 Day		
Sample	Height (in)	Diameter (in)	Volume (in^3)
4HUMckd	4.63	4.02	58.77
5HUMckd	4.62	4.02	58.64
6HUMckd	4.63	4.02	58.77

Volumetric Stability of Fly Ash - 2 inch cube samples

			12/4/97	(0 days)				12/11/97	(7 days)			
Sample Type	Cure	Sample #	Height (1)	Length (2)	Width (3)	Volume (in^3)	Weight (g)	Height (1)	Length (2)	Width (3)	Volume (in^3)	Weight (g)
Council Bluffs Fly Ash	Air	10	2.024	2.012	2.024	8.242	266.1	2.027	2.012	2.024	8.255	229.1
Council Bluffs Fly Ash	100% Humidity	11	2.010	2.029	2.009	8.193	265.2	2.010	2.032	2.010	8.209	269.1
Council Bluffs Fly Ash	Soaked	12	2.032	2.015	2.005	8.209	264.3	2.027	2.022	2.008	8.230	268.7
Neal 3 Fly Ash	Air	13	2.007	1.995	2.025	8.108	250.0	2.010	1.996	2.027	8.132	204.1
Neal 3 Fly Ash	100% Humidity	14	2.006	2.018	2.005	8.116	250.5	2.010	2.020	2.010	8.161	252.7
Neal 3 Fly Ash	Soaked	15	2.014	2.022	1.996	8.128	249.5	2.021	2.026	2.001	8.193	251.9
Ottumwa Fly Ash	Air	16	1.996	2.007	2.020	8.092	246.6	1.995	2.012	2.022	8.116	212.6
Ottumwa Fly Ash	100% Humidity	17	1.985	2.002	2.010	7.988	243.8	1.986	2.004	2.011	8.004	255.6
Ottumwa Fly Ash	Soaked	18	2.007	2.027	2.003	8.149	246.3	1.999	2.030	2.006	8.140	257.4
Prairie Creek Fly Ash	Air	19	2.003	2.031	2.005	8.157	248.0	2.002	2.032	2.005	8.156	212.0
Prairie Creek Fly Ash	100% Humidity	20	2.004	2.024	2.012	8.161	248.1	2.007	2.026	2.016	8.197	257.9
Prairie Creek Fly Ash	Soaked	21	2.033	2.007	2.031	8.287	249.9	2.033	2.008	2.032	8.295	260.4

			12/18/97	(14 days)				12/23/97	(21 days)			
Sample Name	Cure	Sample #	Height (1)	Length (2)	Width (3)	Volume (in^3)	Weight (g)	Height (1)	Length (2)	Width (3)	Volume (in^3)	Weight (g)
Council Bluffs Fly Ash	Air	10	2.025	2.013	2.022	8.242	229.1	2.024	2.012	2.023	8.238	229.0
Council Bluffs Fly Ash	100% Humidity	11	2.011	2.031	2.010	8.210	269.5	2.011	2.031	2.011	8.214	269.7
Council Bluffs Fly Ash	Soaked	12	2.028	2.020	2.009	8.230	270.7	2.029	2.020	2.009	8.234	273.0
Neal 3 Fly Ash	Air	13	2.009	1.999	2.024	8.128	204.2	2.008	2.000	2.025	8.132	204.1
Neal 3 Fly Ash	100% Humidity	14	2.008	2.021	2.009	8.153	253.5	2.010	2.021	2.010	8.165	253.7
Neal 3 Fly Ash	Soaked	15	2.023	2.028	2.003	8.218	252.6	2.020	2.027	2.004	8.205	252.9
Ottumwa Fly Ash	Air	16	1.996	2.010	2.022	8.112	212.6	1.995	2.011	2.023	8.116	212.5
Ottumwa Fly Ash	100% Humidity	17	1.986	2.005	2.010	8.004	256.1	1.985	2.004	2.011	8.000	256.4
Ottumwa Fly Ash	Soaked	18	2.001	2.032	2.008	8.165	258.5	2.002	2.033	2.008	8.173	258.8
Prairie Creek Fly Ash	Air	19	2.000	2.030	2.005	8.140	211.9	2.001	2.031	2.004	8.144	211.8
Prairie Creek Fly Ash	100% Humidity	20	2.007	2.026	2.014	8.189	258.8	2.008	2.027	2.014	8.197	259.2
Prairie Creek Fly Ash	Soaked	21	2.035	2.011	2.033	8.320	261.0	2.034	2.011	2.033	8.316	261.2

Volumetric Stability of Fly Ash - 2 inch cube samples

			12/31/97	(28 days)				1/12/98	(35 days)			
Sample Type	Cure	Sample #	Height (1)	Length (2)	Width (3)	Volume (in^3)	Weight (g)	Height (1)	Length (2)	Width (3)	Volume (in^3)	Weight (g)
Council Bluffs Fly Ash	Air	10	2.024	2.012	2.022	8.234	229.0	2.022	2.011	2.022	8.222	229.0
Council Bluffs Fly Ash	100% Humidity	11	2.011	2.028	2.010	8.197	269.9	2.010	2.029	2.010	8.197	270.0
Council Bluffs Fly Ash	Soaked	12	2.031	2.021	2.011	8.255	274.7	2.031	2.021	2.012	8.259	275.4
Neal 3 Fly Ash	Air	13	2.008	1.999	2.025	8.128	204.0	2.006	1.998	2.025	8.116	204.0
Neal 3 Fly Ash	100% Humidity	14	2.009	2.020	2.011	8.161	254.0	2.008	2.021	2.010	8.157	254.3
Neal 3 Fly Ash	Soaked	15	2.022	2.031	2.006	8.238	253.5	2.022	2.030	2.006	8.234	254.1
Ottumwa Fly Ash	Air	16	1.995	2.012	2.022	8.116	212.5	1.996	2.009	2.021	8.104	212.5
Ottumwa Fly Ash	100% Humidity	17	1.985	2.004	2.011	8.000	256.8	1.986	2.004	2.010	8.000	257.2
Ottumwa Fly Ash	Soaked	18	2.002	2.033	2.009	8.177	259.6	2.001	2.033	2.010	8.177	260.0
Prairie Creek Fly Ash	Air	19	2.000	2.031	2.005	8.144	211.6	1.999	2.030	2.003	8.128	211.6
Prairie Creek Fly Ash	100% Humidity	20	2.006	2.026	2.014	8.185	259.5	2.007	2.026	2.014	8.189	259.9
Prairie Creek Fly Ash	Soaked	21	2.035	2.009	2.033	8.312	261.5	2.035	2.009	2.034	8.316	261.9

			1/15/98	(42 days)				1/22/98	(49 days)			
Sample Name	Cure	Sample #	Height (1)	Length (2)	Width (3)	Volume (in^3)	Weight (g)	Height (1)	Length (2)	Width (3)	Volume (in^3)	Weight (g)
Council Bluffs Fly Ash	Air	10	2.023	2.010	2.022	8.222	228.9	2.024	2.009	2.022	8.222	228.9
Council Bluffs Fly Ash	100% Humidity	11	2.010	2.029	2.010	8.197	270.0	2.009	2.029	2.010	8.193	269.9
Council Bluffs Fly Ash	Soaked	12	2.030	2.021	2.012	8.254	275.4	2.030	2.020	2.012	8.250	275.5
Neal 3 Fly Ash	Air	13	2.007	1.998	2.023	8.112	204.0	2.007	1.998	2.023	8.112	204.0
Neal 3 Fly Ash	100% Humidity	14	2.008	2.021	2.010	8.157	254.3	2.007	2.021	2.010	8.153	254.2
Neal 3 Fly Ash	Soaked	15	2.021	2.030	2.007	8.234	253.9	2.021	2.030	2.007	8.234	254.0
Ottumwa Fly Ash	Air	16	1.995	2.008	2.021	8.096	212.4	1.994	2.008	2.021	8.092	212.4
Ottumwa Fly Ash	100% Humidity	17	1.986	2.003	2.010	7.996	257.2	1.985	2.003	2.011	7.996	256.9
Ottumwa Fly Ash	Soaked	18	2.002	2.033	2.010	8.181	260.2	2.001	2.033	2.010	8.177	260.4
Prairie Creek Fly Ash	Air	19	1.999	2.029	2.002	8.120	211.4	1.999	2.029	2.003	8.124	211.5
Prairie Creek Fly Ash	100% Humidity	20	2.007	2.026	2.014	8.189	260.0	2.007	2.025	2.014	8.185	259.9
Prairie Creek Fly Ash	Soaked	21	2.034	2.010	2.035	8.320	261.9	2.034	2.008	2.035	8.311	262.0

Volumetric Stability of Fly Ash - 2 inch cube samples

			1/30/98	(56 days)				2/6/98	(63 days)			
Sample Name	Cure	Sample #	Height (1)	Length (2)	Width (3)	Volume (in^3)	Weight (g)	Height (1)	Length (2)	Width (3)	Volume (in^3)	Weight (g)
Council Bluffs Fly Ash	Air	10	2.023	2.008	2.023	8.218	228.9	2.023	2.008	2.022	8.214	228.9
Council Bluffs Fly Ash	100% Humidity	11	2.010	2.029	2.010	8.197	270.0	2.010	2.029	2.010	8.197	270.1
Council Bluffs Fly Ash	Soaked	12	2.030	2.019	2.012	8.246	275.7	2.030	2.019	2.012	8.246	275.9
Neal 3 Fly Ash	Air	13	2.006	1.998	2.024	8.112	204.0	2.006	1.998	2.024	8.112	203.9
Neal 3 Fly Ash	100% Humidity	14	2.007	2.021	2.010	8.153	254.3	2.007	2.021	2.010	8.153	254.5
Neal 3 Fly Ash	Soaked	15	2.021	2.029	2.007	8.230	254.2	2.020	2.029	2.007	8.226	254.2
Ottumwa Fly Ash	Air	16	1.994	2.008	2.020	8.088	212.4	1.994	2.008	2.020	8.088	212.4
Ottumwa Fly Ash	100% Humidity	17	1.985	2.003	2.011	7.996	257.0	1.985	2.003	2.011	7.996	257.2
Ottumwa Fly Ash	Soaked	18	2.002	2.033	2.010	8.181	260.6	2.002	2.033	2.010	8.181	260.6
Prairie Creek Fly Ash	Air	19	1.999	2.029	2.003	8.124	211.5	1.998	2.029	2.002	8.116	211.5
Prairie Creek Fly Ash	100% Humidity	20	2.007	2.026	2.014	8.189	259.8	2.007	2.026	2.014	8.189	259.8
Prairie Creek Fly Ash	Soaked	21	2.034	2.008	2.035	8.311	262.1	2.034	2.008	2.035	8.311	262.2

			2/13/98	70 days				2/20/98	(77 days)			
Sample Name	Cure	Sample #	Height (1)	Length (2)	Width (3)	Volume (in^3)	Weight (g)	Height (1)	Length (2)	Width (3)	Volume (in^3)	Weight (g)
Council Bluffs Fly Ash	Air	10	2.023	2.008	2.022	8.214	229.0	2.023	2.008	2.022	8.214	229.0
Council Bluffs Fly Ash	100% Humidity	11	2.010	2.029	2.010	8.197	270.2	2.010	2.030	2.010	8.201	270.2
Council Bluffs Fly Ash	Soaked	12	2.030	2.019	2.012	8.246	276.4	2.030	2.019	2.012	8.246	276.4
Neal 3 Fly Ash	Air	13	2.006	1.998	2.024	8.112	203.9	2.006	1.998	2.024	8.112	204.0
Neal 3 Fly Ash	100% Humidity	14	2.007	2.021	2.010	8.153	254.6	2.007	2.021	2.010	8.153	254.6
Neal 3 Fly Ash	Soaked	15	2.020	2.029	2.006	8.222	254.4	2.020	2.029	2.006	8.222	254.5
Ottumwa Fly Ash	Air	16	1.994	2.008	2.020	8.088	212.4	1.994	2.008	2.020	8.088	212.4
Ottumwa Fly Ash	100% Humidity	17	1.985	2.003	2.011	7.996	257.5	1.985	2.003	2.011	7.996	257.5
Ottumwa Fly Ash	Soaked	18	2.002	2.033	2.010	8.181	260.9	2.002	2.033	2.010	8.181	261.0
Prairie Creek Fly Ash	Air	19	1.997	2.029	2.002	8.112	211.6	1.997	2.029	2.002	8.112	211.9
Prairie Creek Fly Ash	100% Humidity	20	2.007	2.025	2.014	8.185	260.3	2.007	2.025	2.014	8.185	260.4
Prairie Creek Fly Ash	Soaked	21	2.034	2.008	2.035	8.311	262.4	2.034	2.008	2.035	8.311	262.7

Volumetric Stability of Fly Ash - 2 inch cube samples

			2/27/98	(84 days)				3/6/98	(91 days)			
Sample Name	Cure	Sample #	Height (1)	Length (2)	Width (3)	Volume (in^3)	Weight (g)	Height (1)	Length (2)	Width (3)	Volume (in^3)	Weight (g)
Council Bluffs Fly Ash	Air	10	2.023	2.008	2.022	8.214	229.0	2.023	2.007	2.022	8.210	228.9
Council Bluffs Fly Ash	100% Humidity	11	2.010	2.030	2.010	8.201	270.2	2.010	2.030	2.010	8.201	270.2
Council Bluffs Fly Ash	Soaked	12	2.030	2.019	2.012	8.246	276.5	2.030	2.019	2.012	8.246	276.5
Neal 3 Fly Ash	Air	13	2.006	1.998	2.024	8.112	204.0	2.006	1.998	2.024	8.112	203.8
Neal 3 Fly Ash	100% Humidity	14	2.007	2.021	2.010	8.153	254.6	2.007	2.021	2.010	8.153	254.7
Neal 3 Fly Ash	Soaked	15	2.020	2.029	2.006	8.222	254.7	2.020	2.029	2.006	8.222	254.8
Ottumwa Fly Ash	Air	16	1.994	2.008	2.020	8.088	212.4	1.994	2.008	2.020	8.088	212.4
Ottumwa Fly Ash	100% Humidity	17	1.985	2.003	2.011	7.996	257.5	1.985	2.003	2.011	7.996	257.6
Ottumwa Fly Ash	Soaked	18	2.002	2.033	2.010	8.181	261.2	2.002	2.033	2.010	8.181	261.3
Prairie Creek Fly Ash	Air	19	1.997	2.029	2.002	8.112	211.6	1.997	2.029	2.002	8.112	211.6
Prairie Creek Fly Ash	100% Humidity	20	2.007	2.025	2.014	8.185	260.3	2.007	2.025	2.014	8.185	260.5
Prairie Creek Fly Ash	Soaked	21	2.034	2.008	2.035	8.311	262.7	2.034	2.008	2.035	8.311	262.8

			3/13/98	(98 days)				3/20/98	(105 days)			
Sample Name	Cure	Sample #	Height (1)	Length (2)	Width (3)	Volume (in^3)	Weight (g)	Height (1)	Length (2)	Width (3)	Volume (in^3)	Weight (g)
Council Bluffs Fly Ash	Air	10	2.023	2.007	2.022	8.210	228.8	2.023	2.007	2.022	8.210	228.9
Council Bluffs Fly Ash	100% Humidity	11	2.010	2.030	2.010	8.201	268.3	2.010	2.030	2.010	8.201	270.2
Council Bluffs Fly Ash	Soaked	12	2.030	2.019	2.012	8.246	276.7	2.030	2.019	2.012	8.246	276.7
Neal 3 Fly Ash	Air	13	2.006	1.998	2.024	8.112	203.8	2.006	1.998	2.024	8.112	203.7
Neal 3 Fly Ash	100% Humidity	14	2.007	2.021	2.010	8.153	254.1	2.007	2.021	2.010	8.153	254.7
Neal 3 Fly Ash	Soaked	15	2.020	2.029	2.006	8.222	255.0	2.020	2.029	2.006	8.222	255.1
Ottumwa Fly Ash	Air	16	1.994	2.008	2.020	8.088	212.4	1.994	2.008	2.020	8.088	212.4
Ottumwa Fly Ash	100% Humidity	17	1.985	2.003	2.011	7.996	256.1	1.985	2.003	2.011	7.996	257.4
Ottumwa Fly Ash	Soaked	18	2.002	2.033	2.010	8.181	261.4	2.002	2.033	2.010	8.181	261.5
Prairie Creek Fly Ash	Air	19	1.997	2.029	2.002	8.112	211.5	1.997	2.029	2.002	8.112	211.6
Prairie Creek Fly Ash	100% Humidity	20	2.007	2.025	2.014	8.185	258.1	2.007	2.025	2.014	8.185	260.6
Prairie Creek Fly Ash	Soaked	21	2.034	2.008	2.035	8.311	263.0	2.034	2.008	2.035	8.311	263.0

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