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**FIELD-TEST PROGRAMS OF POTENTIAL USES FOR
RESIDUE FROM FLUIDIZED-BED-COMBUSTION BOILERS**

Experimental Road Base, Columbus, Ohio; Production
of Synthetic Aggregate

Technical Progress Report

January 1982

Work Performed Under Contract No. AC21-77ET10415

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FIELD-TEST PROGRAMS OF POTENTIAL USES FOR
RESIDUE FROM FLUIDIZED-BED-COMBUSTION BOILERS

TECHNICAL PROGRESS REPORT

- EXPERIMENTAL ROAD BASE - COLUMBUS, OHIO
- PRODUCTION OF SYNTHETIC AGGREGATE

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WORK PERFORMED UNDER CONTRACTS WITH
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INTRODUCTION

The information presented in this report relates to several field tests undertaken to determine the feasibility of applying results of research studies conducted on residuals from atmospheric fluidized bed (AFB) boilers.¹ The primary purpose of this investigation is to evaluate AFB waste for potential commercial uses.

Based on these studies, it has been established that two applications show promise in the areas of stabilized base pavement construction and in the production of synthetic aggregates. Both of these developments are based on the use of the AFB residue with pulverized coal fly ash. It has been determined that mixtures using these two materials form cementitious products ideally suited for construction applications.

In the case of road base, the AFB/pulverized coal fly ash mixtures serve as a replacement for other cementitious matrixes in stabilizing road aggregate. In addition, the mixture can be compacted into ingots or brick shapes which can be cured under ambient conditions to provide a coarse aggregate that can be stockpiled for future use. Crushing of the hardened shapes can be readily accomplished using conventional crushing and screening operations to produce aggregates meeting highway specifications.

This report describes initial tests using full scale production equipment procedures to confirm the findings of the research investigation. The field programs were supported jointly by the US Department of Energy¹ and the Appalachian Regional Commission². In addition, the Ohio Department of Transportation provided technical support, laboratory services, and are currently cooperating in monitoring the test sections of the pavement construction.

¹Morgantown Energy Technology Center, Morgantown, West Virginia; US Department of Energy Contract No. DE-AC21-77ET10415.

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EXPERIMENTAL ROAD BASE

During the first two weeks of October 1981, a total of eight road base test sections were installed on the property of the Ohio Department of Transportation's Research and Testing Laboratory in Columbus, Ohio. The subgrade was prepared on October 5 and 6, the base courses were constructed on October 7 through 9, and the wearing surface was applied during the week of October 12. The base courses of each of the test sections contained hydrated fluidized bed residue, pulverized coal fly ash, and a combination of graded limestone and sand aggregate. The basic objective of the test sections is to show that the spent bed material from a fluidized bed boiler can be used, in combination with fly ash and a suitable commercial aggregate, to produce a stable and serviceable road base material. The location of the test area on the property is shown in Figure 1.

DESCRIPTION OF TEST SECTIONS

The location of each test section within the test area is shown in Figure 2. Each section is approximately 100' long and 10' wide. The total width of the roadway is 20' with one 10' section on each side of the centerline. Adjacent longitudinal sections are separated by a transition section of crushed limestone that is 2' long and 20' wide. The purpose of the transition sections is to provide positive separation and load transfer between each pair of test sections and to absorb any linear expansion that might occur. The cross section of each test section is shown on Figure 3. The specific purpose for each test section is given in Table I. Polyethylene sheeting (4 mils thick) was installed along all transverse and longitudinal edges in order to prevent the intrusion of excessive moisture into the bases.

MATERIALS USED

The fluidized bed residue was obtained from the Babcock & Wilcox boiler installation in Alliance, Ohio. A typical gradation and chemical analysis of this material are shown in Figure 4 and Table II respectively. The pulverized coal fly ash was obtained from the John Amos power plant of the American Electric Power Service Corporation, Saint Albans, West Virginia. The properties of the fly ash are given in Table III.

The aggregate that was used in the mixes, along with the fluidized bed residue and the pulverized coal fly ash, was a mixture of graded limestone and manufactured sand. The aggregate conformed to ODOT Specification 301. The aggregate gradation is shown in Table IV. A crushed limestone was used in the 2' wide transition sections.

The bituminous wearing surface conformed to requirements of ODOT Item 404, Asphaltic Concrete Surface.

PAVED AREA

FIGURE 1
LOCATION OF TEST AREA

FIGURE 2 **LAYOUT OF EXPERIMENTAL ROAD BASE SECTIONS**

SECTIONS ① AND ② WITH EXPANSION JOINTS

SHADED AREA REPRESENTS 2 FT.
 WIDE TRANSITION SECTIONS OF
 6" OF RIVER GRAVEL.

FIGURE 3

EXPERIMENTAL ROAD BASE CROSS SECTIONS

Section Number	Cross Section	
	(All cross sections were surfaced with a 2" bituminous wearing course)	
1	6" base	6:14:80 mix*

	Compacted soil subgrade	
2	8" base	4:10:86 mix

	Compacted soil subgrade	
3 & 4	6" base	6:14:80 mix
	6" subbase	Stabilized soil**

	Compacted soil subgrade	
5	6" base	6:14:80 mix

	Compacted soil subgrade	
6	6" base	6:14:80 mix (with 2% portland cement added)

	Compacted soil subgrade	

*Ratio by weight of fluidized bed residue:pulverized coal fly ash:aggregate.

**The in situ soil in Section 3 was stabilized by the addition of 6 percent fluidized bed residue and 10 percent pulverized coal fly ash by weight. In Section 4 it was stabilized by the addition of 10 percent portland cement.

***4 mil polyethylene sheet.

TABLE I
PURPOSE FOR EACH TEST SECTION
(SHOWN IN FIGURES 2 AND 3)

Section Designation	Purpose
1	To evaluate the performance of a recommended, durable, road base mix containing fluidized bed residue.
1 (with expansion joints)	To check the effect that commonly used expansion joints will have on damping any expansion that might occur.
2	To evaluate a road base composition with the lowest feasible amount of fluidized bed residue.
2 (with expansion joints)	To check the effect that commonly used expansion joints will have on damping any expansion that might occur.
3	To determine if a stabilized soil layer will retard movement of moisture into base and improve structural properties of pavement section; also to evaluate fluidized bed residue as a soil stabilizer.
4	Same as Section #3 but does not include evaluation of fluidized bed residue as a soil stabilizer.
5	To evaluate effectiveness of fabric or plastic barrier in preventing water intrusion into base.
6	To evaluate the effectiveness of small additions of portland cement in improving the performance of the base.

FIGURE 4

GRADATION OF FLUIDIZED BED RESIDUE

TABLE II
TYPICAL CHEMICAL ANALYSIS OF ALLIANCE RESIDUE

Chemical Composition ¹ (% by Weight)	
Major Constituents	
LOI ²	0.58
SiO ₂	5.88
R ₂ O ₃	5.51
CaO (total)	55.70
SO ₃ ⁼	30.14
MgO	1.86
Composition Analysis	
LOI ²	0.58
CaSO ₄	51.24
Free CaO	34.60
MgO	1.86
Inerts	11.39

¹Major constituents

²LOI = loss on ignition

TABLE III
ANALYSIS OF FLY ASH

Constituent	% by Weight
SiO ₂	59.37
Al ₂ O ₃	28.28
Fe ₂ O ₃	4.5
TiO ₂	1.7
CaO	0.72
Na ₂ O	0.30
K ₂ O	2.65
MgO	0.45
SO ₃ ⁼	0.25
Loss on Ignition	1.31
Retained on #325 sieve	21.01

TABLE IV
GRADATION OF AGGREGATE USED IN ROAD
BASE MIXES (ODOT 301 GRADATION)

Sieve Size	Percent Finer by Weight
2"	100
1"	75 - 100
$\frac{1}{2}$ "	50 - 85
# 4	25 - 60
8	15 - 45
16	10 - 35
50	3 - 18
200	1 - 7

LABORATORY TESTING

PRE-CONSTRUCTION EVALUATION: MIX DESIGN - BASE COURSE

A mix design program showed that a mixture of 6 percent fluidized bed residue, 14 percent pulverized coal fly ash, and 80 percent aggregate represented an optimum combination. This design satisfied the following criteria:

- adequate 28 day compressive strength
- minimal expansion potential
- satisfactory durability as predicted by freeze/thaw and wet/dry evaluations

The 4:10:86 mix contained the lowest amount of fluidized bed residue in order to provide satisfactory strength. This mix has a lower expansion potential than the 6:14:80 mix.

SUBGRADE CHARACTERISTICS AND STABILIZED SOIL TESTS

Samples of the subgrade soil were obtained along the proposed route. Four exploratory holes were made; three were 3' deep and one was 8' deep. Samples were obtained from three of the locations. The samples from Holes 1, 2, and 4 showed the material to be a low to medium plasticity clay (CL), while from Hole 3 the material appeared to be a mixture of cinders, stone, and a small amount of clay. The properties of these materials are shown in Table V.

The soil samples, representative of that from Holes 1 and 2, were selected for a minimal soil stabilization evaluation. Two of the experimental sections were to have stabilized subgrades; one (Section 3) was to be stabilized with AFB residue and pulverized coal fly ash and one (Section 4) with portland cement. Several compositions were prepared and the 7 day compressive strengths of Proctor size cylinders were determined. The results of these tests are given in Table VI. Although these strengths were somewhat low, it was evident that the soil had been cemented by both of the admixtures. The test specimens were soaked in water four hours prior to testing. If no hardening occurred, they would have disintegrated during the soaking period. A stabilized soil mix of 6 percent fluidized bed residue, 10 percent pulverized coal fly ash, and 84 percent soil was recommended for Section 3 and an addition of 10 percent portland cement was recommended for stabilizing the subgrade in Section 4.

TESTING CURING CONSTRUCTION

Testing performed during construction was limited to in-place density testing of the subgrade and the base course. In addition, test specimens

TABLE V
PROPERTIES OF SUBGRADE SOILS

Hole No.	% Passing #200	Liquid Limit	Plasticity Index	Maximum Dry Density (pcf)	Optimum Moisture (%)
1	65.8	37	16	105.2	17.7
2	71.4	40	22	105.2	17.7
3	33.1	-	NP	114.6	12.0

TABLE VI
 COMPRESSIVE STRENGTHS OF SOIL STABILIZED CYLINDERS
 (Soil was obtained from subgrade at test site)

Composition (% by Weight)				Dry Density of Test Cylinder (pcf)	Compressive Strength* (psi)
AFB Residue	Pulverized Coal Fly Ash	Portland Cement	Soil		
6	10	-	84	100.8	88
9	12	-	79	99.2	76
10	10	-	80	100.3	91
-	-	9	91	104.0	123
-	-	11	89	105.4	264

*Compressive strengths were determined after a 7 day cure at 100°F and after soaking for 4 hours.

were prepared for later evaluation of compressive strengths and freeze/thaw resistance of the base course mixtures.

Nuclear equipment was used to record the in-place densities. The densities obtained are shown in Table VII.

POST-CONSTRUCTION EVALUATION

- Compressive Strength

A series of cylindrical (Proctor size) specimens were prepared from the base course materials that were supplied to the job. The materials were representative of the mixtures used in Sections 2 (4:10:86 mix), 4 and 5 (6:14:80 mix), and 6 (6:14:80 mix + 2 percent portland cement). At this time the compressive strengths for 7, 28, and 60 days have been obtained and are tabulated in Table VIII.

- Pavement Monitoring

Monitoring of the pavement consists of periodic visual inspections and linear measurements designed to provide the data for evaluating dimensional stability. Visual inspections are being made at least twice a month by Ohio Department of Transportation (ODOT) personnel in order to evaluate the overall surface condition and quality of the pavement in each of the test sections. Particular attention is being devoted to the monitoring of longitudinal and transverse surface profiles and to evidence of pavement deterioration. Periodic visual inspections are also planned by one or more members of the research team. In addition, photographic records will be maintained of the pavement surface condition for each of the test sections.

In order to more accurately determine whether or not expansive chemical reactions are occurring within certain portions of the test pavement, dimensional measurements are being taken by ODOT personnel between a number of control points at locations throughout the test pavement. In all, a total of 48 steel pins ($\frac{1}{2}$ " diameter x 8" long) were driven through the bituminous wearing surface and into the underlying base course near the corners of each of the test sections. These pins were referenced to control points (steel pins or concrete nails) that were positioned in fixed locations adjacent to the pavement itself.

The location of the 48 steel pins within the experimental pavement sections is shown in Figure 5. Also shown is the layout of 18 control spikes placed at intermediate locations between the steel pins. The control spikes were driven directly into the stabilized base materials after the wearing surface at each control spike location had been cored. In this way, any expansive movements within the base course materials can be measured directly between control spikes without being hindered by control spikes that were driven through the overlying wearing surface.

TABLE VII
IN-PLACE DENSITIES RECORDED DURING CONSTRUCTION

Subgrade		Base Course	
Station	Dry Density (pcf)	Station	Dry Density (pcf)
0 + 25, 5' rt	108.0	0 + 25, 5' rt	127.4
0 + 70, 3' rt	102.5	0 + 70, 3' rt	120.8
0 + 42, 5' lt	107.0	0 + 42, 5' lt	110.9
0 + 63, 5' lt	110.0	0 + 63, 5' lt	113.4
1 + 25, 5' lt	96.7	1 + 25, 5' lt	114.5
1 + 75, 5' lt	94.0	1 + 75, 5' lt	119.3
1 + 40, 8' rt	97.5	1 + 40, 8' rt	110.1
1 + 75, 3' rt	105.6	1 + 75, 3' rt	109.7
2 + 40, 3' rt	108.2	2 + 40, 3' rt	107.2
2 + 25, 8' lt	106.4	2 + 25, 8' lt	112.6
2 + 65, 6' lt	105.5	2 + 65, 5' lt	112.8
2 + 65, 5' rt	105.2	2 + 65, 5' rt	111.6
3 + 25, 8' lt	105.9	3 + 25, 8' lt	103.7
3 + 40, 6' rt	100.4	3 + 40, 6' rt	113.9
3 + 70, 6' rt	126.9	3 + 70, 6' rt	106.4
3 + 80, 5' lt	116.3	3 + 80, 5' lt	108.9
		1 + 68, 4'	118.3
		2 + 45, 3' rt	107.5

TABLE VIII

COMPRESSIVE STRENGTHS OF BASE COURSE MIXES

(Test specimens were prepared from
materials supplied to the job)

Section No.	Composition (% by Weight)			Compressive Strength (psi)		
	AFB Residue	Pulverized Coal Fly Ash	Aggregate	7 Day	28 Day	60 Day
2	4	10	86	53	320	517
4	6	14	80	87	360	435
5	6	14	80	68	400	532
6*	6	14	80	600	1500	1595

*Two percent cement was added to this composition.

FIGURE 5.
Location of Dimensional Monitoring Points - Roadway Sections

Dimensional measurements are being taken between adjacent control points (either steel pins or control spikes) on a regular basis (approximately one month). The measurements will be compared with initial measurements taken immediately after installation in order to determine what, if any, expansion (or contraction) is taking place in different portions of the test installation.

CONSTRUCTION

Construction of the test sections was carried out using standard construction procedures. However, because of the experimental nature of the project, there were requirements that differed from normal highway construction. Among these requirements were:

- The installation of transition sections between the 100' experimental sections.
- Covering the sides, ends, and in one section the subgrade with a 4 mil thick polyethylene sheet.
- Varying the base course mix design to include three different mixes in the eight sections.
- Including stabilized subbases in two of the eight sections.

The construction proceeded without difficulty. The first step, after laying out the sections, was the grading and rolling of the subgrade (Figures 6 and 7). Included in the subgrade preparation was the stabilization of the soil in Sections 3 and 4. The existing soil in these sections was scarified to a depth of 6". The stabilizing admixture was deposited, spread, and mixed with a grader (Figure 8) and, finally, compacted to the desired density. In the case of Section 3, the stabilizing admixture, which consisted of a mixture of AFB residue and fly ash, was premixed in a concrete batch mixer at the Grandview plant of Anderson Concrete Company. Using the unit weight of the subgrade material, the amount of admixture required to give a 6 percent AFB residue, 14 percent fly ash, and 80 percent subgrade soil was computed. This amount of admixture was spread evenly on the subgrade, mixed with the soil using the scarification teeth on the grader, and then rolled to the proper density using a 12 ton tandem roller.

The subgrade of Section 4 was stabilized by adding 10 percent portland cement (Figure 9). Since only one material was involved in the admixture, no premixing was necessary. Spreading, mixing, and rolling were identical to Section 3.

After completion of the subgrade, the various base courses were constructed. The base course material for all sections was pre-blended (also at the Grandview plant of Anderson Concrete Company).

Blending was performed in a 12 cubic yard concrete batch mixer. Batch quantities of 12.5 tons were used. Initially the AFB residue was introduced into the batch mixer and hydrated to a damp condition by the addition of 15

FIGURE 6
SUBGRADE PREPARATION

FIGURE 7
ROLLING SUBGRADE

FIGURE 8
DEPOSITING 6:14:80 MIX ON SECTION 5

FIGURE 9

MIXING CEMENT INTO SOIL FOR STABILIZED SUBGRADE

percent water. Mixing time for this operation was 10 minutes. The fly ash and aggregate components of the mixture were then added and mixing was continued for another 10 minutes. Additional water was then added to obtain a final moisture content of approximately 8 percent. The material was then discharged from the batch mixer into a truck and was taken to a stockpile. The stockpile was covered with a polyethylene cover which remained on until the material was placed in the base course.

The transition sections were placed between two transverse wooden forms that were located at the ends of each of the experimental sections. After the transition was filled with crushed stone and the adjoining experimental sections were filled, the wooden forms were removed thus providing a continuous smooth surface. Figure 10 shows a transition section in the process of being filled. Final compacting of the entire length of the experimental roadway was accomplished by the use of a vibratory roller (Figure 11). The finished pavement prior to the installation of the asphalt wearing surface is shown in Figures 12 and 13.

Base course construction was completed on Friday, October 9, 1981. The tack coat was placed on the following day and four days later, on Wednesday, October 14, a 1½" bituminous wearing surface was constructed. The wearing surface conformed to ODOT Item 404, Asphaltic Concrete Surface.

As of this date, December 12, 1981, the experimental roadway is in an as-built condition with no sign of expansion or other evidence of deterioration.

FIGURE 10
FILLING TRANSITION SECTION

FIGURE 11
FINISHED ROLLING WITH VIBRATORY ROLLER

FIGURE 12
FINISHED BASE LOOKING SOUTH

FIGURE 13
FINISHED BASE LOOKING NORTH

PRODUCTION OF SYNTHETIC AGGREGATE

Two trial runs, designed to show the feasibility of producing brick from mixtures of fluidized bed residue and pulverized coal fly ash for subsequent use in the manufacture of quality aggregate, were made on commercially available brick making machines. One of the trials was performed at the McAvoy Vitrified Brick Company, Phoenixville, Pennsylvania and one was at the Gray's Ferry Brick Company, Franklinville, New Jersey. The trial at McAvoy was largely unsuccessful due to plugging of the extruder; however, it is felt that a change in the mix composition and procedure will remedy this problem. It is hoped that further testing with this equipment will be possible. At Gray's Ferry, brick were successfully made using several different mixtures. The materials used at Gray's Ferry included fluidized bed residue, pulverized coal fly ash, sand, and, in one mix, portland cement. The procedures used in each trial are described in the sections that follow.

McAVOY VITRIFIED BRICK COMPANY, PHOENIXVILLE, PENNSYLVANIA

The AFB residue from Georgetown University was conditioned and mixed with fly ash at the Downingtown plant of Highway Materials, Inc. Forty percent water, by weight of the residue, was added to the residue and mixed in a pug mill. Pulverized coal fly ash was then incorporated into the mix in the ratio of 30 percent residue to 70 percent fly ash (by weight). The material was stockpiled for 7 days and then transported to the brick making plant of McAvoy.

The brick machine at this plant produces a long extruded ribbon of material. The cross section of this ribbon is equivalent to the width and height of a standard brick. The ribbon is then cut into sections thus producing a "raw" brick that is the required length. The brick are stacked on pallets by hand and normally put into kilns for "firing." In the case of the AFB residue product, no heat is required in the curing of the extruded product.

Previous laboratory work with the residue/fly ash mix had shown that the mixture was readily extrudable. However, the storage time, when the residue and fly ash were mixed together, seemed to change the consistency of the material. Because of this, the mixture plugged up the extruder and it was impossible to produce brick. A number of attempts were made, which included the addition of more water and of small amounts of bentonite. Adding water was ineffective and it was not possible to properly incorporate the bentonite into the mix in the short mixing span that was available. Experimentation with this equipment was suspended until further notice. It appears likely that some change in the mix and elimination of the storage time for the residue/fly ash mixture will be necessary in order to be able to successfully extrude the composition in this equipment.

GRAY'S FERRY BRICK COMPANY, FRANKLINVILLE, NEW JERSEY

A second attempt to produce brick, as the first step for producing aggregate, was carried out at Gray's Ferry. This attempt met with much more success. In this case, the brick machine is a semi-batch machine in which the material is pressed into a mold under high pressure. Figure 1 shows the brick machine with a conveyor, feeding in the material, at the top of the press. The conveyor shown is the second conveyor in the system. The first one can be seen in Figure 2 where it is shown at the discharge point of the mixer which mixed the AFB residue, fly ash, and water together. The finished brick are shown in Figure 3 as they are being removed from the press, and in Figure 4 as they are resting on a short conveyor belt. The brick are then placed on the pallets shown in Figure 5 and moved to a storage and curing area.

LABORATORY EVALUATION OF PRODUCT

Brick were successfully made from four different mixes shown in Table I. Most of them were stored outdoors and are being examined and evaluated periodically. Some of the brick have been cured in a moist room and are being broken in compression in accordance with the schedule shown in Table II. As soon as the compression tests indicate that a significant hardening has occurred, the pieces remaining after the strength test shall be further crushed and graded to a typical aggregate gradation. Suitable aggregate tests are to be conducted as sufficient material becomes available.

As of this date, the brick strengths shown in Table III have been obtained.

These trial runs have shown that it is feasible to use commercially available processes to form high strength block equivalent to products previously formed on a laboratory scale. Crushed samples of the block also performed well when compared with a commercial limestone road aggregate. In view of the encouraging results from these tests, plans have now been formulated that will result in the production of 400 tons of the material. A full scale trial use of the aggregate in both a highway bituminous surface and in a stabilized base is also planned.

FIGURE 1

GRAY'S FERRY BRICK MACHINE. CONVEYOR
THAT SUPPLIES MATERIAL IS VISIBLE AT TOP

FIGURE 2
BOTTOM OF MIXER SHOWING DIS-
CHARGE POINT ONTO CONVEYOR

FIGURE 3
FINISHED BRICK BEING REMOVED FROM PRESS

FIGURE 4
FINISHED BRICK ON CONVEYOR ADJACENT TO PRESS

FIGURE 5
FINISHED BRICK ON PALLET

TABLE I
COMPOSITIONS OF MIXTURES USED IN FOUR TRIAL RUNS

Trial No.	Mix Composition (By Weight)	
	AFBR/FA Mix ¹	Sand
1	1 part	1 part
2	2 parts	1 part
3	100%	-
4 ²	2 parts	1 part

¹The ratio of AFBR/FA was 3 to 7 by weight.

²Approximately 4 percent portland cement was added.

TABLE II

TEST SCHEDULE - FOR MONITORING BRICK COMPRESSIVE STRENGTHS

(Two brick will be broken for each strength determination)

Trial No.	Total Number of Test Brick Required	Breaking Schedule Curing Time (Days)					
		14	28	60	180	365	730
1	12	✓	✓	✓	✓	✓	✓
2	12	✓	✓	✓	✓	✓	✓
3	6		✓	✓		✓	
4	6	✓	✓	✓			

NOTE: Check mark (✓) indicates a strength determination is to be made at that age.

TABLE III
BRICK STRENGTHS

Trial No.	Mix Composition (By Weight)		Compressive Strengths (psi) for Curing Conditions Shown ²			
			7 Days @ 100°F	Moist Room @ 73°F		
	AFBR/FA Mix ¹	Sand		14 Days	28 Days	60 Days
1	1 part	1 part	1792 ³	1542	3375	4200
2	2 parts	1 part	1057	1267	2050	2575
3	100%	-	1500	-	2958	3967
4 ⁴	2 parts	1 part	1342	1200	2958	3483

¹The ratio of AFBR/FA was 3 to 7 by weight.

²Brick were stored outdoors for 6 days prior to the controlled curing period.

³Each strength is the average obtained from two brick.

⁴Approximately 4 percent portland cement was added.