Use of Fly Ash in Fiber-Reinforced Aerated Concrete Products

Final Report Draft 1

Submitted to:

Navajo Flexcrete Building Systems

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December 2012

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Executive Summary

Fly ash is produced by coal-fired electric or steam generating plants. This material can partially be replaced with Portland cement to be used in concrete products. Blended cement materials have been used for more than seven decades to improve the strength and durability characteristics of concrete. Navajo FlexCrete uses fly ash in its lightweight fiber-reinforced aerated concrete blocks. This report summarizes the chemical oxide-analysis test results for the used fly ash and discusses the benefits of using this by-produced material in concrete. The fly ash used by Navajo FlexCrete has high silica and low calcium-oxide which are indicators of excellent properties for use in cementitious products. The fly ash traditionally used by the Flexcrete building systems in their products has been classified as class-F fly ash according to ASTM C618. Our tests have indicated that that no hazardous impurities were found in the material. In order to maintain the quality control criteria, it is suggested that a sample of fly ash is sent to a certified laboratory (for example CTL Group) periodically (twice a year, at a cost of about $300-400) for chemical analysis. A short letter is prepared and presented along with this report that includes a brief introduction to the benefits of using fly ash in aerated concrete blocks. This letter can be presented to costumers or agencies who have questions about using fly ash. We will be happy to do a follow up with anyone who expresses the need for additional literature in regards to the use of fly ash.

What is Fly Ash?

Fly ash is produced by coal-fired electric or steam generating plants. Typically, coal is pulverized and blown with air into the boiler's combustion chamber where it immediately ignites, generating heat and producing a molten mineral residue. Boiler tubes extract heat from the boiler, cooling the flue gas and causing the molten mineral residue to harden and form ash. Coarse ash particles, referred to as bottom ash or slag, fall to the bottom of the combustion chamber, while the lighter fine ash particles, termed fly ash, remain suspended in the flue gas. Prior to exhausting the flue gas, fly ash is removed by particulate emission control devices, such as electrostatic precipitators or filter fabric bag-houses. More than 100 million tons of fly ash is produced each year and as much 20-30% is used in a variety of engineering applications [1]. Fly ash is classified mainly based on its chemical composition and oxide analysis.

Using Fly Ash in Concrete

When cement is partially replaced by fly ash, the blended product is referred to as blended cement. These materials have been used for more than seven decades to improve the strength and durability characteristics of concrete materials. One of the main benefits of the use of coal ash products is in reducing the potential damage caused from durability issues such as alkali-silica reaction (ASR) or sulfate attack. The effectiveness of pozzolanic admixtures such as fly ash, silica fume, slag, and metakaolin in improving the durability of concrete is well known and recognized by ACI 201 on concrete durability [2]. Since they are partially replaced for cement, pozzolanic materials can produce more economical and more environmentally-friendly products. Fly ash is also recognized in the US Green Building Council's LEED system as a post-industrial recycled material. The use of fly ash in concrete enhances the recycled material content of a building and is recognized as a beneficial strategy for reducing the CO_2 emission related to cement production.

In addition to the economical and environmental benefits of using fly ash in concrete, the technical advantageous of this material is of significance and has been the subject of many studies [1]. American Association of State Highway Transportation Officials (AASHTO) M 295 [3] and American Society for Testing and Materials (ASTM) Specification ASTM C 618 [4] define the chemical composition of fly ash classes (F and C) as shown in Table 1. Chemical composition of fly ash is related to the mineral chemistry of the original coal and any additional fuels or additives used in the combustion or post-combustion processes. A periodic chemical analysis test is necessary for ensuring the quality of fly ash. In comparison with cement, fly ash is typically higher in SiO_2 and Al_2O_3 and lower in CaO contents. Typically, fly ash has fine spherical particles as shown in Figure 1. These materials can improve the microstructure of concrete, as well as changing the chemical behavior of the hydration products, due to the particle size and reactivity with calcium hydroxide during the hydration process.

Table 1. Fly ash specifications for class C and F (ASTM C-618)

Chemical Requirement	**Min/Max**	**Class**	**Class C**
SiO2 + Al2O3 + Fe2O3	min %	70	50
SO3	max %	5	5
Moisture Content	max %	3	3
LOI	max %	5	5
Optional Chemical Requirement			
Available Alkalis	max %	1.5	1.5
Physical Requirement			
Fineness (+325)	max %	34	34
Pozzolanic Activity / Cement (7 Days)	min %	75	75
Pozzolanic Activity / Cement (28 Days)	min %	75	75
Water Requirement	max %	105	105
Autoclave Expansion	max %	0.8	0.8
Uniformity Requirement: Density	max %	5	5
Uniformity Requirement: Fineness	max %	5	5
Optional Physical Requirement			
Multiple Factor (LOI x Fineness)		255	--
Increase in Drying Shrinkage	max %	0.03	0.03
Uniformity Requirement: Air Entraining	max %	20	20
Cement / Alkali Reaction:	max %	0.02	--

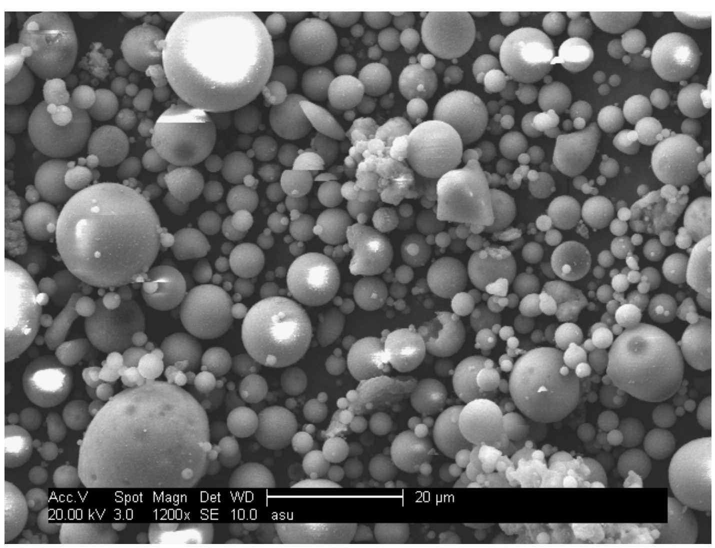

Figure 1. Typical class F fly ash particles (image obtained by scanning electron microscopy)

In the area of general concrete materials applications of fly ash use with replacement levels as much as 50% and 60% weight content of fly ash are commonly practiced [5]. Mortars and concrete with fly ash have shown good performance with strength levels reaching 10,000 psi after 90 days. Various approaches are available for developing mix designs with high volume of fly ash concrete [6][7].

One of the primary benefits of use of fly ash is in its ability to improve the durability of concrete materials. Fly ash is known to increase the durability of concrete in terms of sulfate attack from soils or water, freeze thaw, and chloride permeability. Sulfate attack of fly ash blended concrete with and without a C_3A-rich cement has been studied in numerous studies with favorable results [8][9][10][11]. Several investigators have studied freeze-thaw resistance [12][13]. By comparing the equivalent 28-days strength of fly ash and OPC concrete it has been observed that the permeability decrease due to increased use of fly ash is more pronounced in lower strength concrete [14].

New applications for fly ash blended concrete have also been developed at an increasing rate. These areas include: autoclaved cellular concrete (ACC) [15][16][17] of up to 70% use of fly ash and cement-based composite systems reinforced with glass fibers [18]. Transportation related applications include pavement foundations and roller compacted concrete [19][20] (as much as 82% fly ash used). Fly ash blended concrete has also been used as a means of reducing the Radon gas emissions [21][22].

The EPA Regulations

On June 21, 2010, the U.S. Environmental Protection Agency (EPA) published a proposal to regulate coal combustion residuals, including fly ash, under the Resource Conservation and Recovery Act (RCRA). The potential harm of coal products came to national attention in late 2008, when an impoundment holding disposed waste ash failed in Kingston, Tennessee. They used natural ponds to dewater the fly ash that resulted in the movement of fly ash slurry in the river and damaging the environment. The U.S. Environmental Protection Agency decided to regulate the coal ash byproducts and limit their applications. The EPA's proposed regulations were meant to prevent any unpermitted discharge of a pollutant in contravention of the Clean Water Act.

In a letter to EPA in 2009, American Concrete Institute (ACI) mentioned that "It is ACI's opinion that designating fly ash as a hazardous waste will result in little or no fly ash being used in concrete in the US. We anticipate the concrete industry will no longer specify its use; and fly ash producers would not permit its beneficial use due to liability concerns, preferring to impound fly ash rather than allow its use. Further, the designation of fly ash as a hazardous waste is counter to the goal of sustainability." [23].

The most recent regulations and discussions can be found on EPA's website [24]. A notice of data availability (NODA) was announced and invited comment on additional information obtained by EPA in conjunction with the June 21, 2010 proposed rule. This additional information is generally categorized as follows:

1. Chemical constituent data from coal combustion residuals;
2. Facility and waste management unit data;
3. Information on additional alleged damage cases;
4. Adequacy of State programs; and
5. Beneficial Use.

The most recent update on EPA's website about fly ash introduces the applications of fly ash as following dated on June 12, 2012 [25]:

- Raw material in concrete products and grout
- Feed stock in the production of cement
- Fill material for structural applications and embankments
- Ingredient in waste stabilization and/or solidification
- Ingredient in soil modification and/or stabilization
- Component of flowable fill
- Component in road bases, sub-bases, and pavement
- Mineral filler in asphalt

Fly Ash for FlexCrete Blocks

Lightweight fiber-reinforced aerated concrete blocks produced by FlexCrete® has approximately 50% of replacement for cement by fly ash. The fly ash is by-produced in a local power plant in Page, AZ. Using fly ash makes these blocks green construction materials. Samples of this fly ash were tested by the Construction Technology laboratories, (CTL Group) for chemical oxide-analysis. The results are presented below, showing compatibility with ASTM C 618 that is also shown. No hazardous impurities were detected in the fly ash and its use in concrete blocks does not have any hazardous potentials. For quality control purposes, it is recommended that samples of fly ash are sent to a certified laboratory periodically (every three months or so). Using fly ash in FlexCrete blocks makes this material a sustainable and environmentally-friendly construction material.

Oxide Analysis of Fly Ash

CTL GROUP

Client:	**Arizona State University**	CTL Project No.:	**405796**
Project:	**XRF Testing**	CTL Proj. Mgr.:	**Scott Nettles**
		Analyst:	**Ross Kelly**
Contact:	**Amir Bonakdar**	Approved:	*RW Stevenson*
Submitter:	**Amir Bonakdar**	Date Analyzed:	**September 27, 2012**
Date Received:	**September 18, 2012**	Date Reported:	**September 27, 2012**

REPORT OF CHEMICAL ANALYSIS

Client's Sample ID:	F-1
Material type:	Fly ash
CTL Sample ID:	3225402

Analyte	Weight %
SiO_2	60.38
Al_2O_3	22.69
Fe_2O_3	5.11
CaO	4.45
MgO	1.37
SO_3	0.34
Na_2O	2.22
K_2O	1.34
TiO_2	0.84
P_2O_5	0.13
Mn_2O_3	0.02
SrO	0.19
Cr_2O_3	0.02
ZnO	0.01
BaO	0.35
L.O.I. (950° C)[2]	0.46
Total	99.92
T-Alk ($Na_2O + 0.658K_2O$)	3.10

Thermogravimetric Analysis - As Received Basis (C311-11b)

Free moisture (Ambient-105° C)	0.05
L.O.I. (105° C - 750° C)	0.47
L.O.I. (750° C - 950° C)	-0.01

Calculations per ASTM C618-12

$SiO_2+Al_2O_3+Fe_2O_3$	88.2
L.O.I. 750° C (dry 105° C basis)	0.47

ASTM C618 For Fly Ash

Designation: C 618 – 99

Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete[1]

TABLE 1 Chemical Requirements

	Mineral Admixture Class		
	N	F	C
Silicon dioxide (SiO_2) plus aluminum oxide (Al_2O_3) plus iron oxide (Fe_2O_3), min, %	70.0	70.0	50.0
Sulfur trioxide (SO_3), max, %	4.0	5.0	5.0
Moisture content, max, %	3.0	3.0	3.0
Loss on ignition, max, %	10.0	6.0[A]	6.0

[A]The use of Class F pozzolan containing up to 12.0 % loss on ignition may be approved by the user if either acceptable performance records or laboratory test results are made available.

TABLE 2 Supplementary Optional Chemical Requirement

NOTE 1—This optional requirement applies only when specifically requested.

	Mineral Admixture Class		
	N	F	C
Available alkalies, as equivalent, as Na_2O, max, %[A]	1.5	1.5	1.5

TABLE 3 Physical Requirements

	Mineral Admixture Class		
	N	F	C
Fineness:			
Amount retained when wet-sieved on 45 µm (No. 325) sieve, max, %[A]	34	34	34
Strength activity index:[B]			
With portland cement, at 7 days, min, percent of control	75[C]	75[C]	75[C]
With portland cement, at 28 days, min, percent of control	75[C]	75[C]	75[C]
Water requirement, max, percent of control	115	105	105
Soundness:[D]			
Autoclave expansion or contraction, max, %	0.8	0.8	0.8
Uniformity requirements:			
The density and fineness of individual samples shall not vary from the average established by the ten preceding tests, or by all preceding tests if the number is less than ten, by more than:			
Density, max variation from average, %	5	5	5
Percent retained on 45-µm (No. 325), max variation, percentage points from average	5	5	5

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