White Paper WP005

Fly Ash Information and Discussion

WP005
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Figure 1 - Fly Ash

Definition of Fly ash[1]

Fly ash is one of the residues generated in the combustion of coal. Fly ash is generally captured from the chimneys of coal-fired power plants, and is one of two types of ash that are jointly known as coal ash. The other type, bottom ash, is removed from the bottom of coal furnaces. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably. However, all fly ash includes substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline) and calcium oxide (CaO). Both are endemic ingredients in many coal bearing rock strata.

Toxic constituents depend upon the specific coal bed makeup, but may include one or more of the following elements or substances in quantities from trace amounts to several %: arsenic, beryllium, boron, cadmium, chromium, chromium VI, cobalt, lead, manganese, mercury, molybdenum, selenium, strontium, thallium, and vanadium, along with dioxins and PAH compounds.

In the past, fly ash was generally released into the atmosphere, but pollution control equipment mandated in recent decades now requires that it be captured prior to release. In the U.S., fly ash is generally stored at coal power plants or placed in landfills. About 43% is recycled, often used to supplement Portland cement in concrete production. Although fly ash has been claimed to be neither toxic nor poisonous, many are still concerned about exposure though skin contact and inhalation of fine particle dust. Two of the chemicals present in fly ash that cause concern are crystalline silica and lime, which have been shown to cause lung damage, but only in sufficient quantities. These chemicals are however counteracted and are not hazardous when fly ash is used in concrete production/products.

Fly Ash Creation Process[2]

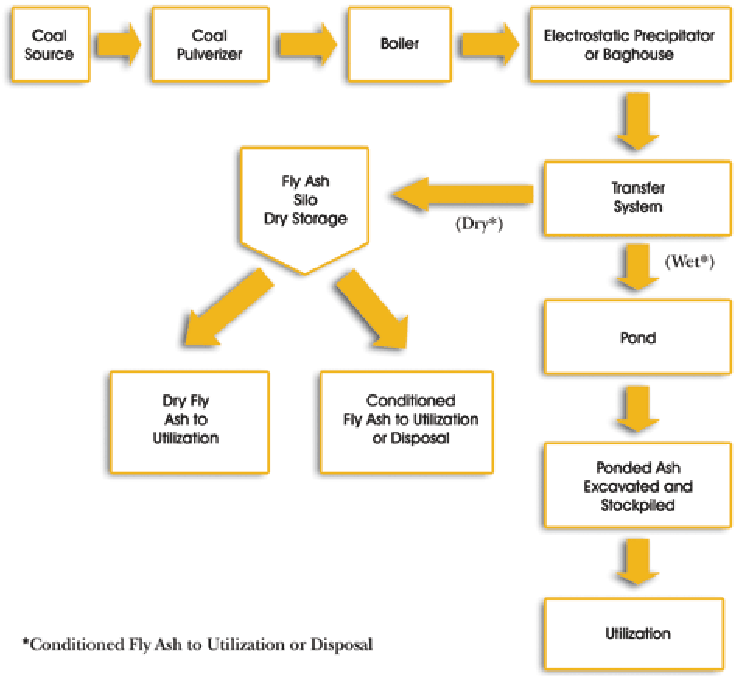

Figure 2 - Creation Process Map

Chemical composition and classification of Fly Ash[1]

Fly ash material solidifies while suspended in the exhaust gases and is collected by electrostatic precipitators or filter bags. Since the particles solidify while suspended in the exhaust gases, fly ash particles are generally spherical in shape and range in size from 0.5 µm to 100 µm. They consist mostly of silicon dioxide (SiO_2), which is present in two forms: amorphous, which is rounded and smooth, and crystalline, which is sharp, pointed and hazardous; aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3). Fly ashes are generally highly heterogeneous, consisting of a mixture of glassy particles with various identifiable crystalline phases such as quartz, mullite, and various iron oxides.

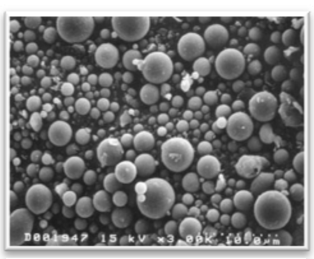

Figure 3 - Fly Ash Particles at 2,000x Magnification

Fly ash contains many additional environmental toxins in significant amounts. These include arsenic (43.4 ppm), barium (806 ppm), beryllium (5 ppm), boron (311 ppm), cadmium (3.4 ppm), chromium (136 ppm), chromium VI (90 ppm), cobalt (35.9 ppm), copper (112 ppm), fluorine (29 ppm); lead (56 ppm); manganese (250 ppm), nickel (77.6 ppm), selenium (7.7 ppm), strontium (775 ppm), thallium (9 ppm), vanadium (252 ppm), and zinc (178 ppm).

Two classes of fly ash are defined by ASTM C618: **Class F fly ash** and **Class C fly ash**. The chief difference between these classes is the amount of calcium, silica, alumina, and iron content in the ash. The chemical properties of the fly ash are largely influenced by the chemical content of the coal burned (i.e., anthracite, bituminous, and lignite).

Not all fly ashes meet ASTM C618 requirements. Although depending on the application, meeting the ASTM requirement may not be necessary. Ash used as a cement replacement must meet strict construction standards; 75% of the ash must have a fineness of 45 µm or less, and have carbon content, measured by the loss on ignition (LOI), of less than 4%. However, ASTM has not established environmental fly ash standards in the United States. In the U.S., LOI needs to be less than 6%. The particle size distribution of raw fly ash is very often fluctuating constantly due to changing performance of the coal mills and the boiler performance. This makes it necessary that fly ash used in concrete needs to be processed using separation equipment such as mechanical air classifiers. Especially important is the ongoing quality verification.

Class F fly ash[1]

The burning of harder, older anthracite and bituminous coal typically produces **Class F fly ash**. This fly ash is pozzolanic in nature and contains less than 10% lime (CaO). Possessing pozzolanic properties, the glassy silica and alumina of **Class F fly ash** requires a cementing agent. This can include Portland cement, quicklime, or hydrated lime, with the presence of water, in order to react and produce cementitious compounds. Alternatively, additions of a chemical activator such as sodium silicate (water glass) to a **Class F fly ash** can lead to the formation of a geopolymer.

Class C fly ash[1]

Fly ash produced from the burning of younger lignite or sub bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, Class C fly ash will harden and gain strength over time. Class C fly ash generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C fly ash does not require an activator. Alkali and sulfate (SO_4) contents are generally higher in Class C fly ashes.

At least one U.S. manufacturer has announced a production of a fly ash brick containing up to 50% Class C fly ash. Testing shows that the bricks meet or exceed the performance standards listed in ASTM C 216 for conventional clay brick. It is also within the allowable shrinkage limits for concrete brick in ASTM C 55, Standard Specification for Concrete Building Brick. It is estimated that the production method used in fly ash bricks will reduce the embodied energy of masonry construction by up to 90%. Bricks and pavers have been available in commercial quantities since the end of 2009.

Quality of Fly Ash[2]

Quality requirements for fly ash vary depending on the intended use. Fly ash quality is affected by fuel characteristics (coal), co-firing of fuels (bituminous and sub-bituminous coals), and various aspects of the combustion and flue gas cleaning/collection processes. The four most relevant characteristics of fly ash for use in concrete are loss on ignition (LOI), fineness, chemical composition and uniformity.

LOI is a measurement of unburned carbon (coal) remaining in the ash and is a critical characteristic of fly ash, especially for concrete applications. High carbon levels, the type of carbon (i.e., activated), the interaction of soluble ions in fly ash, and the variability of carbon content can result in significant air-entrainment problems in fresh concrete and can adversely affect the durability of concrete. AASHTO and ASTM specify limits for LOI. However, some state transportation departments will specify a lower level for LOI. Carbon can also be removed from fly ash.

Some fly ash uses are not affected by the LOI. Filler in asphalt, flowable fill, and structural fills can accept fly ash with elevated carbon contents.

Fineness of fly ash is most closely related to the operating condition of the coal crushers and the grindability of the coal itself. For fly ash use in concrete applications, fineness is defined as the percent by weight of the material retained on the 0.044 mm (No. 325) sieve. A coarser gradation can result in a less reactive ash and could contain higher carbon contents. Limits on fineness are addressed by ASTM and state transportation department specifications. Fly ash can be processed by screening or air classification to improve its fineness and reactivity.

Some non-concrete applications, such as structural fills are not affected by fly ash fineness. However, other applications such as asphalt filler are greatly dependent on the fly ash fineness and its particle size distribution.

Chemical composition of fly ash relates directly to the mineral chemistry of the parent coal and any additional fuels or additives used in the combustion or post-combustion processes. The pollution control technology that is used can also effect the chemical composition of the fly ash. Electric generating stations burn large volumes of coal from multiple sources. Coals may be blended to maximize generation efficiency or to improve the station environmental performance. The chemistry of the fly ash is constantly tested and evaluated for specific use applications.

Some stations selectively burn specific coals or modify their additives formulation to avoid degrading the ash quality or to impart a desired fly ash chemistry and characteristic.

Uniformity of fly ash characteristics from shipment to shipment is imperative in order to supply a consistent product. Fly ash chemistry and characteristics are typically known in advance so concrete mixes are designed and tested for performance.

Guidance documents used for fly ash quality assurance.

ACI 229R	Controlled Low Strength Material (CLSM)
ASTM C 311	Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete
AASHTO M 295 ASTM C 618	Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete
ASTM C 593	Fly Ash and Other Pozzolans for Use With Lime

ASTM D 5239	Standard Practice for Characterizing Fly Ash for Use in Soil Stabilization
ASTM E 1861	Guide for the Use of Coal Combustion By-Products in Structural Fills

Fly Ash Re-use[1]

The re-use of fly ash as an engineering material primarily stems from its pozzolanic nature, spherical shape, and relative uniformity.

Fly ash recycling, in descending frequency, includes usage in:

- Portland cement and grout
- Embankments and structural fill
- Waste stabilization and solidification
- Raw feed for cement clinkers
- Mine reclamation
- Stabilization of soft soils
- Road subbase
- Aggregate
- Flowable fill
- Mineral filler in asphaltic concrete
- Other applications include: cellular concrete, geopolymers, roofing tiles, paints, metal castings, and filler in wood and plastic products.

Figure 4 - Precast Concrete Tub Girders

Fly Ash Use in Concrete[4]

Once fly ash is encapsulated in concrete, it does not leach out any toxins, making concrete more environmentally friendly. This makes fly ash an ideal replacement for Portland cement, which has an energy-intensive manufacturing process and releases high amounts of CO^2.

Fly Ash usage facts:

- Reacts with the calcium hydroxide during the cement and water mixture and takes on cementitious properties
- Concrete with fly ash
  - Is stronger, less permeable, and reduces the alkalinity
  - Is more workable
  - Hydrates slower which reduces the heat of hydration
  - Less expensive due to the replacement of Portland cement with less expensive fly ash
- Used in approximately half of the concrete placed in the United States

Some concrete producers have voiced concerns using some fly ash retards hydration and can increasing set times and create slower strength gains. These concerns are and have been overcome by gaining experience and knowledge with using admixtures and proper proportioning.

Environmental Protection Agency Activity[3, 4]

Due to a recent containment pond rupture in Tennessee which spilled more than 5.4 million cubic yards of coal ash slurry/wet fly ash into a nearby river the Environmental Protection Agency (EPA) is taking a closer look at fly ash regulations.

The EPA is taking steps given political pressure to reclassify fly ash under the Resource Conservation and Recovery Act (RCRA). The final decision of Fly Ash reclassification has not been made as of July 2010 but is being hinged on the EPA's call for public opinion regarding two options.

> The first option the EPA is proposing is the reclassification of Fly Ash as Subtitle C classification. This classification will permit the EPA to create and regulate a comprehensive program of federally enforceable requirements for management and disposal of "Special wastes" – Fly Ash.
>
> The other option under Subtitle D of the RCRA gives the EPA the authority to set performance standards for waste management facilities. Subtitle D would be enforced primarily through citizen suits.

With respect to both options the EPA has proposed, the Bevill exemption for beneficial uses of coal combustion residuals (CCRs) will remain intact as long as the CCRs are recycled components in products (including concrete) instead of being placed in impoundments or landfills.

Key Differences Between Subtitle C and Subtitle D Options[5]

	SUBTITLE C	SUBTITLE D
Effective Date	Timing will vary from state to state, as each state must adopt the rule individually-can take 1 – 2 years or more	Six months after final rule is promulgated for most provision: certain provisions have a longer effective date
Enforcement	State and Federal enforcement	Enforcement through citizen suits; States can act as citizens.
Corrective Action	Monitored by authorized States and EPA	Self-implementing
Financial Assurance	Yes	Considering subsequent rule using CERCLA 108 (b) Authority
Permit Issuance	Federal requirement for permit issuance by States	No
Requirements for Storage, Including Containers, Tanks, and Containment Buildings	Yes	No
Surface Impoundments Built Before Rule is Finalized	Remove solids and meet land disposal restrictions; retrofit with a liner within five years of effective date. Would effectively phase out use of existing surface impoundments	Must remove solids and retrofit with a composite liner or cease receiving CCRs within 5 years of effective date and close the unit
Surface Impoundments Built After Rule is Finalized	Must meet Land Disposal Restrictions and liner requirements. Would effectively phase out use of new surface impoundments.	Must install composite liners. No Land Disposal Restrictions
Landfills Built Before Rule is Finalized	No liner requirements, but require groundwater monitoring	No liner requirements, but require groundwater monitoring
Landfills Built After Rule is Finalized	Liner requirements and groundwater monitoring	Liner requirements and groundwater monitoring
Requirements for Closure and Post-Closure Care	Yes; monitored by States and EPA	Yes; self-implementing

The requirements under subtitle D are those that the EPA will be proposing based on statutory authority. Each state, under their own programs, can adopt requirements for which the EPA does not have authority.

While the co-proposed RCRA subtitle D regulations do not include provisions for financial assurance, the EPA has stated that classes of facilities within the Electric Power Generation, Transmission, and Distribution Industries are among those for which the EPA plans to develop, as necessary, a proposed regulation under the authority of the Comprehensive Environmental Recovery and Liability Act (CERCLA) 108(b)[6].

Effect of EPA Activity[3, 4]

Although the second option/classification listed above will keep regulations as they are, the first option/classification will have significant ramifications to the concrete industry as a whole. It will create significant cost issues and transportation adjustments. Landfills will become overwhelmed with dumping, and the availability of fly ash could be eliminated all together. Additionally, fly ash suppliers are concerned if harm comes to anyone coming into contact with fly as that there will be legal liabilities. The use of fly ash, as seen in the public eye and the political atmosphere surrounding the containment rupture accident in Tennessee, is classifying it as an environmental pollutant.

Industries which directly or indirectly deal with cement and concrete are mounting a large effort to combat the EPA classifications. The main themes of these efforts include the fact that fly ash has not harmed anyone and that the issues with fly ash disposal can be addressed without restricting its beneficial usage.

What Can be Done? [3, 4]

The public can contact his/her congressional representatives and senators, or the EPA Administrator, Lisa Jackson, urging them to concentrate on the facts surrounding fly ash and not rely solely on public and political opinions.

A public comment submittal form has been created by the EPA – USE IT!

http://www.regulations.gov/search/Regs/home.html#submitComment?R=0900006480b06eac

Many professional organizations including; the Precast/Prestressed Concrete Institute (PCI), American Concrete Institute (ACI), and the American Society for Testing and Materials (ASTM), among others, have submitted official letters to the EPA voicing their concerns. These organizations have and continue to publish numerous articles and papers regarding fly ash.

EnCon Companies – Fly Ash additions to concrete mixes

Subsidiary	Product	Fly Ash Class C or F (%)
Atlanta Structural Concrete		F - 20
Concrete Products of Northern California		
EnCon Colorado	Hollow-core	C - 15
	Girders	C - 25
EnCon Northwest		
EnCon Utah		
EnCon Washington	N/A	N/A
Stresscon		

EnCon Design, LLC
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Denver, Colorado 80264
303.298.1900

Includes subsidiary companies and precast products manufactured by:

EnCon Utah, EnCon Washington, EnCon Northwest, EnCon Colorado, Stresscon Corporation, Atlanta Structural Concrete

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1. Information provided by Wikipedia.com
2. "Fly Ash Facts for Highway Engineers" written and distributed by the U.S. Department of Transportation Federal Highway Administration.
3. American Concrete Institute EPA Proposed Regulation of Fly Ash website content.
4. "The Fly Ash Threat" published by Concrete Producer Magazine, January 2010.
5. "Wastes – Non-Hazardous Waste – Industrial Waste" section of the Environmental Protection Agencies website.
6. A complete explaination and disucssion regarding the CERCLA is avaiable on the EPA's website at: http://www.epa.gov/superfund/contacts/sfhotlne/over.pdf