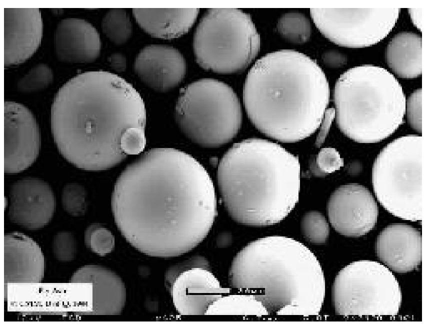
COAL (FLY) ASH

To go into depth on fly ash would be beyond the scope of this paper. Nevertheless, believe us ASH IS CASH.

During the course of the research on my blended cement, I realized that the research carried out on fly ash during the 70's & the 80's was obsolete. Fly ash available from the modern super thermal power plants typically contain around 1% carbon, as the boilers are far more efficient (the Indian IS: 3812 code still has the upper limit of carbon as 12%, while the ASTM C-618 6%). The high velocity of the flue gases in the burning zone produce fly ash of much greater fineness than were achieved earlier. Also this modern day fly ash plays a far more active role in concreting than was thought earlier.

Fly ash is a powdery substance obtained from the dust collectors in the electrical power plants that use coal as fuel. From the cement point of view the mineralogy of fly ash is important. 80-90% of it is glass .It starts out as impurities in coal- mostly clays, shales, limestone & dolomite. They cannot be burned so they turn up as ash, & at high temperatures fuse to become glass. Due to the high speed of the flue gasses the molten glass turns into tiny beads of glass, 40% being less than 10 micron in size (1000 microns is 1mm, cement is approx. 25micron), & these are the principal contributors of the 7 & 28 days strength. Sizes between 10 to 45 microns react slowly to give the concrete strength from 28 days to a year & sizes over 50 micron behave like sand particles & do not matter excepting as a filler.



ADVANTAGES ON ADDITION OF FLY ASH IN CONCRETE

Increased (later) Compressive Strength

Increased Workability

Reduced heat of hydration (CANMET, Canada found that 10 ft cubes had a temperature rise of only 35 deg Celsius vs. 65 deg using Portland cement)

No leaching of Calcium Hydroxide crystals on to the surface (those white patches)

Increased Durability -(low Chloride Ion penetration, i.e. very low coulomb rating that further decreases with time).

Decreased Permeability

Reduced Sulfate Attack

Decreased Bleeding & Segregation

Reduced Drying Shrinkage

ENGINEERING PROPERTIES OF FLY ASH

Some of the engineering properties of fly ash that are of particular interest when fly ash is used as an admixture or a cement addition to PCC mixes include fineness, LOI, chemical composition, moisture content, and pozzolanic activity. Most specifying agencies refer to ASTM C618.

Fineness: Fineness is the primary physical characteristic of fly ash that relates to pozzolanic activity. As the fineness increases, the pozzolanic activity can be expected to increase.

Pozzolanic Activity (Chemical Composition and Mineralogy):Pozzolanic activity refers to the ability of the silica and alumina components of fly ash to react with available calcium and/or magnesium from the hydration products of Portland cement. ASTM C618 requires that the pozzolanic activity index with Portland cement, as determined in accordance with ASTM C311, be a minimum of 75 percent of the average 28-day compressive strength of control mixes made with Portland cement.

Loss on Ignition: LOI value should not exceed 3 or 4 percent, even though the ASTM criteria is a maximum LOI content of 6 percent. This is because carbon contents (reflected by LOI) higher than 3 to 4 percent have an adverse effect on air entrainment. Fly ashes must have a low enough LOI (usually less than 3.0 percent) to satisfy ready-mix concrete producers, who are concerned about product quality and the control of air-entraining admixtures. Furthermore, consistent LOI values are almost as important as low LOI values to ready-mix producers, who are most concerned with consistent and predictable quality.

Moisture Content: ASTM C618 specifies a maximum allowable moisture content of 3.0 percent. Some of the properties of fly ash-concrete mixes that are of particular interest include mix workability, time of setting, bleeding, pumpability, strength development, heat of hydration, permeability, resistance to freeze-thaw, sulfate resistance, and alkali-silica reactivity.

Workability: At a given water-cement ratio, the spherical shape of most fly ash particles permits greater workability than with conventional concrete mixes. When fly ash is used, the absolute volume of cement plus fly ash usually exceeds that of cement in conventional concrete mixes. The increased ratio of solids volume to water volume produces a paste with improved plasticity and more cohesiveness.

Time of Setting: When replacing up to 25 percent of the Portland cement in concrete, all Class F fly ashes and most Class C fly ashes increase the time of setting. However, some Class C fly ashes may have little effect on, or possibly even decrease, the time of setting. Delays in setting time will probably be more pronounced, compared with conventional concrete mixes, during the cooler or colder months.

Bleeding: Bleeding in concrete is usually lower because of the greater volume of fines and lower required water content for a given degree of workability.

Pumpability: Pumpability is increased by the same characteristics affecting workability, specifically, the lubricating effect of the spherical fly ash particles and the increased ratio of solids to liquid that makes the concrete less prone to segregation.

Strength Development: Previous studies of fly ash concrete mixes have generally confirmed that most mixes that contain Class F fly ash that replaces Portland cement at a 1:1 (equal weight) ratio gain compressive strength, as well as tensile strength, more slowly than conventional concrete mixes for up to as long as 60 to 90 days. Beyond 60 to 90 days, Class F fly ash concrete mixes will ultimately exceed the strength of conventional PCC mixes. For mixes with replacement ratios from 1.1 to 1.5:1 by weight of Class F fly ash to the Portland cement that is being replaced, 28-day strength development is approximately equal to that of conventional concrete. Class C fly ashes often exhibit a higher rate of reaction at early ages than Class F fly ashes. Some Class C fly ashes are as effective as Portland cement in developing 28-day strength. Both Class F and Class C fly ashes are beneficial in the production of high-strength concrete. However, the American Concrete Institute (ACI) recommends that Class F fly ash replace from 15 to 25 percent of the Portland cement and Class C fly ash replace from 20 to 35 percent.

Heat of Hydration: The initial impetus for using fly ash in concrete is stemmed from the fact that the more slowly reacting fly ash generates less heat per unit of time than the hydration of the faster reacting Portland cement. Thus, the temperature rise in large masses of concrete (such as dams) can be significantly reduced if fly ash is substituted for cement, since more of the heat can be dissipated as it develops. Not only is the risk of thermal cracking reduced, but greater ultimate strength is attained in concrete with fly ash because of the pozzolanic reaction. Class F fly ashes are generally more effective than Class C fly ashes in reducing the heat of hydration.

Permeability: Fly ash reacting with available lime and alkalies generates additional cementitious compounds that act to block bleed channels, filling pore space and reducing the permeability of the hardened concrete. The pozzolanic reaction consumes calcium hydroxide (Ca(OH)2), which is leachable, replacing it with insoluble calcium silicate hydrates (CSH). The increased volume of fines and reduced water content also play a role.

Resistance to Freeze-Thaw: As with all concretes, the resistance of fly ash concrete to damage from freezing and thawing depends on the adequacy of the air void system, as well as other factors, such as strength development, climate, and the use of deicer salts. Special attention must be given to attaining the proper amount of entrained air and air void distribution. Once fly ash concrete has developed adequate strength, no significant differences in concrete durability have usually been observed. There should be no more tendency for fly ash concrete to scale in freezing and thawing exposures than conventional concrete, provided the fly ash concrete has achieved its design strength and has the proper air void system.

Sulfate Resistance: Class F fly ash will generally improve the sulfate resistance of any concrete mixture in which it is included. Some Class C fly ashes may improve sulfate resistance, while others may actually reduce sulfate resistance and accelerate deterioration. Class C fly ashes should be individually tested before use in a sulfate environment. The relative resistance of fly ash to sulfate deterioration is reportedly a function of the ratio of calcium oxide to iron oxide.

Alkali-Silica Reactivity: Class F fly ash has been effective in inhibiting or reducing expansive reactions resulting from the alkali-silica reaction. In theory, the reaction between the very small particles of amorphous silica glass in the fly ash and the alkalis in the Portland cement, as well as the fly ash, ties up the alkalis in a non-expansive calcium-alkali-silica gel, preventing them from reacting with silica in aggregates, which can result in expansive reactions. However, because some fly ashes (including some Class C fly ashes) may have appreciable amounts of soluble alkalis, it is necessary to test materials to be used in the field to ensure that expansion due to alkali-silica reactivity will be reduced to safe levels. Fly ash, especially Class F fly ash, is effective in three ways in substantially reducing alkali-silica expansion:
1) it produces a denser, less permeable concrete
2) when used as a cement replacement it reduces total alkali content by reducing the Portland cement; and 3) alkalis react with fly ash instead of reactive silica aggregates.

Class F fly ashes are probably more effective than Class C fly ashes because of their higher silica content, which can react with alkalis.

MATERIAL PROPERTIES

Physical Properties

Fly ash consists of fine, powdery particles that are predominantly spherical in shape, either solid or hollow, and mostly glassy (amorphous) in nature. The carbonaceous material in fly ash is composed of angular particles. The particle size distribution of most bituminous coal fly ashes is generally similar to that of a silt (less than a 0.075 mm or No. 200 sieve). Although subbituminous coal fly ashes are also silt-sized, they are generally slightly coarser than bituminous coal fly ashes.

The specific gravity of fly ash usually ranges from 2.1 to 3.0, while its specific surface area (measured by the Blaine air permeability method)) may range from 170 to 1000 m^2/kg.

The color of fly ash can vary from tan to gray to black, depending on the amount of unburned carbon in the ash. The lighter the color, the lower the carbon content. Lignite or subbituminous fly ashes are usually light tan to buff in color, indicating relatively low amounts of carbon as well as the presence of some lime or calcium. Bituminous fly ashes are usually some shade of gray, with the lighter shades of gray generally indicating a higher quality of ash.

Chemical Properties

The chemical properties of fly ash are influenced to a great extent by those of the coal burned and the techniques used for handling and storage. There are basically four types, or ranks, of coal, each of which varies in terms of its heating value, its chemical composition, ash content, and geological origin. The four types, or ranks, of coal are anthracite, bituminous, subbituminous, and lignite. In addition to being handled in a dry, conditioned, or wet form, fly ash is also sometimes classified according to the type of coal from which the ash was derived.

The principal components of bituminous coal fly ash are silica, alumina, iron oxide, and calcium, with varying amounts of carbon, as measured by the loss on ignition (LOI). Lignite and subbituminous coal fly ashes are characterized by higher concentrations of calcium and magnesium oxide and reduced percentages of silica and iron oxide, as well as a lower carbon content, compared with bituminous coal fly ash. Very little anthracite coal is burned in utility boilers, so there are only small amounts of anthracite coal fly ash.

Table below compares the normal range of the chemical constituents of bituminous coal fly ash with those of lignite coal fly ash and subbituminous coal fly ash. From the table, it is evident that lignite and subbituminous coal fly ashes have a higher calcium oxide content and lower loss on ignition than fly ashes from bituminous coals. Lignite and subbituminous coal fly ashes may have a higher concentration of sulfate compounds than bituminous coal fly ashes.

The chief difference between Class F and Class C fly ash is in the amount of calcium and the silica, alumina, and iron content in the ash. In Class F fly ash, total calcium typically ranges from 1 to 12 percent, mostly in the form of calcium hydroxide, calcium sulfate, and glassy components in combination with silica and alumina. In contrast, Class C fly ash may have reported calcium oxide contents as high as 30 to 40 percent. Another difference between Class F and Class C is that the amount of alkalis (combined sodium and potassium) and sulfates (SO_4) are generally higher in the Class C fly ashes than in the Class F fly ashes.

Normal range of chemical composition for fly ash produced from different coal types(expressed as percent by weight).

Component	Bituminous	Subbituminous	Lignite
SiO_2	20-60	40-60	15-45
Al_2O_3	5-35	20-30	10-25
Fe_2O_3	10-40	4-10	4-15
CaO	1-12	5-30	15-40
MgO	0-5	1-6	3-10
SO_3	0-4	0-2	0-10
Na_2O	0-4	0-2	0-6
K_2O	0-3	0-4	0-4
LOI	0-15	0-3	0-5

Although the Class F and Class C designations strictly apply only to fly ash meeting the ASTM C618 specification, these terms are often used more generally to apply to fly ash on the basis of its original coal type or CaO content. It is important to recognize that not all fly ashes are able to meet ASTM C618 requirements and that, for applications other than concrete, it may not be necessary for them to do so.

The loss on ignition (LOI), which is a measurement of the amount of unburned carbon remaining in the fly ash, is one of the most significant chemical properties of fly ash, especially as an indicator of suitability for use as a cement replacement in concrete.

Quality Control

Fly ash used in concrete should be as consistent and uniform as possible. Fly ash to be used in concrete should be monitored by a quality assurance/quality control (QA/QC) program that complies with the recommended procedures in ASTM C311.(6) These procedures establish standards for methods of sampling and frequency of performing tests for fineness, loss on ignition (LOI), specific gravity, and pozzolanic activity such that the consistency of a fly ash source can be certified.

DESIGN CONSIDERATIONS

Mix Design

Concrete mixes are designed by selecting the proportions of the mix components that will develop the required strength, produce a workable consistency concrete that can be handled and placed easily, attain sufficient durability under exposure to in-service environmental conditions, and be economical. Procedures for proportioning fly ash concrete mixes differ slightly from those for conventional concrete mixes. Basic mix design guidelines for normal concrete and high-strength concrete are provided by ACI.

One mix design approach commonly used in proportioning fly ash concrete mixes is to use a mix design with all Portland cement, remove some of the Portland cement, and then add fly ash to compensate for the cement that is removed. Class C fly ash is usually substituted at a 1:1 ratio. Class F fly ash may also be substituted at a 1:1 ratio, but is sometimes specified at a 1.25:1 ratio, and in some cases may even be substituted at a 1.5:1 ratio. The percentage of Class F fly ash used as a percent of total cementitious material in mortar or structural concrete mixes usually ranges from 15 to 30 percent by weight. This percentage usually ranges from 20 to 35 percent when Class C fly ash is used.

Mix design procedures for normal, as well as high-strength, concrete involve a determination of the total weight of cementitious materials (cement plus fly ash) for each trial mixture that is being investigated in the laboratory. The ACI mix proportioning guidelines recommend a separate trial mix for each 5-percent increment in the replacement of Portland cement by fly ash. If fly ash is to replace Portland cement on an equal weight (1:1) basis, the total weight of cementitious material in each trial mix will remain the same. However, because of differences in the specific gravity values of Portland cement and fly ash, the volume of cementitious material will vary with each trial mixture.

To select a mix proportion that satisfies the design requirements for a particular project, trial mixes must be made. In a concrete mix design, the water-cement (w/c) ratio is a key design parameter, with a typical range being from 0.37 to 0.50. When using a blended cement, the water demand will probably be somewhat reduced because of the presence of the fly ash in the blended cement. When fly ash is used as a separately batched material, trial mixes should be made using a water-cement plus fly ash (w/c+f) ratio, sometimes referred to as the water-cementitious ratio, instead of the conventional w/c ratio.

CONSTRUCTION PROCEDURES

Material Handling and Storage

When fly ash is used as a mineral admixture, the ready-mix producer typically handles fly ash in the same manner as Portland cement, except that fly ash must be stored in a separate silo from the Portland cement.

Mixing, Placing, and Compacting

Placement and handling of fly ash concrete is in most respects similar to that of normal concrete. Fly ash concrete using Class F fly ash has a slower setting time than normal concrete. As a result, finishing operations may have to be delayed, possibly by 1 to 2 hours, depending on the temperature. Also, fly ash concrete surfaces may tend to be more sticky than normal concrete during placement and finishing, although properly proportioned concrete mixes containing fly ash should benefit workability and finishing. Normal procedures for screeding, finishing, edging, and jointing of conventional PCC are also applicable to fly ash concrete.

Curing

The slower strength development of concrete containing Class F fly ash may require that the moisture be retained in the concrete for a longer period of time than what is normally required for conventional concrete. The proper application of a curing compound should retain moisture in the concrete for a sufficient period of time to permit strength development. Normal curing practices should be adequate for concrete containing Class F fly ash.