TECHNIQUES FOR THE UTILIZATION OF FLY ASH

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Since the introduction of pulverized-coal boilers in the 1920-1930 decade, the problem of fly ash collection and disposal has been a major problem to the electric utility industry. The quantity of fly ash produced and which is not collected is becoming an increasingly greater air pollution problem, subject to control by municipalities, states and the Federal Government. Every emphasis is therefore being made to reduce the amount of fly ash escaping to the atmosphere by the installation of fly ash collecting equipment, where it does not exist, and by increasing the collection efficiency of equipment where it is already installed. This reduction in air pollution, however, aggravates the already difficult problem of disposal of the collected fly ash. At Duquesne Light Company there are twenty pulverized-coal boilers, and in 1964 they produced nearly 500,000 tons of fly ash. In the United States in 1962, more than eleven million tons of fly ash were collected; and it is estimated that by 1980, there will be twenty-five million tons produced annually. At Duquesne Light Company the fly ash produced was collected by mechanical collectors and electrostatic precipitators, sometimes in combination. The collected fly ash is generally handled in two ways. One method is to transport it from the collection hoppers to a silo in a dry state and, after passing through a wetting pug mill, it is loaded on trucks and hauled to the ash disposal area. A second method is to remove the fly ash from the hoppers, mix it with water and sluice it to an ash pond. When the pond becomes full and has been dewatered by drainage and evaporation, it is dug with power equipment and hauled to the ash disposal area.

Duquesne has been disposing of fly ash in these ways for more than twenty years and has found that they are wasteful and represent a continuing expense, from which no benefits can be realized. The dump areas, at best, are unsightly and are a source of secondary fly ash entrainment. The unsightliness and the dust source of the dump areas are an annoyance to the nearby populace, and in some locations this annoyance has caused a considerable amount of ill feeling toward the Company. There have been acts of harassment by the public and legislative action by certain municipalities to prevent the dumping of fly ash. For these reasons, it has been increasingly difficult to locate and obtain new dumping areas which are located at reasonable distances from a generating station. All practical and reasonable methods to find solutions to these problems, and thereby placate the neighbors, have been tried by Duquesne, but mostly without too much success. This is especially true if the dump area is still being used. For dumps no longer in use, a method which has been used successfully to eliminate secondary fly ash entrainment has been to cover the dump area with topsoil and plant with grass seed. In many locations, these areas have been made useful to municipalities for recreational activities. However, it is not possible to use these filled areas for heavy buildings because fly ash will not support heavy loads, the inherent tendency being to "flow" when subjected to great pressures or excessive moisture. Taking all facts into consideration, it can be concluded that the present procedure of dumping is a very undesirable method of disposing of fly ash.

Confronted with these conditions, the Duquesne Light Company has been actively engaged, for more than fifteen years, in searching for other methods for the disposal of fly ash in an economic manner. Duquesne has financed, both privately and jointly with other companies, research projects to determine the feasibility of new methods for the utilization of fly ash. In addition, it has

worked closely with national organizations such as the Edison Electric Institute which, of course, also recognizes that with the increase in pulverized-coal boilers, the disposal of fly ash is becoming a more acute problem.

Several worthwhile uses have been found for fly ash, one of which is in the construction of asphalt roadways. Fly ash has proven to be very effective as a "choking" material for the large, heavy slag base courses, because of its fluidity, and as a replacement for limestone dust in the surface course. In 1953, working in conjunction with Bituminous Coal Research, Inc., Duquesne Light Company constructed a special asphalt roadway at its Phillips Power Station near Aliquippa, Pennsylvania, for the purpose of determining the effect on the durability of this type of roadway when fly ash is substituted for other materials. The road is approximately 170 feet long and runs from a passing highway to the station coal truck scale. The road, over which all of the station trucked coal passes, is considered to be a very heavy one and handles an average of 160 trucks per day for a five-day week at an average loaded weight of at least 25 tons. Various combinations of standard and fly-ash-containing surfaces and bases were installed to compare the different types of construction. The road, as constructed, consists of a 1-inch sand base, two 6-inch large slag bases, a 2-inch binder course and a 1-inch surface course. Fly ash was used for filling ("choking") between the large slag of the bases and as a substitute for limestone dust in the surface course. The road is still in use and did not require repair until May 1965, when very minor repairs were made. The results of the test indicate that those portions of the road which were constructed using fly ash, as previously described, have performed as well, if not better, than the portions using regular construction materials with respect to surface wear and general road upkeep. It was due mostly to the results of this test road that the Pennsylvania State Highway Department accepted fly ash as a suitable material in their asphalt road specifications. With the prospect of having a market for its fly ash, the Duquesne Light Company installed fly ash bagging facilities at its Phillips Station. The fly ash is marketed by a local contractor under the name of "Durosil". There has, however, never been any real demand for the product in this area.

Although subsequently there have been roads in other areas similarly constructed, there has not been any real wide-spread use of fly ash for this purpose. Electric utilities, whose primary interest is generating electric power, have, perhaps, not attempted to push greatly the uses of fly ash for road construction. This method of utilization also would not nearly approach the total amount of fly ash produced each year by the electric industry, and its seasonal demand would produce problems of storage or intermittent disposal.

Due to its pozzolanic properties, another use for fly ash is as a concrete additive substituted for cement. Although fly ash cannot be wholly substituted for cement, it has been shown to be effective when used as a replacement in quantities up to 25-30 per cent of the cement used in bulk concrete and concrete block. Much research has been done by the electric utility industry, as well as many other interested organizations, to determine the effects of substituting fly ash for cement in the preparation of concrete. The Battelle Memorial Institute has been engaged for several years in research for the Edison Electric Institute for the purpose of determining cementitious characteristics of fly ash and the effect of variations in chemical composition of different ashes. As long ago as 1952, Duquesne Light Company engaged the Pittsburgh Testing Laboratory to perform tests on concrete containing fly ash. Using basic 1:2:3 and 1:2:4 concrete mixes, fly ash was substituted for cement in amounts of 10, 20 and 30 per cent. The concrete samples were then used to conduct compressive and fracture tests. In 1954 Duquesne Light Company, when installing a new concrete roat at its Elrama Station, used fly ash in 10, 20 and 25 per cent quantities in certain test sections of the road. Concrete samples taken at that time were also tested by Pittsburgh Testing Laboratory.

The results of these tests, as well as tests by many other organizations, indicate that fly ash can be substituted successfully for cement in concrete up to 25-30 per cent replacement and still produce a concrete which exceeds the minimum compressive strength. The following table shows the compressive strength of concrete with various percentages of fly ash substituted for Portland cement. The data was taken from tests performed by the National Ready-Mixed Concrete Association.

Cement Replaced Per Cent	Compressive Strength, psi		
	7 days	28 days	3 months
0	3 320	5 180	6 050
10	2 800	4 690	5 330
20	2 270	4 040	5 380
30	1 900	3 440	4 820
40	1 470	2 740	4 180

It can be seen that as the fly ash percentage increases, the compressive strength of the concrete decreases. However, the strength increases considerably with time until, with a 20 per cent substitution, the fly ash concrete exceeds the regular concrete at about 100 days. The degree of substitution is generally a function of the chemical properties and fineness of the fly ash. The ASTM has set chemical standards for fly ash acceptance; however, many cities and federal agencies have set their own, and sometimes more rigid, standards. The exact effect of the chemical composition is not known in all cases. However, it is known that the greater the percentage of carbon in the fly ash, the weaker will be the concrete. This effect will be partially offset, however, by increased fineness of the material. All of the combinations of circumstances affecting the strength of the concrete, however, are not yet known; and, therefore, considerable research has yet to be done in order to know completely the chemical effects.

The following table shows the physical and chemical properties of Duquesne Light Company fly ash as compared to the ASTM specifications for fly ash to be used in concrete:

Chemical Composition - % by Weight	ASTM	D.L. Co.
Silica (SiO_2)		41-51
Aluminum Oxide (Al_2O_3)	70 max.	26-32
Iron Oxide (Fe_2O_3)		9-14
Magnesium Oxide (MgO)	5.0 max.	0.4-1.0
Sulphur Trioxide (SO_3)	5.0 max.	0.3-0.8
Available Alkalies (Na_2O)	1.5 max.	0.5-1.5
Moisture content @ 105°C	3.0 max.	0.1-0.3
Ignition loss @ 750°C	12.0 max.	3-7
Physical Properties		
Fineness, Blaine Method, cm^2/g	-	2800-4200
Specific Gravity	-	2.3-2.5
Soundness, per cent	0.5 max.	0.07-0.2
Mean particle size, microns	9.0 max.	6.7-10.0

The cement-water reaction in regular concrete liberates lime in the form of calcium hydroxide. After the concrete hardens and is exposed to water, the calcium hydroxide, which is water soluble, will leach out with time, leaving voids in the concrete. Leaching begins soon after the concrete is placed and continues for its lifetime. The free calcium hydroxide is attacked by various sulfates and

other compounds, increasing the permeability of the concrete and thereby leading to deterioration and decrease in durability. Therefore, concrete should contain a minimum of calcium hydroxide in order to increase its durability and decrease its permeability. By using fly ash in concrete, the fly ash takes advantage of the hydrated lime freed in the cement-water reaction by combining with it. A chemical reaction between the hydrated lime and the silicon and aluminum oxides in the fly ash produces insoluble cementing compounds. These aid the hardened particles in the remaining cement mixture to make fly ash concrete superior to ordinary concrete in strength, durability, watertightness and resistance to various acids, alkalies and sulfates. As would be expected, the fly-ash-containing concrete does not harden as rapidly as regular concrete; however, the fly ash concrete will, in time, become stronger than the regular concrete. It can be seen on Figure 1 that for the particular fly ash-cement combination used (20 per cent fly ash, 80 per cent Portland cement), the fly ash concrete becomes harder after about 100 days.

This same lime-fly ash chemical reaction that takes place in concrete also occurs when mixing fly ash with lime and aggregate — a combination which has been used to build low cost temporary roads, airport runways and parking lots. Actually, the Romans used a similar combination for road building nearly 2,000 years ago, except volcanic ash was used in place of fly ash. It is from this ancient use that the word "pozzolanic" is derived.

To date, a limited amount of fly ash has been used by the bulk concrete users. The largest project to date which utilized fly ash as a substitute for cement was the Hungry Horse Dam in northwest Montana. This dam, which contains 3,086,000 cubic yards of concrete, used 126,000 tons of fly ash with a resultant saving of $1.5 million. Various other dams and buildings throughout the country, including Duquesne Light Company's Shippingport Atomic Power Station, have been built using fly-ash-containing concrete.

If all the concrete used contained fly ash, there would be no difficulty in disposing of all the fly ash that is currently produced. However, there are several factors which presently tend to limit the marketing of fly ash on that large a scale.

First, some degree of consistency, with respect to the properties of fly ash, is needed before it can be used in concrete. These properties vary from location to location and from time to time, because there is no attempt to control fly ash properties. It must be remembered that fly ash is a by-product of electric power generation and its properties depend, to a large extent, on how that generation is performed and also on the original composition of the coal which is burned. For instance, a station which is base loaded will produce fly ash with a lower carbon content than a station whose electrical output, and therefore coal burning rate, continually fluctuates.

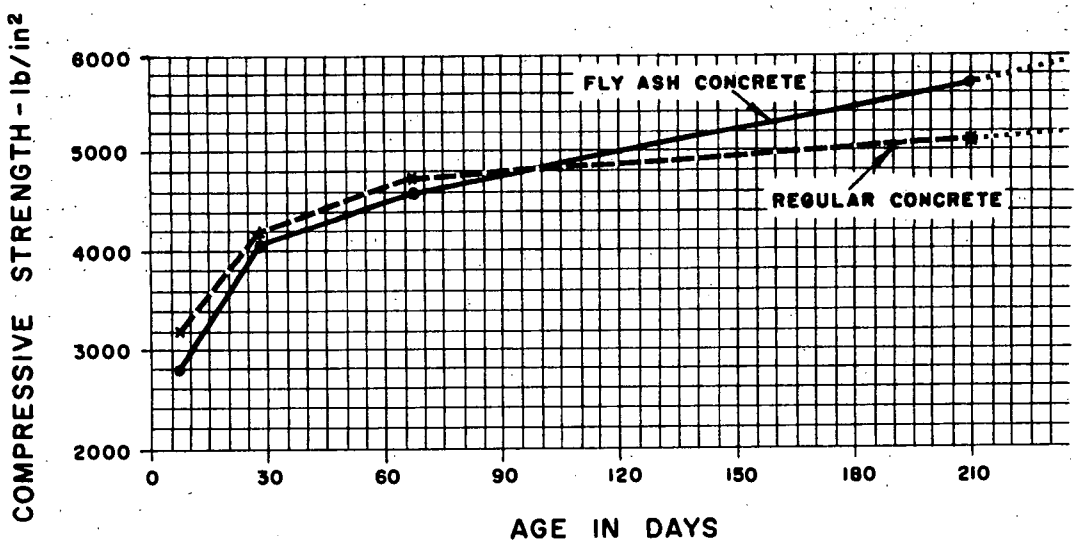
Second, the basic composition of the coal burned may contain excessive amounts of undesirable elements. For instance, fly ash may contain excessive iron and therefore impart an undesirably darker color or may result in staining when incorporated into concrete blocks or other masonry products.

Third, the bulk concrete mixing plants are not always conveniently located to fly ash sources; and, therefore, transportation can be a problem or at least costly enough to eliminate possible savings.

Fourth, the handling and storage of fly ash can be a problem if it is used in large concrete projects like dams and buildings. In construction projects such as these, the need for fly ash is intermittent and storage facilities would therefore be required to meet the demand when needed.

FIGURE - 1

COMPRESSIVE STRENGTH OF FLY ASH CONCRETE VS. REGULAR CONCRETE



Fifth, the electric utility industry, as a whole, has probably not pushed sufficiently hard to develop a market for the material nor to enlighten concrete users sufficiently. All electric utility companies do not have fly ash disposal problems, since some companies use other fuels and still other companies have not experienced problems with dumping because of geographical location. However, evaluating all factors, it is evident that, at least in certain areas, many problems exist and that much research is still needed if fly ash is to be substituted for Portland cement in any great quantities.

Fly ash has been tried as a substitute material in various processes by many industries. The previous uses discussed are known to be successful; some other processes have been reasonably successful and can use fly ash; while still others have found fly ash to be an unsuitable material for a particular use.

Experimental work has been done on using fly ash as a substitute for core sand for steel and aluminum castings. Although the castings using fly ash molds were smoother, they tended to develop pitting; and also, there was the ever present problem of handling the fly ash.

Fly ash was tested as an extender in paint and as a filler in putty. It proved to be of no value in paint, and particle size was too large for putty.

Some fly ash is being used in asphalt roofing and siding materials, but has been rejected for floor tile because of its dark color.

A building block was tested using lime and fly ash and containing no Portland cement. The blocks had a smooth surface which made them difficult to handle. Also, they were more brittle, tended to chip and spall after installation and were heavier than regular block. They were rejected because they afforded no advantage over the regular block.

An investigation was made into the possibility of using fly ash as a constituent in brick making. It was rejected because when mixed with clay, the material packed too hard, was too abrasive and the bricks were too brittle.

Fly ash was tested for use in a sound deadening plaster, but its color was objectionable.

Fly ash has been tried as an admixture to fertilizer, replacing foundry sand, but was found to be too fine and dusty.

Some agricultural experiments have been conducted on pot plantings of soy beans by adding fly ash to the soil. The fly ash produced a substantial increase in growth and an improvement in color.

Fly ash was tried as a filler for abrasive soap, but was found to be inferior to the pumice which was being used. It was also found to be unsuccessful as a filler material in paper and rubber.

Fly ash was tried as a sound and heat insulator, but was found to pack excessively and absorb moisture when exposed to air.

Insulating cement has been made containing fly ash which results in less shrinkage cracks, and therefore is considered to be superior to other materials used.

Fly ash has been substituted for pumice in buffing compounds and for whiting in tooth paste. It did not produce the desired polished finish when used for buffing, and it was too hard for use in tooth paste.

When fly ash was substituted for clay in ceramic tile, there was no improvement in product quality and it cost more to manufacture. As a substitute for diatomaceous earth in plastics, it resulted in a product of poorer quality.

When tried as a filter for water and oil purification, replacing sand and fuller's earth, fly ash did not produce desired clarification of the water or oil.

The utilization of the individual chemicals of which fly ash is composed may be a possible use in the future. The Bureau of Mines has experimented with removing traces of germanium which have been found in some fly ashes. The extraction of other elements and compounds may be feasible in the future.

It is evident that uses for fly ash have been attempted by many industries, but with only limited success. Those that have found the product useful do not use fly ash in sufficient quantities to consume any great percentage of the yearly production.

To date, the most promising method for utilizing fly ash appears to be as a lightweight aggregate. However, the fly ash must first be sintered and crushed and then it can be used as a substitute for fine or coarse aggregate in concrete, concrete block, roadways and anywhere else where aggregates are required.

The possibility of sintering fly ash came to light in the early 1950's when efforts were made by certain companies to sinter fly ash without first pelletizing. The process was not successful. It was found that pelletizing was necessary and could be accomplished only after adding expensive binders. Experimentation continued to improve pelletizing equipment, mostly in conjunction with iron ore, so that by 1960 pelletizing could be accomplished without binder admixtures. By 1961, pelletizing and sintering tests with fly ash in various pilot plants demonstrated that fly ash sintering plants of a commercial size were now technically and economically feasible. Since that time, three fly ash sintering plants have been installed, one each at Consolidated Edison Company in New York City; Niagara Mohawk Power Company in Buffalo, New York; and at Detroit Edison Company in Detroit, Michigan. All three of these plants utilize the same basic design produced by the McDowell-Wellman Company. The Stirling Sintering Company of Pittsburgh, Pennsylvania, also has installed a small plant near Duquesne Light's Phillips Station. The McDowell-Wellman process and the Stirling process are similar in that pelletizing is achieved by adding water to the fly ash in a rotating drum. Still another process has been developed by the G. & W.H. Corson Company of Plymouth Meeting, Pennsylvania, whereby pelletizing is accomplished through an extrusion process. Both of the processes then feed the pellets into a gas-fired oven at approximately 2000°F, and the carbon in the fly ash is burned while at the same time sintered pellets are formed. These pellets can be crushed to various sizes to give either a fine or coarse aggregate.

The chief advantage of sintered fly ash aggregate is its light weight. When sized to concrete block grade, sintered fly ash weighs 48-50 lbs./cu.ft., while another common block aggregate material, expanded slag, weighs 68-72 lb./cu. ft. This weight differential causes a reduction in block weight from approximately 35 lb. to 25 lb. This reduction can mean a decrease in building structure costs, handling cost and shipping cost. In addition to the reduction in costs realized in using the block, the block containing fly ash aggregate can be produced at a lower cost, since it has been shown that less Portland cement is required to produce a block of comparable strength with fly ash than with regular aggregate. The ASTM specifications for a 28-day cured concrete block having a minimum shell face thickness of 1-1/4" is 1000 psi compressive strength. Tests which have been performed on block made from Duquesne Light Company fly ash and sintered in the Corson Company plant have shown compressive strengths of 1580 to 1920 psi, depending on the quantity of Portland cement used.

Tests have also been performed on bulk concrete made using fly ash as a coarse and fine aggregate. These tests have shown that where the ASTM compressive strength test requires 4000 psi for 28-day cured concrete, the fly-ash-containing concrete was tested to 4910 psi, which surpasses the 4800 psi concrete made using expanded slag as an aggregate. It can readily be seen that concrete and concrete block using fly ash aggregate greatly exceed the minimum established strength requirements. When used in roadway construction, concrete containing fly ash aggregate as an added benefit has been shown to be more skid resistant.

With the advantages previously mentioned, the market for fly ash aggregate appears to be almost unlimited. Present surveys have indicated that a real demand can be established, provided a quality product can consistently be produced by the sintering plant. Because fly ash sintering is a relatively new concept, operational difficulties have been encountered by the three utilities previously mentioned which have fly ash sintering plants; however, all feel that most of the problems that still exist are due to inexperience of operation and newness of equipment design. Duquesne Light Company, at the time of preparation of this paper, is proceeding with the design and will install a fly ash sintering plant at its Elrama Station. With the expectation of being able to turn a costly expense into a profit-making operation, it is anticipated that more companies will likewise investigate the possibilities of sintering fly ash. It is even possible that future designs of pulverized coal burning stations will incorporate fly ash sintering facilities as an integral part of the station design and operation.

The electric utility industry, as a whole, is very enthusiastic over the possibilities of sintered fly ash, feeling that perhaps at last a use has been found that can utilize all of the fly ash that is produced and end once and for all the problems presently encountered in fly ash disposal.