Fly ash

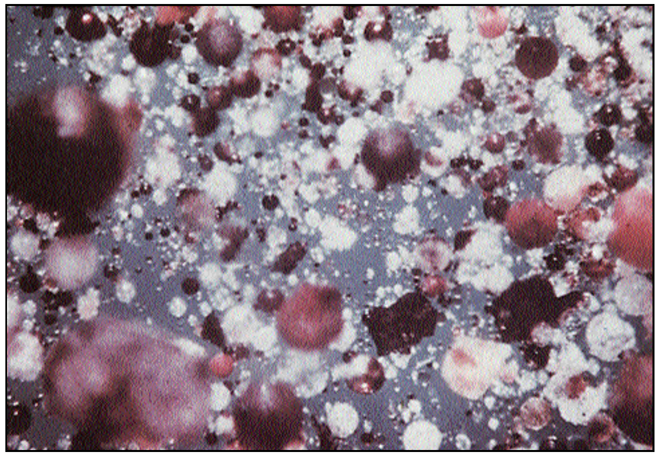
How much to use?
What are the cost savings?

What are typical proportions of portland cement and fly ash for a concrete containing fly ash? And what are the typical cost savings when a fly ash mix is compared with a non-fly ash concrete having the same strength? The benefits of using fly ash in concrete have been described in many research reports and other publications (see CONCRETE CONSTRUCTION, May 1982, page 417). Standards of the American Society for Testing and Materials (ASTM) define acceptable fly ash properties and describe testing procedures. American Concrete Institute (ACI) specifications provide for fly ash use in structural concrete. Governmental agencies as well as commercial concrete producers have had extensive experience in using fly ash. But can the cost savings be more precisely pinned down?

We could safely say that cement contents of 564 pounds per cubic yard, without admixtures, or 517 pounds per cubic yard, with a water reducer, are typical for a design strength of 4000 psi. Cement, aggregate, admixture properties and quality control will have some effect on the cement content; but the numbers given are representative of common practice. Can fly ash mixes be described in a similar manner? First we have to differentiate between the two types of ash available.

Class F and Class C ashes

Most available information, until recently, has dealt with Class F ash. This is ash produced from bituminous coals commonly available in the central and eastern parts of the country, somewhat less commonly in the west. Class F ash is generally low in lime and by itself has little or no cementitious value. It slowly combines with calcium hydroxide released during portland cement hydration to form new cementing compounds. Although ultimate strength is improved, use of Class F ash sometimes results in longer setting times and lower early strengths.



Spherical in shape and finer than cement, fly ash particles range from 0.00004 to 0.006 inch in diameter.

More recently Class C ash has come into common use. It is produced from subbituminous or lignite coals from western sources and has a higher lime content than Class F ash. This gives the Class C ash some cementitious qualities of its own—it will chemically react with water, even if cement isn't present. Concrete setting times and early strengths are affected far less when Class C ash is used. This difference in the Class F and Class C ashes is great enough to affect the concrete mix proportions.

Fly ash concrete trial mixes

Properties of fly ashes from different sources vary considerably. There are some differences between cements as well, and there are differences in the efficiency of different cements and different ashes in combination. In spite of these variables, it is possible to examine mix designs within the bounds of a reasonable guideline. Table 1 is just that—a guideline. It provides a starting point for trial mixes that can be tested to determine the most efficient combination of fly ash and portland cement to produce a given strength. It also provides a basis for es-

TABLE 1. A GUIDELINE FOR PORTLAND CEMENT-FLY ASH TRIAL MIXES

28-day design strength at 3- to 4-inch slump	Portland cement, pounds per cubic yard	Fly ash, pounds per cubic yard	Total cementitious content, pounds per cubic yard	Admixture
3000 psi	320-360	100-160	460-480	Water reducer Air-entraining agent*
4000 psi	370-410	130-180	530-550	Water reducer
5000 psi	470-510	140-180	630-650	Water reducer

* Air entrainment suggested to aid in placement and finishing of lean mixes. Air entrainment in higher strength mixes may be expected to require some increase in total cementitious content to maintain strength.

timating the potential for cost savings that fly ash concrete may allow within a given market area.

From Table 1 select a portland cement content and a fly ash content within the suggested ranges. When added together the total should be within the range of total cementitious content suggested. This becomes the starting point for the trial mixes that will have to be tested to verify the optimum fly ash and portland cement proportions.

Because a Class C ash has cementitious qualities of its own and Class F ash does not, the amount of Class C ash that may be used is usually greater. This is true when early strengths are important and may be true when only 28-day strengths are of concern. Table 1 shows the total weight of portland cement and fly ash for a 4000 psi concrete to be about 540 pounds. With a Class C ash it may be possible for over 30 percent of that total cementitious content to be fly ash with excellent results. A starting point of 370 pounds of cement and 170 pounds of fly ash might be selected. With a Class F ash, which can be expected to produce lower early strengths, the same application might allow only 20 to 25 percent ash, especially if 3- or 7-day strengths are important. The starting point might then be 410 pounds of cement and 130 pounds of fly ash. Final proportions are chosen based on test results.

Cold weather is also a consideration. Early strength gain is reduced with the use of either Class C or Class F ash. Especially with Class F ash, colder weather can be expected to require that lower percentages of ash be used. The effect of cold weather also makes the handling of concrete test cylinders critical. The contractor and ready mix producer should demand that cylinders used as a basis for acceptance of concrete be protected in the field at 60 to 80 degrees F and taken into the laboratory the day after they are made. The American Society for Testing and Materials Standard C 31 governs this procedure, and it is one that is all too often ignored.

Early strengths

With Class C ashes, designing a mix for early strength is little different from designing for a specific early strength with a Type I cement, non-fly ash mix. Class C ash mixes and non-fly ash mixes designed for the same 28-day strength may well have similar 3-day and 7-day strengths also. Although upward adjustments in the percentage of portland cement may be helpful, early strength requirements can be met with economical fly ash mixes.

High strength concrete

Fly ash serves a very useful purpose in high strength concrete. There is considerable experience confirming that the high strengths achieved by using a minimum of 10 to 15 percent fly ash by weight of the total cementitious content cannot be attained by using additional portland cement. Fly ash provides later strength gain that cement alone will not in these high cement content mixes.

Cost savings

Cement costs vary from approximately $50 to $75 per ton or 2.5 to 3.75 cents per pound. Fly ash prices range from $15 to $40 per ton or 0.75 to 2 cents per pound. Unlike portland cement, the major portion of the cost of fly ash is in transportation. Remote location from the fly ash source can double or triple fly ash prices. Location also affects cement prices but not nearly to the same extent. Using the costs applicable in a given area it is possible to make some cost estimates for fly ash and non-fly ash mixes of comparable strength. Assume that tests with locally available materials have confirmed the following cementitious contents for a 4000 psi 28-day strength.

564 pounds of cement with no admixture

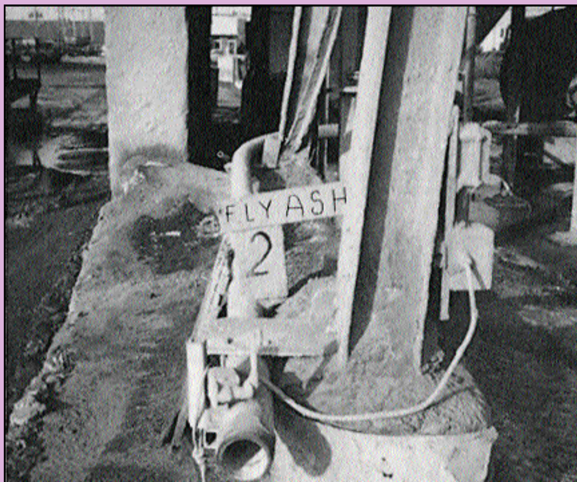
517 pounds of cement with a water reducer

390 pounds of cement, 150 pounds of fly ash with a water reducer

Assuming 3 cents per pound or $60 per ton for cement, 1.2 cents per pound or $24 per ton for fly ash, and 40 to 45 cents per cubic yard for the water reducer, the costs of the total cement and admixture for each mix are shown in Table 2.

TABLE 2. SAMPLE COST COMPARISONS OF CEMENTITIOUS CONTENT OF CONCRETES WITH AND WITHOUT FLY ASH

	CEMENT ONLY		CEMENT WITH WATER REDUCER		CEMENT WITH FLY ASH AND WATER REDUCER	
	Weight, pounds per cubic yard	Cost	Weight, pounds per cubic yard	Cost	Weight, pounds per cubic yard	Cost
Cement564	$16.92		517	$15.51	390	$11.70
Fly ash					150	$ 1.80
Water reducer				$ 0.41		$ 0.43
TOTAL	**564**	**$16.92**	**517**	**$15.92**	**540**	**$13.93**



CAUTION

Fly ash looks like portland cement.
It is blown into a storage silo just like cement.
Drivers do make mistakes.

Fly ash in place of cement will probably not be detected in the silo or in the concrete until long-delayed setting time or lack of strength gain has been noticed.

Identify the silos and the pipes clearly! Leave no room for error. Do not depend on driver judgment to know which silo takes cement and which silo takes fly ash.

Because cement, fly ash and admixture prices vary throughout the country, cost differences will also vary. These calculations simply illustrate how savings can be examined. Depending on the strength requirements of the concrete, the proximity of the ash source and comparative local cement and ash prices, the cost savings for cementitious materials can range from $1.50 to $4.00 per cubic yard.

Counterbalancing at least some of the cost savings are the additional facilities and quality control that the use of fly ash will require of the concrete producer. Class C ash, unlike Class F, will set up in the presence of moisture. It must be transported and stored in the same way as cement is transported and stored. Class F ash must also be kept dry, but for a different reason. The batching operation requires that it be dry and flowable. In each case an additional silo, bin and handling facilities are needed.

Monitoring the storage and handling of fly ash is extremely important. There have been instances of fly ash being pumped into a cement silo, or of fly ash leaking into an adjacent cement bin. The result was concrete containing too much ash in place of cement. The concrete looked and handled like a normal mix and the error was discovered only when the concrete didn't set up or gain strength fast enough. To prevent such errors delivery, storage and handling of fly ash must be closely supervised. The pneumatic fill pipes on the cement and fly ash silos must be carefully located and clearly marked.

CAUTION

Fly ash flows very freely, more freely than cement.

Fly ash can be abrasive.

Inspect the bin with care to be certain that wear from abrasion does not create openings through which fly ash can flow. This is especially important if cement and fly ash are stored in adjacent bins.

The need for additional quality control by the concrete producer represents another early cost. An adequate testing program is necessary for all mixes using fly ash so that proportions and strengths for standard mixes can be documented. A program for monitoring ash quality, with emphasis on uniformity, should also be maintained with the cooperation of the fly ash supplier.

Other benefits

The contractor or owner benefits from the use of fly ash concrete include improved concrete placeability and finishability, reduced bleeding, easier and more efficient pumping, reduced heat of hydration and a longer period of significant strength gain. Fly ash concrete is more resistant to the harmful effects of alkali-aggregate reaction and, with the exception of some Class C ashes, is more resistant to sulfate attack. These benefits provide reasons for using fly ash concrete quite apart from any price differential.

How much fly ash to use? How much will it save?

Under favorable conditions the proportion of fly ash can be as much as 35 percent of the total cementitious content of the concrete, defined as the total weight of the portland cement and the fly ash.

High early strength requirements, lower temperatures, and reactivity of the ash could reduce the optimum ash content to 20 percent of the cementitious content. Extreme low temperatures would be even more restrictive.

The cost savings potential in the cementitious materials may range from $1.50 to $4.00 per cubic yard. Additional concrete production costs will also have to be measured.

As with all concrete, a thorough testing program should verify the optimum mix proportion with fly ash for the full range of mixes in which it will be used.

PUBLICATION #C850321