Table 7. Flexural strength of concrete containing different types of fly ash and silica fume

Mixture Designation	Flexural Strength (MPa)		
	3 Days	28 Days	56 Days
OPC	6.7	7.8	8.1
OFA15	5.8	7.3	7.6
CFA15	6.1	7.4	7.9
GFA15	6.4	7.7	8.0
SF15	6.3	7.2	7.5

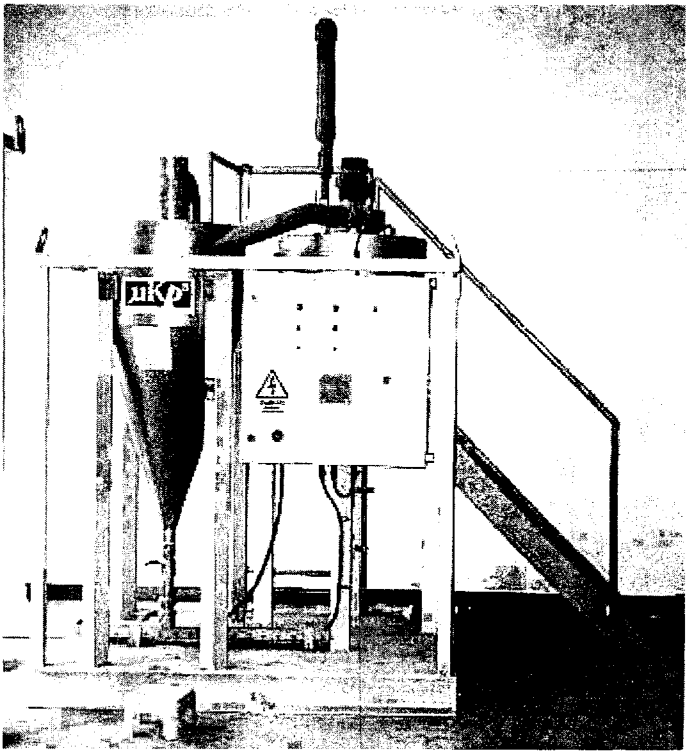


Fig. 1. Air-classifier Machine

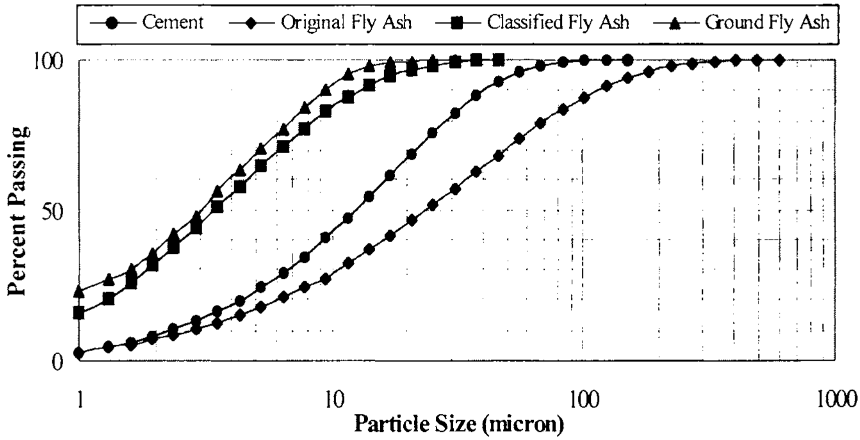


Fig. 2. Particle size distribution of cement, original, ground, and classified fly ash

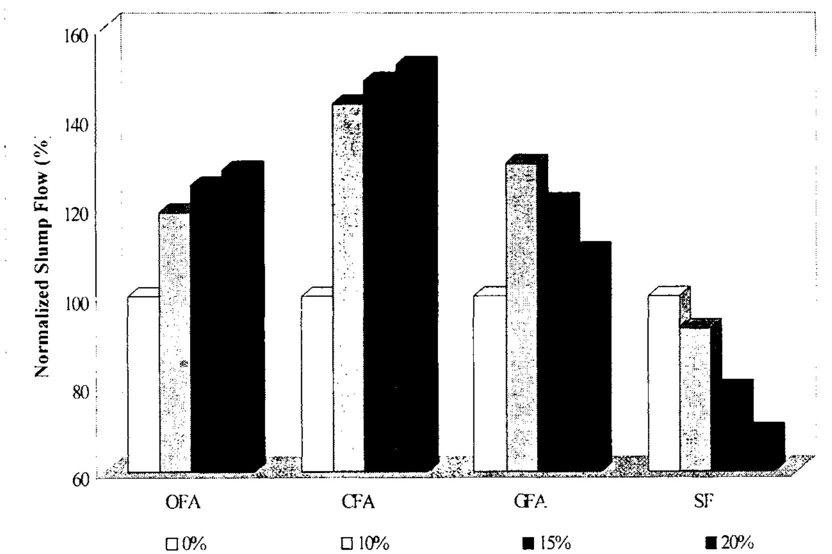
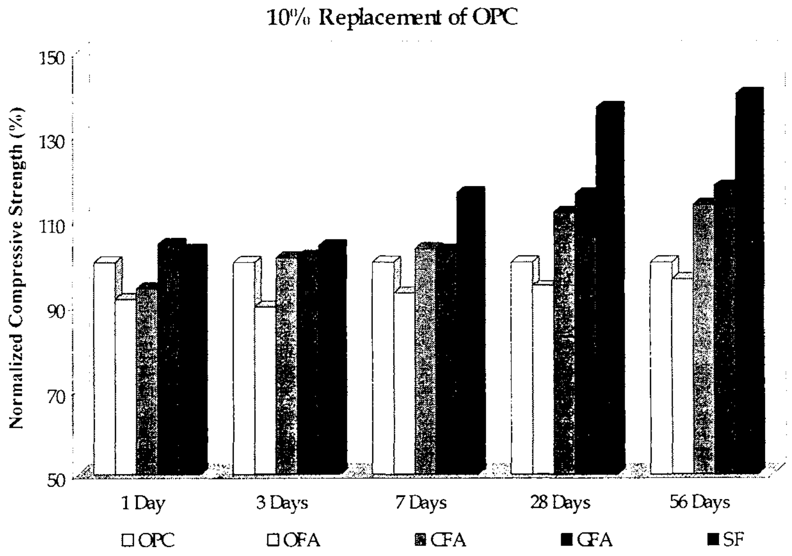


Fig.3. Effect of different types of fly ash and silica fume on the slump-flow of high-performance concrete.



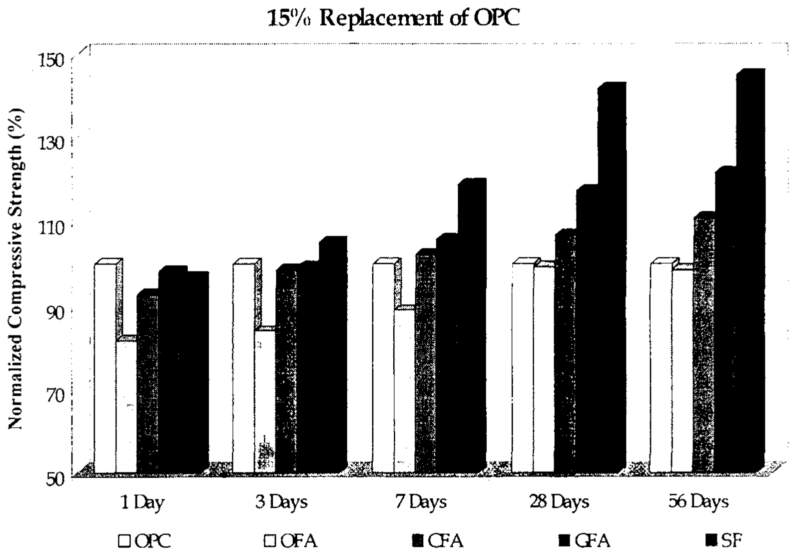


Fig. 4. Effect of types and amount of fly ash on the compressive strength of concrete at different ages

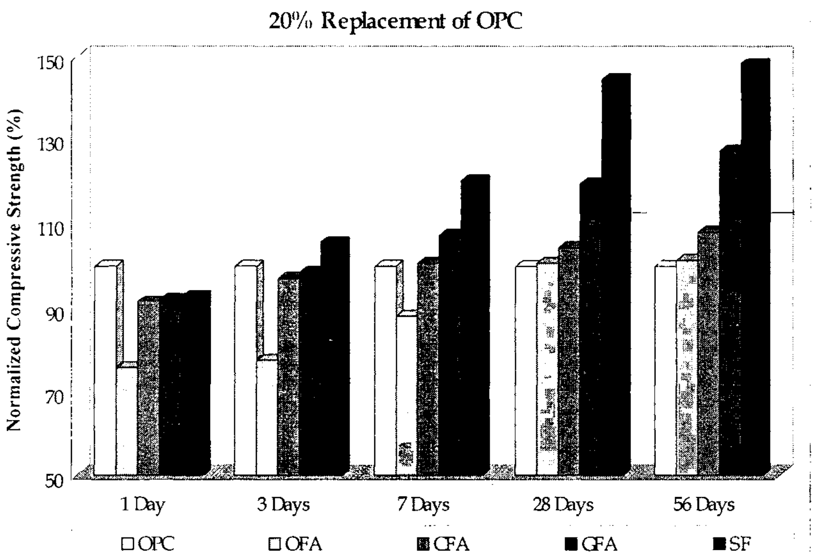


Fig. 4. (Cont'd.) Effect of types and amount of fly ash on the compressive strength of concrete at different ages

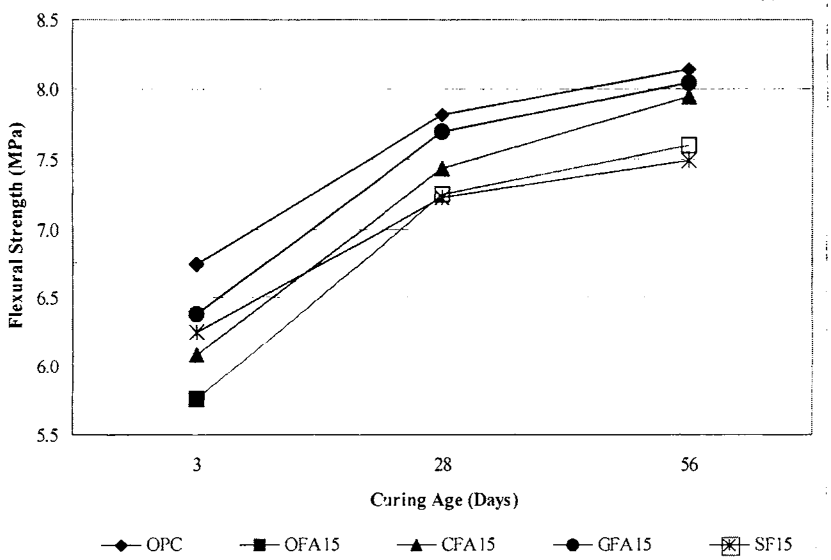


Fig. 5. Effect of types and amount of fly ash and silica fume on the flexural strength of concrete

SP 200-17

The U.S. Power Industry's Activities to Expand Coal Ash Utilization in Face of Lower Ash Quality

by D.M. Golden

Synopsis: This paper describes a five-year Electric Power Research Institute (EPRI) program directed toward increasing ash utilization in the cement and concrete market within the United States, in the face of the impacts on ash quality due to more aggressive NOx controls. EPRI is undertaking this program to provide the technical basis for protecting the bulk sale of coal ash in high-volume applications in cement and concrete and other high volume civil engineering applications. In addition to higher carbon levels in ash from NOx control systems, problems associated with ammoniated ash have become a major concern for coal-fired facilities in recent years as a result of the increased use of ammonia-based environmental control technologies. Many coal-fired power producers have become concerned that post-combustion NOx controls could lead to fly ash containing high levels of ammonia. Therefore, EPRI conducted a research program designed to assist power producers evaluate and mitigate the impacts of high carbon and ammoniated ash.

Keywords: AEA admixtures; ammoniated ash; blended cement; coal ash utilization; fly ash; high carbon ash; unburned carbon

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INTRODUCTION

The current usage of coal by utilities in the United States results in the production of over 105 million tons (95 million mt) of solid combustion by-products each year, (ACAA, 1999)(**1**). A predicted increase in coal usage in the United States will only intensify the challenges associated with the disposal or utilization of the by-products.

American utility industry interest is growing in ammonia-based N0x reduction processes in response to more restrictive air quality emissions limits. Flue gas N0x can be converted to elemental nitrogen through both high-temperature use of ammonia (SNCR – selective non-catalytic reduction) and the use of ammonia with a catalyst (SCR – selective catalytic reduction). The trade-off from the cleaner air is contaminated fly ash that cannot be used in its largest market, the concrete industry. The problem is the both the SNCR and SCR technologies use an inefficient conversion of ammonia which results in ammonia emissions (slip), and the deposition of ammonia on fly ash. EPRI has initiated a research program to address issues associated with ammonia-contaminated fly ash, related to odor concerns, ash utilization, disposal and groundwater contamination issues.

In the United States, approximately 80% of the coal ash by-products are in the form of fly ash, which has a lower utilization rate than the bottom ash. In response to industry requests, EPRI (the collaborative R&D organization with membership of over 700 electric utililites) initiated an ash utilization research and development program in the mid-1990s to mitigate the problems resulting from the use of the newer NOx controls on ash quality, so as to protect the high value concrete reuse market for ash. This program has been divided into five principal areas:

- Reduction in carbon in ash,
- Assessment of removal methods for ammonia from ash

- Characterization of ammonia on different ash types
- Development of blended cements incorporating ash, and
- Development of new AEA admixtures for high ash concretes

Ash Use in Concrete: Historical Perspective

Historically, the use of fly ash in the United States has been primarily directed towards its use in concrete. This is an ideal example of waste product utilization since there are both technical and economical benefits from its use. However, the quantity of ash used in concrete is but a small portion of the volume produced. In fact, if ash was used in all the concrete made in the United States, it would still be only a minor percentage of the volume available. In 1999, only a quarter of all fly ash produced could have been used in cement at a 20 % replacement rate. It is estimated that only one-quarter of the ash produced in the United States will meet the requirements of ASTM C618-83 for concrete-quality fly ash. Fly ash has several distinct functions in concrete. It is (1) a pozzolan, (2) a workability modifier, (3) a fine aggregate, and (4) an adsorbent of air-entraining agents. Additionally, the chemical properties of both fly and bottom ashes make them potentially useful raw materials for the manufacture of Portland cement clinker.

Since the use of fly ash as a partial replacement for portland cement in concrete was first introduced over 60 years ago, most practical uses have involved one of three approaches:

- Use of relatively large volumes of ash (up to 60%) as portland cement replacement in mass concrete where early strength is not required and ultimate strengths are in the range 25 to 35 MPa;

- Use of relatively small volumes of ash (10–25% replacement) in structural concrete;

- Compacted and flowable backfills or road bases containing large quantities of fly ash (up to 90%) for applications where minimal strength development is demanded.

As the demands placed on structural concrete increase, especially in the area of durability, there has been a growing use of all types of supplementary cementing materials in what might be regarded as "tailored concretes." As part of these developments, structural concrete incorporating high volumes of low-calcium (ASTM Class F) fly ash was developed at CANMET in 1987.

In this type of concrete, the water and cement contents are both kept at low levels of concrete, and the proportion of fly ash in the total cementitious materials ranges from 55 to 60%. Subsequently, similar developments have been reported with the investigation of various HVFA compositions for use in pavement and structural applications based on ASTM Class C fly ashes and Class F materials.

The development of HVFA concretes, to the point at which they can be extensively used in structural applications at the commercial level, has considerable potential value to the utility industry. Clearly, technology that permits the use of three, or more, times the amount of fly ash in concretes than is currently employed can significantly extend the market for fly ash in construction. The concrete market for ash in the US currently is the largest market for ash, representing over half of the ash sold. As environmental concerns stimulate moves that render by-product disposal from coal combustion increasingly difficult and expensive, utilization of these materials will play an essential and growing function in the future of ash management.

The most commercially attractive of these HVFA concrete materials are proportioned to contain more fly ash than portland cement. By careful selection of mix proportions and the use of superplasticizers, concretes with the following features have been produced:

- Low portland cement content (~150 kg/m^3), permitting them to be produced at less cost and less energy demand than conventional concretes.

- High workability.

- Reasonable strength and high elastic modulus: for example, concretes produced at the CANMET laboratory in Ottawa under EPRI sponsorship, have been shown to develop compressive strengths greater than 40 MPa by 28 days with early-age strength in the range 10–15 MPa at 3 days .

- Good durability in chemically aggressive environments.

For commercial acceptance of HVFA concretes in structural applications, in addition to having available an extensive compilation of engineering data, it is necessary to understand the ways in which their chemical, physical and microstructural properties differ from conventional portland cement systems. It is also necessary to know how they affect mechanical properties such as strength, modulus of elasticity, stress-strain behaviour and the mode of crack propagation.

Previous studies have shown that fly ash is a reactive component in HVFA systems. As curing proceeds, fly ash increasingly becomes a contributor to the binder component. Thus, it must be assumed that the binder in HVFA concretes is different in chemical and physical properties from hydrated portland cement and that these differences change with time for as long as the concrete continues to cure.

The 1993 EPRI study has further developed this understanding through an investigation of the mechanisms responsible for HVFA hydration and bonding using a range of model materials (i.e. cement and fly ash types). These data have then been considered in regard to how they could affect mechanical properties and durability of HVFA concretes. The details are beyond the scope of this paper, but are available in EPRI Report TR-103152. (**2**) EPRI also continued the research into the performance of HVFA concrete systems, in lightweight concrete applications. (**3**)

Impacts of NOx Controls on Ash Characteristics and Concrete Quality

Many U.S. utilities with coal-fired boilers are being required to reduce emissions of NOx. All new facilities must meet even lower emission limits. Many older units used combustion techniques based on high single stage combustion efficiency. Under these conditions, NOx emissions are rather high. The use of NOx reduction technologies—combustion system technologies such as low NOx burners (LNB) or overfire air (OFA), or post-combustion system technologies such selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR)—on electric power plants has, in some cases, had a negative impact on the utilization of the coal ash in certain markets, largely as a result of increased levels of unburned carbon and other chemical residuals that are left in the ash.

Combustion modifications seek to reduce the creation of NOx by reducing the peak flame intensity—lowering the temperature, reducing the oxygen level, etc. These changes also impact important fly ash characteristics. Typically, the unburned carbon (UBC) level in the ash increases. Lower flame temperatures also cause less ash melting. As a consequence, the ash morphology is less spherical. These changes lead to greater variability in fly ash properties that are important to ash users.

Post-combustion controls use chemical reagents (usually ammonia) to react with NOx and reform N_2 and water. Traces of the reagents are adsorbed on the fly ash and can affect by-product markets. A common problem is the odor of ammonia when the ash is wetted.

Carbon

Carbon has always been a common component in fly ashes produced from the combustion of fossil fuels such as coal. Carbon contents in coal ash varies over a wide range (less than 0.5% to more than 20%) depending on factors such the rank of the coal, the condition of the pulverizers, and the load conditions of the plant. For plants without NOx reduction technologies, ash carbon levels of 5% of less are typically found in base-loaded plants burning bituminous coal. However, in contrast, carbon contents of up to 10% or above are often found in non-base loaded plants, particularly those burning bituminous coals. Lower rank subbituminous and lignite coals typically have higher levels of burnout and produce ashes with much lower carbon contents. Carbon is a problem in concrete in view of the difficulty it creates with regulating air contents, due to the sensitivity of AEA admixtures to carbon levels.(**4**)

Little has been published on the chemical and physical characteristics of the carbon in fly ash. In view of the importance that the carbon fraction has on the marketability of ash, this is unfortunate. Earlier work conducted for EPRI suggested that carbon