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Energeia

Coal Fly Ash:
A Retrospective and Future Look

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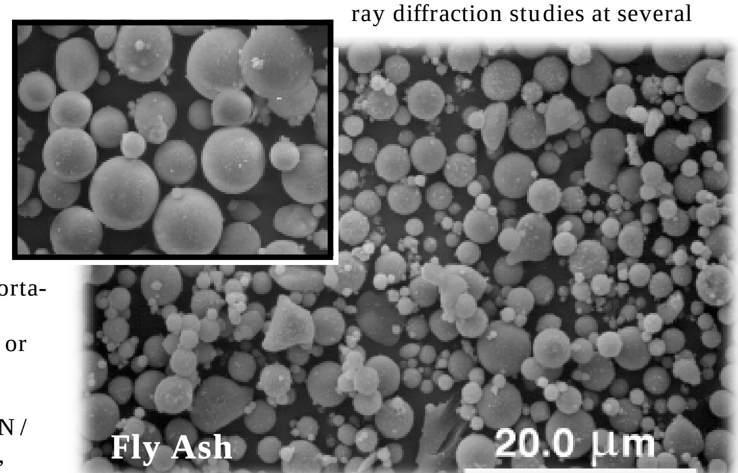
INTRODUCTION

In 1996, approximately 7.28 million metric tons (8.02 million short tons) of coal fly ash was used in the United States in cement and concrete products. The amount of fly ash in typical structural concrete applications ranges from 15 to 35 % by weight, with amounts up to 70 % for mass concrete in dams, walls, and girders and for roller-compacted concrete pavements and parking areas.

Various concrete mixtures are produced with coal fly ash, including regular weight and lightweight concretes, high-strength concrete, low-slump paving concrete, and architectural concrete. With the principal exception of high-strength concrete, these mixtures are routinely air-entrained for added workability and for resistance to freezing and thawing. A state-of-the-art report on the use of coal fly ash in concrete has been prepared by the American Concrete Institute (ACI): Use of Fly Ash in Concrete, ACI 232.2R-96. Fly ash for use as a mineral admixture in concrete is covered in a specification published by the American Society for Testing and Materials (ASTM): Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete, ASTM C618.

FLY ASH SPECIFICATIONS

Worldwide, specifications for fly ash use in portland cement concrete are the most common compared to stabilization, structural fill, and other uses. In the United States in the late 1940s and throughout the 1950s, the use and acceptance of fly ash in concrete created the need for national specifications for mineral admixtures. Preparations for specifications began in 1948 by the American Society for Testing and Materials. In 1953, ASTM Specification C350-54T was adopted for fly ash as an admixture, but only as fine aggregate. In 1960, it was extended to cover fly ash as a pozzolan. Natural pozzolans and fly ash were combined into C618 in 1968 as mineral admixtures. The test methods were covered in ASTM C311. In 1977, Class C fly ash (from lignite and subbituminous coals) was added to C618. Fly ashes from bituminous and anthracite coals were classified as Class F ashes. One difference between the Class C and F ashes is the limit of 50 % for the combination of SiO_2, Al_2O_3, and Fe_2O_3 for Class C and 70 % for Class F. In addition, specification AASHTO M295 was adopted by the American Association for State Highway and Transportation Officials (AASHTO). The various state departments of transportation use either AASHTO M295 or ASTM C618, or modifications. Canada has CAN / CSA A23.5-M86, which is very similar to C618. Specifications used in the rest of the world have been based on the ASTM C618 specification. The European Union (EU) countries are working on a common specification, EN 450. At present, almost every European country has a separate specification. South Africa and the Asian and other Pacific rim countries also have specifications similar to ASTM C618.



RESEARCH

In general, the fly ashes from subbituminous and lignite coals are characterized by higher CaO, MgO, and SO_3 and lower SiO_2 and Al_2O_3 than the bituminous fly ashes. The bituminous fly ashes and some lignite fly ashes with less than 10 % total CaO consist mostly of aluminosilicate-type glass and generally do not contain any crystalline compounds of calcium. Fly ashes with more than 15 % total CaO consist mostly of a calcium aluminosilicate glass, as well as a substantial amount of crystalline compounds of calcium such as C_3A, C_4A_3 S, CS, and CaO. Because of the presence of cementitious calcium compounds and a reactive glass, the high-calcium fly ash is quite suitable for use in portland cement concrete.

The variability of the Class C ashes from location to location led to extensive x-ray diffraction studies at several research centers, with the conclusion that the mineralogy was more important than the chemical analysis and that the classification by coal source was

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Coal Fly Ash, continued

erroneous. Several databases have been established to compare fly ashes with well-characterized ashes that have proven successful in concrete. However, for the fly ash broker and the concrete ready-mix producer, x-ray data is too complex, so ASTM is confronted with attempting to produce a performance-oriented rather than a prescription-type standard. There is a need to classify fly ashes according to potential pozzolanic activity and cementitious properties as well as alkali aggregate reactivity and sulfate resistance, if required by the consumer. Because of the many different fly ashes, several studies are being conducted to better understand the complexities of alkali aggregate reactivity and sulfate resistance with respect to fly ashes in concrete.

The availability of high-lime fly ashes containing compounds found in cement has led to high-strength concretes produced by the addition of fly ash and plasticizers. The ball-bearing effect produced by the spherical fly ash particles has resulted in better concrete pumpability as well as easier finishing with trowels and other tools. Using fly ash in concrete has also resulted in less permeability due to the spherical particles.

The research has been extensive, including complex x-ray diffraction and scanning electron microscope studies, as well as laboratory-scale studies of concrete mixes, sulfate resistance, alkali reactivity, and permeability. In addition, many small test plots and full-scale pavement sections have been constructed as research projects.

NEW CANADIAN SPECIFICATION

Revisions to the Canadian Standards Association CSA A23.5 are being balloted, and one of the approved changes to the specification is the classification system for fly ashes. The main purpose of classifying fly ashes for use in concrete is to distinguish between ashes that have different effects on the properties of fresh and hardened concrete. Neither the coal source nor the oxide sum ($SiO_2 + Al_2O_3 + Fe_2O_3$) of the ash was felt to be adequate for this purpose, and the approach adopted was to use the total calcium content (expressed as percentage CaO) for the basis of classification. In the revised specification due to be issued in 1998, it is proposed to have three categories of ash characterized as low, intermediate, or high calcium content as follows:

Type	% CaO
F	<8
CI	8–20
CH	>20

There are no other differences between the chemical and physical requirements for the various types of fly ash with the exception of the loss-on-ignition (LOI) limit. Type F will have a maximum LOI of 8 % compared with 6 % for Types CI and CH (existing limits are 12 % for Type F and 6 % for Type C).

A number of studies have shown that the rate of heat development in blended portland cement–fly ash systems increases with the calcium content of the fly ash. It is well established that for concretes of equal water-to-cementitious material ratio (W / CM), concrete containing low-calcium fly ash will develop strength at a slower rate than plain portland cement concrete. However, strength parity may be expected at between 28 and 90 days, and the longterm strength (beyond 90 days) of the fly ash concrete will be greater. Many workers have established that high-calcium fly ashes can be used on a mass-for-mass replacement basis for portland cement (up to 30 to 40 % replacement) without detriment to the early-age strength of concrete. Higher early-age strength of the concrete with high-calcium fly ash is a further corollary of the increased reactivity with calcium content. The calcium content and particle-size distribution of the fly ash are the most important parameters governing the strength development rate in normally cured portland cement–fly ash mixtures. Except for the calcium content, variations in the chemical constituents of fly ash appear to have no effect on its reactivity.

Although high-calcium fly ashes appear to offer an advantage over low-calcium ashes in terms of increased reactivity and strength development, they do not offer the same increased resistance to chemical attack with regard to sulfates and alkali–silica reaction. Low-calcium fly ashes exhibit a high sulfate resistance, and intermediate-calcium ashes show high-to-moderate resistance, whereas high-calcium fly ashes show variable performance, with some ashes

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Coal Fly Ash, continued

giving higher expansions than the control mortars. The reduced efficiency of high-calcium ashes in controlling expansion due to alkali–silica reaction has been fairly well documented. It is clear that higher levels of high-calcium fly ashes are required to control expansion to an acceptable level. Indeed, for some fly ashes, the level required may be in excess of 50 %. Although there is a very clear distinction between the properties of the Type F and Type CH fly ashes, a whole suite of materials is available with calcium content in the range of 8 to 20 % CaO, which is to be classified as Type CI by the new CSA A23.5 standard. It is not possible to generalize about the properties of ashes that fall within this group, nor about their performance in concrete. We still require appropriate performance tests to accurately predict the performance of a particular fly ash in concrete.

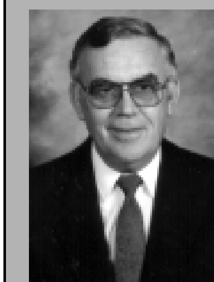
At the December 1997 meeting of ASTM C09.24 on ground slag and pozzolanic admixtures, after Dr. Michael Thomas had presented the new Canadian specification, the subcommittee voted unanimously to consider changing ASTM C618 to conform to the Canadian specification.

BARRIERS TO THE USE OF FLY ASH

The passage of the Clean Air Act and its subsequent amendments set the United States (and many other countries) on a course that has committed billions of dollars to protecting the environment. Due to 1990 revisions to the Clean Air Act, coal-fired power plants must comply with the acid rain provisions and reduce SO_2 and NO_x emissions. Until clean coal technologies emerged, the flue gas scrubber, developed in the 1960s, was the only commercial technology capable of achieving the SO_2 reduction required under the Clean Air Act Amendments. There are two categories of conventional scrubbers: wet and dry. Both remove only SO_2; neither reduces NO_x emissions. As the global demand for coal increases worldwide, so too will the generation of emissions and emission control systems for both SO_2 and NO_x.

There is much discussion about the changes in ash quality that come with the new NO_x emission regulations and retrofitting low-NO_x burners, with increasing concerns about the detrimental effects of high carbon carryover into combustion ash. Fly ash carbons constitute the char particles that are left in the ash after the incomplete combustion of coal in the furnace, rendering the ash above specification for ASTM C618 applications for concrete, particularly for bituminous ashes. If the carbon content can be lowered, more fly ash will meet the quality requirements of the concrete industry. Beneficiation processes for selective separation of unburnt carbon from fly ash are therefore of interest. At least two kinds of ash beneficiation processes are available: a dry process that involves triboelectric static separation and a wet process based on froth flotation for reducing carbon and consequently the LOI of fly ash. In looking to the future, research is also being conducted on new nonionic air-entraining agents, which are unaffected by the type of coal ash and produce entrained air, which is stable.

The American Coal Ash Association, Inc. (ACAA) has represented the coal combustion product (CCP) industry in the United States since 1968. ACAA's mission is to advance the management and use of CCPs in ways that are technically sound, commercially competitive, and environmentally safe. If you would like to become a member of the ACAA, contact theorganization at ACAA@ix.netcom.com, fax 703-317-2409, phone 703-317-2400.



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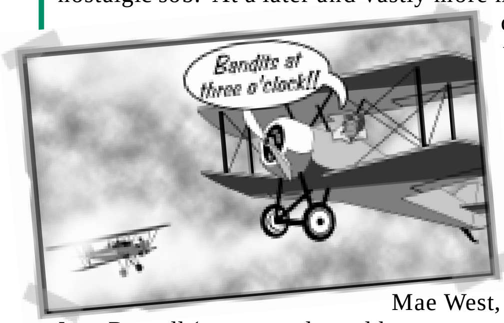
COMMENTARY

Into The Wide Blue Yonder

Frank Derbyshire
Director, CAER

Some of my earliest and most forceful impressions of air travel were gleaned from avidly reading boy's adventure stories, notably the escapades of James Bigglesworth, a.k.a. Biggles, ace fighter pilot in the first and second World Wars. His breathtaking adventures and thrilling aerial dogfights carved a lasting image of what it must be like to brave the perils of uncharted skies - the lone aviator and machine pitted in a duel of wit and skill against the elements and the foe. Even today, the siren call, "Bandits at three o'clock" - a phrase that can still be occasionally heard in the inner sanctums of the research community - evokes a nostalgic sob. At a later and vastly more mature stage in my development, these visions were embellished by the introduction of Celluloid Heroines. An especially endearing feature was the presence of a figure resembling Mae West, Rita Hayworth, or Jane Russell (now supplanted by names such as Kim Basinger, Mira Sorvino, and Madonna), who would be loitering around the mess when one returned from a particularly tricky and demanding sortie, hoping for a strategic debriefing, "Say, you lookin' for me, Fly Boy?"

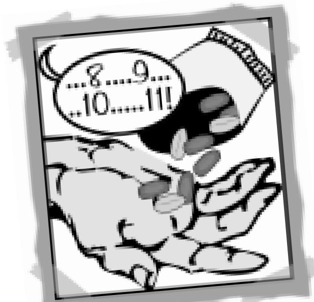


Thus equipped with this foretaste of the mystique, danger and excitement of air travel did I, years later, embark upon my maiden flight on a commercial aircraft - a move that I now recognize as the first tentative step that would eventually lead to the attainment of Frequent Flier status. Naturally, I was more or less aware that I probably wouldn't be able to sit up with the pilot, lock my gunsights on the tailplane of a Messerschmitt 109, go into tight banking turns, or pull out of a seemingly irretrievable vertical dive. For such events are apparently not integral to commercial aviation. Nonetheless, it was different, it was special, and it was unlike the then comparatively crude passenger treatment on buses, trains, and boats.

For a start, you had to check in. This was a slow and hushed process, rather reminiscent of a Doctor's waiting room, that clearly suggested that you had joined the few, those happy few, who were privileged to journey above the clouds. On the plane, you were ushered to your seat by a polite, well-presented, and remote stewardess who undoubtedly belonged to a vastly superior social class. You were lavished (a comparative term) with attention - magazines, newspapers, drinks - and even the meals seemed to have been prepared with a modicum of personal attention. In those days, one could almost believe that the process of travelling was almost as interesting as arriving at one's distant destination.... some faraway place with a strange-sounding name.

Those days have long since become a distant memory for the economy class traveller. Today, flying is a mass transit medium. It has lost its erstwhile exotic flavor and has more or less fallen to the same level as roughing it on buses, trains, and boats where, interestingly, the quality has actually improved. Now flying is about as thrilling as supermarket shopping. You become part of a leaderless, directionless throng, and are jostled by impatient milling crowds at the check-in, in the lounges, at the boarding gate and baggage claim, and you wrestle with other passengers and their endless overhead luggage when embarking and disembarking. And the attention-lavishing has undergone a steep decline too. Unless you can afford to fly in first or business class, or realize this status through the redemption of frequent flier points - an unlikely situation, you have a higher probability of winning the lottery - then you are condemned to a very different journey. You are confined in undersized seats, and struggle to gain an elbow's purchase on the narrow armrests and to find a place to put your feet. Sleep is difficult if not impossible, because of space constraints, and because the small child located in the row behind has developed a consuming interest in continuously kicking the back of your seat. The once mighty herds of charming and fawning flight attendants who used to roam peacefully along the aisles and gangways eagerly seeking opportunities to fill a glass, to provide reading materials, to set the tray table with crisp white linen and cutlery at mealtimes, and to answer all manner of inane questions without snarling, are now all but extinct. Now there remain but a few overworked stragglers who can be spotted at takeoff and landing, and during the routine distribution of what are optimistically termed refreshments, snacks, or on very long flights, meals. At all other times, which now usually coincide with the showing of a movie or video in a darkened cabin, they are a shy and elusive breed.

So, as the frequent traveller sits, as frequent fliers frequently do, watching out of the plane window, while feasting on a complimentary drink and packet of peanuts (there can be as many as twelve peanuts per packet) and calmly observes the loose rivets jiggling and rattling on the engine mounting (some of the aircraft in service can be quite old), the same old inevitable questions bubble to mind; "Why am I doing this?" and "Is it worth the effort?"



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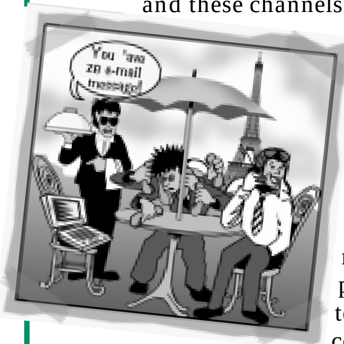
In my opinion, the answer is yes to both questions. Because in spite of all of the aggravation of travel - cost, delays, inconvenience, and boredom - our ability to communicate is truly world wide, and to remain competitive in any field - and research is no exception - we must establish and maintain contact with collaborators and customers around the globe. Admittedly, we can send and receive messages almost instantly via media such as the telephone, fax, and e-mail, and these channels serve effective purposes.



However, there is a limit to the extent of the information that can be exchanged through the written or spoken word. Indeed, there is a real prospect that misunderstandings can be, and are, made and propagated, sometimes deliberately. Ultimately, there arises a need to provide the missing color and texture to these impersonal communications through personal contact, when facial expressions, intonations, and body language can supply the absent ingredients. This is the way in which humans have conducted business transactions ever since the time that they exchanged greetings by hitting each other over the head with a handy rock or club (a fashion that could usefully be revived on occasion).

A handshake, a greeting made in person, and a convivial meeting can be worth volumes of text, and air travel allows us to be within a day's journey of more or less anywhere and anyone in the world. Nor should we forget how its availability has altered our perspective of distance and time. Not long ago, if someone emigrated from Europe to one of the new worlds, America or Australia, it was unlikely that they would be seen again, or perhaps not more than once in a lifetime. Now, people regularly conduct relationships, business and personal, over these same vast distances.

Although our technology has advanced tremendously, and continues to advance, allowing communication at the speed of light, and through all manner of subtle devices (some of which should be restricted or banned from use by specific groups: namely, the use of laser pointers by frantic hand-waving types, and mobile phones by garrulous poseurs) our species has not kept pace in terms of evolution. We have failed miserably to develop advanced senses through genetic transformations that could have equipped us with antennae, X-ray vision, or the facility to conduct telepathic conversations. We are still the same old homo sapiens that not too long ago was talking to his or her fellow homo sapiens by the grunt method, and by drawing suspect graffiti on cave walls (techniques that have successfully withstood the test of time). Clearly, we need help to cope with the faster, more intrusive pace of life that we have imposed upon ourselves.

And here, air travel is our salvation, and not the last straw that breaks the camel's back, as some might think. Because, unless or until we develop a matter transmitter that can move us instantly from A to B and then B to A, or even C, air travel is the best way by which we can hope to traverse long distances. And this means that our journey will proceed at a more leisurely pace than the rate at which we are bombarded with information and deadlines. There is too, the added bonus of air travel over matter transport in that we might just arrive at the other end without sporting body parts that used to belong to a fly or other life form that was an inadvertent fellow transportee.

All this is excellent news, because the itinerant is provided with time to relax and to think, luxuries that are not normally available in the workplace. Of course, there are some who are unable to enjoy the advantages that their peregrinations afford because they will not or cannot sever the electronic umbilical cords that connect them to their work. Sometimes, I agree, it may be necessary to beam up to Head Office, but often the perceived "compelling need" is prompted by a form of insecurity or is based upon the conceit that you are indispensable and that business as usual cannot proceed in your absence. Meanwhile at Head Office, the frequent fussy messages and instructions that you send probably induce considerable annoyance to those left to guard the fort, those who probably consider that you are indeed dispensable and that business has been proceeding much more smoothly than usual due to your absence.

Personally, I regard the interludes associated with air travel as extremely welcome. From my in-transit solitude, I benefit because it is a kind of mini-sabbatical. I can relax from daily stress, and even begin to believe that my brain might still be a functioning organ. From the overall journey, I meet old friends, make new ones, and learn of recent developments. A net outcome is that often I am inspired by my thoughts and experiences, and sometimes conceive of novel ideas, all of which assist my work. Perhaps this is what is meant by Blue Sky research.

In any event, to return to my opening remarks, the business traveller, like my hero Biggles, often must take his or her work into the air. But there most of the similarity ends. In the modern world, and in peacetime, the obstacles are different, as are the rules of engagement, and presumably the tactics. Nevertheless, Biggles always came through, and that is the principal message. Persevere, and like Biggles, you may be able to pull it off.

Frank Derbyshire
CAER Director

The 36th Annual Kentucky Coal Utilization Conference

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The topics to be presented at this meeting include: deregulation, global warming, coal innovations, and environmental issues. The meeting will include a tour of the CAER.

The conference features a social hour reception, 11 technical papers, a buffet lunch, and an "Evening at Spindletop." Certificates for Professional Development are available.

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