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QUALITY CONTROL OF HIGHWAY CONCRETE CONTAINING FLY ASH

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

This report is essentially a synthesis of pertinent information concerning the use of fly ash as an ingredient in concrete for highway construction. It has been prepared to provide a basis for an adequate response by the Department of Highways and Transportation to requirements of the Resource Conservation and Recovery Act and the Environmental Protection Agency pertaining to the use of this by-product in concrete purchased with federal funds. Special attention is given to the quality control and acceptance problems associated with highway usage of fly ash concrete, with emphasis on problems relating to air entrainment. References to the background literature that established the suitability of fly ash as a pozzolan and its use in concrete are given.

The requirements for fly ash as set forth in ASTM Specification C618 are reviewed and the characteristics to be expected from concrete containing fly ash are discussed.

It is recommended that the Virginia Department of Highways and Transportation permit the use of fly ash in concrete at the option of the contractor with prior approval by the state. It is also recommended that suitable specifications for this use be prepared following the guidelines previously recommended by the Concrete Research Advisory Committee.

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INTRODUCTION

In 1976 Congress passed the Resource Conservation and Recovery Act (RCRA). The stated objectives of this act are the protection of human health and the environment and conservation of valuable material and energy resources through prudent management and the utilization of solid wastes. As a part of its responsibilities under this act, the Environmental Protection Agency (EPA) has proposed a guideline for federal procurement of cement and concrete containing fly ash. This guideline, if adopted in its entirety, would have the effect of requiring any agency purchasing concrete with federal funds to permit bidders to submit bids on the basis of either (a) concrete containing fly ash as an admixture (FAC), (b) concrete using a blended cement in which fly ash is the pozzolan (1PC), or (c) concrete in which portland cement is the sole binding agent (PCC). The guideline would also require that specifications be of a performance type rather than a recipe type. Contracts would be awarded on the basis of the lowest bid, regardless of the type of concrete to be furnished, whether FAC, 1PC, or PCC. For equal bids, the concrete containing the most fly ash would be accepted.

Under the RCRA such rules would apply to all federal-aid highway and transportation projects. Consequently, implementation of such rules would have a substantial effect on the procurement of concrete for highway construction, including significant changes in specifications. While mandatory adoption is not now proposed by the EPA, the proposal makes clear that positive action towards voluntary compliance is expected and the lack of such action could lead to a mandatory requirement. This study was therefore undertaken to establish the state of the art with respect to the use of FAC or 1PC in highway construction and to summarize quality control procedures and specifications now in use. The reported problems associated with such control procedures and specifications are also reviewed. Recommendations concerning the optimum specifications and procedures under the conditions prevailing in Virginia are made.

On January 8, 1981, a public hearing was held on the EPA-proposed guidelines. At the hearing, the opinions expressed varied from complete support to opposition to some of the provisions of the proposal. Opposition viewpoints centered around the implied mandatory nature of the guideline and the requirement for dual bids. While the EPA representatives did not indicate whether or not modifications would be made in the proposal, they did indicate that they were operating under a mandate by Congress to issue the guideline by May 1981 and would attempt to meet that date. Implementation of the provisions of the guideline would be expected within one year of the date of issuance.

BACKGROUND

The use of fly ash as an ingredient in concrete is not new. As discussed in Technical Report CR79-2 of the Tennessee Valley Authority (TVA) on "Properties and Use of Fly Ash in Portland Cement Concrete",(1) research results on the pozzolanic action of fly ash were published as early as 1914 in the Engineering News Record. The TVA report also references the significant pioneering work in the field of fly ash concrete that was conducted in the 1940's and 1950's. During this period the usefulness of fly ash in concrete was well established and the advantages as well as some of the disadvantages were identified. The Bureau of Public Roads conducted studies of the characteristics of fly ash and fly ash concrete in the early 1950's, and concluded that a substantial amount of the portland cement in concrete could be replaced with fly ash without adversely affecting the long-term strength of the concrete.(2) One of the BPR studies was directed towards evaluating various test methods for fly ash and showing the relationship of the characteristics of the fly ash to its effect on the characteristics of mortar and concrete.(3) Round robin tests were conducted by ASTM Committee C-9(4) and studies on the fundamental characteristics of fly ash were reported by Minnick during this period.(5)

A comprehensive evaluation of factors affecting the use of fly ash in a number of applications was made by Abdun-Nur and his findings were reported at the 1960 meeting of the Highway Research Board. Highway Research Board Bulletin 284 describes this evaluation and includes an annotated bibliography of the literature on the subject for the period 1934 through 1959.(6)

The Virginia Department of Highways and Transportation participated in this early evaluation of fly ash in concrete by installing experimental curbs and gutters. This project in Louisa, Virginia, involved two concrete mixtures in which 20% and 33% of the cement was replaced by fly ash. Control concretes were made with Type II cement. A recent evaluation of the long-time performance of these installations showed that after 25 years of service the fly ash concretes were internally sound and retained compressive strengths equal to or greater than those of the control concrete. However, greater surface scaling had occurred for the fly ash concrete than for the controls. The concrete with 33% fly ash replacement exhibited greater scaling than did that with 20% replacement. Over the years, all of the concretes have had severe exposure to deicing salts.[7]

The collective results of the reports cited above indicate that significant improvements in concrete properties can be expected from the use of suitable fly ash. These are summarized in the TVA report as follows:

a. improved workability

b. reduced segregation

c. reduced bleeding

d. reduced heat of hydration

e. reduced drying shrinkage

f. increased resistance to sulfates

g. increased ultimate tensile and compressive strength

h. reduced permeability[1]

Another advantage also discussed in the TVA report and substantiated by a number of research studies is the reduction of destructive expansion caused by the alkali-aggregate reaction.

The TVA report lists the disadvantages of the use of fly ash as a replacement for cement on a one-to-one ratio by weight as:

a. lowered early strength

b. lowered freeze-thaw durability in non-air-entrained concrete

c. increased air-entraining admixture dosage

The problem identified by Meininger[8] of the rapid loss of entrained air between the time of initial mixing of concrete and the time of its placement is also related to "c" above. The tendency for increased scaling in the presence of deicing salts as shown by the Virginia experiments is also a potential disadvantage. Such scaling tends to create a negative impression with the general public, even though the concrete may be sound.

As will be discussed later, most of the apparent disadvantages of fly ash concrete, based on one-to-one substitution, can be overcome by appropriate measures. For example, use of an amount of fly ash greater than the amount of cement replaced generally restores strengths to acceptable values. Also, when comparisons of freeze-thaw resistance are made on the basis of equal strengths of fly ash concrete and concrete without fly ash no apparent differences are noted.

In 1968 the National Ash Association was organized to promote the use of ash from the burning of coal and to assist in the development of information on its properties and technological potential. Five symposia on the utilization of all forms of coal ash (fly ash, bottom ash, and boiler slags) have been held over the past 12 years.[9,10,11,12,13] Many of the 205 presentations that have been made in these symposia place considerable emphasis on the characteristics of fly ash as an ingredient in concrete and the potential for use that FAC offers in a number of applications.

It is beyond the scope of this report to review all the aspects of fly ash usage in concrete. Consequently, only the potential advantages and problems from the standpoint of highway pavement and bridge construction will be considered, with the greatest emphasis being on the fly ash properties that should be controlled by specifications and the associated problems of quality control of concrete in which fly ash is used as an admixture. When fly ash is used as an ingredient in blended cements (Type 1P), the fly ash control problem is transferred to the cement manufacturer. Type 1P cement can often be used for highway construction with no significant changes in specifications for the concrete properties and with only a few additional precautions for proper controls.

SPECIAL CONSIDERATIONS FOR THE USE OF FLY ASH IN HIGHWAY CONSTRUCTION

Even though research studies have clearly shown that the use of the proper amount of good quality fly ash can improve the properties of concrete, the use of FAC or 1PC in highway construction is still somewhat limited. A survey recently conducted showed that 19 states permitted the use of FAC in pavements, but only four of these had constructed more than 100 lane-miles (167 lane-kilometers).[14] Similarly, 16 states permitted the use of 1PC but only two had constructed more than 100 lane-miles (167 lane-kilometers) with this product. This lack of general use in highway construction may result partly from a reluctance to change on the part of highway departments, but there are also some real difficulties that must be overcome and some situations in which the use of fly ash is not economically attractive for highway construction. On the other hand, there are some special situations for which FAC or lPC provide a cost-effective solution to a problem and there is renewed interest in their use from environmental and economic aspects.

A report by West Virginia summarized that state's recent experience with fly ash in portland cement concrete pavements.(15) The report states that fly ash concrete pavements placed in West Virginia have strength and durability characteristics at least as good as pavements constructed with concretes that do not include fly ash as a cement substitute. The initial comparisons made in West Virginia were on the basis of using 94 lb. (42.6 kg.) of fly ash to replace an equal weight of cement (equivalent to 1 bag in U. S. practice). Less durability was indicated by ASTM C666 (Rapid Freeze-Thaw Durability) for fly ash concrete than for the standard concrete. However, the 28-day compressive strengths of cores and cylinders showed higher values for the standard concrete. At 90 days and 182 days, no statistically significant difference in strength was obtained. There was also no statistically significant differences between the two concretes for flexural strength at either 28 or 90 days.

On the basis of these results West Virginia revised its specifications to permit the optional use of fly ash. The specification allows replacement of up to 1 bag of cement with an equal volume of fly ash. The fly ash must conform to ASTM C618, Type F, with a maximum loss on ignition of 6%. The experience with concretes containing fly ash placed under this specification has been satisfactory. At present, West Virginia restricts the use of fly ash in concrete after October 1, unless special approval is obtained and cold weather precautions are taken. With such precautions there has been no evidence of poor performance by the fly ash concrete and no scaling has been observed.

West Virginia reports a belief that the successful use of fly ash as a cement substitute in pavement construction is primarily a function of the following three things.

1. The contractor must develop a mix design with the materials chosen for the work. The data presented on the mix design must indicate the potential for providing adequate strength, air content, and workability.

2. A stable source of high quality fly ash is a must. The fly ash should not only meet ASTM specification C618, but should also have a high degree of uniformity from shipment to shipment.

3. There must be a viable quality assurance system that includes a contractor quality control program that assures specification compliance.

Cost analyses have shown that the use of fly ash provides significant savings under West Virginia conditions.

Choice of Type 1P Cement or Use of Fly Ash as an Admixture

As has been indicated, fly ash can be added to concrete either as an ingredient in the blended cement (Type 1P) or as an admixture at the time the concrete is mixed. When fly ash is an ingredient of the blended cement, the problem of controlling the quality of the fly ash becomes the responsibility of the cement manufacturers. They also control the amount of fly ash blended or interground with the portland cement clinker and are responsible for manufacturing products that comply with the cited specification, usually ASTM C595, Type 1P or its equivalent AASHTO M240, Type 1P. When approved for use by state transportation departments, such cements are generally permitted as alternatives to other approved types and the requirements for the concrete are the same regardless of the cement type used. Because of the possibility that concretes made with Type 1P cements will achieve a different rate of strength development from similar concretes made with Type I or Type II cements, some states restrict the use of Type 1P cements for some applications, such as in concrete for bridge decks, and also will not allow their use during the colder months of the year. Type 1P cements are also likely to require greater amounts of air-entraining agents to provide an equal amount of entrained air in concrete than other types of portland cements, and special attention must be given to assure proper air entrainment. The proponents of blended cements claim the advantages previously listed for use of fly ash in concrete, with the added advantage to the cement consumer of not having to be concerned with fly ash quality and control of the amount added to each batch of concrete. However, under present marketing conditions blended cements cost essentially the same as Type I portland cements. Consequently, there's no economic advantage to a state to promote its use, and any advantage to a contractor would be primarily a result of an increased productivity because of better workability and easier finishing of 1PC. At the present time the supply of blended cement on the market is somewhat limited but there is a growing interest on the part of some cement manufacturers in providing a blended cement. It provides a way of reducing the overall energy consumption per ton of product and increasing plant capacity with a low capital expenditure, since the same amount of clinker from the kiln provides more finished blended cement than other types. The manufacture of 1P cement is also consistent with the aims of the RCRA in that it utilizes a by-product.

When fly ash is added as an admixture at the concrete mixer, there is a potential for saving money because it costs less than portland cement. However, there are several countering aspects that must be considered. Facilities must be provided for storing and handling fly ash. Quality control tests must also be made on the fly ash and a greater amount of air-entraining agent is needed for air-entrained concrete. When the costs of needed facilities can be spread over a large volume of concrete such as at a ready-mix plant that would supply fly ash concrete to a large number of projects, the additional capital expenditures and additional cost of testing can be prorated so that relatively lower concrete production costs can be realized on each project. However, the installation of such facilities for a limited number of experimental projects is unattractive from the economic point of view.

Whether fly ash is added as an admixture or as a part of the blended cements, the resulting concrete should behave similarly, assuming the proportion of fly ash to portland cement is equal and the fly ash is of equal fineness and well distributed. Consequently, although the following discussions generally refer to problems associated with fly ash added as an admixture, references to the behavior of concrete containing fly ash apply regardless of the method of its addition.

Fly Ash Characteristics

The characteristics of fly ash vary considerably depending on the type of coal burned and the manner in which the ash is removed from the stack. Many older installations removed fly ash by mechanical means. This procedure did not completely capture the finest particles from the stack gases and resulted in a coarser collected ash. More modern installations employ electrostatic precipitators that normally have a much better efficiency of collecting the smaller particles, and the collected ash is consequently much finer. Modern installations also usually result in more efficient burning of the coal, with correspondingly less unburned constituents, mostly carbon, in the fly ash.

Studies have shown that the fineness of the fly ash governs to a great extent its pozzolanic activity and also greatly affects the workability of concrete. Some of the coarser fly ashes collected by mechanical means are not suitable for use as a pozzolanic material in concrete. Consequently, as will be discussed in more detail later, minimum fineness is a requirement of most fly ash specifications where the fly ash is to function as a pozzolan.

The amount of carbon or other unburned constituents in a fly ash can also vary significantly. This can affect the color of FAC, which is not considered to be of any great concern for highway construction. However, the carbon, usually measured by loss on ignition, can adversely affect the air-entrainment system of the concrete as will be discussed later.

Availability at Time and Point of Use

The logistics of handling fly ash and the distance from the source of the fly ash to the concrete mixing plant have a significant effect on the use of fly ash in highway concrete. Fly ash is produced continuously as power is generated and it must be stockpiled at its source or removed to a storage area immediately after generation. Although more power producing companies are developing an interest in disposing of ash in such a way that it is usable for other applications, many still dispose of fly ash, bottom ash, and boiler slag together in settlement ponds. When this is done, the material becomes difficult and uneconomical for further use. Even when a given source of fly ash is marketed for use as a pozzolan, the potential economic advantage is greatly dependent on the distance the fly ash must be shipped for a given project as compared to the distance portland cement must be shipped. The relative advantage also depends on the volume of material needed and the mode of shipment available. For example, shipment by barge over waterways or by rail would be considerably more economical than truck shipments over highways. With respect to highway construction, many states do not have provisions for the use of material in their concrete because no suitable fly ash is available in their areas. As previously discussed, the greatest opportunity for reducing costs by the use of fly ash will occur where a ready-mix concrete plant has the facilities to store and handle the fly ash at its site. In such cases the capital outlay to establish such facilities can be spread over a number of projects and cost reductions approaching the differences in the cost of fly ash and the cement used are possible.

Changes Required in Design and Control

When fly ash is used as an admixture, the concrete mix should be designed for optimum characteristics. Substitution of fly ash for cement on a 1:1 basis does not give optimum results. Often the weight of the fly ash added is as much as 1.5 times the weight of the cement replaced. This need for redesigning the concrete, and for controlling an additional material (fly ash) as well as taking special precaution to assure adequate air entrainment, tends to discourage the use of fly ash concrete for highway purposes.

In fact, the added cost of testing might be greater than the saving in cost of material. Thus, unless improvements can be expected from the standpoint of the durability or other properties of the concrete, there is often little incentive for the use of fly ash as an admixture in highway construction. The problem of proper control of air entrainment is of considerable concern, since placement of FAC without adequate entrained air can cause early failure of a serious and costly nature.

When fly ash is added as an ingredient of the blended cement, the initial concrete design will normally be based on trial mixtures utilizing the blended cement. Consequently, needed differences from mixtures employing all portland cement are automatically taken into account. However, the problems associated with proper control of air entrainment will be present and must be dealt with.

Difference in Rate of Strength Development

A number of highway engineers are concerned with the slow rate of strength development reported for concrete containing fly ash. These concerns result from research findings that show comparisons of strength gains of two concretes containing the same aggregate. In one case portland cement is the only binding constituent and in the other a portion of the cement is replaced by fly ash on a volume-for-volume or weight-for-weight basis. In such cases the FAC will have lower strengths at early ages, but usually develop strengths greater than that of PCC at later ages. The rate of strength development during cold weather is also of concern. Some states using FAC in highways do not permit placement after a specific date in the fall and not prior to a specific date in the spring. Similar restrictions are placed on the use of blended cements in cold weather.

As has been pointed out by Lovewell and Hyland,[16] concrete using fly ash as one of the ingredients to be added at the mixer should be designed for optimum characteristics with the material at hand. Usually an amount of fly ash is added in excess of the amount of cement removed. When necessary, adjustment in the amounts of fine aggregate is also made. When so designed, FAC with adequate strengths at early ages can be placed and usual limits for strengths of highway concrete at early ages can be met. If the specification for FAC is based on the needed characteristics of the concrete for the conditions to be encountered, it shouldn't matter if the concrete used develops strength at a faster or slower rate than does some other combination of ingredients, as long as the desired strength level is attained at the specified age. However, a number of highway departments specify the amount of cement that can be replaced by fly ash and compare the properties of the FAC with similar concrete containing the usual amounts of cement. This leads to the fear that early strengths might be inadequate. Problems might be encountered if normal procedures for removing forms for structures or opening pavements to the use of construction traffic are such that dependence is placed on strength development at a greater rate than that actually required by the specification. To avoid this possibility, some states require a greater delay in removing forms from concrete structures with FAC or IPC over that normally used for concrete with Type I or Type II cement.

THE CONTROL PROBLEM FOR FLY ASH CONCRETE IN HIGHWAYS

Considerable progress has been made over the last 20 to 30 years towards establishing the properties of a fly ash that are needed for good results when it is used as a pozzolanic ingredient of concrete.

Contributions have been made by a number of organizations and people and no attempt will be made to reference all such developmental work in this report. Collectively, this work forms the technological basis of ASTM Specification C618, the "Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Cóncrete". This specification includes four classes of pozzolans: N = raw or calcined natural materials, F = fly ash produced from burning anthracite or bituminous coal, C = fly ash produced from lignite or subbituminous coal, and S = other pozzolans meeting the applicable requirements for class S pozzolans (processed pumicites, calcined and ground shales, etc.). Since the present concern is with fly ash of a type likely to be available in Virginia, only the class F pozzolans will be considered in the following discussion.

Mielenz has presented three papers at the International Symposia on the Use of Ash from Burning Coal (1967, 1973, and 1979) concerning the development of specifications for fly ash as a pozzolan.(18,19,20) These papers show that although there are some minor differences, all major national organizations generally use ASTM C618 class F pozzolans as the basis for their specification for fly ash used in concrete. The survey of state transportation department practices showed that most of them also cite C618, class F, or have a specification equivalent to it, except that a lower limit on loss on ignition is used.(14) In most cases the limit is 6.0% rather than the 12.0% given in C618. The elements of the specification for fly ash, with special emphasis on their significance with respect to highway construction, are discussed in the following sections.

Chemical Requirements

Total Oxides

The sum of silica, alumina, and iron oxide must exceed a minimum of 70%. Some states still retain separate limitations for silica and alumina as well as the total oxides, but it is likely that materials meeting the requirements of C618 will also meet such specifications. Early studies sought to establish a relationship between the results of various pozzolanic activity tests and various percentages of individual oxides.[3,5] However, definitive relationships could not be established. Consequently, since by definition the pozzolan must have components capable of reacting with lime in the presence of water, a minimum on total silica, alumina, and iron oxide to assure that sufficient reactive constituents are present is all that is required.

Sulfur Trioxide (SO_3)

The maximum SO_3 content permitted in the fly ash is 5.0%. The cooperative tests reported by Committee C-9 in 1962[4] showed that the SO_3 content of fly ash influenced to some degree the early compressive strengths of mortar and concrete specimens, with higher SO_3 contents resulting in higher strengths. This finding is consistent with present-day recognition that different cements require different amounts of SO_3 for the development of maximum strength and that the limits in effect for cements at that time generally were set below the optimum amount. Thus, the added SO_3 from fly ash was an advantage. However, a maximum limit on SO_3 is considered necessary to avoid an excess in the hardened concrete that could contribute to a disruptive sulfate reaction.

Moisture

A 3.0% limit is placed on moisture content in order to minimize caking and packing of the fly ash in shipping and storage, to control uniformity of fly ash shipments, and to avoid sale and handling of significant amounts of water as a part of the admixture.[17] Some states have reduced this limit to 1.0%.

Loss on Ignition

As mentioned, the maximum permissible loss on ignition is closely related to the amount of carbon or unburned coal constituents in the fly ash and is limited to 6.0% or less by all the state transportation departments using the material. ASTM Specification C618 permits a loss on ignition up to 12.0%. Mielenz reported that the C9 subcommittee had given consideration to lowering the C618 limit on loss on ignition, but did not do so because the subcommittee had not received information on any instance in which loss on ignition up to 12.0% had been shown to be the cause of failure or unacceptable quality of fresh or hardened concrete in construction, when the fly ash met other applicable requirements of ASTM C618. This finding does not take into account the difficulties in air entrainment attributable to high-carbon fly ashes. While it is true that C618 has safeguards that if met diminish the danger from high carbon fly ash, the additional problem in controlling air entrainment when such fly ashes are used justifies setting a lower limit for loss on ignition.

More air-entraining agent is usually required to entrain a given amount of air in FAC than is required for a similar concrete not containing fly ash. This increase is needed because of several phenomena. First, there is a greater surface area within the concrete mixture because fly ash is normally finer than cement and is usually added in greater amounts than the cement replaced. Because of this, a greater volume of air-entraining agent is needed to provide the same surface concentrations of the active air-entraining ingredient. A second phenomenon leading to a requirement for more air-entraining agent is related to the carbon content of fly ash. The carbon absorbs a portion of the air-entraining agent, which makes it unavailable for creating the needed conditions for stable air bubbles. The amount of absorption varies with the amount of carbon present and, possibly, with the form of such carbon. Thus, variations in the loss on ignition (carbon content) result in a need to vary the amount of air-entraining agent. Meininger has also shown that there can be a significant loss of air with time and possibly erratic behavior[8] for some combinations of ingredients, and has suggested that the presence of organic constituents other than carbon may interact with the air-entraining agent to reduce its effectiveness.

These problems are not eliminated by the 6.0% maximum limit for loss on ignition used by most states, but they are minimized to some extent. In response to the recent survey, several states indicated that problems with erratic entrainment of air are not encountered with fly ashes having carbon contents less than 3.0%, and some have adopted a limit for loss on ignition or carbon in this range.[14] The feasibility of establishing a 3.0% or 4.0% limit for loss on ignition should be determined. It is recognized that the carbon in the fly ash can fluctuate depending on the burning conditions at the power plant, and extremely low limits could create serious marketing problems for the fly ash supplier in some locations. Consequently, the limit should be set to minimize the air-entrainment problem to a maximum extent, without being so restrictive that competition would be adversely affected or costs unnecessarily increased.

Magnesium Oxide

Requirements for magnesium oxide content are given in C618 as an optional requirement that applies only when specifically requested. The purpose, of course, is to avoid unsoundness of the concrete that might occur if the magnesium is present in a form that is capable of hydrating in the hardened concrete with accompanying expansion and disruption. C 618 permits acceptance of magnesium contents in excess of 5.0%, provided the autoclave expansion or contraction limit of 0.8% is not exceeded.

Available Alkalies

In some areas where aggregates subject to alkali-aggregate reaction are present it is desirable to limit the water soluble alkalies in the concrete. For this purpose, available alkalies in the fly ash are determined after an intimate mixture of lime, fly ash, and water has been stored for 28 days at 100°F (37.8°C). The available alkalies are those soluble in hot water after the period of storage.

The proportion of the total alkalies that become water soluble when the fly ash is mixed with lime and water is dependent on the temperature during storage and the length of time the material is stored. Thus "available alkalies" may not relate to the conditions actually existing in field concrete. However, the maximum limit established provides protection against excessive amounts of sodium and potassium ions in the hardened concrete. This requirement should not be used where there is no danger of encountering reactive aggregates.

Acidity of Fly Ash

Some state specifications have a requirement that the pH of a water slurry of fly ash be a minimum of 7.0 (neutral). This requirement apparently originated in Alabama in the 1950's but no technological basis for the requirement could be found. Most fly ashes will show an alkaline reaction in this test with the pH in the 10-12 range. Should an acid reaction be detected (pH less than 7.0), the amount of acid present would not likely be sufficient to significantly affect the alkalinity of a cement-fly ash mixture because of the large amount of hydroxyl ion present when the cement begins to hydrate. Consequently, a requirement for acid neutrality does not appear needed, unless there is a fear of adverse reactions during storage or from corrosion of handling equipment for the fly ash.

Physical Requirements

Particle Shape

In addition to its chemical composition, the physical state and particle size and shape of a fly ash are important. This is illustrated by the photomicrograph of a fly ash shown in Figure 1. This picture, provided by the Federal Highway Administration, was made by a scanning electron microscope at a magnification of 8,500x and shows the typically spherical shape of the fly ash particles, some of which are hollow. Material of this type easily complies with the requirement for pozzolanic activity index discussed in the following sections. By way of contrast, the particle shape and much larger size of the volcanic ash from the Mt. St. Helens eruption in 1980 is illustrated in Figure 2. This material has a chemical composition similar to that of good pozzolans but is not suitable for use in this manner because of its coarseness and the platy shape of the silica present. The photomicrograph was taken at a magnification of only 480x, about 1/18 of that used for Figure 1. While there is some strength development when mixed with lime, this material does not comply with requirements of the test for pozzolanic activity given in C618.

Fineness

Assuming the presence of sufficient silica and alumina and the typical particle shape illustrated in Figure 1, fineness is the primary physical characteristic of a fly ash that relates to its pozzolanic activity. Present specifications generally include a requirement for a maximum amount retained on the No. 325 (45 μm) sieve when wet sieved. The limit in C618 is set at 34%. In order to avoid material with too high amounts of inert or essentially nonreactive constituents, C618 has an optional maximum for a "multiple factor", which is the product of loss on ignition and the amount retained on the 325 (45 μm) sieve. The limit is set at 255. This factor eliminates materials for which both the loss on ignition and the amount retained on the 325 sieve (45 μm) would be a maximum. Thus, for a maximum of 12.0% loss on ignition the amount retained on the 325 (45 μm) sieve cannot exceed 21.2%. Likewise, if the amount on the 325 (45 μm) sieve is a maximum, the loss on ignition cannot exceed 7.5%. The use of a 6.0% limit on loss on ignition as employed by most highway agencies eliminates the need for the multiple factor requirement.

Earlier versions of C618 also included limits on surface area as determined by the Blaine air permeability method, but these have been deleted because the subcommittee found no consistent relationship of this property to the performance characteristics of pozzolans in mortar or concrete. The subcommittee finding is generally supported by other early research. An article

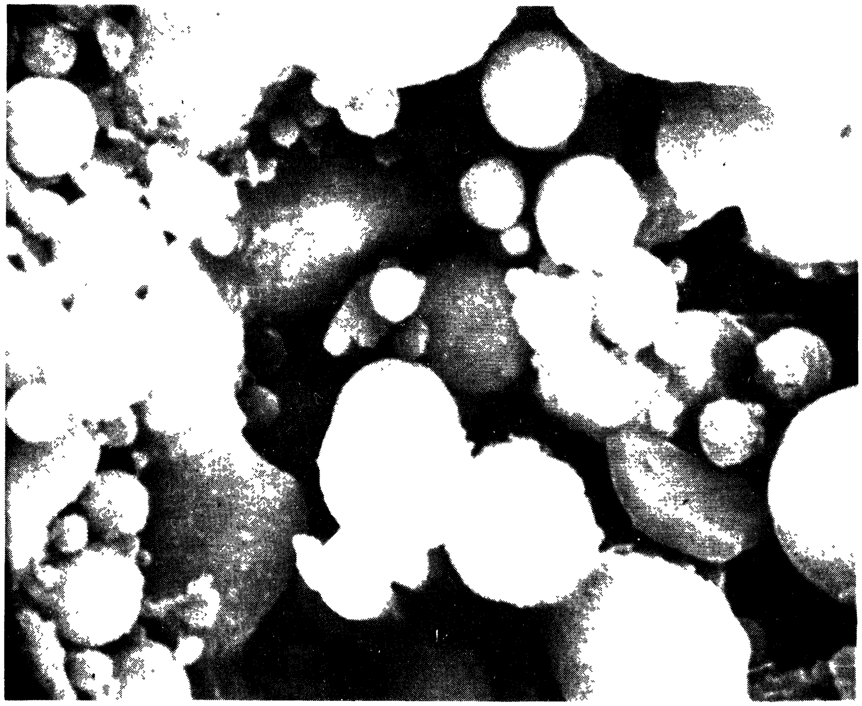

Figure 1. Photomicrograph of fly ash (Scanning electron microscope - 8500 x).

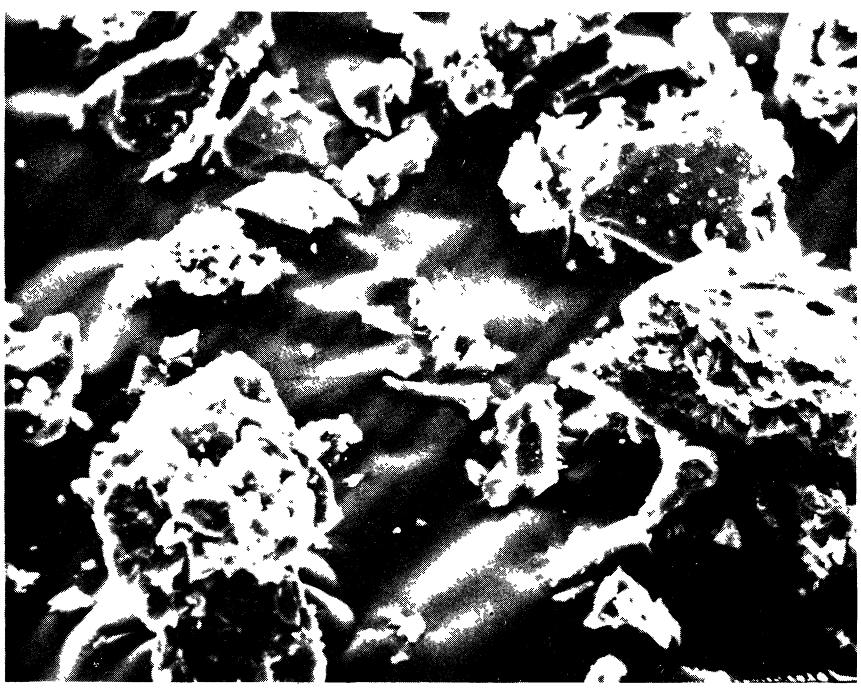

Figure 2. Photomicrograph of volcanic ash from Mt. St. Helens (Scanning electron microscope - 480 x)

in Cement and Concrete Research, July 1980, reports a better correlation between strength developed in the pozzolanic activity test with the specific surface determined by the Blaine apparatus than with the amount passing the 325 (45 μm) sieve.[21] However, this work is based on fly ash samples from a single source. The loss on ignition for all fly ashes tested in this study is also relatively low, varying from 1.8% to 3.8%.

The study also shows that the relationship between pozzolanic activity and the amount retained on (or passing) the No. 325 (45 μm) sieve is essentially linear for materials having about 75% to 90% passing (25% to 10% retained on) the No. 325 sieve. Inasmuch as this is the fineness range of most fly ashes used as pozzolans in the U. S., the findings support the usefulness of the limits on the amount passing the No. 325 (45 μm) sieve as a means for quality control of fly ash, even though the author of the report recommended reconsideration of the use of the specific surface as determined by the Blaine apparatus as a specification requirement. It should also be noted that, based on earlier work,[3,4] it would not be expected that the same fineness for materials from different sources would always give the same strength in the pozzolanic activity test. Differences in chemical and mineral composition and possibly particle shape would have an effect in addition to fineness. Consequently, for specifications and quality control a minimum limit for the amount passing the No. 325 (45 μm) sieve as now included in C618 is indicated to be the best choice of fineness measurements available at the present time.

Pozzolanic Activity Index

The requirement for pozzolanic activity is that the strength developed by the specimens of the test mixture, in which 35% of the volume of the cement is replaced with the same volume of the fly ash being tested, shall be a minimum of 75% of the strength of the control specimens after storage at 100 ± 3°F (38 ± 1.7°C) for 28 days. An activity test with lime is also included in C618. The requirement in this case is a minimum compressive strength of 800 psi (5,500 kPa) after 7 days. In this test, which is described fully in ASTM Method C311, the specimens are stored at 73.4 ± 3°F (23 ± 1.7°C) for 1 day and at 131 ± 3°F (55 ± 1.7°C) for 6 days. Efforts are now being made by ASTM Committee C-9 to adopt requirements for a 7-day activity test with portland cement. Under the proposed changes the fly ash would be acceptable on the basis of the 7-day test, but would be rejected only if it failed the 28-day test. Most suitable fly ashes would meet the 7-day limits. Consequently, for such materials, the time for establishing suitability as a pozzolan would be greatly reduced.

Autoclave Soundness

The requirement for the autoclave soundness test is a maximum of 0.8% expansion or contraction. The soundness test is normally conducted with specimens containing 25 parts by weight of fly ash and 100 parts by weight of a portland cement conforming to C150. However, if the fly ash is to be used in amounts greater than 20% of the cementitious material in the project mix design, the test specimens for autoclave expansion shall contain that anticipated percentage. This test protects against the delayed expansion that could occur in concrete if sufficient amounts of MgO are present as periclase, which expands as it hydrates.

Uniformity Requirements

The uniformity of the fly ash is controlled in C618 by limiting the variability of the specific gravity and fineness as measured by the amount retained on the No. 325 (45 µm) sieve. The requirement is that any sample tested shall not deviate from the average of the 10 previous tests, or the total of all tests if the number is less than 10, by more than 5 percentage points. In addition, C618 contains an optional requirement applicable when air-entrained concrete is involved. The amount of air-entraining agent to give 18% air by volume in mortar shall not vary by more than 20% of the average of the preceding 10 tests, or the average of all tests where the number is less than 10.

Drying Shrinkage

The TVA report cited previously points out that drying shrinkage is more of a function of the volume of the paste, the water-cement ratio, and the type of aggregate than of the composition of cementitious material. Since the addition of fly ash usually increases paste volume, the drying shrinkage may also be increased by a small amount if the water content remains constant. If the water content is reduced by the use of fly ash, shrinkage due to increased paste volume is compensated for. Results of tests by Davis at the University of California and by the TVA are cited that show the drying shrinkages of plain concrete and fly ash concrete to be essentially the same.[(1)] Thus, potential differences in drying shrinkage between fly ash concrete and similar concrete without fly ash are not considered a significant problem for most applications. However, C618 provides for an optional requirement, which can be requested by the purchaser, that limits the difference in drying shrinkage between test mortar bars containing fly ash and that of similar mortar bars without fly ash.

In this test, described in C311, the same amount of cement is used in the control mix and the test mix and a portion of the Ottawa sand is replaced with fly ash in the latter. The water content is adjusted to provide for the same flow. The maximum difference permitted is 0.03% at an age of 28 days.

Reactivity with Alkalies

An optional requirement of maximum mortar bar expansion of 0.020% can be requested by the purchaser. Such tests need not be requested unless the fly ash is to be used with aggregate that is regarded as deleteriously reactive with alkalies. Fly ash has been successfully used to reduce the danger from alkali-silica reaction in concrete, and this test would be needed in the highway field only as a means to ensure that the danger of expansion had been eliminated. The tests may be made with any high-alkali cement. However, if the cement or cements to be used are known and available, the test for mortar bar expansion should be made with each of them.

QUALITY ASSURANCE PROCEDURES

Test Frequency and Source Approval for Fly Ash

The standard procedures for sampling and testing fly ash are given in ASTM Method C311. Some of the procedures are time consuming, and if complete tests are attempted for all shipments of fly ash to a highway project, the extra cost of testing may become so high that any economic advantage from using fly ash is lost. Consequently, it is important to establish a frequency schedule for tests that provides adequate quality assurance at a reasonable cost and also permits decisions within a reasonable time. ASTM Method C311 for sampling and testing fly ash provides for several methods of sampling and recommends that tests for fineness, moisture, specific gravity, loss on ignition, soundness and the 7-day lime-pozzolanic activity be made on each 400 tons (360 tonnes) of material. Other tests, including chemical analysis and 28-day cement-pozzolanic activity, are made for each 2,000 tons (1,800 tonnes). The sample used for the 2,000-ton (1,800-tonne) tests is made up of a composite of 5 previously tested samples representing 400 tons (360 tonnes) each.

Tests made on the basis of these quantities are more suitable for monitoring the production and storage of fly ash or for use on massive concrete structures such as dams than for highway projects.

A mile of concrete pavement containing an amount of fly ash equivalent to replacing 15% to 20% of the cement requires 200 to 300 tons (180-270 tonnes) of fly ash depending, of course, on the percentage used and pavement thickness and width. On this basis, the frequency of tests called for in C311 would result in only one test for most highway projects that have been built to date. As a result, there are very few reported data to show the degree of variability of the characteristics of fly ash from the same source when used in highway projects. However, the consensus of those most knowledgeable is that the chemical composition of the inorganic portion of the ash is not likely to vary significantly, as long as the same coal is burned in the same plant and no extraneous matter such as lime or sodium carbonate is added to control pollution. Problems could arise, of course, where different coals or varying blends of several coals are burned. Loss on ignition and fineness are somewhat dependent on the condition of burning and how well the collectors function. More variability in these characteristics is expected than in the inorganic chemical composition. Most sources processing fly ash for sale in compliance with ASTM Specification C618 monitor these characteristics on a frequent basis, often daily.

A review of specifications used by those highway and transportation departments making the most use of fly ash shows that most have established a system for approving the source of fly ash. Initial approval may be on the basis of the state's tests or tests provided by the fly ash producer through an independent testing laboratory. The product is then accepted by certification of compliance. Random or periodic check tests are usually made by the state. Some states use the frequency of testing described in C311 as the basis for checking sources, but others require sampling each 100 tons (90 tonnes) of material with some tests such as fineness and loss on ignition being made on each sample. Other tests are made on composite samples representing amounts up to 500 tons (450 tonnes).

The experience of most states using the system of approved sources has been satisfactory. Alabama has used fly ash in concrete pavements since 1953 with good results. For much of this period only one approved source was available, although three sources are now approved. The only difficulty reported by Alabama is an occasional problem with air entrainment when the loss on ignition exceeds 3%. In such cases an increase in the amount of air-entraining agent used solves the problem. Minnesota samples a silo of fly ash as it is filled and approves the fly ash on the basis of the tests made on the samples taken. Once approved, the silo is sealed and contractors then draw material from it. Two sources of fly ash have been approved for Minnesota's use, both of which are based on "western coal", which results in a relatively high calcium oxide content in the fly ash — about 13%. The loss on ignition of these fly ashes is usually less than 1%. Consequently, Minnesota reports that although a higher dosage of air-entraining agent is required than for similar concrete without fly ash, it has had very little trouble in maintaining the entrained air at proper levels.

Control of Entrained Air in Fly Ash Concrete

From the standpoint of the Virginia Department of Highways and Transportation, the problem of assuring that adequate entrained air is in the hardened fly ash concrete is a major concern. Poor performance of fly ash concrete has resulted from inadequate entrained air in some parts of a recent project on which fly ash concrete was used, even though satisfactory results were attained on other portions of the project with the same materials and with adequate entrained air. The reason for the entrained air content being too low in the failed components cannot be explained by the records of the tests made at the time the concrete was placed.

In other instances in Virginia informal trial batches of concrete containing fly ash have been reported to yield erratic results with respect to air entrainment. This has led to a reluctance to use fly ash until more information is gained concerning the rate of loss of air content in the fly ash concrete and means to assure adequate air at the time of placement are available.

It has long been recognized that when fly ash is used in concrete a greater amount of air-entraining agent is needed to entrain a given amount of air than is needed for comparable concrete without fly ash. As previously discussed, this is partly caused by the increased surface area within the concrete, since fly ash is usually finer than cement, and is partly caused by the presence of carbon or carbon compounds that are believed to adsorb the air-entraining agent and thus render it ineffective.(1) For a given source of fly ash this latter phenomenon increases with increases in the loss on ignition.

Correspondence with one representative of a fly ash producer attributes the erratic behavior and the loss of entrained air during mixing to the abrading action of coarse aggregate. It is reasoned that the abrading action increases the surface area of the carbon and the effect is almost the same as increased carbon content because of increased absorption of the air-entraining agent. However, some of the results reported by Meininger cannot be completely explained by this phenomenon.(8)

As previously mentioned, most states indicated that problems with erratic amounts of entrained air content for the same ingredients do not occur when the loss on ignition of the fly ash is about 3% or less. The work reported by Meininger showed that the loss of air with time occurred with some combinations of fly ash, cement, and sand with one fly ash that had a loss on ignition as low as 2.9%.[8] Consequently, on the basis of present knowledge a completely safe limit cannot be established. However, problems are minimal at loss on ignition values of 3% or less.

Meininger also showed that different cements and different air-entraining agents could react differently with the same proportions of other ingredients in the fly ash concrete.[8] Under the present state of knowledge, tests for air content should be made on each load of concrete immediately prior to its placement. For these tests, the average of two determinations with a Chace air indicator should provide adequate control, provided the Chace indicator being used has been carefully calibrated against the air-pressure meter. This recommendation is based on the findings of a recent study at the Research Council in which the calibration and need for correction factors with the Chace indicator were discussed.[22] As indicated by this study, the average of two results by the Chace indicator cannot be relied on to provide a precision equal to that obtained by the air-pressure meter but the use of two tests eliminates much of the danger of gross erros and significant variations in air content can be detected quickly. This quick detection of change is of paramount importance when each load of concrete is being tested. For any load of concrete for which compliance to the specification for air content may be in doubt when determined by the Chace indicator, a determination must be made by the air-pressure meter and the decision to accept or reject made on the basis of that test. Until better knowledge is available concerning the batch-to-batch uniformity of air content in fly ash concrete, it is extremely important that each load be tested. The durability of the product is at stake and costs of replacing failed concrete can be exceedingly high.

Proportioning for Fly Ash Concrete

As discussed earlier, highway engineers generally consider the use of fly ash as a pozzolan to be a replacement for part of the cement. Consequently, most highway and transportation department specifications are based on the maximum amount of cement that is replaced. For most highway applications this maximum has been set at 15%. One state, Georgia, limits the maximum replacement to 8%. Florida permits up to 20% replacement for incidental highway structures such as box culverts, etc., but establishes the limit at 15% for pavement concrete.[14]

As stated in ACI 212 on guidelines for the use of admixtures in concrete,

> When fly ash is used as part of the total cementitious materials, curing time to attain equal strength with concrete containing an equal amount of portland cement alone should be longer. To obtain approximately equal compressive strengths at early ages between 3 and 28 days, concrete mixtures made with fly ash must have a total weight of portland cement and fly ash greater than the weight of the cement used in the comparable concrete not containing fly ash.[23]

In keeping with this recommendation a number of states establish a specification requirement that the amount of fly ash used equal 1.1 to 1.5 times the weight of cement removed. As Lovewell and Hyland have pointed out, some additional adjustment in water or fine aggregate may also be needed for optimum qualities in the concrete.[16] Ideally, a performance specification based on the strength and durability of the concrete would be used. However, there are uncertainties about the ability of present tests such as freeze-thaw and soundness to predict the overall durability of concrete containing less than usual amounts of cement. As a result, most states are reluctant to base the acceptance of concrete on tests for strength alone, and will establish a minimum for the amount of a designated type or types of cement to be used.

The approach taken by ACI 345 in guidelines for concrete for bridge decks offers a means of writing a specification for FAC.[23] The ACI guideline states that for bridge deck concrete, a minimum of 564 pounds (6 sacks) of cement per cubic yard (33.5 kg./m^3) be used except when a pozzolan is present. In this case the cement plus fly ash must be equal to or greater than 564 lb./$yd.^3$ (33.5 kg/m^3). There is also a requirement that the ratio of water to cementitious material (cement plus pozzolan) be no greater than 0.45. This same principle could be used for concretes used for other purposes, with proper designation of the minimum amount of cement or cement plus fly ash and a suitable limitation on the water to cementitious material ratio.

Strength Requirements

Twenty-eight day strength requirements for FAC or lPC should be the same as the requirements for portland cement concrete. The extent to which tests made at earlier ages can be relied upon for acceptance must be determined by experience. Any concrete that meets present criteria for acceptable strength at early ages would be acceptable, but because of the potentially slower strength development many acceptable concretes may not reach the acceptable strength level established by experience for portland cement concrete not containing fly ash. Tests at later ages, for example, 90 days, may be needed to establish the level of strength for fly ash concrete at maturity. However, it is believed that specification requirements should not be based on such later ages.

NEEDED RESEARCH

This review of the literature shows that considerable information on fly ash and the properties of fly ash concrete is available. However, it is probable that many persons engaged in highway concrete construction at the field level are not completely aware of such information. Thus, one major effort needed is that of technology transfer to make field personnel and construction managers aware both of the potential for good results with fly ash concrete and the pitfalls that could lead to unsatisfactory performance. There are also some areas for which additional information is needed. For the most part, the needed information relates to problems of quality control under field conditions and the effects of normal variations encountered in the field on the performance of the concrete. It is emphasized that purely laboratory investigations that are not associated with field construction are not likely to provide significant new information. It is important that experimental or trial use be made of fly ash concrete to solve the problems of most concern. These are discussed in the following sections.

1. The air entrainment problem —

   While the need for additional air-entraining agent to provide adequate entrained air in concrete has been well established, there is little information to show whether or not under field conditions the same amount of air-entraining agent in different batches provides essentially the same amount of entrained air. The effect of normal fluctuations in loss on ignition of the fly ash or in the amounts of fly ash, cement, or other ingredients has not been quantitatively established. It has also not been established whether or not some air-entraining agents work better with some materials than with others. Such work is needed.

More information is also needed on the extent to which various combinations of materials lose entrained air in transit or in standing in trucks prior to placement. There is also a need to establish the cause of such air loss and means to prevent or minimize it.

2. Variability of fly ash from same source —

Fly ash suppliers are usually willing to certify compliance with ASTM C618, and apparently feel confident that day-to-day variability of ash resulting from burning the same coal will be minimal and create no problems. The loss on ignition and fineness might vary because of changes in burning conditions and these characteristics are monitored frequently. However, there appears to be little published information to indicate on a quantitative basis the extent of day-to-day or shipment-by-shipment variations in the characteristics of fly ash. Such information would be very valuable as an aid in determining the risks of accepting noncomplying material on the basis of a few randomly selected samples. In particular, the variability of loss on ignition on a quantitative basis needs to be established.

3. Slower strength development —

More information is needed to quantitatively establish typical strength vs. time curves for fly ash concretes under both laboratory curing conditions and field conditions. Such knowledge would permit a valid assessment of whether or not the potentially slower rate of strength gain for fly ash concrete is of practical significance under normal highway construction practice. The quantitative relationship of strengths developed at various field temperatures to that developed under standard curing conditions needs to be established.

4. Diagnostic tests —

Recognizing that uncertainties and disputes can always occur, there is a desire for tests to estimate the amount of fly ash in a hardened concrete. However, the complexities are such that on the basis of present knowledge quantitative tests do not appear possible.

GUIDELINES FOR USE OF FLY ASH IN CONCRETE BY VIRGINIA DEPARTMENT OF HIGHWAYS AND TRANSPORTATION

In view of the national policy to utilize by-product materials to the fullest extent possible in order to conserve materials and energy as well as protect the environment, and also recognizing that for some applications concrete containing fly ash can perform in a manner superior to that of similar concrete without fly ash, specific guidelines for the use of fly ash in highway construction projects are needed. The findings of this study support the recommendations made on the basis of the preliminary, state funded study of practices of other state transportation agencies. These interim guidelines, which were recommended for adoption at the May 14, 1980, meeting of the Concrete Research Advisory Committee, are given in the Appendix A.

The significant policy reflected by the proposed guidelines and additional information and comment are as follows:

1. Fly ash may be used either as an ingredient of a blended cement or as an admixture. The use of Type 1P blended cement is already approved for some applications in Virginia.

2. Use will be at the option of the contractor with approval by the state on a project-to-project basis. One criterion for approval by the state should be that the contractor making the request have a good knowledge of the properties of fly ash concrete. He must be willing to apply additional control measures, if needed, to assure compliance to the specifications — particularly with respect to air entrainment. If ready-mix concrete is to be supplied, the adequacy of the facilities of the ready-mix producer should be established prior to approval.

3. For initial projects with any group of materials, the concrete mix design should be carefully checked by the state. A one-for-one substitution of fly ash for the cement removed either by volume or by weight is not recommended. The weight of fly ash added should always exceed the weight of cement removed.

4. The fly ash used should conform to ASTM Specification C618, except that a maximum of 6% loss on ignition would be required instead of the 12% now permitted by C618. On the basis of information

received after preparation of these guidelines, it may be feasible to lower the loss on ignition maximum to 3%. Apparently most major suppliers of fly ash in Virginia are willing to certify compliance of their product to this lower limit. The source of fly ash should be approved by the state. Complete tests for compliance to C618 are time consuming and are difficult to repeat on a shipment-by-shipment basis. Thus, efforts should be made to accept fly ash by certification after a preliminary evaluation of a source, provided that source has established a record of acceptable production. If dealing with a new source, means to pretest a silo of the fly ash to be used on a given project should be sought. The requirement that tests for fineness and loss on ignition be made for each shipment of fly ash to the mixing site should be retained only until a record of variability can be established. Reduced testing on a statistical basis should be adopted once the probability of compliance is established.

5. The proper control of air entrainment is the most critical aspect of the use of fly ash concrete. This is also true when Type 1P blended cement is used. It must be clearly understood by the contractor that he is responsible for the concrete having the proper amount of air at the time of placement and not just when the concrete leaves the mixing plant. He must also realize that a different amount of air-entraining agent is required for fly ash concrete than for concrete without fly ash. Until sufficient data are available to judge the probability of compliance based on reduced testing, the requirements for determining the air content on each load of concrete should be strictly adhered to. In all cases where compliance would be in doubt based on determinations with the Chace air indicator, tests should be made with the air-pressure meter and the decision made on that result. All noncomplying concrete should be rejected.

6. It would not be expected that properly proportioned fly ash concrete would be deficient in ultimate strength. However, the possibility that strength development in the field may be slower than is customary for concrete without fly ash should be kept in mind. This would be particularly true in cold weather. Consequently, precautions should be taken with respect to form removal or use of a pavement slab by construction equipment. Guidance should be established by tests on cylinders cured under the same temperature and moisture conditions.

AVAILABILITY AND CHARACTERISTICS OF FLY ASHES IN VIRGINIA

A significant aspect of the feasibility of utilizing fly ash concrete in Virginia under these guidelines is the availability and costs of fly ashes with a history of successful use and a willingness of the fly ash supplier to certify compliance to ASTM Specification C618. Accordingly, a brief questionnaire was sent to eight possible fly ash suppliers. Replies were received from six companies. Five of those replying indicated that they would supply and certify material in compliance with ASTM Specification C618 and with the added stipulation that the loss on ignition would not exceed 6.0%. The sixth company did not consider its fly ash suitable for use in concrete.

Four of the five companies supplying materials meeting C618 indicated that each ash was derived from the same power plant and that the coal burned was from the same local area if not the same mine. These companies all indicated that they could certify compliance to a maximum limit of 3.0% on loss on ignition. The fifth company supplies material from a number of power plants and, although it reported that the majority of them used coals from a single source, it reported that some receive coal from varied sources through transloaders. This company indicated that a 3.0% maximum limit on loss on ignition could not be certified for ash from all sources. Limits varying from 3.5% to 5.0% were considered feasible depending on the fly ash source.

The general estimates of costs per ton of fly ash ranged from $9 to $45, depending on the distance from the source to the point of use. The higher costs were based on truck delivery over long hauls. For rail delivery over equal distances costs would be reduced. A list of the major contacts for each fly ash supplier is included in Appendix B. These suppliers should not be taken to be the only usable sources in Virginia.

RECOMMENDATIONS

On the basis of this study, the following recommendations are made.

1. Action should be taken to prepare special provisions to the standard specifications for concrete to implement the guidelines for use of fly ash in concrete for highway construction recommended by the Concrete Research Advisory Committee.

2. A program should be undertaken as soon as possible to determine quantitatively the extent of problems associated with attaining proper air entrainment in fly ash concrete. Such a program should include tests with concrete components normally used in various districts of the state. Fly ashes used in such tests should be those that are commercially available in the geographical area involved and should comply with ASTM Specification C618.

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APPENDIX A

INTERIM GUIDELINES FOR USE OF FLY ASH IN CONCRETE BY THE VIRGINIA DEPARTMENT OF HIGHWAYS AND TRANSPORTATION

1. Fly ash may be used as an ingredient in concrete furnished to the Virginia Department of Highways and Transportation in two ways.

    (a) As a separate ingredient added to the concrete mixer.

    (b) As a component of the hydraulic cement.

    The special limitations and procedures that apply in each case are as follows:

2. For fly ash added at the concrete mixer:

    2.1 The use of fly ash shall be at the option of the contractor, with approval by the state on a project-to-project basis.

    2.2 Proportions of ingredients of the fly ash concrete shall be approved by the state. Fly ash may replace up to 15 percent by weight of the cement that would normally have been used in the concrete without fly ash. However, depending on circumstances such as the need for early strength and optimum workability, the amount of cement replaced may be less than the amount of fly ash added, but at no time shall the amount of fly ash be less than the amount of cement replaced.

    2.3 The fly ash used shall be from a source approved by the state and shall conform to ASTM Specification C618 for a Class F pozzolan, except that the loss on ignition shall not exceed 6.0 percent.

    Approval of a fly ash source by the state shall be based on certified test results from an independent laboratory attesting that the product conforms to the specification with respect to inorganic composition and pozzolanic activity, or on tests made by the state. Conformity to the requirements for loss on ignition and fineness shall be determined by tests on each shipment of fly ash to the mixing site.

2.4 Special control procedures for determining the dosage of air entraining agent and the amount of air entrained in the concrete at the mixer shall be employed. These shall include trial determinations of the amount of air entraining agent required to provide the specified amount of entrained air at the anticipated time of discharge. Such trials must be made with fly ash, cement, sand, coarse aggregate, and air entraining agent to be used in the project.

2.5 During construction, the air content of the fly ash concrete shall be determined by testing each load of concrete at the point of discharge by means of two air content determinations with properly calibrated Chace air meters. The average of the two tests shall be within the range of air contents specified.

In case of dispute, a single determination of the air content by means of an air pressure meter shall be made. Results of this test will govern acceptance or rejection of the load of concrete in question. The amount and type of air entraining agent used for each load shall be recorded.

2.6 Concrete containing fly ash as a separate ingredient shall meet all strength requirements usually specified for the class of concrete being furnished. Precautions must be exercised with respect to form removal or load applications to fly ash concrete, especially in cold weather, since the rate of strength development may be slower than for normal concrete even though the minimum requirements are satisfied.

3. For fly ash as an ingredient of the hydraulic cement:

3.1 Use of blended cement shall be at the option of the contractor, with approval by the state on a project-to-project basis. When approved for use, the blended cement shall meet the requirements of AASHTO Specificarion M240 — Type 1P, except that the pozzolan used must be fly ash and shall not exceed 20 percent by weight of cement.

3.2 When Type 1P cement is used, the special control procedures and increased frequency of testing as covered in Items 2.4 and 2.5 shall be applied.

3.3 Concrete made with Type 1P cement shall meet all strength requirements usually specified for the class of concrete being furnished. The precautions concerning strength development and form removal given in 2.6 also apply.

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APPENDIX B

SUPPLIERS OF CERTIFIED (ASTM C618) FLY ASH IN VIRGINIA

1. National Minerals Corporation
   Route 4, Box 189B
   Indiana, Pennsylvania 15701
   Representative: Chuck Meadowcroft
   Phone (412)349-5612

2. Ash Management Corporation
   6600 Powers Ferry Road
   Atlanta, Georgia 30339
   Representative: Bill G. Fletcher
   Phone (404)943-1900

3. Kanawha Valley Fly Ash
   1716 Pennsylvania Avenue
   Charleston, West Virginia 25302
   Representative: Jack Peters
   Phone (304)346-1637

4. Seaboard Fly-Ash Division
   Seaboard Industries, Inc.
   1 Post Office Road
   Waldorf, Maryland 20601
   Representative: Harvey F. Greenwell
   Phone (301)843-2081

5. Monier Resources, Inc.
   2708 Church Street
   Greensboro, North Carolina 27405
   Representative: A. H. "Tee" Morgan
   Phone (919)375-4066