

UPDATE ON FLY ASH TECHNOLOGY RELATING TO HIGHWAY CONSTRUCTION
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by

Woodrow J. Halstead
Research Consultant

(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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SUMMARY

This report abstracts the information concerning the use of fly ash in highway construction contained in the Proceedings of the Sixth International Ash Utilization Symposium held March 7-10, 1982, at Reno, Nevada. The Proceedings include 54 papers, only 25 of which are abstracted. Some of the information has been previously reported but new evaluations, particularly for fly ashes obtained from sub-bituminous coal, are presented.

The papers reviewed show the successful use of fly ash as a filler in asphalt pavements, for soil stabilization, for base course construction, in hydraulic cement concrete, and as a grout for "mud-jacking" portland cement concrete pavements. These developments reflect the growing use and importance of fly ash in highway construction and the need for all highway engineers to become aware of its potential.

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INTRODUCTION

The Sixth International Ash Utilization Symposium was held March 7-10, 1982 at Reno, Nevada, and the Proceedings have been published by the Morgantown Energy Technology Center, U. S. Department of Energy. Cosponsors of the symposium were the American Public Power Association, the Department of Energy (DOE), the Environmental Protection Agency (EPA), the Electric Power Research Institute, Edison Electric Institute, the Federal Highway Administration (FHWA), the National Coal Association, the New York Power Pool, and the National Ash Association.

The federal agencies' interests in this symposium stem from their involvement in conserving energy and in utilizing fly ash to avoid its disposition in a manner that might have harmful environmental effects. Further, the FHWA is interested in providing a low cost material for a number of highway applications. The commercial interests, of course, seek to devise means for disposing of or marketing the fly ash in the most efficient and profitable manner.

For this update, all the papers published in the proceedings, consisting of 915 pages in two volumes, have been reviewed and information relating to highway construction and concrete technology has been abstracted except that information previously summarized in the Research Council report entitled "Quality Control of Highway Concrete Containing Fly Ash" is not included. An abbreviated version of that report is included in volume 2 (page 394) of the Proceedings.⁽¹⁾

VOLUME OF FLY ASH PRODUCTION

In the opening remarks at the symposium, Halow reported that United States consumption of coal was approximately 600 million tons in 1980 and is expected to rise to one billion, 400 million tons by the year 2000.⁽²⁾ On this basis, the production of all ash will amount to about 200 million tons, which is more than double the

current production. The current use of fly ash as a by-product amounts to only about 10 million tons. Volumes of these magnitudes offer both a problem and an opportunity. The problem is that as a waste or by-product, the ash must be disposed of or stored in a manner that is not detrimental to the environment. The opportunity is that the ash constitutes a valuable resource that with proper processing and evaluation provides a low cost and low energy raw material for a number of industrial applications.

UTILIZATION OF FLY ASH IN HIGHWAY CONSTRUCTION

Potentially, fly ash has a number of uses in highway applications, as was discussed in the previously cited Research Council report.⁽¹⁾ The presentation by Sommerfeld at the symposium reviewed much of the same material and summarized the objectives of the FHWA's Demonstration Project No. 59 concerning the use of fly ash in highway construction.⁽³⁾ The conclusions stated by Sommerfeld are:

If the Federal Government continues its strong role in the effective use and disposal of waste products, public highway officials may have no choice but to consider using fly ash as a construction material in road construction and maintenance. It would be in the best interests of these officials to become as knowledgeable as possible with this material and its use. So as to avoid many costly mistakes that have been made in the past, fly ash, like any construction material, must be engineered when used in construction applications. In addition, the variability of fly ash itself can have adverse effects in any application, if this variability is not known or not planned for. The misconception that fly ash is an inexpensive filler material has resulted in many job failures in the past; this should not be repeated in the future. Fly ash use must be designed and engineered for each separate application and project.

FLY ASH IN ASPHALT PAVEMENT

The Wyoming Highway Department made a study of the effectiveness of fly ash as a replacement for portland cement and hydrated lime added as a filler in the production of asphaltic concrete mixtures.⁽⁴⁾ The properties of asphaltic concrete containing concrete additions of two different fly ashes at 1%, 3%, and 6% and

four combinations of cement, lime, and fly ash were compared to those of mixtures containing only natural fines, a chemical anti-stripping agent, 2.0% hydrated lime, and 2.0% portland cement. The fly ashes contained 6.18% and 24.74% CaO, respectively. The results showed that, with respect to Marshall mixture design criteria, acceptable asphaltic concrete mixtures can be produced in the laboratory with up to 6.0 fly ash by weight of the aggregate. Asphalt concrete mixtures containing up to 6.0% fly ash generally have lower asphalt requirements and lower voids in the mineral aggregate.

Data obtained from the immersion-compression test showed that additions of 3.0% or 6.0% of either the fly ashes combined with 0.5% cement or 1.0% lime resulted in asphaltic concrete mixtures with moisture resistance characteristics comparable to those of mixtures containing the 2.0% portland cement, 2.0% hydrated lime, or a chemical antistripping agent.

USE OF FLY ASH IN SOIL STABILIZATION AND BASE COURSES

Self-hardening Fly Ash for Soil Stabilization

A self-hardening fly ash from a Wyoming low sulfur, sub-bituminous coal was shown to be effective as a soil stabilizing agent for clays and sands.⁽⁵⁾ Stabilization is best in sands and clays because of the effective mechanical interlock with soil particles. The strength of the soil and self-hardening fly ash develops rapidly when the combination is compacted immediately after mixing. Seven-day unconfined compressive strengths up to 1,800 lb./in.² were obtained from 20% fly ash-80% sand mixtures. Delay in compaction after mixing the fly ash with the soil resulted in a loss of strength. With a 2-hour delay, over a third of the strength was lost and with 4 hours delay over half of the strength was lost. Gypsum and some commercial concrete retarders were effective in reducing the detrimental effect of delayed compaction. Field tests confirmed the need for adequate mixing and rapid compaction.

Coal Refuse-Fly Ash Mixtures as a Base Course Material

A study was performed for the FHWA by GAI Consultants and West Virginia University to establish the potential use of mixtures of coal refuse and fly ash as highway base course materials.⁽⁶⁾ The conclusions stated that coal refuse and fly ash samples obtained from selected areas of potentially high use exhibited a wide variability in their physical, chemical, and engineering properties.

Some unstabilized coal refuse-fly ash combinations had adequate strength in the CBR and Hveem stabilometer tests to satisfy current base course criteria; however, the results of wet/dry and freeze/thaw durability tests suggest that the long-term durability of unstabilized blends is questionable. Several stabilized coal refuse-fly ash mixtures met recommended strength and durability criteria.

Portland cement and lime stabilized coal refuse-fly ash base courses require thinner surface and base layers than a crushed stone base for the same loading, temperature, and subgrade conditions when evaluated by the FHWA VESYS predictive design procedure.

The predicted performance levels of asphalt pavements with stabilized coal refuse-fly ash base courses can be equal to and better than those for crushed stone.

The use of stabilized coal refuse-fly ash blends as substitutes for conventional base course materials appears to be feasible. However, additional study is recommended before general in-service use of these mixtures is undertaken. Field testing of various mixtures and tests on additional sources of material are recommended to determine long-term durability.

An Engineering Evaluation of Blended Coal By-Product
Materials for Stabilized Base and Highway
Construction Applications

Physical, chemical, and pozzolanic activity properties were determined for class F fly ash samples taken from 18 coal-fired public service electrical power generating plants in Kentucky.⁽⁷⁾ The majority of the fly ash samples met pozzolanic activity criteria for use with lime in nonplastic mixtures.

Selected fly ash samples from 6 Eastern Kentucky electrical generating plants were used to design optimum lime-stabilized fly ash base mixtures. Compressive strength, durability, bearing ratio, and frost susceptibility properties were used to assess the engineering applicability of the materials.

Lime, fly ash, and coal refuse mixtures were designed and evaluated as base materials for various applications. Their compressive strength, durability, bearing ratio, and frost susceptibility properties were determined to be satisfactory.

Use of Kiln Dusts with Fly Ash in Road
Base Compositions

Kiln dust can be combined with fly ash to form a pozzolanic stabilizing material for road base construction.⁽⁸⁾ The reactions that occur are primarily the same as those which occur in lime-fly ash stabilization. The kiln dust is an economical source of the lime. The report giving this information describes research being undertaken in this area. Present efforts are to evaluate the properties of kiln dust, the optimum mixture proportions for kiln dust-fly ash mixtures, and the engineering properties of kiln dust-fly ash-aggregate systems.

Experience with Lime/Fly Ash Road
Bases in Illinois

The use of lime/fly ash aggregate in road bases and subbases is discussed.⁽⁹⁾ Actual job applications are given showing substantial dollar savings over the use of other types of materials. The responsibility of different parties for different aspects of the work is included.

1980s: The Pozzolanic Pavement Era in
American Construction

This paper discusses the potential economic advantages of pozzolanic bases consisting primarily of fly ash and kiln dust.⁽¹⁰⁾ These are said to need only a thin wearing surface. The speaker is primarily promoting the use of a patented product (N-Viro-Crete).

Meeting Today's Engineering Requirements
with Today's Materials

This paper is also a promotion of the patented product N-Viro-Crete.⁽¹¹⁾ It emphasizes the economic advantage of utilizing the product as a base for asphalt pavements. Cost comparisons with various types of construction are given.

Potential of Bottom Ash

This paper is directed to the use of bottom ash as lightweight aggregate for concrete products, as base material, and for asphaltic concrete incorporating bottom ash.⁽¹²⁾ It describes the process for converting bottom ash into lightweight aggregate.

USE OF FLY ASH IN HYDRAULIC CEMENT CONCRETE

Utilization of Class C Fly Ash in Concrete

This paper documents the effects of using a class C fly ash in concrete.⁽¹³⁾ The fly ash used results from the burning of a Wyoming sub-bituminous coal. It was found that a concrete mix containing the fly ash could be designed to achieve the desired compressive strength at either early or late stages. Compressive strengths of 149% and 155% that of a control mixture were obtained at 28 and 56 days, respectively. While the initial setting time is delayed by the use of fly ash, this can be offset by using chemical admixtures.

Use of Fly Ash in Specification Air-Entrained Concrete

Fly ash was used in concrete for construction of a large facility — 60,000 yd.³.⁽¹⁴⁾ The ready-mix concrete was closely inspected. Test data collected over a period of 18 months and the variabilities of strength at 7 and 28 days, cylinder weight at 7 days, air content, slump, concrete temperature, and time between sampling and leaving the plant were determined.

Slump was controlled between 2 and 4 in. at the jobsite immediately before use. To achieve this, batches were prepared at a 4 to 5 in. slump at the plant. The slump varied with time between batching and use. If the slump was greater than 4 in. at the jobsite, the concrete was rejected; if less than 3 in. water was added and the concrete mixed at maximum drum speed.

The air content was required to be between 4.0% and 6.0% at the jobsite. This was obtained by controlling the air content at 5.0% to 6.0% at the plant. All loads were mixed for 2 minutes at maximum drum speed immediately prior to use. This procedure resulted in very few loads with air contents outside specifications. Concretes with fly ash had average air contents from 4.6% to 5.2%, with an average of 4.86% for test periods of 30 consecutive tests. Standard deviations for air contents ranged from 0.5 to 1.0, with an overall average of 0.63.

A maximum water/cement ratio of 0.46 was required. Also a minimum of 420 lb./yd.³ of cement was needed. However, to get the proper slump a total of 540 lb. of cementitious material was used. This consisted of 420 lb. of cement and 120 lb. of fly ash/yd.³ Average strengths of this concrete for each 30 tests varied from 4,720 to 5,320 lb./in.² at 28 days, with the average being 5,130 lb./in.². The standard deviation varied from 304 to 720 lb./in.². The average value was 479 lb./in.².

It was concluded from a comparison of average air contents and standard deviations of air contents of concrete mixes incorporating fly ash and mixes without fly ash that the use of fly ash need not present problems in air-entrained concrete, if the concrete is properly produced and tested.

Use of Fly Ash in Combating Sulfate Attack in Concrete

This report discusses the problem of sulfate attack on concrete and how it can be combated by the use of fly ash.⁽¹⁵⁾ The beneficial effects of fly ash previously reported in the literature generally refer to class F material. The effect of class C material can vary from beneficial to deleterious. The R factor derived by Dunstan is discussed. The sulfate resistances of concrete utilizing fly ashes of various R factors were compared to that of concrete made with type II cement. Relative resistance is given as follows:

R	Sulfate resistance
<0.75	Greatly improved
0.75 - 1.5	Moderately improved
1.5 - 3.0	No significant change
>3.0	Reduced

"R" is equal to $\text{CaO}-5/\text{Fe}_2\text{O}_3$

Sulfate Resistance of Mortars Using Fly Ash

A study was conducted by the Wyoming Highway Department to evaluate the usefulness of fly ash as an ingredient in concrete to increase its sulfate resistance when in contact with sulfate-bearing soils.⁽¹⁶⁾ The project compared the sulfate resistance of mortars containing fly ash as a partial cement replacement with control mortars that did not contain fly ash. Fly ashes from four sources were tested at 10%, 15%, and 20% by weight of cement replaced with an equal weight of fly ash. Three of the fly ashes were class F as defined by ASTM C618 and one was class C. The test procedure was that developed by K. Mather at the Waterways Experiment Station, U. S. Corps of Engineers. It consists of subjecting 1 in. x 1 in. x 11 in. mortar bars to a mixed sodium and magnesium sulfate solution and making measurements of length change, weight change, porosity, and relative dynamic modulus over a period of 360 days.

The data generated indicated that improvements in sulfate resistance over that provided by a type II moderate sulfate resistance cement may be obtained through the use of certain fly ashes in

portland cement concrete. The three class F fly ashes used in the study improved the sulfate resistance (reduced expansion) at all levels of replacement of cement tested (10% to 20%). The class C fly ash did not improve the sulfate resistance. The R factor of the fly ashes tested predicted which of the ashes would and would not improve the sulfate resistance. During testing, mortar bars that contained the fly ashes and provided improved sulfate resistance experienced slightly greater weight losses due to scaling and abrasion than did the control bars. Losses for the fly ash specimens at 360 days were generally in the 2% to 5% range while losses for the control were about 2%.

Answers to the Objections to the Use of Fly Ash in Concrete

This paper reviews some of the more frequently given reasons for not permitting fly ash to be used as an ingredient in concrete and other statements usually made concerning the effect of fly ash on the properties of concrete.⁽¹⁷⁾ It concludes that there are very few objections to the use of fly ash in concrete that can't be responsibly and truthfully satisfied. Some of the aspects discussed are noted below.

Low Strengths at 28 Days

Low strengths at 28 days are obtained if a volume of the cement is replaced by an equal volume of fly ash. However, mix design methods that consider fly ash as one of the initial ingredients are available, and mixes so designed can comply with usual requirements for strength at 28 days. Generally, for such mixes the weight of fly ash plus the weight of cement will exceed the weight of portland cement used in concrete of similar strength levels without fly ash.

Setting Time

It was noted that different cements, as well as the addition of fly ash, produced different setting times. Increased setting time in cold weather also applied to concrete without fly ash as well as to concrete with fly ash. Proper use of accelerators in both cases can minimize problems.

Air Entrainment

It is generally accepted that to achieve the same air content in fly ash concrete as would be obtained in concrete without fly

ash, the dosage of air-entraining agent must be increased. The amount of this increase appears to depend on the loss on ignition. The higher the loss on ignition, the greater the amount of air-entraining agent required. It has been shown that it is difficult to entrain the proper amount of air in concretes containing very high losses on ignition. However, present trends are that the loss on ignition for fly ashes being marketed as a pozzolan are being reduced because of improvements in power plant design and operation. These improvements result in more complete burning of the coal. Where difficulties are encountered the effects and interactions of all the ingredients should be considered.

Scaling

It has been shown that if fly ash concrete has an adequate air void system it should have essentially equal freeze-thaw resistance as concrete without fly ash and of the same strength. The use of fly ash should be beneficial in reducing unsoundness effects from the presence of free lime in the concrete. It should also make the concrete less permeable to chloride and sulfate ions.

Increased Variability

Although it is reasoned that with an additional material in the mixture the variability of the end product would be increased, there is evidence that the variability of a well-controlled job where fly ash is used is no greater than would be expected for similar concrete without fly ash.

Variability of Fly Ash

There is a large variability in the characteristics of fly ash from source to source. Thus source selection and approval is important. However, once a suitable source is accepted, normal variations can be monitored by fineness and loss on ignition, and do not normally cause problems provided the source of coal burned is not changed.

Lack of Curing

Good curing is needed for all types of concrete. However, tests show that fly ash concrete (with moderate amounts of fly ash) is not adversely affected any more than concrete without fly ash.

Sulfate Resistance

Increased sulfate resistance for concrete containing class F fly ash has been generally established. However, the use of certain class C fly ashes may result in a lowering of the sulfate resistance.

Sticky Mix

Fly ash concrete is sometimes reported to be too sticky. This problem can normally be remedied by making an examination of the fines content with a subsequent minor modification of the mix.

Controlling the Effect of Carbon in Fly Ash
on Air Entrainment

This report concerns a study of means to deactivate or pacify the carbon in fly ash with respect to normally used air-entraining agents, or to find other air-entraining agents immune to the effects of the carbon in the fly ash.⁽¹⁸⁾ The conclusions drawn from the study are that chlorine and hypochlorites effectively reduce the requirements for normally used air-entraining agents when used either as a gaseous pretreatment or in the mix water. The treatment is most effective when the carbon is coarse and a high percentage is retained on a 325 mesh sieve. Once the chlorine has been reacted with the carbon, the treatment is permanent. Also tested were individual surface-active agents that normally work with hydrophobic carbon such as that in fly ash. When used alone none of these materials were found to provide satisfactory air void systems as measured by the linear traverse test. However, blends of certain agents such as glucosides and long chain alcohols had a beneficial effect, yielding acceptable results.

Concrete samples made from treated ash are not adversely affected by the treatment based on test work to date. Either the chlorine treatment or surfactants can be used for preventing adverse effects when using air-entraining agents in fly ash concrete. (Authors expect treatment would be applicable in the manufacture of blended cements.)

Effect of Coarse Fraction (+ 325 Sieve) of
Fly Ash on Concrete Properties

This study involved a fly ash from a sub-bituminous coal.⁽¹⁹⁾ Percentages of material retained on the 325 sieve varying from 5% to 38% were tested. The 28- and 56-day compressive strengths of concretes containing fly ashes were generally higher than that of the control concrete without fly ash. The only mix that developed slightly lower 28-day strengths was the one containing 10% equivalent fly ash with 38% retained on the number 325 sieve. However, the difference was statistically insignificant. Finer ashes generally imparted higher long-term strength to concrete.

SPECIFICATIONS AND TEST METHODS

A Critical Look at ASTM C618 and C311

This report states that ASTM C618 is probably the most demanding specification for fly ash in the English speaking world. (20) However, it also states that the time delays involved and the cost of testing are out of proportion to the benefits derived. ASTM C311 does a creditable job of defining the test methods to meet the needs of C618, but neither document attempts to grade testing frequencies for individual tests in a practical manner.

The author points out that fly ash that fails C618 is unlikely to perform well in concrete, but given test results on two or three fly ashes that comply with C618, the prediction of relative performance is seldom easy.

A modification of the definitions of class F and class C fly ash is suggested. Rather than base the definition on the type of coal from which the fly ash is derived, it is suggested that a class F fly ash be defined as one that has no hydraulic properties but that meets all other requirements of C618, and that a material having hydraulic properties be defined as class C, even though the oxides of silicon, aluminum, and iron may exceed 70%. A simple knife-cut setting test such as now used for gypsum plaster is suggested for establishing the class of a new source. The relative importance of all the various tests in C311 and requirements in C618 is discussed. It is concluded that a program based on annual source certification with regular checks for product uniformity would minimize quality assurance problems. Annual tests would include complete chemical analyses and sophisticated particle size determinations. Control tests for sieve residues and ignition loss would be more frequent and used as a measure of uniformity. A departure from characteristic values would initiate an expanded test program to isolate the cause.

Review of American and Foreign Specifications for
Use of Fly Ash in Portland Cement Concrete

This paper compares specifications in use by a number of countries. (21) It points out that the volume of ash utilized in the United States is more than three times that used by any other nation, but the percentage of use (21%) is much lower than the percentage used in most Western European countries. Throughout the world the use of ash in construction is a relatively highly developed technology.

Various proposed classification schemes are discussed, and a new scheme is proposed that would establish a uniform language applicable to most disciplines. Fundamental properties such as particle size, chemical composition, and leachate pH are employed with the use of a triangular graph formed by the intersections of the following three end members: Sialic group ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{TiO}_2$), the calcic group ($\text{CaO} + \text{MgO} + \text{Na}_2\text{O} + \text{K}_2\text{O}$), and the ferric group ($\text{Fe}_2\text{O}_3 + \text{MnO} + \text{SO}_3 + \text{P}_2\text{O}_5$). This system could be used as an aid in determining what utilization method might be best suited for particular types of fly ash, such as iron source, a mineral admixture for concrete, or acid mine reclamation.

A patent issued to W. R. Grace in 1980 is discussed. This involves concrete containing portland cement, fly ash, and aggregates which are capable of attaining high compressive strengths and which contain relatively low proportions of portland cement and high proportions of a select fly ash.

Fly ash with compositions in the following ranges produced concretes with unusually high strengths.

SiO_2	=	24.1 - 43.1
Al_2O_3	=	14.3 - 27.5
Fe_2O_3	=	4.2 - 9.5
$\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$	=	47.9 - 72.4
CaO	=	16.8 - 29.6
MgO	=	3.7 - 8.5
SO_2	=	1.6 - 6.4

The author, in conclusion, suggests a characterization scheme for fly ashes for use in concrete as follows:

1. Little or no reference to the type of coal.
2. Separation into strength-imparting classes by using W. R. Grace composition range, followed by obtaining the degree of strength by a mortar cube test similar to W. R. Grace's reaction test.
3. The fly ashes that fail the W. R. Grace criteria could be used for normal replacement of cement in concrete; i.e., 15% to 25%.

A Simple Test for Evaluation of Quality of Fly Ashes
and Other Pozzolans for Use in the Cement and
Concrete Industry

This paper reviews the chemical tests for evaluating the quality of fly ash and other pozzolans. It concludes that tests such as those determining the percentages of acid and alkali soluble constituents do not provide good correlation with the strength and durability-improving ability of the pozzolan, which should be the real measure of quality for use of the material in the cement and concrete industry.⁽²²⁾ This is because the performance characteristics of a pozzolan in concrete are affected not only by the lime-pozzolan reaction, but also by the morphology and density of the reaction product and the pore-size distribution of the hardened cement paste.

It seems appropriate, therefore, that for use in the portland cement and concrete industry, the evaluation of the potential performance characteristics of pozzolans should be done on the basis of desirable changes in the microstructure of hydrated portland-pozzolan cements, such as the rate at which a pozzolan is able to reduce the volume of large pores in a blended portland-pozzolan cement paste. However, the instrumentation and the techniques for pore size distribution analysis are quite complex and, therefore, beyond the reach of ordinary materials testing laboratories. Permeability to water under pressure can be used as indicative of the existence of a substantial volume of large pores, but again the test equipment and procedure are not simple.

The author found that the rate of penetration of water under atmosphere conditions into a hydrating paste or mortar made with pozzolan cements can be used as an indirect measure of the amount of large pores ($>0.1 \mu\text{m}$) present and, therefore, of the pozzolanic activity. No special equipment is needed for this test and it is simple to carry out.

Experimental work was conducted involving four ashes, two natural pozzolans, and two condensed silica fumes. The results showed that, at least in a qualitative way, the water penetration test was able to discriminate between the good and poor pozzolans.

This study involved tests made at 28 days. However, the author believes that it should be possible to complete the test in 7 to 10 days.

CEMENTS FROM SLAGS AND FLY ASH

Bijen reported on an investigation in the Netherlands of cements made of 60% finely ground hydraulic slag and 40% fly ash

with added activators.⁽²³⁾ He concluded that although such cements met the Dutch cement standard specifications, they offered no significant advantages over cements made with blast furnace slags. Some disadvantages such as the need for adding the activator at the concrete mixer, danger in handling the activator, and reduced setting time generally rule out the use of the synthetic slag cements as an alternative to ordinary portland cement. However, studies with the material will continue.

THE USE OF FLY ASH GROUTS FOR CONCRETE PAVEMENT MAINTENANCE

This paper discusses the use of fly ash grout as a slurry for concrete pavement jacking to restore the original grade and for sealing voids created by pumping action.⁽²⁴⁾ The advantages of fly ash cement grout over other normally used grouting materials such as fine soil or silty loam muds or cement and sand are discussed.

It is stated that the fineness of fly ash particles makes it possible to fill smaller voids than are filled with other grouts and that their spherical shape creates a lubricating action which makes the material easier to pump than those containing only cement or other mineral fillers. These flow characteristics also improve the injection penetration by keeping the grout in suspension and thus avoiding sedimentation. These properties permit installation of a dense layer of low permeability having good durability. In addition, the pozzolanic characteristics of fly ash combined with lime released during the hydration of the cement component of the grout create additional cementation. A more effective bond is developed than that obtained with sand and cement in typical cement/sand grouts.

Setting of the fly ash cement grout occurs in two stages. It loses fluidity within about 20 minutes after pumping and agitation ceases. At this point, the confined grout is capable of supporting substantial loads and will not be displaced, thus the pavement can be opened to traffic. The second stage occurs in 90 to 120 minutes when the grout attains its initial set. Strength will continue to increase over a period of time because of a normal cementing and pozzolanic reactions. A typical mixture used for pavement grouting is 1 part by volume of portland cement, type I or II, and 3 parts by volume of fly ash with sufficient water added to achieve the required fluidity.

Fly Ash Controls the Alkali-Aggregate Reactions of Concrete

This paper describes a 1951 test road built by the Nebraska Highway Department.⁽²⁵⁾ The project successfully demonstrated that

severe cracking of concrete made with an alkali-reactive aggregate could be eliminated by replacing 25% of the cement with fly ash. The concrete made with fly ash developed higher compressive strengths at all ages than did the concrete without fly ash. After 7 years all sections without fly ash were badly map-cracked but no such cracking had occurred in the fly ash sections.

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