ITS

MS-515

Tx

Fly Ash and It's Effect Upon the Properties of Portland Cement Concrete

Prepared for Dr. T.W. Kennedy
in Partial Fulfillment of Course
Requirements for CE 3915

By

R.B. Rogers

The University of Texas, at Austin

December 1, 1980

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

Chapter I

Scope

The purpose of this paper is to expound on the various effects of Fly Ash upon the properties of Portland Cement Concrete. The prompting of studies such as this is because of two overriding concerns which have materialized in the past decade. The first is a shortage of conventional aggregates, as well as, Portland Cement. Secondly, the recent "petroleum crisis" ushered in an era of energy consciousness which has precipitated a reevaluation of current methods and patterns of consuming energy. Therefore, particular attention is focused upon those affects which allow the use of otherwise undesireable materials, or a savings of materials in short supply.

For background, a brief definition of Fly Ash and its production is given so that a better evaluation of the materials potential can be seen. A chemical and mineralogical breakdown of Fly Ash is used to help illustrate how or why Fly Ash effects the properties of Portland Cement Concrete.

A list of these effects is given in summary and brief statement on the potential of Fly Ash as an intregal component of Portland Cement Concrete is given in conclusion.

Chapter II

Background

In order to understand Fly Ash, we must look at the nature and history of coal. Coal is the term applied to vegetal matter with varying amounts of mineral matter and with or without small portions of animal matter, which through geological processes, has become so changed by loss of volatile constituents that it is more or less compact and dark in color. It has a variable chemical composition, and it is not homogenious. It is these variations that have and will continue to be of concern to those who use Fly Ash. As Fly Ash is a by-product of the combustion of coal and is usually associated with the power plants which burn the fossil fuels. Fly Ash is a very fine, light dust which is carried off in the stack gases from a boiler unit and collected by mechanical or electrostatic methods. It is derived primarily from rock detritus which collects in the fissures of coal seams, and constitutes 8 to 14 percent of the weight of the coal. Fly Ash should not be confused with bottom ash, a granular by-product which drops to the bottom of the boiler unit. The quantity and quality of Fly Ash produced are a function of several factors. Coal source, mentioned previously, and method of production are perhaps most influential on the nature of the final product. Most data published on the nature of fly ash relate to fly ash produced from bituminous coals. Anthracitic coal ashes tend to be somewhat higher in carbon content, whereas, lignite and western coal ashes have considerably higher calcium oxide contents, all of which can greatly affect the utilization potential of a fly ash. The specifics of the chemical and mineralogical characteristics are discussed later. After production, the nature of fly ash can be further modified by the handling and storage techniques used. These techniques tend to vary within the utility industry and are a function of the power plant design. Thus, we must realize that if we are to utilize fly ash, material variability must be contented.

Chapter III

Chemical and Mineralogical Composition of Fly Ash

To understand the effects of fly ash on the properties of Portland Cement Concrete a review of the chemical and mineralogical composition of fly ash is necessary.

Mineral matter in coal occurs in two broad types, inherent and extranious, the latter making-up the largest portion. Common minerals identifiable in coals include pyrite, marcasite, calcopyrite, arsenopyrite, stibnite, gypsum, calcite, quartz, siderite, kaolinite, dolomite, apatite, mica and many others. Alteration, decomposition and transformation by heat of this mineral matter during the combustion of pulverized coal produces fly ash, a complex and finely divided solid material.

A typical chemical composition of bituminous fly ash would be as shown in Figure 1.

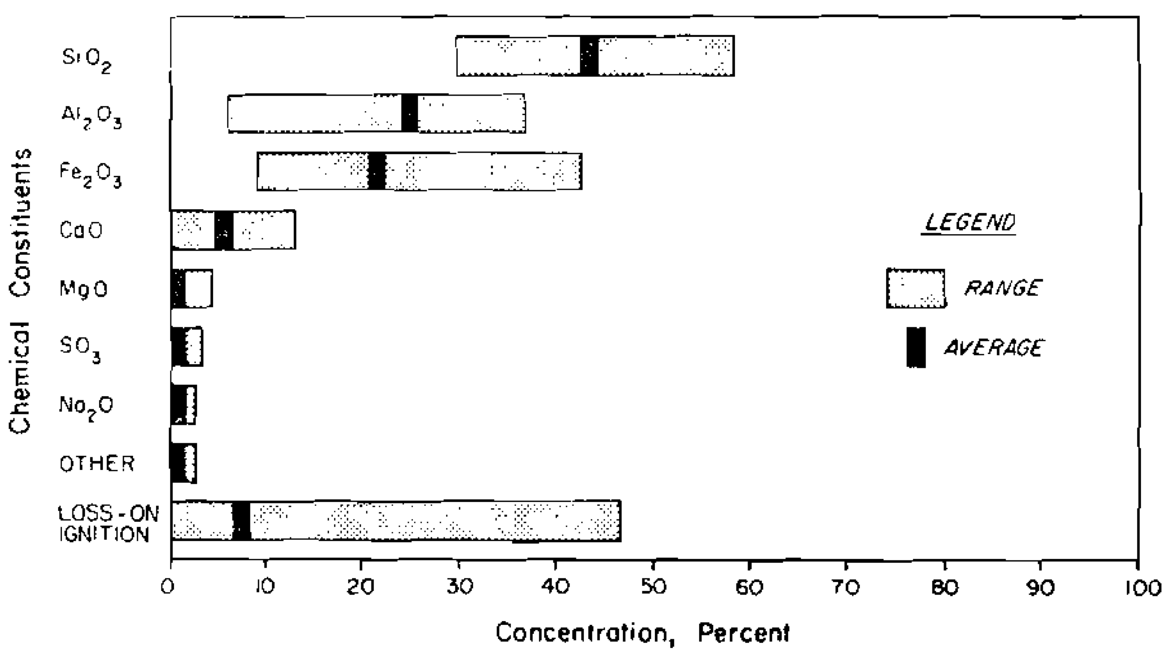

Figure 1. Range of chemical constituents in bituminous fly ashes.

All of the above compounds occur as glass oxides rather than individual elements. *All particles contain* Al_2O_3, SiO_2, Fe_2O_3, and varying amounts of other elements. A high percentage of iron oxide (magnetite) occurs in the 200 mesh size, and trace metals occur in the 600 mesh size. Particles with a high percentage of Alumina may be surrounded by smaller spheroids of trace metals. Extensive x-ray work reveals that all particles contain silica, ironide, and alumina in varying amounts, and the size and appearance of each particle may be quite different.

As previously mentioned, the chemical and mineralogical composition of fly ash is a function of several variables:

1. coal source;
2. degree of coal pulverization;
3. design of boiler unit;
4. loading and firing conditions; and
5. handling and storage methods.

Thus, a high degree of variability can occur in fly ashes, not only between power plants, but within a single power plant. The range of chemical constituents for bituminous fly ashes is indicated in Figure 1. The chemical compositions of fly ashes from lignite coals, western coals, and fly ashes produced from limestone and dolomite injection processes are sometimes significantly different from those of bituminous fly ashes. Chemical compositions of typical lignite and modified fly ashes are compared in Table 1 to that for a typical bituminous fly ash.

Table 1. Comparison of chemical compositions of typical bituminous, lignite, and modified fly ashes.[5]

CONSTITUENT	PERCENT BY WEIGHT			
	BITUMINOUS ASH	LIME MODIFIED ASH	DOLOMITE MODIFIED ASH	LIGNITE ASH
SiO_2	49.10	30.85	30.81	32.60
Al_2O_3	16.25	13.70	12.54	10.70
Fe_2O_3	22.31	11.59	10.72	10.00
TiO_2	1.09	0.68	0.42	0.56
CaO	4.48	33.58	17.90	18.00
MgO	1.00	1.49	14.77	7.31
Na_2O	0.05	1.12	0.72	0.87
K_2O	1.42	0.71	0.99	0.68
SO_3	0.73	2.20	8.09	2.60
C	2.21	1.12	1.76	0.11
L.O.I.*	2.55	1.03	1.95	0.62
H_2O soluble	2.51	22.11	20.39	8.55

*Loss-on-Ignition

TABLE 1.

The amount of calcium oxide (CaO), as shown in Table 1, is very much influenced by the coal source and the use of limestone and dolomite injection processes. The carbon content, on the other hand, is more a function of the efficiency of the particular boiler unit and the fineness of the pulverized coal. Older units tend to produce higher carbon fly ash than newer, more efficient units. The carbon content is usually measured as a percent of weight loss-on-ignition at high temperatures, usually 750° $\pm$ 50°C.

The chemical composition of a fly ash influences its color to a large degree. Fly ashes range in color from cream to dark brown or gray. The cream color is usually produced by a high calcium oxide content, and gray to black by increasing quantities of carbon.

The specific gravity of most fly ashes falls within the range of 2.1 to 2.6. The particle size of fly ash ranges from 1 to 100 microns in diameter for the glassy spheres, with an average of 7 microns, and from 10 to 300 microns in diameter for the more angular carbon particles. In terms of soil grain-size analysis, most fly ash particles fall within the silt range, with small percentages in the fine sand and clay sizes. The range for typical grain-sized distributions for fly ash is shown in Figure 2.

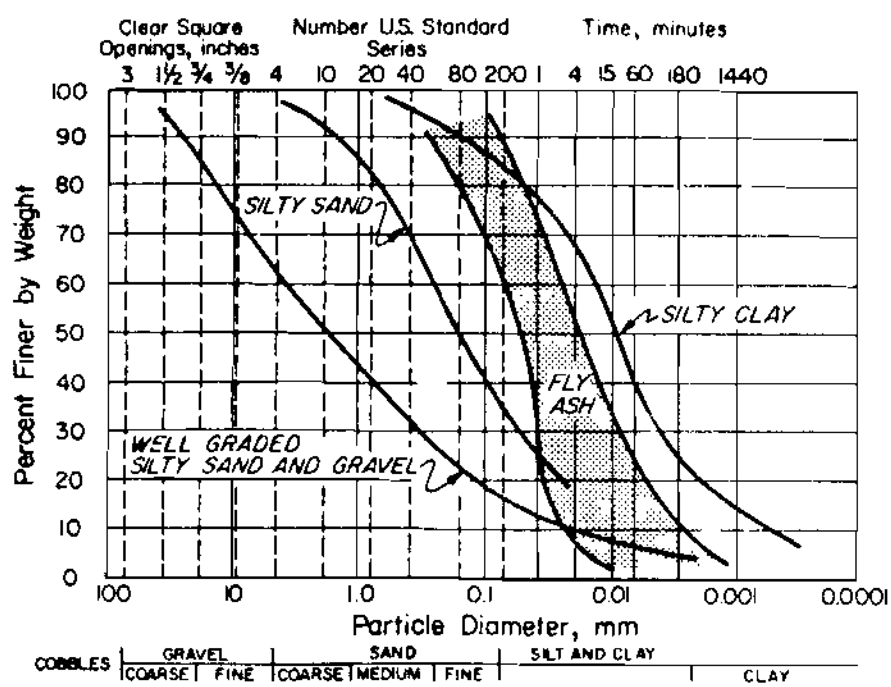

Figure 2. Range of typical fly ash grain sizes.

While chemical analysis is important as it relates to specifications, see Appendix A; the mineralogy reveals factors that may not be apparent in the standard procedures as shown in Table 2.

Table 2. Mineralogical Analysis of Fly Ash.

X-RAY DIFFRACTION		
	BITUMINOUS FLY ASH	LIGNITE FLY ASH
Quartz	20	28
Hematite	4	6
Magnetite	4	
Periclase		6
Calcium Oxide		4
Mullite	6	

A review of the chemical analysis shown in Table 1. would not begin to show the vast differences shown in the mineralogical review of Table 2. The chemical analysis does show a high percentage of calcium oxide, but does not reveal that the majority exists as a glass oxide with a small percentage of free lime. The mineralogical analysis also reveals the presence of periclase which can be very expansive.

While it has been shown that fly ashes do vary, it has also been shown that these variations can be determined and hence there effects on the properties of Portland Cement can also be determined.

Chapter IV

The Effects of Fly Ash Upon the Properties of Portland Cement Concrete

Although fly ash is a waste product of the power generating process, it has been found to have many desirable effects upon the properties of Portland Cement Concrete. The effects are as follows:

A. <u>Reduce the Susceptability of Portland Cement Concretes to Sulfate Attack</u> -

Some concretes are deteriorated by sulfates of sodium, magnisium, and calcium in alkali soils and waters. Sulfates react chemically with the hydrated lime and hydrated calcium aluminate to form calcium sulfate and calcium sulfoaluminate, accompanied by considerable expansion and disruption of the concrete. The increased sulfate resistance of concretes containing fly ash may be explained by the pozzolanic reaction of silica, alumina, and ferric oxide found in fly ash with calcium hydroxide liberated during the hydration of Portland Cement to form relatively stable cementitious compounds. The conversion of calcium hydroxide to complex compounds containing silica, alumina, and ferric oxide provides both physical and chemical basis for improved sulfate resistance. It should be noted here that fly ashes with high calcium oxide contents (lignite or western ashes) have been found to decrease sulfate resistance of the concrete.

B. Reduce Alkali-Aggregate Reaction of Portland Cement Concrete -

The alkali-aggregate phase of chemical reactivity in concrete involves the interaction of alkalies in Portland Cement with certain siliceous constituents of the aggregates in concrete. Products of the reaction can cause excessive expansion, cracking, and general deterioration of the concrete. The term "alkalies" refers to the sodium oxide and potassium oxide present in relatively small proportions. The alkali-aggregate reaction may progress if the following factors exist:

1. sufficient alkali for reaction with silica;
2. silica that is reactive with rather low concentrations of alkali;
3. water available in amounts necessary to continue the reactions;
4. lime free to react with the alkali silicates, releasing the alkali back to solution, or enough alkali present to injure the concrete without regeneration; and
5. enough force to rupture the concrete after damage by the alkali.

An investigation of the chemical and physical properties of fly ash indicates that the addition of finely divided reactive silica (fly ash), will react chemically with and absorb alkalies of the cement. The alkalies are then made unavailable for reaction with the aggregates at a later date. This cement pozzolan (fly ash) reaction takes place while the concrete is in a plastic state and as they are progressively released through hydration, and although sodium silica gel may form, it becomes so disseminated that interior pressures in the concrete member will not accumulate and exceed the tensile strength of the concrete.

C. Increased Strength, Permiability and Workability -

When Portland Cement hydrates, calcium hydroxide (lime hydrate) is liberated. This compound contributes nothing to the strength of concrete. It is soluble in water; therefore, may be removed from concrete by leaching action. The product of this action, efflorescence, sometimes appears on exposed concrete surfaces. When fly ash is combined with the Portland Cement Concrete mix, the lime formed during hydration slowly combines with the fly ash silicas, a pozzolanic reaction, forming a stable cementitious compound which contributes to the strength and water tightness. The strength development of this cementitious material at later ages, 6 to 12 months, is greater than that of regular Portland Cement Concrete. However, the addition of fly ash has other effects on the strength of Portland Cement Concrete which should be considered. First, it should be noted that the carbon in the fly ash results in the requirement of much greater quantities of air entraining agent. Second, the addition of fly ash to the Portland Cement Concrete mix causes an alteration to the volume and consistance of the paste and its effect is more complex. For example:

1. Lean Mixes, or where mix is deficient in fines -

An addition of fly ash will increase the volume of the paste and an improvement in the consistance and hence workability will result. The strength may also increase as a result of having a better graded mix.

2. Rich mixes -

While the addition of fly ash will be advantageous for workability, any increase in volume of paste may produce undesireable effects, such as, increased shrinkage.

The overall effect will depend on the proportions and properties of the other materials. It therefore follows that reference must be made to these to obtain maximum benefit from the particular fly ash under consideration.

D. Decrease Mix Temperature -

The mix temperature of Portland Cement Concrete is due primarily to the hydration of Portland Cement. The replacement of a portion of the Portland Cement with fly ash thereby causes a reduction in the mix temperature. This is partially explained by the slowness of the pozzolanic reaction, as compared to the hydration of cement.

E. <u>Water Requirements</u> -

It has been found that concretes containing low-carbon fly ash (2%) generally require less water than Portland Cement Concrete. However, concretes with fly ashes containing an excess of 2 percent carbon require proportionately more water than does standard concrete and the water requirement for a 20 percent replacement mix is higher than for a 10 percent replacement mix. The effects of varying fly ash with other concrete material held constant are illustrated in Figure 3.

A Slump 64 mm (2½ in) B Slump indeterminate C Slump nil

Figure 3. Different workabilities obtained with fly ash of differing water requirements.

Figure 3. (cont'd) -

Mix proportions (by weight) were:

Water	0.91
Cement	1.00
Fly Ash	.85
Aggregate	6.60

F. Air-Entraining Agent Requirement -

As previously indicated, most fly ash concretes require more air-entraining agent to achieve a given air content than is required for regular concrete. Researchers have shown that the agent is absorbed on and within the fly ash particle, where the agent cannot entrain air or interfere with hydration of the cement. Increasing the amount of agent to compensate for the quantity absorbed by the fly ash achieves the desired air content, and the resultant product is as resistant to freezing-thawing or salt scaling as is regular air-entrained concrete. A correlation appears to exist between agent requirement and carbon content of the fly ash. Agent requirement for constant air content was found to increase with carbon content and with the quantity of fly ash used as a replacement for Portland Cement.

G. Reduction of Bleeding -

When freshly mixed concrete stands undisturbed, a layer of water may appear on the surface of the mix owing to the gravitational settlement of the heavier constitutents. Tests have demonstrated that fly ash does reduce this tendency, as shown in Figure 4, where:

$$\text{Bleeding (precent)} = \frac{\text{Volume of Bleeding Water}}{\text{Volume of Water in Test Specimen}}$$

and

$$\text{Bleeding Water} = \frac{\text{Volume of Bleeding Water}}{\text{Area of Exposed Surface}}$$

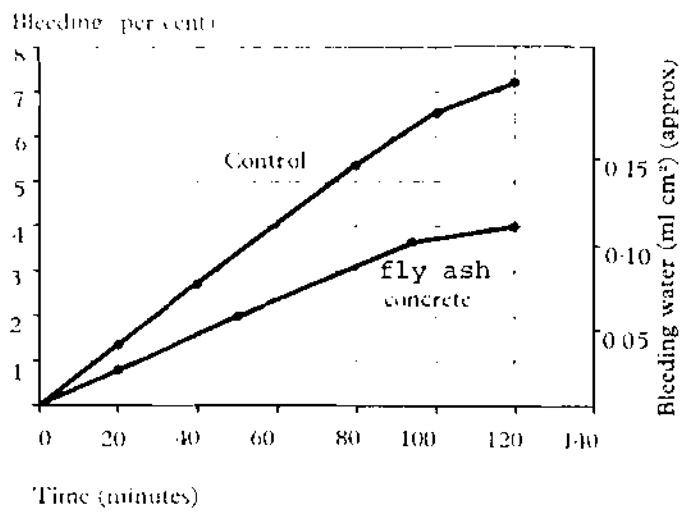

Figure 4. Relative bleeding of ordinary Portland Cement Concrete and Fly Ash Concrete.

H. <u>Appearance</u> -

The small uniformly-sized ball particles of fly ash usually improve the appearance of Portland Cement Concrete.

I. Density -

The fly ash being lighter than cement tends to produce a slight reduction in density.

J. Drying Shrinkage -

Past experiments have shown that replacements of up to 30 percent Portland Cement with fly ash do not materially effect the drying shrinkage, but caution should be used when replacing greater than 30 percent with fly ash or when fly ash is added to a mix without substitution to provide other benefits.

Chapter V

Summary

The literature research reported here indicate what effects may be expected when fly ash is used in Portland Cement Concrete. Major findings were:

1. The performance of fly ash is related to its fineness, carbon content and silica content. These factors alone, however, are not enough to provide a quantitative indication of fly ash quality. Materials which conform to the generally accepted limits for these properties (see Appendix A) may affect concrete quite differently.

2. Fly ash, because of its pozzolanic ability, and fineness contributes to the strength of development of concrete. The contribution is relatively small at the early ages, but becomes greater with increasing age. These benefits are noted primarily in the lean concretes.

3. Fly ash tends to surpress the entrainment of air in concrete. The amount of air-entraining agent required to produce a given air content may be several times as great for fly ash concrete as normal concrete.

4. It does not appear that fly ash is significantly beneficial or detrimental to the freezing and thawing resistance of concrete.

5. Certain fly ashes have been shown to significantly improve the sulfate resistance of concrete.

6. Certain fly ashes have been shown to reduce the harmful expansion due to the alkali-aggregate reaction and hence allow the use of alkali reactive aggregate.

7. The concrete mix temperature can be adjusted by using fly ash as a replacement of Portland Cement.

8. Where bleeding is a problem, the addition of fly ash has been shown to reduce this tendency.

9. The carbon content of the fly ash has been shown to have a significant effect on the water requirement of the concrete mix.

10. The addition of certain fly ashes (those low in carbon) tends to increase the concrete mix workability to the extent coarser aggregate can be sometimes be used than would otherwise be acceptable.

11. It should be recognized that a fly ash Portland Cement Concrete is a new material and as such should be designed for specific job requirements.

The unique effects of fly ash on the properties of Portland Cement Concrete make it a solution for certain engineering and construction problems as well as a substitute for more expensive materials which are dwindling in supply and escalating in cost. These properties will enhance the utilization of fly ash in highway applications.

Chapter VI

Concluding Remarks

It is the opinion of many that energy demands should be taken into account, as well as economic costs, when an analysis of a project is performed. In terms of highway construction materials, the trend in the future will be toward the use of materials which require less energy input in their production handling and placement. Since fly ash is a by-product of another process and must be collected and stored regardless of its potential for utilization, it is obvious that fly ash has a considerable energy advantage over conventional materials. This combined with the beneficial effects of fly ash on the properties of Portland Cement Concrete, as shown in this report, show that concrete can and should be designed for more than over-stress by load.

Bibliography

1. "Pozzolan Cement Study" by S.M. Law, M. Rasoulian, Louisiana, DHT, Dec. 1979.

2. "Effect of Substitutions of Fly Ash for Portions of Cement in Air-Entrained Concrete" by G.H. Larson, Wisconsin, DHT, 1953 HRB Proceedings.

3. Highway Research Record No. 53, Jan. 1964 -

   A. - "Experimental Fly Ash in Concrete Pavement in Michigan" by F.E. Legg, Jr.

   B. - "Use of Fly Ash in Concrete Pavement Constructed in Nebraska" by C.A. Sutton, Neb., DHT.

   C. - "Use of Fly Ash as an Admixture in an Experimental Pavemental Pavement in Kansas" by W.M. Stingly and R.L. Peyton, Kansas, DHT.

   D. - "Use of Fly Ash in Concrete" by the Alabama Highway Department, J.A. Hester and O.F. Smith.

4. "Fly Ash as a Construction Material for Highways" by J.F. Meyers, Raman Pichumani, and B.S. Kapples, May 1976.

5. "Further Laboratory Studies of Portland-Pozzolan Cements" by W.F. Perenchio and P. Klieger, 1976.

6. "Ash in Portland Cement Products" by moderator A.H. Meyer, Texas A&M University -

   A. - "Mixture Design of PC-Fly Ash Concrete" by J.C. Rosner.

B. - "Fly Ash Utilization in Portland-Pozzolan Cements" by A.C. Carter.

C. - "Construction Control and Handling of PC-FA Concrete Products" by C.K. Brown of Gifford-Hill Co.

7. "Fly Ash for Structural Concrete in Aggressive Environments" by T.J. Larson and G.C. Page, Florida, DOT, 1976.
8. ANSI/ASTM C 618-78, Std. Spec. for Fly Ash or Calcined Natural Pozzolan for Use as a Mineral Admixture in PCC.
9. "PFA Utilization" by Central Electric Generating Board, 1972.
10. "Effect of Fly Ash in Concrete" by D.L. Bloom, National Ready Mixed Concrete Association, 1954.
11. "Fly Ash in Paving and Structural Concrete" by G.G. Fowler and R.W. Styron, 1978.
12. "Fly Ash and Its Use in Concrete" by D.E. Grahm, 1972.
13. "Fly Ash Increases Resistance of Concrete to Sulfate Attack" by J.T. Dikaou, 1975.
14. "Fly Ash Utilization" by J.P. Capp and J.D. Spencer, 1970.

ASTM AMERICAN NATIONAL STANDARD ANSI/ASTM C 618-78

Standard Specification For

FLY ASH AND RAW OR CALCINED NATURAL POSSOLAN FOR USE AS A MINERAL ADMIXTURE IN PORTLAND CEMENT CONCRETE[1]

This standard is issued under the fixed designation C 618, the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parenthesis indicates the year of last reapproval.

1. SCOPE

1.1 This specification covers fly ash and raw or calcined natural pozzolan for use as a mineral admixture in concrete where ementitious or pozzolanic action, or both, is desired, or where other properties normally attributed to finely divided mineral admixtures may be desired or where both objectives are to be achieved.

Note 1 - Finely divided materials may tend to reduce the entrained air content of concrete. Hence, if a mineral admixture is added to any concrete for which entrainment of air is specified, provision should be made to assure that the specified air content is maintained by air content tests and by use of additional air-entraining admixture or use of an air-entraining admixture in combination with air-entraining hydraulic cement.

Note 2 - The values stated in U.S. customary units are to be regarded as the standard.

2. APPLICABLE DOCUMENTS

2.1 ASTM Standards:

C 260 Specification for Air-Entraining Admixtures for Concrete[2]; and

[1] This specification is under the jurisdication of ASTM Committee C-9 on Concrete and Concrete Aggregates, and is the direct responsibility of Subcommittee C 09.03.08 on Methods of Testing and Specifications for Admixture.

Current edition approved April 6, 1978. Pub. June 1978. Originally Pub. as C 618-68 T to replace C 350 and C 402. Last previous ed. C 618-77.

[2] Annual Book of ASTM Standards, Part 14.

C 311 Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete [2].

3. CLASSIFICATIONS

3.1 Class N - Raw or calcined natural pozzolans that comply with the applicable requirements for the class as given herein, such as, some diatomaccous earths; opaline cherts and shales; tuffs and volcanic ashes or pumicites, any of which may or may not be processed by calcination; and various materials requiring calcination to induce satisfactory properties, such as, some clays and shales.

3.2 Class F - Fly ash normally produced from burning anthracite or bituminous coal that meets the applicable requirements for this class as given herein. This class fly ash has pozzolanic properties.

3.3 Class C - Fly ash normally produced from lignite or subbituminous coal that needs the applicable requirements for this class as given herein. This class of fly ash, in addition to having pozzolanic properties, also has some cementitious properties. Some Class C fly ashes may contain lime contents higher than 10%.

Note 3 - Currently the usual replacement of cement by Class C fly ash does not exceed 20%.

3.4 Class S - Any pozzolan that meets the applicable requirements for this class as given herein. Examples of materials in this class include certain processed pumicites, and certain calcined and ground shales, clays and diatomites.

4. DEFINITIONS

4.1 Pozzolans - Siliceous or siliceous and aluminous materials which in themselves possess little or no cementatious value but will in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

4.2 Fly Ash - finely divided residue that results from the combustion of ground or powdered coal.

5. CHEMICAL REQUIREMENTS

5.1 Fly ash and natural pozzolans shall conform to the requirements as to chemical composition prescribed in Table 1. Supplementary optional chemical requirements are shown in Table 1A.

Table 1. CHEMICAL REQUIREMENTS

	Mineral Admixture Class			
	N	F	C	S
Silicon dioxide (SiO_2) plus aluminum oxide (Al_2O_3) plus iron oxide (Fe_2O_3), min. %	70.0	70.0	50.0	70.0
Sulfur trioxide (SO_3), max. %	4.0	5.0	5.0	4.0
Moisture content, max. %	3.0	3.0	3.0	3.0
Loss on ignition, max. %	10.0	12.0	6.0	10.0

Table 1A. SUPPLEMENTARY OPTIONAL CHEMICAL REQUIREMENTS

Note - These optional requirements apply only when specifically requested.

	Mineral Admixture Class			
	N	F	C	S
Magnesium oxide (MgO), max. % [A]	5.0	5.0	5.0	5.0
Available alkalies, as Na_2O, max. % [B]	1.50	1.50	1.50	1.50

[A] When the autoclave expansion or contraction of 0.8% max. is not exceeded, an MgO content above 5.0% may be accepted. When the cement to be used in the work is known and available, the mineral admixture should be tested using that cement. Also refer to Table 2, footnote [C].

[B] Applicable only when specifically required by the purchaser for mineral admixture to be used in concrete containing reactive aggregate and cement to meet a limitation on content of alkalies.

6. PHYSICAL REQUIREMENTS

6.1 Fly ash and natural pozzolans shall conform to the physical requirements prescribed in Table 2. Supplementary optional physical requirements are shown in Table 2A.

Table 2. PHYSICAL REQUIREMENTS

	Mineral Admixture Class			
	N	F	C	S
FINENESS:				
Amount retained when wet-sized on No. 325 (45 um) sieve, max. % [A]	34	34	34	34
POZZOLANIC ACTIVITY INDEX: [B]				
With portland cement, at 28 days, min. % of control	75	75	75	75

(cont'd)

[A] Care should be taken to avoid the retaining of agglomerations of extremely find material.

(Cont'd) Table 2. PHYSICAL REQUIREMENTS

	Mineral Admixture Class			
	N	F	C	S
POZZOLANIC ACTIVITY INDEX: [B]				
With lime, at 7 days min. psi (kPa)	800 (5500)	800 (5500)	800 (5500)	800 (5500)
Water requirement, max.% control	115	105	105	105
SOUNDNESS: [C]				
Autoclave expansion or contraction, max. %	0.8	0.8	0.8	0.8
UNIFORMITY REQUIREMENTS:				
The specific gravity and fineness of individual samples shall not vary from the average established by the ten preceding tests, or by all preceding tests if the number is less than ten, by more than:				
Specific gravity, max. variation from average, %	5	5	5	5
Percent retained on No.325 (45-um), max. variation, % points from avg.	5	5	5	5

[B] Neither the pozzolanic activity indix with portland cement nor the pozzolanic activity index with lime is to be considered a measure of the compressive strength of concrete containing the mineral admixture. The pozzolanic activity index with portland cement is determined by an accelarated test, and is intended to evaluate the contribution to be expected from the mineral admixture to the longer strength development of concrete. The weight of mineral admixture specified for the test to determine the pozzolanic activity index with portland cement is not considered to be the proportion recommended for the concrete to be used in the work. The optimum amount of mineral admixture for any specific project is determined by the required properties of the concrete and other constituents of the concrete and should be established by testing. Pozzolanic activity index with portland cement is a measure of reactivity with a given cement and may vary as to the source of both the fly ash and the cement.

[C] If the mineral admixture will constitute more than 20% of the cementitious material in the project mix design, the test specimens for autoclave expansion shall contain that anticipated %. Excessive autoclave expansion is highly significant in cases where water to mineral admixture and cement ratios are low, for example, in block or shotcrete mixes.

Table 2A. SUPPLEMENTARY OPTIONAL PHYSICAL REQUIREMENTS

Note - These optional requirements apply only when specifically requested.

	Mineral Admixture Class			
	N	F	C	S
Multiple factor, calculated as the product of loss on ignition and fineness, amount retained when wet-sieved on No.325 (45-um) sieve, max. % [A]	....	255	....	....
Increase of drying shrinkage of mortar bars at 28 days, max. % [B]	0.03	0.03	0.03	0.03
UNIFORMITY REQUIREMENTS: In addition, when air-entraining concrete is specified, the quantity of air-entraining agent required to produce an air content of 18.0 vol. % of mortar shall not vary from the average established by the ten preceding tests or by all preceding tests if less than ten, by more than, %	20	20	20	20
REACTIVITY WITH CEMENT ALKALIES: [C]				
Reduction of mortar expansion at 14 days, min. %	75	....	....	....
Mortar expansion at 14 days, max.%	0.020	0.020	0.020	0.020

[A] Applicable only for Class F mineral admixtures since the loss on ignition limitations predominate for Class C.

[B] Determination of compliance or noncompliance with the requirements relating to increase in drying shrinkage will be made only at the request of the purchaser.

[C] The indicated tests for reactivity with cement alkalies are optional and alternative requirements to be applied only at the purchaser's request. They need not be requested unless the fly ash or pozzolan is to be used with aggregate that is regarded as deletiously reactive with alkalies in cement. The test for reduction of mortar expansion may be made using any high-alkali cement in accordance with Method C 311, Section 35.1 if the portland cement to be used in the work is

[C] not known, or is not available at the time the mineral admixture is tested. The test for mortar expansion is preferred over the test for reduction of mortar expansion if the portland cement to be used in the work is known and available. The test for mortar expansion should be performed with each of the cements to be used in the work.

7. METHODS OF SAMPLING AND TESTING

7.1 Sample and test the mineral admixture in accordance with the requirements of Method C 311.

7.2 Use cement of the type proposed for use in the work and, if available, from the mill proposed as the source of the cement, in all tests requiring the use of hydraulic cement.

8. STORAGE AND INSPECTION

8.1 The mineral admixture shall be stored in such a manner as to permit easy access for proper inspection and indentification of each shipment. Every facility shall be provided the purchaser for careful sampling and inspection, either at the source or at the site of the work as may be specified by the purchaser.

9. REJECTION

9.1 The mineral admixture may be rejected if it fails to meet any of the requirements of this specification.

9.2 Packages varying more than 5% from the stated weight may be rejected. If the average weight of the packages in any shipment, as shown by weighing 50 packages taken at random, is less than that specified, the entire shipment may be rejected.

9.3 Mineral admixture in storage prior to shipment for a period longer than 6 months after testing may be retested and may be rejected if it fails to meet the fineness requirements.

10. PACKAGING AND MARKING

10.1 When the mineral admixture is delivered in packages, the class, name, and brand of the producer, and the weight of the material contained therein shall be plainly marked on each package. Similar information shall be provided in the shipping invoices accompanying the shipment of packaged or bulk mineral admixture.

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights and the risk of infringement of such rights, is entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St. Philadelphia, PA, 19103, which will schedule a further hearing regarding your comments. Failing satisfaction there, you may appeal to the ASTM Board of Directors.