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POZZOLAN--WHAT IS IT
WHERE IS IT FOUND IN ARIZONA?

By Frank E. Williams

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(For oral presentation at the annual meeting, Arizona Section, American Institute of Mining Engineers, December 5, 1966, Tucson, Arizona)

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by

Frank E. Williams[1]

INTRODUCTION

An investigation of potential pozzolan resources in Arizona was begun in mid-1963 as part of a national project by the Bureau of Mines to locate and evaluate sources of the material. Information contained herein was obtained during this investigation.

TECHNOLOGY AND DEVELOPMENT OF POZZOLAN

Pozzolan Defined

Pozzolan is a powdery form of essentially amorphous silica and alumina that, when partially substituted for cement, may improve the quality of concrete. More formally, pozzolan is defined as a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious 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.[2]

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2/ ASTM Designation: C 219.

Most materials are too coarse in their natural state and must be ground to specified fineness (88 percent passing No. 325 sieve). One type of artifical pozzolan, called fly ash, usually requires no reduction in size, but the effectiveness of even this product is often improved by finer grinding.

History of Pozzolan

In ancient Rome it was discovered that certain finely divided volcanic materials, when added to lime, produced cements having hydraulic properties. These cements were used in the construction of aqueducts, arch bridges, and public buildings, many of which have resisted deterioration to the present time. One such material was a consolidated volcanic ash or tuff found near Pozzuoli, Italy. Material from this deposit became known as pozzuolana, a general term later applied to similar material found in Spain and France. Subsequently the term was used throughout Europe to designate any material possessing pozzuolana-like properties, regardless of geologic origin.

The use of pozzolan in the United States began as early as 1910. However, the only major use to date has been in the construction of a few monolithic concrete structures, such as large dams. Some of the better known dams in which pozzolans were used include:

Hungry Horse Dam, Montana
Elephant Butte Dam, New Mexico
Friant Dam, California
Davis Dam, Arizona-Nevada
Falcon Dam, Texas-Mexico
Glen Canyon Dam, Arizona

The use of pozzolan in other concrete structures and products has been relatively minor. A general lack of knowledge concerning its many potential applications probably has prevented wider acceptance of the material.

Advantages of Using Pozzolan With Portland Cement

Advantages gained by substituting pozzolan for a portion of the cement in concrete are many. Outlined below are the more important advantages along with a brief remark about each.

1. Ordinarily, pozzolan costs much less than Portland cement. When large quantities of cement are required, substantial savings may be realized by substituting pozzolan for a portion of the cement.

2. The plasticity of a concrete mix usually is improved when pozzolan is substituted for part of the Portland cement. This feature saves construction costs by reducing finishing time.

3. Segregation of aggregate and bleeding of water from concrete mixes is reduced. This tends to produce a more uniform concrete instead of one where the fines are near the top and the coarse materials are near the bottom of each pour.

4. Permeability of the concrete is greatly reduced. Canal linings thus are less subject to deterioration from leakage, and dams are more watertight. As the volume of voids in the concrete is less, water filling is reduced, and destruction by freezing usually is not as great.

5. Resistance to attack by sulfate water is increased because pore volume is reduced. Sewer systems with pozzolan concrete pipe do not deteriorate as rapidly as those with standard concrete pipe.

6. Tensile strengths are usually improved and compression strengths are often better than in concretes made with straight cement. Flexing action usually causes less tension cracking in beams made with pozzolan cement.

7. Some pozzolans greatly retard the delayed reaction of certain aggregates with the cement alkalies released as the concrete ages. Such reactions, if not counteracted, usually cause surface spalling and cracking of the concrete.

8. Heat of hydration is released at a slower rate and thus can be more readily controlled during the concrete curing process.[3]

3/ Process of allowing the concrete to harden and assume its maximum strength. This process usually takes several hours or even days.

Expansion, and subsequent cracking, in monolithic pours is reduced.

As with most commodities used in our society, advantages are often accompanied by disadvantages. A potential consumer should weigh both before deciding whether or not a pozzolan should be used.

Disadvantages of Using Pozzolan With Portland Cement

There are certain disadvantages of using pozzolan with cement. Unsatisfactory results invariably are obtained when an inferior pozzolan is used or when excessive replacement of cement by pozzolan is attempted. Some of the disadvantages are critical when pozzolan is used in certain applications. The use of pozzolan in all concrete products is inadvisable. It should be used when some advantage can be gained and when the usefulness of the concrete product can be improved.

Many of the bad features of pozzolan can be overcome by technical means. However, in any attempt to reduce or eliminate a particular disadvantage, operating costs should be considered.

The rate of strength development in concrete is retarded when pozzolan is substituted for a portion of the cement, and the use of pozzolan should be questioned whenever fast strength and short curing periods are desired. There are, however, patented accelerators on the market that will reduce curing times significant amounts and experimentation with such products may possibly overcome this objectionable feature of pozzolans. Nevertheless, most products made with cement partially replaced by pozzolan ultimately develop compressive strengths equal to or even greater than those of normal concretes. For example, an 8- by 8- by 16-inch concrete block made with Portland-pozzolan cement (10-15 percent pozzolan, 90-85 percent Portland cement) and aggregate requires about 90 days curing time to reach the same compressive strength that a standard block reaches in about 28 days. This delay in curing time creates a storage (inventory) problem for manufacturers of concrete products. This time lag can be reduced if the concrete products are moist cured in an autoclave. However, an autoclave large enough to hold several items at one time usually represents too large a capital investment for most concrete product manufacturers.

The elasticity of concrete as well as the flexural strengths of concrete columns also may be lessened by the use of pozzolan. Though both reductions are slight, they must be considered.

The inherent shrinkage of concrete as it dries is largely governed by the water requirements of the concrete mix. Such requirements usually are increased by pozzolan admixtures. However, certain pozzolans--notably diatomaceous earth--require more water than others and thus may produce excessive drying shrinkage which could result in structural failure of the concrete.[4/]

4/ Minute diatom skeletons absorb water which temporarily withholds the water from reaction in the chemical process of hardening concrete.

The resistance of concrete to freezing also may be adversely affected by certain pozzolan admixtures. For instance, if diatomaceous earth is used, the diatoms absorb a portion of the batching water which is not immediately relinquished for the chemical reaction. In freezing weather this water expands, causing the surface of the hardened concrete to spall and deteriorate. Longer and more elaborate curing tends to improve the generally poorer freezing resistance of some pozzolan concretes.

Although pozzolans usually prevent delayed alkali-aggregate reaction, some otherwise suitable materials have been found to add to the deterioration caused by this reaction between aggregates and cement alkalies released during the aging process. The only way to detect such potential deterioration is by lengthy tests of an admixture of each pozzolan in concrete prepared from high-alkali cement and highly reactive aggregate.

General acceptance of pozzolans by consumers has been hindered because there is insufficient data to impress potential users as to significant applications of pozzolans. Experience is slowly gained. Data become lost in files. Potential consumers become impatient. Eagerness of pozzolan-use advocates is thwarted, and consumers are reluctant to accept pozzolan for commercial applications.

Use of Pozzolan in Oilfield Cements

Cements used in oilfields for cementing casing in place must have special and unique qualities that Portland cements do not possess: (1) the slurry weight of oilwell cements must be controlled within certain limits, (2) the cement should be able to set to either high or low strength as desired, (3) ample fluid pumping time must be available, (4) the hardened mass must not be brittle, and (5) the solid cement must resist corrosion by oilfield brines.

Set forth below, are five main undesirable features of Portland cement that virtually eliminate its use for cementing casing in oil-wells (compare these features with the requirements in the above paragraph). Neat cement mixes have higher densities than desired, and, in deep wells, part of the slurry may actually penetrate and seal the producing formation. Mixes made with Portland cement and water have a fixed strength upon hardening. Portland cement begins to harden shortly after water is added and may set before it is in place. Hardened Portland cement is brittle and tends to shatter when perforated with holes needed for oil flow. Finally, Portland cement is susceptible to corrosive action by brine waters and eventually will disintegrate.

Oilwell cementing companies manufacture "oilfield cements," under various trade names, that are essentially intimate 50-50 mixtures of Portland cement and finely ground pozzolan. The pozzolan used may be of any type; however, some types are preferred over others as determined by research.

These oilfield cements have the following desirable features that have brought about their general acceptance as oilwell cementing materials:

1. Low heat generation with subsequent low volume change.
2. Improved tensile strength of hardened cement.
3. Greater resistance to sulfate brines.
4. Reduced leaching rate of soluble compounds.
5. Better pumpability with accompanying lower pump pressures.
6. Lower unit weight.
7. Lower costs.

Physical-Chemical Properties of Pozzolan

The process by which pozzolanic materials change the properties of concrete is not fully understood. However, it is evident that any such change will be governed by both the physical and chemical characteristics of the pozzolan. These latter characteristics, of course, depend largely on the geologic origin, mineral composition, and ultimate processing of the material.

Physical Properties

The physical properties of pozzolan that are most effective in bringing about changes in concrete include specific gravity, particle shape, particle size, and moisture absorbing capacity.

The specific gravity of most pozzolan is 10 to 25 percent lower than that of Portland cement (2.3 to 2.8 compared to 3.1). Pozzolan thus occupies a greater volume than an equal weight of Portland cement, and its partial substitution for cement increases the volume of concrete.

Irregular, angular, porous, or excessively fine particles generally increase the water requirements for a concrete mix of fixed consistency. Excessive water requirements, of course, cause greater drying shrinkage, lower ultimate strength, and decreased resistance to freezing. However, the non-porous spherical particles of fly ash generally require less water than other pozzolans; and admixtures of such material may even reduce the water requirements of the concrete.

Chemical Properties

The complex chemical reactions of pozzolan in concrete are the least understood. Suffice it to say is that a reaction with cement alkalies (largely lime) does take place and that the properties of the finished concrete depend on the rate and extent of such reaction. However, it is known that the cement alkalies released during hydration combine with the pozzolan to form stable complex silicates having cementitious properties. This reaction proceeds slowly, and consequently maximum strength development is not reached as soon as in ordinary concrete. Inasmuch as the cement alkalies combine with the pozzolan, they are no longer available for delayed, possibly deleterious, reaction with the concrete aggregate.

Physical-Chemical Requirements for Pozzolan

Various physical and chemical requirements for pozzolans have been established by the principal users of the material. Such requirements are based on individual needs, and all vary somewhat in detail. Modifications of the general requirements often are specified for particular projects. For example, a canal lining involving intermittent wetting would require different concrete specifications and different qualities of pozzolan than a monolithic dam involving constant saturation.

The two largest users of pozzolan--Bureau of Reclamation and Corps of Engineers--have established their own particular requirements. However, most smaller consumers usually adopt the specifications established by the American Society for Testing and Materials. Tables 1 and 2 show the ASTM requirements.

TABLE 1. - Chemical requirements for raw or calcined natural pozzolans for use as admixtures in Portland cement concrete*

Silicon dioxide (SiO_2) plus aluminum oxide (Al_2O_3) plus iron oxide (Fe_2O_3), minimum, percent	70.0
Magnesium oxide (MgO), maximum, percent	5.0
Sulfur trioxide (SO_3), maximum, percent	3.0
Loss on ignition, maximum, percent	10.0
Moisture content, maximum, percent	3.0

* ASTM Designation: C402-63T

TABLE 2. - Physical requirements for raw or calcined natural pozzolans for use as admixtures in Portland cement concrete*

Fineness:	
Mean particle diameter, microns, maximum	9.00
Amount retained when wet-sieved on No. 325 (44-micron) sieve, maximum, percent	12.0
Pozzolanic activity index:	
Compressive strength with Portland cement, at 28 days, minimum percentage of control	75
Compressive strength with lime, at 7 days, minimum, psi	600
Water requirement, maximum, percentage of control:	115
Change of drying shrinkage of mortar bars at 28 days, maximum, percent:	0.03
Soundness:	
Autoclave expansion of contraction, maximum, percent:	0.50
Amount of air-entraining admixture in concrete; ratio to control, maximum:	2.0
Uniformity requirements:	
The specific gravity of individual samples shall not vary from the average established by the ten preceding samples, or by all preceding samples if the number is less than ten, by more than, percent:	3

TABLE 2. - Continued

In addition, when air entrainment is specified for the concrete, the quantity of air-entraining admixture required to produce an air content of 18.0 percent by volume 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, percent	20
Reactivity with cement alkalies:	
Reduction of mortar expansion at 14 days, minimum, percent	75
Mortar expansion at 14 days, maximum, percent	0.020

* ASTM Designation: C402-63T

Source Rock Minerals and Activity Types

Raw materials that naturally are pozzolanic or those that become pozzolanic after heat treatment are simply called natural pozzolan. Other materials, usually by-products, are called artificial pozzolan.

Pozzolan is normally classified according to mineralogic composition, especially those minerals which cause chemical changes to take place. These minerals are referred to as "active minerals" and are primarily silica, alumina, or iron oxide.

In natural pozzolans the ability to react chemically is due to at least one of five materials: (1) volcanic glass, (2) opal, (3) clay minerals, (4) zeolites, and (5) hydrous aluminum oxides. In artificial pozzolan, glass produced by fusion constitutes the substance for which chemical reaction is credited. The classification of natural pozzolan generally accepted, in descending order of activity, is in the following table (Mielenz, et al, 1951). The clay minerals, Activity Type 3, are further subdivided according to their degree of activity. However, clays normally are not pozzolanic unless they have been calcined.

Activity Type	Active Ingredient
1	Volcanic glass
2	Opal
3a	Kaolinite-type clays
3b	Montmorillonite-type clays
3c	Illite-type clays
3d	Mixed clays with altered vermiculite
3e	Palygorskite
4	Zeolites
5	Hydrous aluminum oxides
6	Nonpozzolans

Active ingredients may not be readily distinguished by means of petrographic analyses and a petrographic classification might not adequately indicate the degree to which the material is pozzolanic. As an example, tuffs and volcanics ashes often are pozzolanic because of rhyolite glass, but many of these tuffs or volcanic ashes contain other minerals contributing different chemical properties. These tuffs or ashes also owe their pozzolanic properties to clays, zeolites, or opal, all minerals which are not glass. In order to compare petrographic descriptions with intensity of pozzolan activity the following designation is given (Mielenz, et al, 1951):

Activity Type	Petrographic Description
1	Rhyolite pumicites and tuffs Dacite pumicites and tuffs
1, 3a* 1,3b*	Altered pumicites and tuffs
2	Diatomite and diatomaceous earth Opaline chert
2,3b*	Opaline shales
3a	Kaolin clays
3b	Bentonitic clays and shales Fuller's earth
3c	Illite clays and shales
3d	Glacial clays and silts
3e	Attapulgus clay
4	Zeolitic tuffs and ashes
5	Bauxite

*This is a mixed activity type owing to different alteration products which depend on weathering environment.

Pozzolanic Materials in Activity Type 1

Rhyolite tuffs and pumicites and a few dacite tuffs and pumicites are included in Activity Type 1. Although to date andesitic tuffs or ashes have not been acceptable, it may be discovered by additional research that these, too, might often be suitable as pozzolans.

Materials that are formed similarly to those above, but are unsuitable as pozzolan, include andesite, basalt, and basaltic tuffs or ashes. Obsidian, perlite, and other glass minerals are often pozzolanic; however, these materials usually are not used as pozzolan due to very high grinding costs.

Pozzolan in this activity type is active fundamentally because of its volcanic glass content. There are, however, other reactive minerals, such as clays, opal, or zeolites, present in most tuffs and volcanic ash deposits. Also, there are non-reactive minerals present in many tuffs or volcanic ashes. However, the latter merely act as filler materials and do not combine chemically in any cement reaction.

Through testing data, it has generally been demonstrated that potential pozzolan whose glass content is less than 60 percent cannot pass strength requirements for the finished concrete. Also, unless other reactive minerals are present, a minimum of 90 percent of the material must be glass in order for the material to pass a prescribed test for alkali-aggregate reaction. It should be understood that all materials containing the above proportions of volcanic glass may not necessarily pass these particular test requirements. This is usually due to the particle size of the reactive ingredients; if the glass is too coarse, it will not contribute to pozzonlanic reactivity. In this case, the pozzolanic reactivity normally can be improved by grinding the material to sufficient fineness.

Pozzolanic Materials in Activity Type 2

Materials in Activity Type 2 are more reactive chemically than those in Type 1 but other properties tend to make these pozzolan materials less acceptable. Diatomaceous earth and opaline chert constitute the minerals in this classification. Both materials owe their pozzolanic activity to the presence of opal; but because the opal occurs so differently in each of these rock types, the pozzolanic activity of each is different.

The size, shape, and porosity of the opal particles in diatomaceous earth makes this material highly reactive, but coincidentally increases the water requirement. As a consequence, diatomaceous earth should be used cautiously. While the chemical activity enhances concrete products, the increased water requirement produces an undesirable effect.

Opaline chert, while possessing desirable pozzolanic compounds, does not have the high porosity and subsequent high water requirements of diatomaceous earth. It is one of the most effective pozzolans available for combating delayed alkali-aggregate reaction; however, the material normally does not occur in quantities that are large enough to supply demands.

Pozzolanic Materials in Activity Type 3

All pozzolan in Activity Type 3 are clays and require calcination at temperatures exceeding 1,000° F. in order to produce the desired effect. This induced pozzolanic activity is brought about by thermal disintegration of the crystalline structure. Amorphous silicates thus formed are pozzolanic when ground to the specified fineness.

Pozzolanic Materials in Activity Type 4

Silica-rich zeolites present in certain tuffs allow them to be classed as pozzolan; however, since zeolites are relatively uncommon, they are not considered as prime sources for pozzolan.

Pozzolanic Materials in Activity Type 5

Although waste materials remaining from the extraction of aluminum from bauxite are considered as potential sources of pozzolan there are no data publically available on pozzolan in this activity type.

Pozzolanic Materials in Activity Type 6

Strictly speaking, those classified in Activity Type 6 are not pozzolanic. The minerals in this group are non-reactive and consist of quartz, feldspar, carbonates, micas, amphiboles, and pyroxenes. These minerals act as filling material in pozzolan concrete products, but they do not enter into chemical union with cement compounds.

GENERAL LOCATION OF ARIZONA POZZOLAN

Diatomaceous Earth

Diatomaceous earth is a general term applied to many sedimentary deposits. It commonly is composed of fragments of an infinite number of minute diatom skeletons, from which its name is derived. Contamination by clay or other materials alters physical properties, but pure diatomaceous earth is chalk white and has a fine sandy texture. The pure material is light, weighing from 20 to 40 pounds per cubic foot in lump form and 5 to 16 pounds per cubic foot in dry powder form. Diatomaceous earth is also known as kieselguhr or diatomite, and preferably not as tripoli, tripolite, infusorial earth, and fossil flour.

In Arizona, diatomaceous earth deposits generally occur in drainage areas of the San Pedro, Gila, and Verde Rivers. These deposits crop out in many places but in only a few areas are they of size and purity that might constitute a commercial deposit. Any deposit too high in calcium content usually is not acceptable commercially.

Diatomaceous earth occurs in Pleistocene or Pliocene sediments as bedded deposits normally covered by Quaternary and Recent detritus (Trischka, 1929).

Pumice and Pumicite

Pumice is a term applied to highly cellular glassy lava. The term pumicite is applied to volcanic glass, in sand-sized particles, that has been classified by means of wind or water transportation. The term rhyolite sand often is used for this concentrated pumicite. If the particles are slightly or wholly cemented the rock is known as a tuff. The tuff becomes ignimbrite if the material was subjected to volcanic heat. Another term for tuff, usually restricted to German literature, is trass.

Although pumice (pumicite) occurs in several areas in Arizona, the deposits most well known for their pozzolan properties are located in the volcanic fields near Flagstaff. It is from this area that 210,000 tons of good quality pozzolan was supplied to the Glen Canyon Dam.

One deposit, on Sugarloaf Mountain, might be considered as a good pozzolan source for several years.

Perlite

Perlite refers to naturally occurring volcanic glass that often expands quickly when heated to form a highly porous media. Usually the material is finely ground and passed through a rotary kiln where each particle pops into a larger lightweight mass. It is frequently called "popcorn perlite" for this reason.

Perlite occurs in scattered areas of Arizona but only in one place near Superior is it concentrated enough so as to constitute economic deposits under present conditions. These deposits, near Picketpost Mountain, are presently mined and processed into lightweight aggregate for roofing material. It is not mined for use as a pozzolan.

A second large perlite deposit occurs near Aguila, but no mining is presently taking place.

Tuff and Volcanic Ash

There are many areas in the State that are covered by outcrops of Tertiary volcanics including tuff and volcanic ash deposits. There are, however, only three areas of twelve evaluated that contain tuff and volcanic ash occurrences that could be considered as pozzolan sources as based on chemical assays. These are located near Nogales, Wickenburg, and Apache Junction.

In all three areas, tuff occurs in horizontal beds 20 to 40 feet thick. Two deposits were mined in the past for use as lightweight aggregate.

Miscellaneous Materials

Two other possible sources of pozzolan occur as bentonic clays along U. S. Highway 89 near Cedar Ridge and as felsite on Union Pass near Davis Dam.

Fly Ash

About 100 tons per week of fly ash is produced at the Joseph City power plant of the Arizona Public Service Co. This material probably will make excellent pozzolan as based on chemical and physical tests.

CONCLUSIONS

Among Arizona's natural resources are large deposits of highly siliceous materials, some of which qualify as pozzolans. These pozzolans generally occur throughout the State, but are concentrated in larger deposits in the vicinity of Flagstaff. One such deposit, the Sugarloaf, has been partially mined for use as pozzolan. Reserves here are unknown, but test pits have revealed sufficient exposures to conclude that several million tons of material are available.

A second source of pozzolan that probably could supply material for many years is Arizona Public Service Co.'s Cholla power plant at Joseph City. The fly ash waste product at this plant is good quality pozzolan which needs little or no treatment.

Any other pozzolan deposit in Arizona would probably meet strong competition from the above named sources.

Unless a local market is available for pozzolan, these resource occurrences in Arizona probably will not be exploited in the near future. So far, the only market has been one contract-type construction job, the Glen Canyon Dam. No other commercial application of pozzolan of note has been made in Arizona.

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Clarence Morgan FastLite

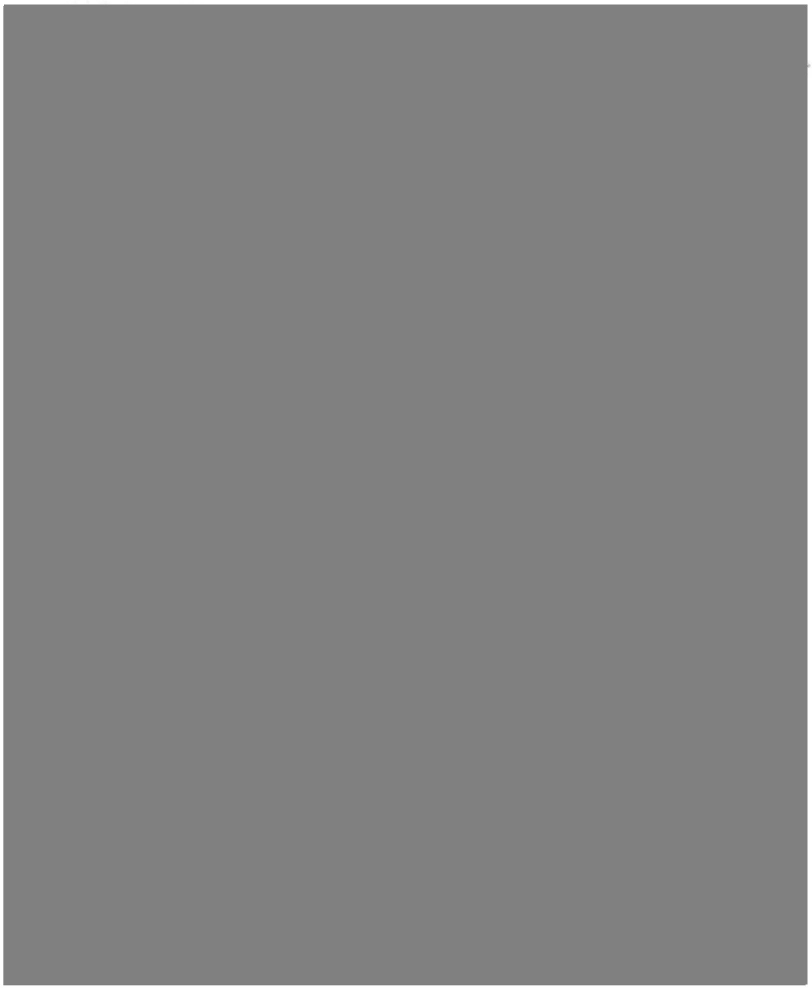
Josyna Ledwidge - Quintoo

Torre Tanita - Glendale AZ

Pumice

Pozzolan

Arizona firm mines 200,000 tons of pozzolan for Glen Canyon dam



See 'Rock Products' 3/1965 - p 97

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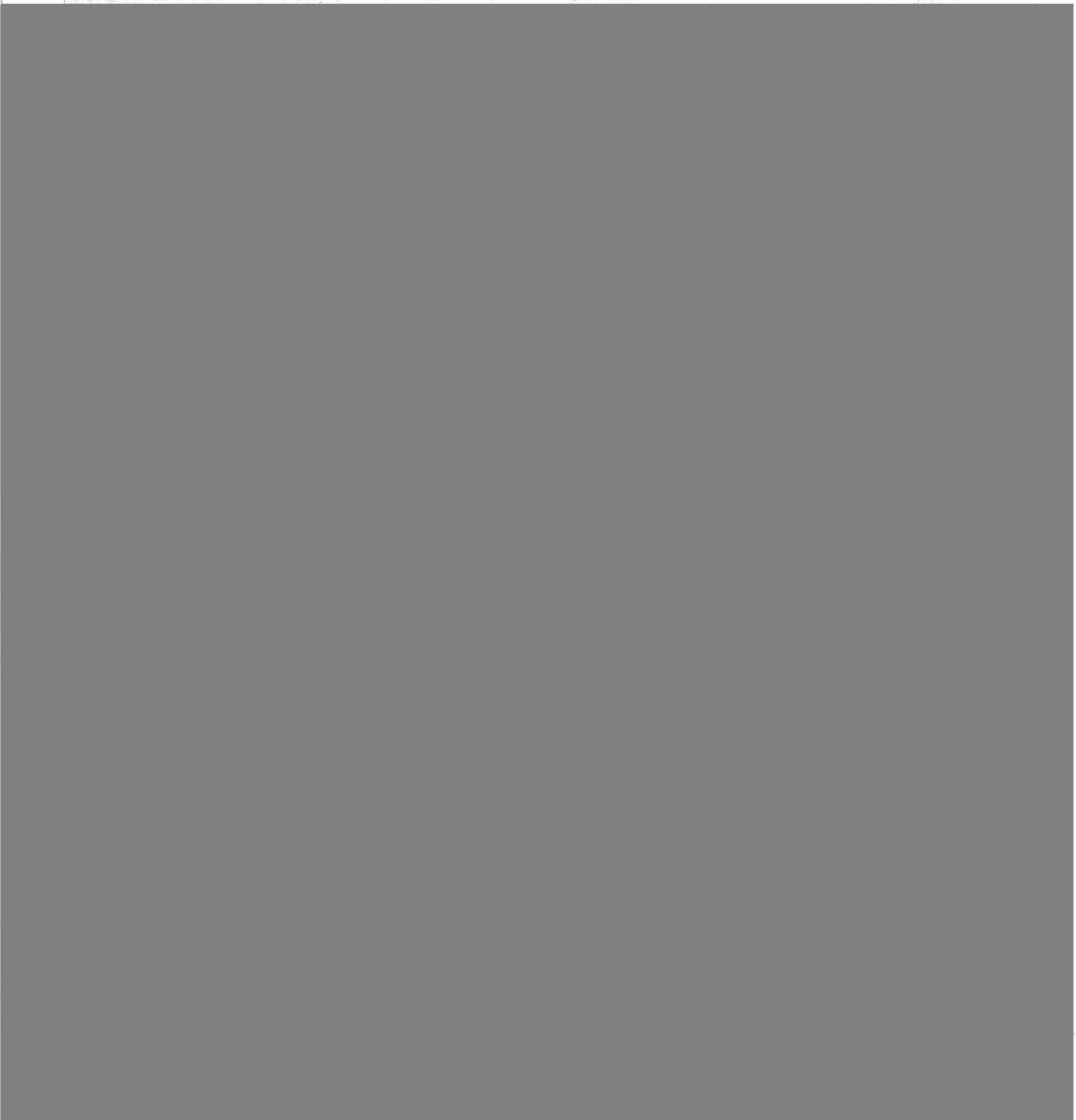

DEPARTMENT OF MINERAL RESOURCES

STATE OF ARIZONA

FIELD ENGINEERS REPORT

Mine: BONNER POZZOLAN DEPOSITS

Date: May 26, 1959

District: Flagstaff, Coconino County

Engineer: Travis P. Lane

Subject: Visit to deposit and plant.

[illegible]

The Pozzolan deposits are located approximately 25 miles north from Flagstaff on U. S. Highway 89. The deposits are numerous over an area of several square miles. The light buff-colored pozzolan is covered by about 6 feet of overburden.

Owner: B. B. Bonner, of
Bonner Construction Co.
14 E. Santa Fe Ave.
Flagstaff, Arizona

Operator: J. B. Shotwell (sole proprieter)
Box 1422
Flagstaff, Arizona

Supt: Tom C. Burney

Mr. Shotwell is building a plant to process the Bonner pozzolan material for delivery to the U. S. Bureau of Reclamation at the Glen-Canyon dam site. The material is to be ground to 95% - 325 M, and will be mixed at the dam site with cement in the proportions of 1/3 pozzolan and 2/3 cement. Mr. Shotwell's contract calls for delivery of 250,000 tons of ground pozzolan with delivery to begin at the same time that the Clarkdale cement plant begins to deliver cement - in August of this year.

Bonner will contract the mining and delivery of the material to the plant. The plant is located in the area of the deposits and is 1/4 mile east of the highway. It consists essentially of 3 stages of crusher-grinding units, a dryer, screens, and classification system. Expected capacity is 30 TPH. The plant and pit operation will employ about 10 men.

DEPARTMENT OF MINERAL RESOURCES

STATE OF ARIZONA

FIELD ENGINEERS REPORT

Mine Bonner Pozzolan Date September 30, 1960

District Flagstaff, Coconino Co. Engineer Travis P. Lane

Subject: Visit, Sept. 15, 1960

This property was first described in a Department of Mineral Resources report dated May 26, 1959 and later memos.

Recently the project was taken over by the Standard Gilsonite Company, 343 So. State Street, Salt Lake City 11, Utah, and is now operated as the Pozzolan Division of that company. Darrell W. Sumner is Supt., address: Box 1422, Flagstaff, Arizona.

Following the plant start-up about a year ago a considerable number of "bugs" was encountered and equipment changes and circuit revisions were necessary. The original Williams roller mills have been replaced by two 8' x 36" Hardinge mills, and two more of these mills are now being installed. The Bureau of Reclamation specifications are quite exacting with consequent need for extremely selective mining and close control of size of product. The grind requirement is still not completely satisfactory. The present size requirement is that all must be finer than 325 M, actually 9000 Blaine. The plant only recently began producing and shipping ground pozzolan at a sustained volume rate. The present output is averaging about 200 TPD. This will soon be stepped up to 400 TPD. 17 men are employed including Mr. Sumner. Pozzolan will be mixed with cement in the proportion: 1 part pozzolan to 2 parts cement. The use of pozzolan with cement gives the concrete mix extra strength for the following more important reasons:

1) It combines with free lime hydrated from the cement to form a cementeous property of its own.

2) It reduces the heat of hydration and while the set is slower the final product is harder.

3) The action of acid and alkali on the concrete is inhibited.

4) The cement is more impervious (dense).

The material flow in the plant is essentially as follows: The incoming material is dumped on a grizzly w/8" openings from which the undersize passes over a screen (where the plus 2" size is discarded) to a surge pile. Next it goes to rolls set at 1/2" opening, then to a dryer (the natural moisture content is from 6 to 15%). From the dryer the material goes to two 8' x 36" Hardinge ball mills in closed circuit with air separators and finally to the shipping bins (silos).

Bonner Pozzo...

Pozzolana At Damsite

R. 4/7/60

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BONNER POZZOLAN DEPOSITS

COCONINO COUNTY
FLAGSTAFF

MEMO

Visited the Bonner Pozzolan plant on Aug. 19. Construction is essentially complete. The project is waiting upon settlement of the Page strike when shipment will begin to the Glen Canyon dam site (at about the same time that cement shipments are made from the new Clarkdale cement plant).

September 4, 1959 TRAVIS P. LANE

Visited the Bonner Pozzolan deposit and the processing plant which is expected to go into production around the first of October (shortly after the strike is settled at the Glen Canyon dam project). The sacks in which the ground product will be shipped are marked "Raw Material by B. B. Bonner; transported by Shupe Bros.; manufactured by J. B. Shotwell; for use at Glen Canyon Dam." The company address is Tuba Star Route. Mr. Darrel W. Sumner is Supt. Tom Burney who supervised the plant construction is working on other projects for "Concrete Aggregates" which is the Seattle firm controlled by J. B. Shotwell. I gathered some samples of raw material for Art Flagg for the Department of Mineral Resources Museum.

TRAVIS P. LANE - Weekly Report - 9-19-59

C. A. Richardson of Denver Equipt. Co. said that the Bonner Pozzolana plant has installed the ball mill to grind the pumice to 95% minus 325 mesh.

FRANK P. KNIGHT - Memo - 5-24-60

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ference :

ing World

August 1961 p.49

Bonner Pozzol

Pozzolana At Damsite

[redacted]

Telephone (602) 974-6031

Joseph A. Ledwidge
Vice President

Quinn & Co., Inc.
Member
New York Stock Exchange, Inc.

11001 N. 99th Ave., Suite 120
Peoria, Arizona 85345

Chemical requirement	Class N	Class F	Bonner Deposit Class N	SugarLoaf Deposit Class N
Silicon dioxide (SiO_2), plus aluminum oxide (Al_2O_3), plus iron oxide (Fe_2O_3), min., percent.	75.0	75.0	94.46	87.90
Magnesium oxide (MgO), max., percent.	5.0	5.0	0.41	0.26
Sulfur trioxide (SO_3), max., percent.	4.0	4.0	Trace	0.00
Loss of ignition, max., percent.	8.0	8.0	4.00	1.39
Moisture content, max., percent.	3.0	3.0	0.46	0.07
Available alkalies, max., percent.	2.0	2.0	1.82	1.02

TABLE II. Physical requirements

Physical requirement	Class N	Class F	Bonner Deposit Class N	SugarLoaf Deposit Class N
Fineness, surface area, sq cm/cu cm, min.	12,000	6,500	1932	1804
Pozzolanic strength of cement-pozzolan mortar at 28 days, min., percent of control.	80	75	91	88
Compressive strength of lime-pozzolan mortar at 7 days, min., p.s.i.	900	900	909	824
Increase in drying shrinkage of mortar bars at 28 days, max., percent	0.04	----	0.012	0.004
Soundness, autoclave expansion, max., percent 1/.	0.50	0.50		
Water requirement, increase in flow (over control, at stipulated water content), min.2/.	0	0	103.8	99
Reactivity with cement alkalies, reduction of mortar expansion at 14 days min., percent.3/.	60	60	74	62
			July 1960	May 1963

1/ The specimen shall remain firm and hard and show no signs of distortion, cracking, checking, pitting, or disintegration when subjected to the autoclave expansion test.

2/ This requires that a mortar with a class N pozzolan and 112 percent of the water content of the control mortar, or a mortar with a class F pozzolan and 103 percent of the water content of the control shall have a flow equal to or greater than that of the control.

This requirement applies only when specified (see 6.2).

Fed Spec SS-P-570B

ADDRESS REPLY TO:
DISTRICT ENGINEER
SACRAMENTO DISTRICT
CORPS OF ENGINEERS, U.S. ARMY
P. O. BOX 1739
SACRAMENTO 8, CALIFORNIA

CORPS OF ENGINEERS, U. S. ARMY
OFFICE OF THE DISTRICT ENGINEER
SACRAMENTO DISTRICT
WRIGHT BLDG., 1209-8TH ST.
SACRAMENTO, CALIFORNIA

RECEIVED
OCT 1 1956
DEPT. MINERAL RESOURCES
PHOENIX, ARIZONA

REFER TO FILE NO. SPKGC 800.1

10 OCT 1956

Arizona Department of Mineral Resources
413 Home Builders Building
Phoenix, Arizona

Gentlemen:

Advance information has been received from the Office, Chief of Engineers, Washington, D. C. that, as a result of investigations at the Waterways Experiment Station, Vicksburg, Mississippi, pozzolanic materials may be used in certain Civil Works construction. In order to secure data which will be used during investigation, design, and construction stages of these Civil Works structures, a questionnaire data sheet and a tabulation of test requirements have been prepared and distributed to producers of pozzolanic materials. Copies of these forms are inclosed for your information.

Information on sources of supply and addresses of companies which produce pozzolanic materials in Arizona will be greatly appreciated.

FOR THE DISTRICT ENGINEER:

Sincerely yours,

for F. KOCHIS
Chief, Engineering Division

2 Incl
1. Data Sheet
2. Tables

PRODUCER OF POZZOLANS OR POZZOLANIC MATERIALS

Name of manufacturer: ____________________

Office location: ____________________

Telephone number: ____________________

Plant location: ____________________

Telephone number: ____________________

Location of source material and supply: ____________________

____

____

Pozzolanic product (brand name and short mineralogic description):

____

____

____

Geologic formation and age: ____________________

Method of processing (description): ____________________

____

____

____

Names of owners or company officials: ____________________

____

____

____

____

____

Plant capacity (tons/24 hour day): ____________________

____

Estimated cost per ton (F.O.B. plant): ____________________

Sacked __________ Bulk __________

Chemical composition of pozzolan product	Percent
Silicon dioxide (SiO_2) ______	______
Iron oxide (Fe_2O_3) ______	______
Aluminum oxide (Al_2O_3) ______	______
Magnesium oxide (MgO) ______	______
Calcium oxide (CaO) ______	______
Sulfur trioxide (SO_3) ______	______
Exchangeable alkalies as Na_2O ______	______
Loss on ignition ______	______
Moisture content ______	______
Carbon content ______	______

Physical properties of pozzolanic product

Fineness:

Material retained on a 325 mesh sieve, percent ________

Blaine fineness meter, square centimeters per gram ________

Compressive strength, percent of control 28 days ________

Drying shrinkage, percent ________

Water requirement, percent ________

Specific gravity ________

Weight per cubic foot ________

____

____

Reactivity

Reduction of expansive reaction at 14 days, percent ________

Other pertinent data: ________

____

____

Please send completed form to:

District Engineer
Sacramento District
Corps of Engineers
P.O. Box 1739
Sacramento 8, California

Attn: A. R. Mead

Tables Prescribing Requirements for Portland-Pozzolan Cement and Pozzolan as Covered by Federal Specification SS-C-208b

A. PORTLAND-POZZOLAN CEMENT:

Requirements:

1. Portland cement or Portland-cement clinker used in the portland-pozzolan cement shall conform to the requirements for chemical composition for type I, Federal Specification SS-C-192. Pozzolans used in portland-pozzolan cement shall conform to requirements specified in table III.

2. The percentage of pozzolan in the portland-pozzolan cement shall not be less than 15 percent nor more than 35 percent, by weight. The manufacturer shall state the source, amount, and composition of the pozzolan used in the finished portland-pozzolan cement. The amount of pozzolan in the finished cement shall not vary more than ±5.0 percentage points by weight from the amount stated by the manufacturer.

Detail Requirements. - The portland-pozzolan cement shall conform to the requirements for chemical properties prescribed in table I, and to physical properties prescribed in table II.

TABLE I. - Chemical Requirements

TEST	TYPE I	TYPE IA
	Percent	Percent
Sulfur trioxide (SO_3), maximum	2.5	2.5
Moisture content, maximum	3.0	3.5
Ignition loss, maximum	3.0	3.0

TABLE II. - Physical Requirements

TEST	TYPE I	TYPE IA
Fineness:		
Residue No. 325 sieve, maximum, percent........	12	12
Blaine fineness meter:		
Average value, minimum, sq. cm./g................	2900	2900
Minimum value, any one sample, sq. cm./g........	2700	2700
Soundness, autoclave expansion, maximum, percent....................................	0.5	0.5
Time of setting, Gillmore test:		
Initial, minimum, minutes........................	60	60
Final, maximum, hours............................	10	10
Compressive strength: (4.4.6) minimum:		
1 day in moist air, 6 days in water, lb./sq. in	1500	1250
1 day in moist air, 27 days in water, lb./sq. in....................................	3000	2500
(The strength at 28 days shall be greater than at 7 days.)		
Air entrainment: percent by volume................	0-12	15-21
Water requirement, maximum, ml....................	320	280
Drying shrinkage (4.4.11), maximum, percent........	0.12	0.11
Mortar expansion:		
At age of 14 days, maximum, percent..............	0.020	0.020
At age of 8 weeks, maximum, percent..............	0.060	0.060
False set, minimum, penetration mm................	10	10
(This requirement applies only when specifically requested in the invitation for bids.)		

Type I. - Portland-Pozzolan cement non-airentraining.

Type IA. - Portland-pozzolan cement airentraining.

b. Pozzolan. - Pozzolan which is blended with finished portland cement to produce portland-pozzolan cement shall meet the requirements prescribed in table III. The fineness requirements need not apply to pozzolan which is interground with portland-cement clinker to produce the portland-pozzolan cement. For evaluating the contribution to compressive strength, coarse pozzolans shall be ground only to the extent of having a residue on the No. 325 sieve of 12±2 percent. For materials such as diatomaceous earth with essentially no residue on a No. 325 sieve, the minimum residue need not apply.

TABLE III. - Physical requirements - Pozzolan

TEST	TYPE P[1]	TYPE F[2]
Fineness		
Residue No. 325 sieve, maximum, percent........	12.0	12.0
Blaine fineness meter, minimum, sq. cm./g.....	- -	3000
Contribution to compressive strength (4.5.3):		
Percent of control 28 days, minimum...........	75	85
(The compressive strength of the portland-pozzolan cubes at 90 days shall not be less than the strength at 28 days.)		

[1]Type P refers to natural materials such as clays, shales, diatomaceous earths, tuffs, volcanic ash and pumicite, either calcined or uncalcined. Many natural pozzolans are improved by calcining between 1,400°F. and 1,800°F.

[2]Type F refers to fly ash, an artificial pozzolan which is a fine ash collected from the flue gases at the stacks of power plants burning pulverized coal.

STATE OF CALIFORNIA
GOODWIN J. KNIGHT, Governor
DEPARTMENT OF NATURAL RESOURCES
DeWITT NELSON, Director

DIVISION OF MINES
Ferry Building, San Francisco 11
OLAF P. JENKINS, Chief

MINERAL INFORMATION SERVICE

Vol. 7 | October 1, 1954 | No. 10

MINERAL INFORMATION SERVICE is a monthly news release concerning the mineral resources and industry of CALIFORNIA, designed to inform the public of the discoveries, operations, markets, statistics, and new publications. It is distributed without cost upon request.

POZZOLANS IN CALIFORNIA

by

Frederick W. Drury, Jr.*

Origin

Cements have been used in construction for several thousand years, first in mortar for masonry construction and much later in concrete. Original cements were produced by calcination of gypsum, but during the Roman and Greek eras calcined limestone was employed with water and sand, gravel, crushed stone, tile, brick and certain volcanic materials. The builders noted that combinations of certain of these materials produced mortars which were not only stronger and more durable, but which would harden under water. These superior materials were principally volcanic ashes, found near Naples and the adjacent port of Pozzuoli, from which locality such materials drew their name of "pozzuolana," or "pozzolan" as they are known today. Roman territorial expansion carried the use of pozzolans into much of western Europe and England, though in the latter country, ground tile or brick was used instead of unavailable volcanic materials.

In time, other natural and artificial materials were used as pozzolans with considerable success. Outstanding examples of the Roman use of pozzolanic mortar and concrete are the Roman Pantheon, the Colosseum, and the Basilica of Constantine, all structures in a remarkable state of preservation after 2000 years of exposure to the elements.

Recently a sample of pozzolanic concrete taken from a submerged pier near Pozzuoli was submitted to the American Concrete Institute for testing. Preliminary study shows the sample to be in excellent condition despite centuries of exposure to aggressive sea water. However, freezing and thawing resistance has been found to be low, so perhaps some of the longevity of such structures built with pozzolan-lime cement can be attributed to the relatively mild Mediterranean climate.

After the decline of the Roman Empire and the advent of the Middle Ages, the art of concrete manufacture was lost, and consequently was of no significance until the discovery of portland cement by Aspdin a century ago.

Aspdin's discovery, complemented by the early investigations of Smeaton, Feret, Vicat and Le Chatelier encouraged development of the concrete industry as we know it today. Because portland cement was a homogeneous material with relatively constant composition and characteristically produced higher strengths in mortar and concrete, use of all other types of cement declined rapidly. In recent years, however, it has been recognized that some of the limitations of portland cement could be overcome by the admixture of a suitable pozzolan.

Contemporary use of pozzolan

Portland-pozzolan cements have been used extensively in Europe, particularly for marine and hydraulic structures. In many cases their use was dictated by economy, but in general, their primary purpose was to produce concretes less permeable to the passage of moisture and more resistant to the action of aggressive waters.

The first substantial quantity of portland-pozzolan cement used in the United States was in the Los Angeles Aqueduct (1910-1912). Savings of some $700,000 over the cost of non-pozzolanic portland cement resulted. Though certain handling problems occurred, the finished concrete was excellent in every respect. Recent inspections of this aqueduct have shown conclusively that an unusual degree of watertightness and freedom from leaching was obtained.

The employment of a pumice pozzolan in Friant Dam resulted in savings of some $301,000 in cost of portland cement. Similar savings were made in construction of Bonneville Dam and of numerous structures by the Los Angeles County Flood Control District.

In the early 1930's, the Santa Cruz Portland Cement Company began production of High Silica Ce-

*Chief Engineer, The Airox Company, 307 W. Eighth Street, Los Angeles 14, California

ment, composed of portland cement interground with a mixture of lime and calcined Monterey shale. Structures throughout California, including the piers of the Golden Gate Bridge and portions of the San Francisco - Oakland Bay Bridge attest to the quality of this pozzolanic cement.

In 1937, about 15,000 barrels of portland-pozzolan cement containing calcined Puente shale were employed in lining over 2000 feet of arch of the San Jacinto Tunnel.

More recently numerous projects of the Bureau of Reclamation have been completed with the aid of pozzolan; Hungry Horse Dam (fly-ash), Cachuma Dam (calcined oil-impregnated diatomite), Davis Dam (calcined Puente shale and calcined oil-impregnated diatomite), Falcon Dam (calcined scoria).

Of more interest to the California concrete industry, however, is the rapidly growing use of pozzolan in structural concrete as well as in mass concrete which, until recently, absorbed most of the pozzolan produced.

For example, calcined precipitated silica and calcined oil impregnated diatomite were used extensively in concrete pipe and structures of the East Bay Municipal Utility District for improving sulfate and acid resistance and for decreasing permeability.

Calcined oil-impregnated diatomite was used in Big Creek #4 Dam of the Southern California Edison Company and is currently being used in construction of the Morro Bay Steam Power Plant of Pacific Gas and Electric Company, the Union Oil Coking Plant near Guadalupe, California, and Santa Felicia Dam near Piru, California.

Pozzolanic Reaction

Calcium hydroxide (hydrated lime) is liberated during hydration of portland cement. The lime contributes nothing to the strength of concrete, and because it has low solubility may be removed by leaching action. Deterioration of the concrete usually results.

American Society for Testing Materials Standard C 219-53T defines a pozzolan as "a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious 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."

The primary reaction product is usually considered to be hydrous monocalcium silicate. However, most pozzolans contain substantial amounts of material other than silica, and more complex reactions involving alumina, iron, and the alkalies probably take place.

Generally speaking, the better pozzolans appear to be those of high fineness with a silica constituent of amorphous form. Thus finely ground quartz, though meeting the definition of a pozzolan, is extremely slow to react with lime whereas finely ground opal is exceptionally reactive. Because chemical composition does not aid particularly in determining pozzolanic activity, it becomes necessary to judge the efficiency of a pozzolan by indirect tests and past performance.

For these reasons, progress has been slow toward establishment of American Society for Testing Materials standards for pozzolans, although a tentative standard for fly-ash as a pozzolan has been promulgated. However, newly issued Federal Specification SS-C-208b for portland-pozzolan cement and American Society for Testing Materials Proposed Tentative Specification C 340-54T for portland-pozzolan cement do place certain requirements on pozzolans considered suitable for use in portland-pozzolan cements.

To date the most widely accepted specification for pozzolan per se is that advanced by the Bureau of Reclamation and incorporated in recent general specifications for Reclamation Projects. Copies of this specification and methods of testing pozzolans may be obtained from the Office of the Chief Engineer, Bureau of Reclamation, Denver Federal Center, Denver, Colorado.

In many cases specifications for pozzolan incorporate sections of the above mentioned specifications, or merely refer to "approved sources of pozzolan" based on performance records of the pozzolans concerned.

The most recent example of this form of specification is Specification No. 4 of the United Water Conservation District of Ventura County. Item 20 in this specification states: "raw materials. The raw material from which the siliceous material is produced shall be an opaline cherty shale, oil impregnated diatomaceous shale, chert of porcelaneous rock found in the Monterey formation or other Miocene strata of similar lithology....." Certain additional physical limitations are also placed on the processed pozzolan.

Until such time as detailed and suitable tests are developed for distinguishing between good and poor pozzolans, specifications will probably continue to be based on known performance records of commercially produced pozzolans. Inasmuch as pozzolans vary so widely in their effects on concrete, this practice would appear to be advisable.

Classification of Pozzolans

Pozzolans may be divided into two principal classes: (1) artificial pozzolans and (2) natural pozzolans.

Artificial pozzolans include fly-ash (precipitated residue from flue dust in the burning of powdered coal), silica fume, and calcined bauxite - all by-products of industrial processes. Few fly-ashes are suitable for use as pozzolan, the limiting factors being carbon content, fineness, and uniformity of composition. For certain technical and economic reasons, artificial pozzolans cannot be considered practical for use in California at the present time.

Natural pozzolans may be divided into two principal classes: (1) Those derived from volcanic rock in which the amorphous constituent is glass produced by fusion and (2) those derived from rocks or earth in which the silica constituent contains opal.

Constituting the first class are the volcanic ashes, pumice, obsidian, scoria, and tuffs.

Constituting the second class are the diatomites, cherts, shales and clays containing substantial quantities of opaline silica.

The pozzolanic properties of many of the materials of the second class, and a few of those of the first class, may be improved through calcination at some optimum temperature below fusion. Some materials not normally pozzolanic such as the clays, may be rendered pozzolanic by calcination.

Most natural pozzolans require fine grinding, although pumicite used in Friant Dam was so exceptionally fine in its natural state that no further grinding was necessary. Such deposits are rare, however.

Prospecting for Pozzolanic Materials

Few laboratories are equipped to properly test deposits which might be exploited to produce a quality pozzolan. However, the Bureau of Reclamation has studied potential sources of supply in California, and this information may be found in reference (3). Should doubt exist as to the potentialities of a deposit, samples of the source material may be sent to the Bureau of Reclamation laboratory in Denver for testing, provided survey of the deposit indicates it can be practically processed into pozzolan. Factors to be considered are the extent and uniformity of the deposit, the cost of mining, the cost of calcining, the cost of processing and the cost of shipment to potential consumers.

Most major portland cement manufacturers have thoroughly investigated sources of pozzolanic materials, although few such companies are processing pozzolan for inter-grinding or blending at the present time.

Use of Pozzolans with Portland Cement

Pozzolans may be interground or blended with portland cement to produce portland-pozzolan cement, or may be produced separately for use as an admixture. The latter method is gaining favor because a much higher degree of job control may then be obtained. This is particularly important when it is realized that pozzolans are used in varying proportions in accordance with job requirements. For example, the quantity of pozzolan used to improve sulfate resistance will differ from that used to control alkali-aggregate reaction, etc.

Proportioning Pozzolan in Concrete Mixes

Pozzolans may be used as additions to or as replacements of a portion of the portland cement in in concrete. When used as additions, pozzolans are employed in small amounts, sufficient only to affect the properties of fresh concrete. Present practice overwhelmingly favors the use of pozzolan as an integral ingredient in concrete, in which case it is looked upon as a part of the cementitious material as is portland cement. When compared with a normal cement concrete, the use of pozzolan in this manner reduces the amount of portland cement required.

Because of differences in specific gravities, substitution of pozzolan for part of the portland cement usually increases yield unless the mix design is altered, generally by reduction in sand content.

In general, optimum quantities of pozzolan depend upon (1) properties desired in fresh and hardened concrete (2) character and fineness of the pozzolan (3) composition of the portland cement (4) richness of the mix (5) grading of the aggregate. Because of the varied effects of different pozzolans in concrete, this optimum quantity must be determined by experiment and experience. Percentages of replacements, on a weight basis, may vary from 10 to 35 percent. Most producers of pozzolan in California can furnish information relative to optimum quantities of their pozzolan required in concrete for any specific purpose.

Effects of Pozzolan upon Fresh Concrete

When used as cement replacements, natural pozzolans characteristically increase plasticity and cohesiveness and decrease the tendency towards bleeding and segregation of concrete mixes. These desirable effects may be further enhanced by the judicious use of air entrainment.

Most effective are the finely ground diatomites, opaline shales, and calcined clays. Less effective are the volcanic glasses.

For a given slump, natural pozzolans may increase the water requirement. However, proper mix design and/or the use of a suitable wetting agent are effective in reducing to normal the water requirement of concretes containing pozzolan. With pozzolanic concrete, workability is more accurately defined by the Powers remolding apparatus than by the slump test. This may be effectively shown in the ease with which pozzolanic concrete may be vibrated.

Effects of Pozzolan upon Hardened Concrete

An analogy can be drawn between the effects of pozzolan upon hardened concrete and the characteristic action of Type V (sulfate resistant) portland cement. As tested, (see pages 51 and 52 of reference 4), Type V Portland cement is slow in early age strength gain, but at later ages gives high strength development. It is very low in heat generation, a factor of great importance in mass concrete. It is high in sulfate resistance. According to the Concrete Manual (Reference (4), p. 52) "Type V cement is, from a theoretical point of view, the nearest approach to an ideal cement." Unfortunately, Type V cement is a premium cement not readily available.

In general, use of California pozzolans (natural pozzolans), in proper amounts results in concrete of lower cost having less heat generation, maximum rate of heat development at an earlier age, lower permeability, greater resistance to aggressive soils and waters, higher later age strengths, and freedom from leaching.

Substitution of pozzolan for a portion of the portland cement not only results in a low cement content which, in itself, is highly desirable, but also compensates for any undesirable characteristics of the concrete that would be introduced if the cement content were similarly reduced without addition of the pozzolan.

Detailed discussion of the aforementioned benefits of pozzolan in concrete is impractical in this paper. For further information the reader is referred to the listed references and to the brochures issued by the existing commercial producers of pozzolan in California.

Alkali-Aggregate Reaction

The most important use of pozzolan in California is in controlling the alkali-aggregate reaction.

In the early 1940's, T.E. Stanton discovered that certain rocks and minerals reacted with alkalies released during hydration of portland cement and caused rapid deterioration of concrete. Examples of such deterioration may be seen throughout California, although such deterioration is most obvious in coastal areas.

From 1941 to 1947 knowledge of the mechanism and control of this reaction accumulated and full dependence for protecting concrete structures against this reaction was placed upon a limitation of the alkali content of portland cement to 0.60 percent. In 1947, however, tests with a very low alkali portland cement and aggregate proposed for use in Davis Dam indicated excessive reactive expansion. Forthwith the decision was made to require use of pozzolan in the concrete of this important structure. This was a tacit acknowledgment that limitation of the alkali content of portland cement within practical limits may not be sufficient to protect concrete permanently against alkali-aggregate reaction.

As a consequence of this vital work with pozzolans in countering alkali-aggregate reaction, suitable pozzolans are now used extensively with and without low-alkali portland cement as a positive means of insuring the dimensional stability of concrete. The trend is toward using pozzolan whenever aggregates of known or questionable reactivity are employed.

Merriam (Reference (5)) discusses known and suspected sources of reactive aggregate in California, and should be a part of the library of every engineer who enjoys responsibility for concrete mix design.

American Society for Testing Materials Specification C33-52T recognizes the alkali-aggregate reaction problem when it states in part that reactive aggregates may be used "with the addition of a material that has been shown to inhibit undue expansion due to the alkali-aggregate reaction."

Great caution should be exercised in the selection of a pozzolan for positive control of the alkali-aggregate reaction. Relatively few pozzolans will satisfactorily control the alkali-aggregate reaction when used in optimum quantities. For example, a pozzolan used as a 15% replacement of total cementitious material may enhance the desirable properties of concrete, but may be insufficient to control the alkali-aggregate reaction.

Future for California Pozzolans

Pozzolans in concrete are not cure-alls. When properly used, however, they can result in the placement of superior concrete at lower cost. The obvious question would be, then, why are pozzolans not used in larger quantities than at present? The answer to this question contains the key to the future for California pozzolans.

Through the efforts of the Portland Cement Association and many other trade and research organizations, the production of quality concrete is now less of an art and more of a science. Constant improvements are taking place, but the time required for exhaustive testing and acceptance of new methods and materials is long. All materials have limitations which must be thoroughly understood. Recent major construction such as the Morro Bay Steam Power Plant shows what a good pozzolan properly employed can do to enhance the desirable properties of concrete. More such projects are currently under construction. Within the next few years it is probable that the performance record of suitable pozzolans in structural concrete will be universally recognized.

Another factor in widespread use of pozzolan is cost. Although pozzolans now commercially produced are less costly than all types of portland cement, installation of bulk facilities for handling pozzolan at transit-mix plants is a major cost item. It would appear, however, that within the near future plants within the reactive aggregate areas will seriously consider installation of such facilities for two reasons: (1) Customers will demand absolute protection from the alkali-aggregate reaction and will want other desirable qualities of pozzolanic-concrete (2) Cost of concrete will be reduced.

Other Uses of Pozzolans

The tonnage of pozzolan employed in concrete products is rapidly increasing. However, the benefits of pozzolan in this large and growing industry are not so specifically identified as in monolithic concrete.

In the concrete block industry for instance, pozzolans have been used primarily to overcome deficiencies in raw materials such as lack of fines in sand or poor grading of aggregate. In some cases, pozzolans have permitted adjustment of mix designs which resulted in superior products at lower cost.

Perhaps the largest potential market for pozzolans in the concrete product industry is in concrete pipe of all types.

The East Bay Municipal Utility District has installed thousands of feet of pre-cast and centrifugally spun concrete pipe containing large percentages of pozzolan as a partial portland cement replacement. Reports on the performance of this pipe indicate the desired results of (1) improved resistance to sulfate and acid attack, and (2) remarkable reduction in permeability have been achieved. Costs, techniques and results obtained in the use of pozzolan by the East Bay Municipal Utility District are available (Reference 11).

It is important to note that when pozzolan is employed in concrete products, additional curing is often necessary to gain maximum effectiveness from the pozzolanic reaction. However, as the search for improved concrete products continues, it is likely that the use of suitable pozzolans will continue to increase despite changes that may be required in techniques of manufacture.

Climatic conditions in California have generally precluded the outlay of capital for installation of autoclaves. However, the outstanding results achieved in the midwest and east, combined with the ultimate economy of autoclaved products makes it seem probable that in due course manufacturers of concrete products in California will seriously consider the advantages of autoclaving.

Almost without exception, materials high in silica such as pozzolans prove very beneficial in the autoclaving process.

Investigations now under way indicate a market potential for pozzolan, in combination with lime, for soil stabilization. Comprehensive testing in Texas has indicated that excellent results, from the standpoint of quality and economy, can be obtained in the stabilization of many soils with lime-pozzolan mixtures.

California Manufacturers of Pozzolan

California pozzolans are produced for blending with portland-cement or a separate ingredient for admixture.

At the present time, two portland cement manufacturers are known to produce portland-pozzolan cements utilizing fixed percentages of pozzolan replacement:

Permanente Cement Company
Kaiser Building
Oakland 12, California
Portland Pozzolan Cement

Monolith Portland Cement Company
3326 San Fernando Road
Los Angeles, California
Monolith "Tufa"

The writer is not acquainted with the physical and chemical characteristics or the service records of the pozzolans used by these companies.

Two companies are actively manufacturing pozzolan for sale as a separate ingredient for blending with portland cement or for admixture.

(1) The Airox Company, manufacturers of "Airox Pozzolan" (calcined oil-impregnated diatomite)
Offices: 307 West Eighth Street
Los Angeles 14, California
Plant: Orcutt-Casmalia Road
Santa Maria, California

(2) The Basalt Rock Company, manufacturers of "Basalt Pozzolan" (calcined precipitated silica)
Offices: 8th and River Streets Plant: Napa, California.

Further information regarding composition, nature, use and cost of these pozzolans can be obtained by writing to the companies concerned.

Conclusion

Many materials in California may be considered potential sources for pozzolan, but should be thoroughly investigated before exploitation is undertaken.

Pozzolans of high quality can be used to produce superior concrete at low cost, but must be used cautiously and according to manufacturer's recommendations.

Few pozzolans will satisfactorily inhibit alkali-aggregate reaction when used in reasonable quantities. Pozzolans high in opal or consisting of finely ground diatomite are generally the most active, and contribute most to sulfate resistance. Calcined clays, otherwise suitable as pozzolans, may contribute little or nothing to sulfate resistance.

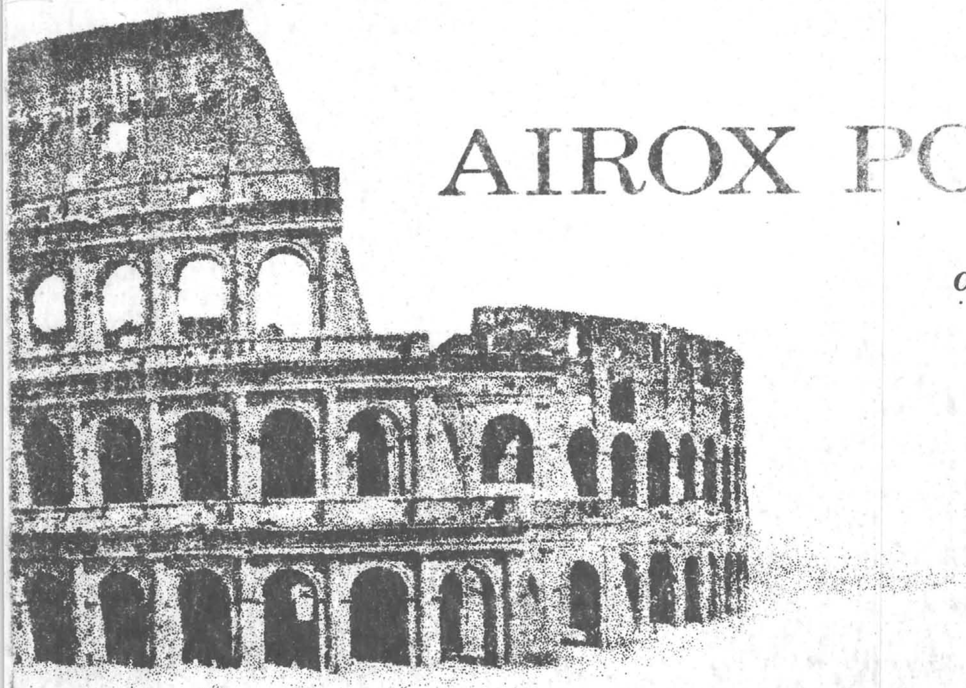
Any pozzolan being considered for use in concrete should meet accepted standards and should have a satisfactory performance record.

REFERENCES

1. Am. Soc. Testing Materials; Special Tech. Pub. 99, Symposium on Use of Pozzolanic Materials in Mortars and Concretes, 1949.
2. Am. Soc. Testing Materials; ASTM Standards on Mineral Aggregates, Concrete, and Nonbituminous Highway Materials, Oct. 1952.
3. U.S. Bur. Reclamation, Research and Geology Div. Materials Inv. Rept. MI-10, Investigations of Construction Materials for Projects in Region 2.
4. U.S. Bur. Reclamation; Concrete Manual, 5th Edition, Sept. 1949.
5. California Div. Mines; Special Rept. 27, Alkali-Aggregate Reaction in California Concrete Aggregates, by Richard Merriam, 1953.
6. U.S. Bur. Reclamation, Research and Geology Div. Petrographic Lab. Rept. Pet-90B, Materials for Pozzolan: A Report for the Engineering Geologist.
7. Federal Specification SS-C-208b; Cement; Portland-Pozzolan.
8. United Water Conservation District of Ventura County, California; Specification No. 4, Furnishing Pozzolan for Santa Felicia Dam and Appurtenant Works, June 1954.
9. Am. Soc. Civil Engineers, Proc. Dec. 1940; Expansion of Concrete Through Reaction Between Cement and Aggregate by Thomas E. Stanton.
10. The Airox Company; Advance Information concerning Airox Pozzolan for Concrete, Brochure.
11. East Bay Municipal Utility District; Pozzolanic Materials and their Use in Concrete Pipe and Structures by Walter R. McLean.

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

The annual fall meeting of the Pacific Section of the American Association of Petroleum Geologists will be at the Biltmore Hotel, Los Angeles, on November 11 and 12. Program will consist of a series of technical papers on petroleum geology in the Pacific states; no field trips are scheduled.



AIROX POZZOLAN

an ancient material . . . . .
improves
modern structural
cement !

THE ORIGIN OF POZZOLAN

Pozzolan is one of the many legacies we owe to classical Rome. The Romans found that certain finely divided siliceous materials, when mixed with lime, produced cements having hydraulic properties. One such material, found near Pozzuoli (Puteoli), Italy, became known as "pozzuolana," a general term defining similar materials found on the Continent. Later, the term "pozzolan" was adopted to designate any siliceous material which would combine with lime in the presence of moisture to form cementitious compounds. For many centuries hydraulic cements composed solely of pozzolan and lime were used with historic success throughout Europe. The Aqueduct of Claudius (312 B.C.), the great public baths (27 B.C.), and the Colosseum itself (80 A.D.) are among the numerous classical structures in existence today that attest to the durability of pozzolanic concrete.

AIROX POZZOLAN is manufactured from a unique oil-impregnated, diatomaceous (opaline) shale of remarkable homogeneity. This "bituminous rock" is calcined under controlled conditions at temperatures ranging from 1450° to 1550° F. The product of calcination is then very finely ground in a ball mill to a specific surface of 10,000 to 12,000 sq cm per gram – about four times the normal specific surface of Type I portland cement. The result is a product which far exceeds the requirements of even the most exacting specifications for pozzolans. Among the pozzolans tested and approved by such governmental agencies as the Bureau of Reclamation and the Corps of Engineers, Airox Pozzolan registered a distinguished overall performance rating – its pozzolanic activity index proved to be among the highest recorded.

PHYSICAL PROPERTIES

Amount retained when wet-sieved on No. 325 (44-micron) sieve, per cent . . . . . . 8 to 10

Specific surface, by Blaine air-permeability apparatus (porosity constant $\underline{e} = 0.60$), sq cm per gram . . . . 10,000 to 12,000

Specific gravity 2.50

Bulk unit weight, lb per cu ft 47

CHEMICAL ANALYSIS

Silica (SiO_2)	71%
Alumina (Al_2O_3)	16%
Iron oxide (Fe_2O_3)	4%
Lime (CaO)	2%
Magnesia (MgO)	2%
Sulfate (SO_3)	1%
Sodium oxide (Na_2O)	0.8%
Potassium oxide (K_2O)	0.2%
Loss on ignition	3%

THE ADVANTAGES OF AIROX POZZOLAN

- INHIBITS ALKALI – AGGREGATE REACTION
- INCREASES ULTIMATE STRENGTHS
- LIMITS LEACHING
- CURTAILS EFFLORESCENCE
- DECREASES PERMEABILITY
- INCREASES RESISTANCE TO ACIDS
- MINIMIZES SEGREGATION
- LOWERS HEAT OF HYDRATION
- IMPROVES WORKABILITY
- INCREASES RESISTANCE TO ALKALIES
- REDUCES OVERALL COSTS

AIROX-C is an easy-to-use additive with a natural warm earth tone that becomes a permanent non-fading color homogeneous with the finished concrete.

AIROX-C is economical to use and for a small added cost provides all the desirable pozzolanic features and effects color as well. When custom coloring is required, AIROX-C will lower total in-place costs when [illegible] used as a component of the mix formulation. For example, AIROX-C is normally used in a [illegible] [illegible]

AIROX-C ALSO PROVIDES THESE BONUS FEATURES OF SUPERIOR POZZOLANIC ACTION:

- Decreases permeability of hardened concrete, practically eliminates efflorescence.

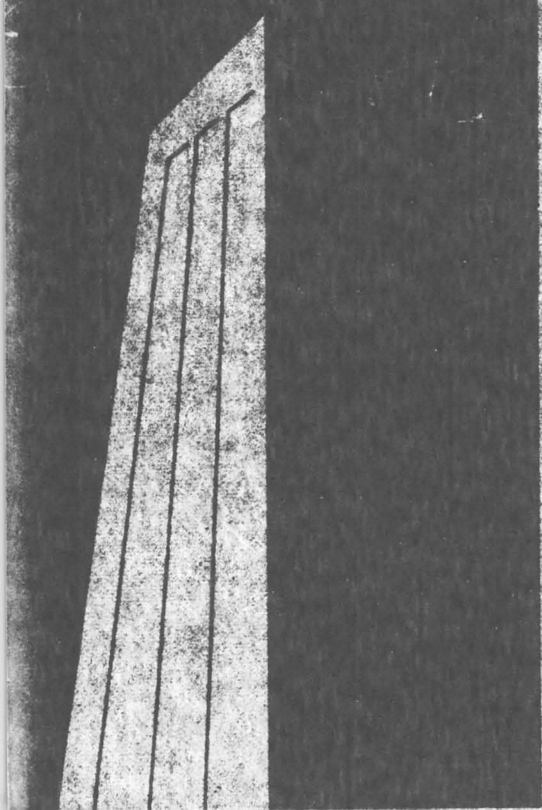
- Adds to plasticity and workability of cements and improves mixing action—speeding application and lowering placement costs.

- Can reduce overall construction costs by acting as a buffering agent, neutralizing reactive aggregates that are often present in locally available materials.

AIROX-C pozzolan is manufactured from a unique oil-impregnated diatomaceous opaline shale of remarkable homogeneity. High-temperature calcination and subsequent controlled grinding and grading results in a product that far exceeds the established requirements of even the most exacting specifications for pozzolans.

AIROX-C *the cement additive that provides permanent color and improves the performance of concrete—*

A product of **Diversified Earth Sciences, Incorporated**... providing proprietary products and services which restore, improve and maintain the environment.



Diversified Earth Sciences, Inc. 10880 Wilshire Boulevard, Suite 612, Los Angeles, California 90024 Telephone (213) 475-0591

GUIDE SPECIFICATION

Cement ____________ ("Replacement" or "additive") as required by these specifications shall be AIROX-C as manufactured by Airox, Incorporated, or an approved equal.

1 Scope*

These specifications cover AIROX-C for use as a color component in portland cement concrete.

*Note: Proper air entrainment is strongly recommended for exposed concrete subjected to freezing and thawing conditions. AIROX-C may cause a reduction in the amount of air entrained; hence, this should be taken into consideration when formulating final mix design.

2 Material

The raw material from which AIROX-C is produced shall be an oil-impregnated diatomaceous shale.

3 Definition

For the purpose of these specifications, AIROX-C is defined as a finely ground, calcined reactive siliceous material capable of effecting a minimum of 85 percent reduction in expansive reaction at 14 days.

4 Proportions

The determination of the proportions of cement, AIROX-C, aggregates, water and admixtures required for concrete of the specified strength shall be established by a recognized testing agency taking into consideration both the workability of the mix and the durability of the concrete. The AIROX-C shall constitute by weight not less than 15 percent nor more than 20 percent of the total cementitious material.

5 Chemical & Physical Requirements

AIROX-C employed as a component in portland cement concrete shall conform to the following:

Chemical

Silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and iron oxide (Fe_2O_3), minimum, per cent. 85

Loss on ignition, maximum, per cent 5

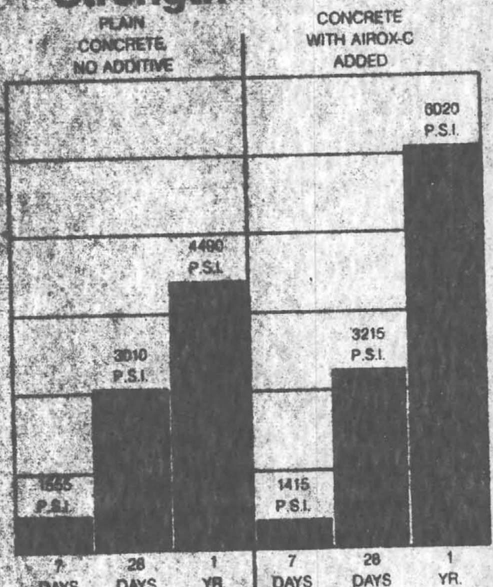
Moisture content, maximum, per cent 2

Physical

Amount retained when wet-sieved on No. 325 (44-micron) sieve, maximum, per cent 12

Fineness, by Blaine air-permeability apparatus (porosity constant e = 0.60), minimum, sq cm per gram 12,000

6 Compressive Strength*



*Tests conducted by Construction Laboratories, Inc., Los Angeles. Details and complete report available upon request.

7 Manufacturer's Certification

At the request of the purchaser, the manufacturer shall certify in writing the source and composition of AIROX-C as well as compliance with requirements outlined under "Methods of Testing," paragraph 9.

8 Inspection

(a) Every facility shall be provided the purchaser for careful sampling and inspection at the source of supply of AIROX-C.

(b) AIROX-C may be shipped on the supplier's certification that it conforms in all respects to these specifications. Permission to ship either before completion of tests or without testing shall in no way relieve the supplier of the responsibility for furnishing a coloring agent meeting the requirements of these specifications. This permission may be revoked should test results indicate the failure of coloring agent to conform with the requirements set forth herein.

9 Methods of Testing

Tests for chemical composition shall be in accordance with ASTM Designation: C-114. Tests for physical properties shall be made in accordance with ASTM Designations: C-114 and C-618, as last revised, with the following exceptions to Table II of C-618...

Physical Requirements:

(a) Pozzolanic activity index

1. With portland cement at 28 days, with minimum percentage of control 90
2. With lime, at 7 days, minimum psi. 1000

(b) Water requirement, maximum percentage of control . . 110

(c) Reactivity with cement alkalis, reduction of mortar expansion, 14 days minimum percent 85

TYPICAL CONCRETE MIX DESIGN WITH AIROX-C POZZOLAN ADDITIVE

Assume that Airox Pozzolan is being employed primarily to control alkali-aggregate reaction, as 18 per cent (by weight) of the total cementitious material (Airox Pozzolan plus portland cement):

Design Data:

Compressive strength	2,500 psi
Cement-plus-pozzolan factor (weight)	5.25
Water/cement-plus-ratio (weight)	0.57
Slump	4 in.
Percentage of air (volume)	1%

Specific Gravity of Materials (Saturated, surface dry)		Percentage of Aggregate by Absolute Volume	
Portland cement	3.15	Sand	36%
AIROX-C	2.48	¾ in.	27%
Sand	2.52	1½ in.	37%
No. 4 to ¾ in.	2.52		
¾ to 1½ in.	2.65		

Weight Computations

Weight of cement-plus-pozzolan	5.25	×	94 lb = 494 lb
Weight of AIROX-C	18%	×	494 lb = 89 lb
Weight of portland cement	494	minus	89 lb = 405 lb
Weight of water	0.57	×	494 lb = 282 lb (or 33.8 gal)

Absolute Volume Calculations

$$\text{Absolute volume of paste} = \underset{\text{(Cement)}}{\frac{405}{3.15 \times 62.4}} + \underset{\text{(Pozzolan)}}{\frac{89}{2.48 \times 62.4}} + \underset{\text{(Water)}}{\frac{282}{62.4}} + \underset{\text{(Entrapped air)}}{\frac{27}{100}}$$

$$= 7.43 \text{ cu ft}$$

Absolute volume of aggregate	27.00	minus	7.43 = 19.57 cu ft
Absolute volume of sand	36%	×	19.57 = 7.04 cu ft
Absolute volume of ¾ in.	27%	×	19.57 = 5.28 cu ft
Absolute volume of 1½ in.	37%	×	19.57 = 7.25 cu ft

Saturated, Surface-Dry Weights for One Cubic Yard

Portland cement	405 lb
AIROX-C	89 lb
Water	282 lb
Sand = 62.4 × 2.52 × 7.04	1,110 lb
¾ in. = 62.4 × 2.52 × 5.28	830 lb
1½ in. = 62.4 × 2.65 × 7.25	1,200 lb

Notes: 1. When converting existing conventional portland cement concrete mix designs to accommodate the incorporation of AIROX-C, the normal sand content (depending upon its grading) should be reduced from [illegible] to [illegible] percent, with corresponding increases in the percentages of coarse aggregate.
2. When an increase in the percentage of entrained air is desired, the amount of air-entraining agent required will be greater for pozzolanic concrete than for conventional portland cement concrete.
3. In structural pozzolanic concrete with AIROX-C it is normally advantageous to employ an approved water-reducing agent.

Write for samples and technical assistance for specific job requirements.

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