HAWAIIAN TRACHYTE ROCK AS A POZZOLANIC ADMIXTURE IN PORTLAND CEMENT CONCRETE

by

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INTRODUCTION

Certain types of igneous materials have been found to exhibit pozzolanic properties. The early utilization of such materials dates back to ancient Rome and Greece when they were used extensively in all types of masonary construction. Thus, the hydraulic cements of the ancients were simply mixtures of suitable pozzolans and lime. In more recent years, materials possessing pozzolanic properties have been used as an ingredient of portland cement concrete.

Davis (4) described a pozzolan as a siliceous material which, while in itself possessing no cementitious value, will in a finely divided form and in the presence of moisture, react chemically with calcium hydroxide at ordinary temperatures to form insoluble compounds possessing cementitious properties.

Although there are a number of short-time tests for evaluating the ability of a pozzolan to combine with calcium hydroxide, its effect upon the properties of hardened concrete can be determined with certainty only by long-time tests.

The study of the pozzolanic activity of the material in question was primarily made for the sake of its economic considerations in the Hawaiian Islands. To the best knowledge of this writer, all of the portland cement used in the Hawaiian Islands is imported from the mainland of the United States at a considerable cost. Such being the case, it seems conceivable that a considerable economy might be effected through the utilization of a native pozzolanic material as a partial cement replacement in portland cement concrete.

Trachyte rock, a material readily available on the island of Oahu in the territory of Hawaii, was deemed as a logical choice for this study. This peculiar species of igneous rock is older in origin than the common lavas found on the other islands of the Hawaiian chain which are geologically known as andesine andesite and olivine basalt. The necessary processing of the trachyte rock from its original solid state to a finely divided state for use as a pozzolan was made in such a way as to simulate actual industrial processing as closely as possible.

A series of laboratory tests were conducted to determine the validity of trachyte rock as a pozzolanic material. These tests consisted of two pozzolanic activity tests as well as a strength and an accelerated exposure test. The pozzolanic activity tests consisted of determining the reduction in alkalinity and reactivity with lime of trachyte rock. The strength and exposure tests entailed the making of thirty 3" x 4" x 16" beams with varying percentages of ground trachyte rock. These ground trachyte rock replacements were made in increments of 0, 20, and 30 percent. Twelve of these beams were made with Blue River sand which is generally found to be a non-reactive sand with a good service record in Kansas. The remaining eighteen beams were made with Republican River sand which is generally found to be a reactive sand with a bad service record in Kansas. These sands were sieved to have a fineness gradation of 3.59. Lone Star cement, which is a type I cement, was used in all mixes. Mixes were made in the proportion of 1:5 by weight.

For each series of beams with differing percentages of ground trachyte rock replacements, the modulus of rupture and compressive strength was determined at the age of 30 days. Similarly, each series of beams with differing percentages of ground trachyte rock replacements were subjected to an accelerated exposure test at the age of 30 days. After subjecting the beams to the accelerated exposure test for approximately 60 days, they were tested for modulus of rupture and compressive strength.

It should perhaps be emphasized that the studies that were made were by no means a complete study of the material. A complete study would involve necessarily long-time tests; the studies that were made here were made on the basis of accelerated short-time tests and, as such, show only a trend in the properties of the material in question.

REVIEW OF LITERATURE

The use of pozzolanic materials in the United States has increased considerably in recent years. Such materials are known to inhibit certain cement-aggregate reactions as well as imparting some other desirable qualities in portland cement concrete.

Blanks (1) discussed the use of portland-pozzolan cement by the Bureau of Reclamation with special emphasis on the useful properties of portland-pozzolan cement in mass concrete.

Blanks (2) reported that fly ash increases workability, renders the mix more plastic, and decreases segregation and bleeding.

He also concluded that the strength of portland pozzolan concrete is, in the long run, generally equal to that of a straight portland cement mix.

Davis (3) reviewed pozzolanic materials and their use in concrete with special emphasis on the nature of pozzolanic action, properties of fresh concrete, properties of hardened concrete and mortar, compressive strengths of concrete, elasticity and creep, volume changes, weathering resistance, resistance to aggressive water, heat of hydration, permeability and alkali-aggregate reaction. Davis (4) discussed the composition of pozzolans and cement replacement applications of pozzolans to concrete construction in general.

Gaskin, Jones, and Vivian (5) discussed petrographic examination to determine cement-aggregate reaction. They observed that cracking, accompanied by gel spots, shows high alkaline aggregate reaction. They also concluded that opal, silica in aggregates and glass in volcanic rocks are generally reactive; basalts and dolerites are generally non-reactive aggregates.

Mielenz, et al., (6) developed a chemical test for the alkali reactivity of pozzolans. They discussed the procedure involved in this test as well as interpreting the significance of the test.

Moran and Gilliland (7) summarized the various methods for determining pozzolanic activity where they affirmed that no suitable relation has yet been found to correlate chemical or physical analysis to pozzolanic activity. They further discussed and interpreted the use of solubility studies, lime absorption tests, optical studies, X-ray analysis and other methods of testing to ascertain pozzolanic validity.

Scholer and Smith (8) utilized two types of accelerated exposure tests in an effort to determine the use of Chicago fly ash in reducing cement aggregate reaction.

The United States Bureau of Reclamation (9) established certain specifications for the calcined reactive siliceous material which they employed in the Davis Dam project in Arizona.

MATERIALS

Trachyte Rock

The first problem was to reduce the trachyte rock to a finely divided state. This process of reducing the trachyte rock to a finely divided state was a necessary preliminary to the actual testing since pozzolanic materials will possess activity only when in a finely divided form. For the sake of industrial economy, it was a chosen objective to reduce the trachyte rock to a degree of fineness roughly approximating the fineness of portland cement. Difficulties encountered in the actual grinding process with a ball mill, however, prevented the attainment of such an ideal state of fineness. As can be seen in Table 2, a greater degree of fineness than that of portland cement was obtained.

It should be pointed out, however, that such a degree of fineness will not exhibit any detrimental effects in the pozzolanic activity of the pozzolan in question. On the contrary, previous research has shown that an increase in the fineness of the pozzolan in question will show a corresponding increase in pozzolanic activity.

Sieve Analysis. A method of analysis used by the Kansas State Highway Commission was utilized in the sieve analysis of the processed trachyte rock in question. The procedure consisted of loading a 325 mesh sieve with 1 gram of the ground trachyte rock, washing the loaded sieve with water for one minute under a ten pound pressure, drying the residue, and weighing the residue.

Blaine Surface Area. Since the Blaine Air Permeability Apparatus was calibrated for the specific testing of portland cement, the results obtained on other materials would necessarily be inaccurate. Such results would, at best, be only good approximations. The results thus obtained through the Blaine Air Permeability Apparatus, however, do show a definite trend in the fineness of the material in question.

Portland Cement

The portland cement used throughout the tests was Type I cement from the Lone Star Company. The chemical analysis is shown in Table 3.

Aggregates

Blue River sand and Republican River sand with a fineness gradation of 3.59 were used. Blue River sand was generally considered to be inoccuous and had a good service record in Kansas while Republican River sand was generally considered to be reactive and had a bad service record in Kansas. Each of the two sands was used in combination with the cement with 0, 20, and 30 percent substitution of trachyte rock for the portland cement.

REDUCTION IN ALKALINITY AND SILICA RELEASE

Probably the only solubility test now in use in a specification is one of the activity tests incorporated by the United States Bureau of Reclamation (9) in the Davis Dam project.

The test determination involves the determination of the reduction in alkalinity in a 1 N. sodium hydroxide solution due to reaction with a finely divided siliceous material.

Moran and Gilliland (7) best describe the limitations of this test:

> The test is not intended to define the general activity of pozzolans, but it has been found to be indicative of the ability of certain classes of materials to counteract the expansion which would result from the alkali-aggregate reaction. This has been established by correlation with the results obtained in the mortar bar test.
>
> While a 40 percent minimum requirement on reduction in alkalinity was considered to be satisfactory for the classes of materials permitted by the requirements of the Davis Dam specifications, a broader application is possible when the silicon dissolved in the sodium hydroxide is also considered.

Moran and Gilliland (7) further developed an empirical formula in an attempt to determine pozzolanic validity using the criteria of reduction in alkalinity and silica release. The developed formula was:

Table 1. Chemical analysis of trachyte rock.

Compound	Percentage	Compound	Percentage
Silicon dioxide	64.22	Ignition loss	3.36
Aluminum oxide	16.33	Potassium oxide	3.52
Ferric oxide	2.71	Sodium oxide	4.38
Calcium oxide	3.68	Manganous oxide	0.01
Magnesium oxide	1.80	Phosphorus pentoxide	0.18
Sulphur trioxide	0.13		

Other chemical data:

Reduction in alkalinity	
percent	28.5
millimoles per liter	313.6
Soluble silica	
millimoles per liter	263.0

Table 2. Physical properties of ground trachyte rock.

Sieve analysis percent passing 325 mesh sieve	93.9
Blaine surface area square centimeters per gram	7750.
Specific gravity	2.575
Percent water for normal consistency	44.10

R, the alkalinity reduction in millimoles per liter plus two-thirds of S, the silica dissolved in the sodium hydroxide solution in millimoles per liter is equal to 630.

This formula actually was plotted for materials which reduce the mortar expansion 75 percent or more in 2 weeks. The mortar had a 20 percent replacement factor. The acceptable materials yield data points falling above and to the right of the plotted formula. The authors admit, however, that this criteria has not proven to be completely satisfactory. The implication of this formula is graphically presented in Fig. 1.

Table 3. Chemical analysis of Lone Star cement.

Compound	Percentage
Silicon dioxide	20.77
Aluminum oxide	5.90
Ferric oxide	2.82
Calcium oxide	63.23
Magnesium oxide	2.77
Sulphur trioxide	2.30
Ignition loss	1.07
Sodium oxide	0.28
Potassium oxide	0.59
Insoluble residue	0.38

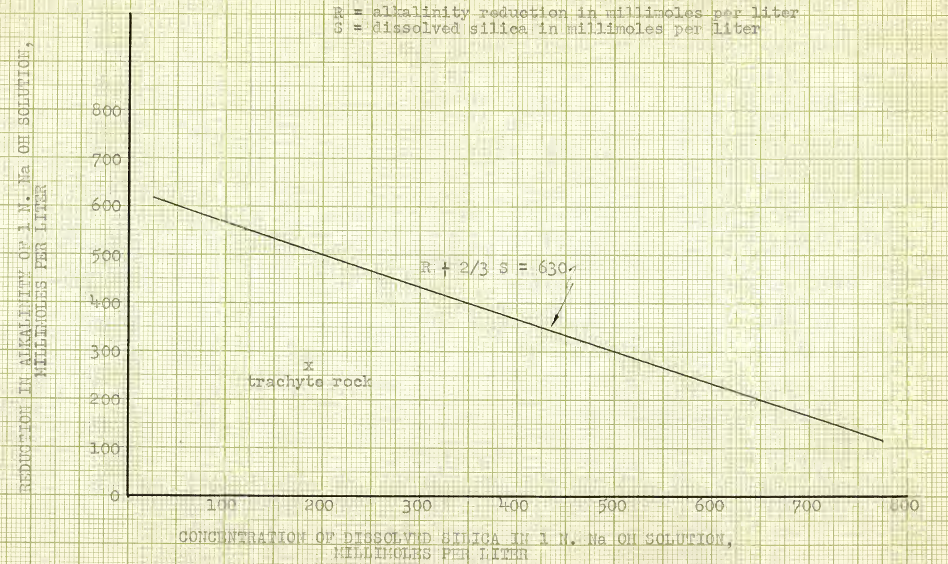

Fig. 1. Relation of dissolved silica to reduction in alkalinity of siliceous materials.

REACTIVITY WITH LIME TEST

The United States Bureau of Reclamation (9) required a lime reactivity test for the calcined siliceous material which was to be used on the Davis Dam project in Arizona and Nevada. In establishing a criteria for compressive stress, they set a lower limit of 600 psi. at 7 days.

Moran and Gilliland (7) found that, in general, active pozzolans will, under this method of test, give better than 1000 psi. in compression at 7 days, whereas poor or intermediate materials will range from 400 psi. to 800 psi., and inactive materials will range well below 400 psi.

Proportioning and Mixing

The mortar contained, by weight, two parts of oven-dry siliceous material, one part of hydrated lime, and nine parts of standard 20-30 sand. The amount of water was determined from the following equation:

$$\text{Percent of water in mortar} = \frac{\text{Percent water for normal consistency of paste}}{6} + 6.5$$

A sufficient quantity of standard mortar was made to mold four cylindrical specimens, 2 inches in diameter and 4 inches in height. The dry materials were vigorously shaken for 2 minutes in a covered container. The mortar was mixed in accordance with the standard method of the American Society of Testing Materials*, except that the final kneading was continued for

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* "Standard method of test for tensile strength of hydraulic cement mortars", ASTM Designation: C 190-44

2 minutes.

Casting the Specimens

Each mold was filled in 4 layers of equal depth, each layer being tamped 25 times with a metal rod weighing 3/4 pound and having a plane face 1 inch in diameter. The tamping was done with sufficient force to insure a uniform specimen. Immediately after the specimens were cast, cardboard covers were placed on the cylinders and the cylinders placed in a metal container and sealed with asphalt and plaster.

Storing

The specimens in the sealed metal container were stored at 70° F. for 24 hours and then stored at 130° F. for 6 days until 4 hours before the time of testing, when the specimens were at 70° F.

Testing

The specimens were carefully stripped and capped with a cement-plaster mixture before testing.

Results

The results of this test are shown in Table 5.

PREPARATION OF BEAMS

Thirty 3" x 4" x 16" beams were made for the purpose of determining the pozzolanic activity of the ground trachyte rock by subjecting these beams to strength and exposure tests.

Table 5. .Compressive strength of mortar at 7 days.

Specimen	Load		Average stress psi.
	pounds	psi.	
A	3280	1042	
B	3740	1190	1105
C	3380	1078	
D	3480	1110	

Mixing and Casting the Specimens

The mixing was done in a portable mixing machine. The materials for a batch were introduced into the mixer in the following manner:

1. The dry materials were placed into the mixer and dry mixed for a period of 30 seconds.

2. Sufficient water was added into the mixer to give a slump of approximately 2 inches and mixed for a period of 1 1/2 minutes.

Immediately following the mixing, the necessary readings to determine slump, air content, and specific weight of the cement mix were made. The molds were then filled in two layers, each layer being carefully compacted with a 1/2 inch tamper. After the top layer of the molds was compacted, they were then vibrated for a period of 30 seconds with an automatic vibrator. The concrete was then cut off flush with the top of the molds and the surface smoothed with a few strokes of the trowel.

Of the 30 beams that were made, 12 were made with Republican River sand; 6 of which were provided with stainless steel gage points to facilitate the measurement of expansion, or shrinkage as the case might be. The additional 18 beams were made with Blue River sand; 9 of which were provided with stainless steel gage points. The proportion of the mixes was 1:5 by weight. Other pertinent mixing data are presented in Table 6.

Observations on the Mixes

All batches were observed to have a marked tendency to flash set within a few minutes after the mixing was completed. However, with the additions of the designated ground trachyte rock replacements, this tendency to flash set seemed to be partially retarded and, generally, rendered the mix more plastic and workable. It was also observed that the concrete with ground trachyte rock replacements improved the finishing properties of the concrete. Although there was a statistical variation in the mixes, the evidence seemed to point out that, with the increasing amount of ground trachyte rock replacements in the mix, the air content of the concrete mixes generally decreased.

Beam Storage

All the beams were stored for 1 day in a moist closet. They were then stripped and stored in the moist room for 6 days. At

Table 6. Mixing data.

Sand	Trachyte percent	Code designation	W/C ratio gal. per sack	Cement factor* bbl. per cu. yd.	Air percent	Slump in.
Blue River	0	M3A	7.26	1.51	2.8	1.0
Blue River	20	M3B	7.39	1.49	1.8	1.5
Blue River	30	M3C	7.38	1.51	1.6	2.0
Republican River	0	M6A**	7.[illegible]	1.54	2.3	2.5
Republican River	20	M6B	7.22	1.53	1.6	3.0
Republican River	30	M6C	7.66	1.53	2.5	2.[illegible]

* Trachyte rock substitution is considered to be part of the cement.
** Data for this batch was obtained from G. [illegible] Smith in unpublished research.

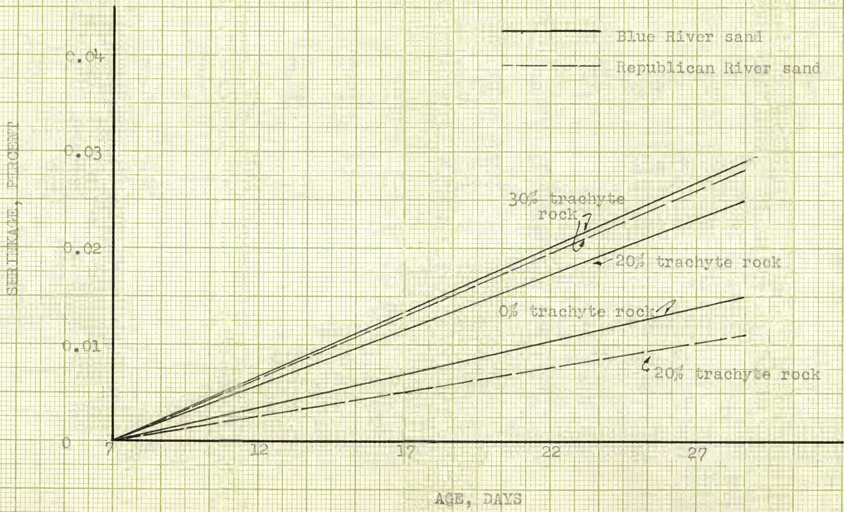

Fig. 2. Relation of drying shrinkage and trachyte rock replacement.

the age of 7 days, the beams were removed from the moist room and stored on racks in the air conditioned laboratory at 74° F. and at 55 to 60 percent relative humidity for 21 days. At the age of 28 days, the beams were placed in water at 70° F. for two days before subjecting them to the strength and exposure tests.

DRYING SHRINKAGE OF BEAMS

To determine the effect of the ground trachyte rock upon drying shrinkage, an initial length measurement of the beams was made at the age of 7 days. This process was then repeated at the age of 28 days.

As can be seen in Fig. 2, the utilization of ground trachyte rock as a cement replacement in the concrete mix increased drying shrinkage materially when contrasted to the drying shrinkage of the basic (0 percent) mix. On drying shrinkage, Davis (4) commented that most pozzolans generally induce a greater drying shrinkage than a straight portland cement mix. He also found, however, that some good pozzolans such as fly ash of low carbon content and a high degree of fineness exhibit no tendencies toward greater drying shrinkage.

STRENGTH TESTS FOR BEAMS

At the age of 30 days, 15 of the 30 beams were subjected to strength tests. These strength tests consisted of a modulus of rupture and a compressive stress test.

The modulus of rupture test was first conducted. This test

Table 7. Modulus of rupture and compressive strengths of concretes at 30 days.

Code designation	Trachyte percent	W/C ratio, gal. per sack	Tension		Compression		Average stresses for series	
			lbs.	psi.	lbs.	psi.	Modulus of rupture psi.	Compression psi.
MK3A-1	0	7.26	1320	715	41500	3450		
MK3A-2	0	7.26	1140	[illegible]	42800	3520	745	3420
MK3A-3	0	7.26	1240	790	39900	3290		
MK3B-1	20	7.33	940	601	33800	2740		
MK3B-2	20	7.33	890	569	32000	2660	596	2710
MK3B-3	20	7.33	965	618	33700	2720		
MK3C-1	30	7.30	600	384*	22100	1840		
MK3C-2	30	7.30	900	575*	24500	2040	499	1930
MK3C-3	30	7.30	780	498	23300	1940		
MK6A-	0	7.00					693	3340
MK6B-1	20	7.22	1080	690	36000	3040		
MK6B-2	20	7.22	840	727	34900	2900	625	3000
MK6B-3	20	7.22	960	614	36600	3000		
MK6C-1	30	7.86	790	505	21500	1700*		
MK6C-2	30	7.86	790	505	20000	2250	505	2330
MK6C-3	30	7.86	790	505	28500	2310		

* These values are not considered in determining the average stress since they differ by more than 15 percent from the average value of all test specimens in a series.

Table 8. Modulus of rupture and compressive strengths of concretes after Exposure 10.

Code designation	Trachyte percent	W/C ratio, gal. per sack	Tension lbs.	Tension psi.	Compression lbs.	Compression psi.	Average stresses for series: Modulus of rupture psi.	Average stresses for series: Compression psi.
MK3A-4	0	7.26	600	401	33500	2810		
MK3A-5	0	7.26	664	421	45000	4000*	405	2810
MK3A-6	0	7.26	600	393	22700	1850*		
MK3B-4	20	7.38	690	415	40200	3740		
MK3B-5	20	7.38	390	334*	34600	3710	368	3725
MK3B-6	20	7.38	590	320	32200	2690*		
MK3C-4	30	7.30	600	383	35000	2520		
MK3C-5	30	7.30	460	294	32000	2662	394	2647
MK3C-6	30	7.30	540	345	28400	2350		
MK6A-	0	7.26					405	3319
MK6B-4	20	7.22	360	230*	29200	2430*		
MK6B-5	20	7.22	580	371*	36400	3040	320	3040
MK6B-6	20	7.22	500	320	40900	3770*		
MK6C-4	30	7.26	480	336	37700	2400		
MK6C-5	30	7.26	580	370	39400	2830	338	2677
MK6C-6	30	7.26	460	306	32600	2720		

* These values are not considered in determining the average stress since they differ by more than 15 percent from the average value of all test specimens in a series.

consisted of subjecting the beams to a concentrated load at the mid-span of the longitudinal axis. The beams were simply supported with an unsupported length of 14 inches.

After the beams were loaded to the ultimate in the modulus of rupture test, one of the ends was capped with plaster. This portion of the test was so conducted to simulate a uniform load over 12 square inches of the specimen.

The procedure described above was then repeated for the remaining beams after subjecting them to the exposure test for a period of approximately 60 days. The results of the strength tests at 30 days are tabulated in Table 7, and the results of the strength tests after the exposure test are tabulated in Table 8.

EXPOSURE TEST OF BEAMS

After the initial 30 day curing period, 15 beams were subjected to an accelerated exposure test. Scholer and Smith (8) developed two forms of accelerated exposure tests intended to simulate long-time exposure conditions under a joint cooperative research program between the Portland Cement Association and the Engineering Experiment Station at Kansas State College. These two tests consisted of a wetting and drying test referred to as Exposure 2, and a continuous spray of water referred to as Exposure 10. Exposure 2 necessarily meant that a testing period of at least 1 year was needed before any significant results ensued. Exposure 10 involved a shorter testing period of approximately 60 days. Time being at a premium, it was decided to subject the beams to Exposure 10 instead of Exposure 2.

Exposure 10 consisted of placing the beams, standing on end, in a tank where they were exposed to a continual spray of water at a rather low velocity but of such intensity and distribution that the water was continually falling on all surfaces of the beams. One complete cycle consisted of changing the temperature of the water from 68° F. to 135° F., and then back to 68° F. This cycle gave a temperature range at the center of the beam of 70° F. to 120° F. This temperature change was obtained automatically and was gradual so as to eliminate any "shock" effect. The automatic controls were set so as to obtain 32 cycles per day or 224 cycles per week.

An initial length measurement was made on the beams before subjecting them to Exposure 10. Thereafter, a length measurement was made every two weeks or approximately every 448 cycles to determine the percent expansion. The expansions resulting from this exposure test are shown in Figs. 3 and 4.

DISCUSSION

It should perhaps be reiterated that these studies are by no means a complete study of the material. A complete study necessarily would involve long-time tests; the studies made here are based on the criteria of accelerated short-time tests and, as such, indicate only a trend in the properties of the material in question.

If this reduction in alkalinity and silica release test is

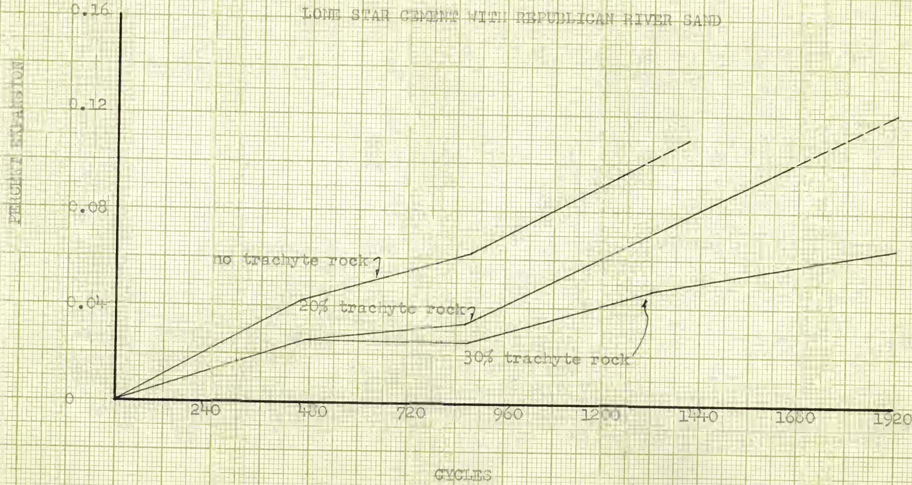

Fig. 3. Expansion obtained from Exposure 10.

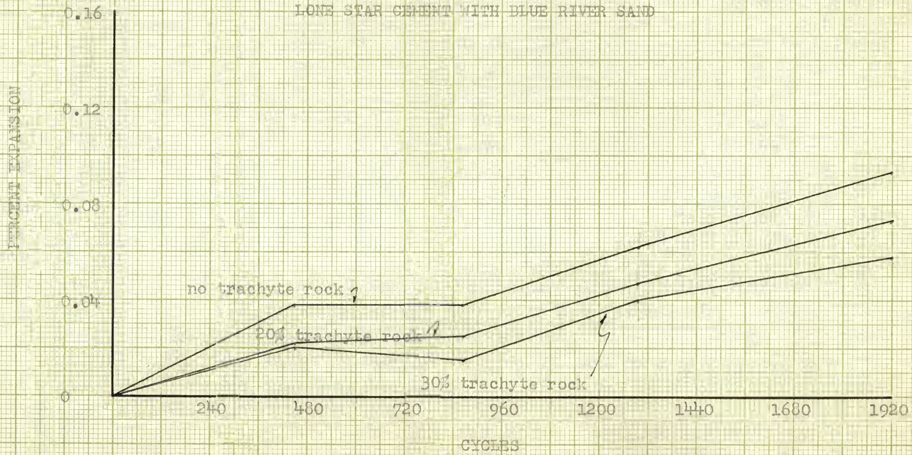

Fig. 4. Expansion obtained from Exposure 10.

to be interpreted as a criteria of pozzolanic activity, then quite obviously, as can be seen from Fig. 1, the trachyte material in question possesses little validity as a pozzolanic material. However, the investigators who developed this test to correlate certain chemical characteristics to pozzolanic activity point out that this test has not proven to be completely satisfactory and that further research is being carried out currently. This test, however, is significant in that it may possibly indicate a trend in the pozzolanic activity of the material in question.

The reactivity with lime for the ground trachyte material showed an average compressive stress of 1105 psi. at the age of 7 days. This compared favorably with the minimum 600 psi. specified by the United States Bureau of Reclamation (9) in its specifications for the Davis Dam project as well as with a number of other pozzolans which have proven to be satisfactory.

Although the Bureau of Reclamation (9) specified a minimum compressive stress of 600 psi., certain types of fly ashes falling well below this lower limit have been known to possess sufficient pozzolanic activity to warrant its utilization as a partial cement replacement in portland cement concrete. Some of these materials with their corresponding compressive stresses at the age of 7 days are shown in Table 9.

Table 10 further analyzes and summarizes the chemical and physical characteristics of the ground trachyte material as a pozzolan. The strength tests seemed to indicate the presence of at least some pozzolanic activity in the ground trachyte material.

Table 9. Results of the lime reactivity test for various fly ashes.*

Identification of fly ash	Total load on cylinders			Average compressive stress at 7 days
	1	2	3	
6	810	960	840	229
9	1670	1720	1460	556
10	1680	1700	1790	592
13	1510	2960	2140	757
14	3300	3260	2560	1045
17	1520	1520	1400	509
19	1280	960	880	357
20	1220	1300	1360	444

* Data from G. M. Smith in unpublished research.

In evaluating and interpreting the results obtained from the strength tests, a method of analogy utilizing average percent reductions in strength was used. Taking the series of beams with an 0 percent replacement as the datum point, the series of beams with a 20 percent replacement evidenced an average decrease of 16 percent in its modulus of rupture and a similar average decrease of 16 percent in its compressive stress at the age of 30 days. The series of beams with a 30 percent replacement evidenced an average decrease of 31 percent in its modulus of rupture and an average decrease of 40 percent in its compressive stress at the age of 30 days.

The preceding average values of percent decrease in strength can now be compared to similar values obtained through the use of an accredited pozzolan. Chicago fly ash is one of many such pozzolans. For the purposes of comparison in this study, the results obtained through the use of Chicago fly ash and Eu Clair sand were utilized. There was an average decrease of 16 percent in the modulus of rupture and an average decrease of 6.3 percent in its compressive stress for the series of beams with a 20 percent replacement. The series of beams with a 30 percent replacement evidenced an average decrease of 19 percent in its modulus of rupture and an average decrease of 27 percent in its compressive stress.

In comparing percent decreases in the strength of the beams utilizing Chicago fly ash and those beams utilizing ground trachyte rock, it will be noted that for the set of beams with a 20 percent replacement, the moduli of rupture was identical while the compressive strength of the beams utilizing ground trachyte evidenced a decrease in strength of 9.7 percent greater than those beams which utilized Chicago fly ash. In the set of beams with a 30 percent replacement, the modulus of rupture of the series of beams utilizing ground trachyte evidenced a decrease which was 12 percent greater than those beams which utilized Chicago fly ash; the compressive strength of the series of beams which utilized ground trachyte evidenced a decrease of strength which was 13 percent greater than those beams which utilized Chicago fly ash.

Table 10. A comparison of some chemical and physical properties.

Characteristic	Specification No. 1904*	Trachyte material	Chicago fly ash**
Chemical composition, percent			
silicon dioxide	min. 60.0	64.22	46.4
total iron oxide			24.9
ferric oxide	min. 2.0	2.71	
aluminum oxide	max. 15.0	16.33	14.8
calcium oxide	max. 10.0	3.68	4.1
magnesium oxide	max. 4.0	1.80	0.5
total alkalies	max. 4.0	7.90	3.3
sulfuric anhydrides		0.13	2.4
ignition loss	max. 7.0	3.36	2.6
others		0.19	1.9
Reactivity with lime compressive stress at 7 days, psi.	min.600.0	1105.0	***
Reactivity with sodium hydroxide reduction in alkalinity, percent	min. 40.0	28.5	
Physical properties			
specific gravity	min. 2.3	2.575	2.51
specific surface, sq. cm. per gm.	min.8000	7750	3380

* Specifications for calcined shale used on Davis Dam project, (9) in literature cited.
** Data from Scholer and Smith, (8) in literature cited.
***See Table 9.

No great amount of significance should be placed on the strength tests performed on the beams after being subjected to Exposure 10. The cyclic temperature change from 68° F. to 135° F.

32 times daily in Exposure 10 comprises a rather severe and rapid temperature fluctuation. By the end of 850 cycles, all the beams that were subjected to Exposure 10 showed visual evidences of hair line crack formations. It is the opinion of the author that these hair line cracks were caused by the severity of the cyclic temperature changes and not due to any abnormal expansion. The fact that, at the end of 850 cycles, no abnormal expansion in the beams was recorded seems to substantiate this opinion. These hair line crack formations would naturally decrease the load capacities of these beams and, as was expected, there was a general decline in the strength of the beams after subjecting them to Exposure 10 with this exception: There was a slight increase in the compressive strength of the beams utilizing the trachyte material.

Davis (4) pointed out that, in general, the compressive and tensile strengths of portland-pozzolan concretes increase with age. He further commented that although portland-pozzolan mixes generally seem to have lower compressive and tensile strengths at early ages when compared to straight portland cement mixes, at later ages the portland-pozzolan mixes generally have a higher modulus of rupture and their compressive stresses tend to equal that of straight portland cement mixes.

In interpreting the results of Exposure 10 to determine cement-aggregate compatability and pozzolanic activity, those concretes which underwent an expansion exceeding 0.10 percent or more would be expected to have a poor service record. The length of time that the test should be carried on may be subject to question but previous research has indicated a 60 day period or 1920 cycles as a reasonable length of time for the tests to be conducted in order to simulate actual field conditions.

CONCLUSIONS

The following conclusions are based upon the limited number of tests hereinbefore mentioned in this text.

1. The use of 20 to 30 percent of the ground trachyte material does not materially modify the usual characteristics of the freshly mixed concrete, but improves the workability of the mix as well as improving the finishing properties.

2. The use of 20 to 30 percent of the ground trachyte material slightly decreases the air content of the mix.

3. Twenty percent of ground trachyte material is sufficient to inhibit expansion for most aggregates.

4. In general, the use of 20 to 30 percent of the ground trachyte rock slightly reduces strengths at early ages.

From the foregoing conclusions, the author believes that the use of ground trachyte rock as a pozzolan possesses definite possibilities. However, before any extensive use is made of the ground trachyte material as a pozzolan, it is strongly recommended that further studies be made to determine the validity of the ground trachyte rock as a pozzolanic material and its effect upon the durability of concrete.

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HAWAIIAN TRACHYTE ROCK AS A POZZOLANIC ADMIXTURE
IN PORTLAND CEMENT CONCRETE

by

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A study of the pozzolanic activity of trachyte rock was made primarily for the sake of its economic considerations in the Hawaiian Islands. It is the opinion of the author that a considerable economy might be effected through the utilization of some native igneous materials as a pozzolanic admixture in portland cement concrete.

For the purposes of this particular study, a number of short-time laboratory tests were conducted. These tests consisted of two pozzolanic activity tests as well as a strength and an accelerated exposure test.

A reduction in alkalinity test incorporated by the United States Bureau of Reclamation in its specifications as an activity test was made. The test determination involved the determination of the reduction in alkalinity of the ground trachyte rock in a 1 N. sodium hydroxide solution as well as a determination of the soluble silica of the trachyte material which was released into the sodium hydroxide solution. The results thus obtained from this test were then compared to the specifications of the United States Bureau of Reclamation as well as to an empirical formula developed by Moran and Gilliland; both of which attempted to define the limits of pozzolanic activity for materials intended for general field service.

In connection with the activity tests previously mentioned, a reactivity with lime test for the ground trachyte material was also made. This test entailed the making of mortar specimens utilizing the ground trachyte material and testing them for compression at the age of 7 days. The results of this test were compared with the lower limit of compressive strength established in the specifications of the United States Bureau of Reclamation.

The strength and exposure tests were made by preparing 3" x 4" x 16" beams with 0, 20, and 30 percent ground trachyte rock replacements for the portland cement that was used. These beams were cured for 7 days in the moist room, 21 days in the air conditioned laboratory, and 2 days in water before subjecting them to the strength and exposure tests.

At the age of 7 and 28 days, length measurements were made on the beams to determine the effect of the trachyte material on drying shrinkage. The strength tests consisted of a modulus of rupture and compressive strength test.

The exposure test consisted of placing the beams in a tank where they were exposed to a continuous spray of water with cyclic temperature fluctuations from 70° F. to 135° F. for approximately 60 days or 1,920 such cycles. There were 32 temperature cycles per day. Length measurements were made on the beams to determine their percent of expansion. This exposure test was made to determine the capacity of the ground trachyte rock to inhibit cement aggregate reaction.

While preparing the beams, it was observed that the use of 20 to 30 percent of the ground trachyte rock does not materially modify the usual characteristics of freshly mixed concrete, but does improve the workability and the finishing properties as well as decreasing the air content of the mix.

Although the results from the reduction in alkalinity test indicated that the trachyte material was not active as a pozzolan, the lime reactivity test indicated that the trachyte material was an excellent pozzolan. The strength tests for the beams with ground trachyte rock replacements showed a good correlation with beams utilizing a similar amount of proven pozzolans. The accelerated exposure test indicated that the trachyte material, when used in increments of 20 to 30 percent, will inhibit cement aggregate reaction.