POZZOLAN OF ÇANAKKALE

by
GULTEKIN ORHON

Submitted to the Faculty of the Graduate School of
Robert College
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE

June 1966

Name: Gültekin Orhon

Date: June 1966

Institution: Robert College

Location: Bebek, Istanbul

Title of Study: POZZOLAN OF ÇANAKKALE

Pages in Study: 62

Major Field: Civil Engineering

Synopsis: The pozzolanic value of a volcanic tuff near Ezine, Çanakkale is determined. A literature survey on pozzolanic cements is made and methods for determining pozzolanic activity are discussed.

P O Z Z O L A N   O F   Ç A N A K K A L E

Thesis Approved:

Thesis Adviser

Dean of the Graduate School

TABLE OF CONTENTS

Chapter | Page

I. GENERAL INFORMATION ON POZZOLAN.................. 1
Introduction....................................... 1
History.. 3
Types of Pozzolans and Some Well Known Deposits. 4
Volcanic Tuffs and Pumicite................... 4
Opaline Materials............................. 5
Clay and Shales............................... 6
The Chemistry of Pozzolanic Reaction............ 6
Properties of Portland-Pozzolan Cement Mixes.... 8
A. Strength Properties........................ 9
1.Compressive Strength..................... 9
2.Tensile Strength......................... 13
B. Heat of Hydration.......................... 14
C. Permeability............................... 15
D. Resistance to Aggressive Waters(Sulfate Resistance)........................ 15
E. Alkali-Aggregate Reaction.................. 17
F. Volume Changes............................. 18
G. Weathering Resistance...................... 18
H. Other Properties........................... 19
I. Lower Costs................................ 19
Properties of Lime-Pozzolan Mortars............. 20

II. EVALUATION OF POZZOLAN......................... 23
A. Tests on Pozzolan Alone........................ 24
Chemical Composition.......................... 24
Lime Absorption Test.......................... 24
Petrographic Analysis......................... 24

Chapter Page

B. Tests on Pozzolan-Lime Mixtures................ 25
Time of Set Test.................................. 25
Compressive and Tensile Strength Tests.......... 26
1.National Standards.............................. 26
U.S.A. 26
a. Pozzolans for Use with Portland-Cement (ASTM C 340-64 T).... 27
b. Pozzolans for Use with Lime (ASTM C 432-65 T).... 28
Germany.. 30
Italy.. 31
Turkey... 32
2. Accelerated Test for Research Purposes....... 32
C. Tests on Portland-Pozzolan Cements............ 34

III. POZZOLAN OF ÇANAKKALE.......................... 36
General Information.............................. 36
Chemical Composition............................. 36
Petrographic Analysis............................ 38
Specific Gravity.................................. 38
Time of Set.. 38
Standard Tests
Pozzolanic Activity Test-ASTM C 340-64 T 39
Lime-Pozzolan Strength Development ASTM C 432-65 T 39
Hydraulic Strength Development ASTM C 432-65 T 40
Turkish Standard Tests-T.S. 29 40
Comparative Tests with Portland-Pozzolan Cement Mixes............................. 41
A. Strength Tests
1.Portland Cement Replacement on Weight Basis....................... 41
2.Portland Cement Replacement on Volume Basis....................... 42

Chapter Page

B. Permeability Test.................................... 44
Interpretation of the Results and Test Methods.......... 46
A. General and Standard Testing Methods............ 46
B. Comparative Tests.................................... 47
Discussion of the Test Methods for Determining Pozzolanic Activity.................. 51

IV. Conclusion.. 53

APPENDIX.. 55

REFERENCES.. 61

PART I

GENERAL INFORMATION ON POZZOLANS

INTRODUCTION

Pozzolans[1] may be defined as, " siliceous or siliceous and aluminous materials, which in themselves possess 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." (6)[2]

Pozzolans are finding wide usage in many countries in construction for improving the quality of concrete and for economic reasons. Turkey, a country which is producing only one type of portland cement, can make use of pozzolan-lime mortars for the construction of less important works, thus increase the amount and types of cement available in the market, also use use portland-pozzolan cement in important works to improve the quality of the concrete being used.

Natural pozzolans are clays, opaline materials and volcanic tuffs. Volcanic tuffs of Kayseri, Murat and Meriç have been exploited by Türkiye Çimento Sanayii for some time, Çorum Cement Factory is producing portland-pozzolan cement in the order of 30% replacement. (5,12,13) Quite an extensive research has been carried out in

----

[1] Most of the literature in Turkish employ the word <u>tras</u> derived from the German "Trass", which defines a specific pozzolanic material. The general name pozzolan will be used throughout this work.

[2] Reference numbers are given in paranthesis.

other areas.[1] Use of artifial pozzolans such as fly ash has also been investigated and recommended.(15) Most of these investigations are on the strength properties, and very little is known about the contribution of the materials to concrete properties such as sulfate resistance, permeability and heat of hydration. A detailed, planned investigation is required to make better use of this potential source of cement.

----

1. Yarar, (Ref.13), indicates: Muş (Merkez), Konya (Dedelik), Kayseri (Felâhiye), Yozgat (Akdağmadeni), Kırşehir (Kösker), Sivas (Divrik), Niğde (Gedikli), Konya (Halkapınarı), Manisa (Soma)

HISTORY

The use of pozzolans antedates recorded history. Probably by chance, the ancients discovered that some volcanic materials when combined with calcined lime greatly improved the quality of mortars. Furthermore these mortars would harden under water as well as air. The Greeks employed the volcanic tuff from the Island of Thera (now called Santorin, and still exploited as a pozzolan resource). The Romans used the red or purple tuff found near the Bay of Naples. The best variety of this material was obtained from the neighbourhood of Pozzolani or Pozzuoli, from where the name pozzolan is derived to designate all mineral matter that show similar properties. The Romans were probably the first to use the volcanic tuff of Rhine, which is known as 'trass'.

The quality of mortars declined during the middle ages, but still the Roman mixture of lime and natural or artificial pozzolans retained its position as the only suitable material for works under or exposed to water. Thus Belidor, a principal authority on hydraulic construction in the 18th century, recommends the use of natural pozzolans wherever available, as well as giving a method for making an artificial mix. In 1756, John Smeaton, upon being called to rebuild the famous lighthouse on Eddystone Rock, made some tests with Dutch Tarras and lime, and in the end employed a mortar prepared with hydraulic lime and pozzolan in equal quantities. (2)

After the development of natural cements during the latter part of the 18th century, and portland cement in the early 19th century, the practice of using pozzolanic cements declined. Although it has been known to engineers that the use of pozzolans with portland cement impart desirable qualities to mortars and concrete, engineers have been extremely cautious about the use of such combinations. Only in the last score have portland-pozzolan mixes come into general recognition as effective cementing materials.

TYPES OF POZZOLANS AND SOME WELL KNOWN DEPOSITS

Pozzolans in general, are classified as natural or artificial. Artificial pozzolans come from the industrial by-products or wastes and include fly ash, such as is produced in powdered-coal burning power plants, powdered brick, burnt oil shale and some slags. Water quenched blast-furnace slags have cementitious qualities in themselves and therefore fall outside the true pozzolan classification.

Naturally occurring pozzolans may be classified into the three distinct groups, namely: Volcanic tuffs and pumicite, opaline materials, clays and shales.

Volcanic tuffs and pumicite:

Ashes and lavas of identifical mineorological composition, forced to solidify as a glass by melting and subsequent quenching, acquire pozzolanic properties. These can be of rhyolitic, andesitic, phonolitic or basaltic types. It should be noted that crystalline volcanic ashes do not show pozzolanic action. The action of true natural pozzolans is determined by the type of original magma, and principally the origin history of the pyroclastic material, on which depends the quantity of glassy fraction and its extent of alteration.

The Italian pozzolans occur near Vesuvius, Naples and Rome. The material is obtained from open pits or quarries. They are pyroclastic, incoherent materials that originated from explosive types of volcanic eruption. The particles of pulverized magma entrained by the gases went through a strong quenching process which made them rich in glassy substance. This glassy substance is unstable and it can undergo zeolitization, which generally enchances pozzolanic activity, or alteration towards the clay minerals, which usually reduces or diminishes pozzolanic activity.

Compact volcanic tuffs, which are used in the pulverized state are quite different from the Italian pozzolans. They originate from the same pyroclastic materials, but involve a transformation process. The best known example is the Rhenish 'trass' obtained by grinding the soft tufaceous trachytic(alkali feldspar) rock found in some parts of Germany. The alteration of the original natural glass has induced cementation of the pyroclastic, incoherent original material, hence caused zeolitization. The final product, that is, tuff, is more reactive to calcium than the original starting material, pozzolan. (9)

There are pozzolans of volcanic origin in Japan, which was first to employ portland-pozzolan cement, Russia, U.S.A., Romania, New Zealand and on the Grecian Island of Santorin.

Opaline materials:

Opaline materials are amorphous forms of hydrous silica with three to twelve per cent water, $SiO_2 \cdot nH_2O$. Among them cherts, which are siliceous sedimentary rocks, and diatomaceous earths composed of the siliceous skeletons of diatoms deposited from fresh or sea water can be mentioned.

There are deposits in Denmark, California, Canada, Algeria and Germany. Except for the Danish deposits, treatment is required to benefit from their pozzolanic character due to the great water requirement which makes the cementing value poor.

Clays and shales:

Clays and shales of montmorillonite,kaolinite and illite types acquire noticable pozzolanic character only upon calcination.The Romans employed clays as a substitute for volcanic ash pozzolan. Horasan,the traditional Turkish cement was also made from burnt clays.Burnt clay has been employed as an addition to lime mortars in India and Egypt,known as Surkhi and Homra respectively, and used in dam and waterworks.

THE CHEMISTRY OF POZZOLANIC REACTION

The chemical and physical mechanisms by which pozzolans react with lime are not fully understood as yet.What R.H.Bogue said in 1947,still holds today;

"The chemistry of pozzolans is still not solved...and only when the chemical action is completely understood will it be possible to design a 'pozzolan' of ideal composition for any particular purpose."However the results of continuous research shed some light on the problem.

Investigations have shown that the amorphous silicate reacts with calcium hydroxide to form a hydrous mono-calcium-silicate, which is compound of relatively low solubility.(2,9,11)

$$SiO_2\cdot H_2O + Ca(OH)_2 + nH_2O \longrightarrow CaO\cdot SiO_2\cdot(n+2)H_2O$$

Further research with X-Ray Diffraction and Differential Thermal Analysis,D.T.A.,have shown a reaction product of calcium-aluminate hydrate, most probably Strätling's Compound, $2CaO \cdot Al_2O_3 \cdot SiO_2 \cdot nH_2O$ (2,9)

Therefore silica and alumina are the main pozzolan constituents that enter the pozzolanic reaction with lime. Table 1. shows the typical chemical composition of some well known natural pozzolans(2) (2,5)

TABLE I

Percentage Composition of Some Pozzolans

POZZOLAN	LOSS ON IGNITION	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	$Na_2O + K_2O$	SO_3
Rhenish Trass	10.1	54.6	16.4	3.8	3.8	1.9	9.0	0.4
Santorin Earth	4.9	63.2	13.2	4.9	4.0	2.1	6.5	0.7
Rome: Segni	5.3	48.2	21.9	9.6	7.5	3.2	4.1	0.3
Rumanian Trass	13.9	62.5	11.6	1.8	6.6	0.7	2.9	-
U.S.A.:Pumicite	3.4	65.7	15.9	2.5	3.4	1.3	6.9	-
Burnt clay	1.6	58.2	18.4	9.3	3.3	3.9	3.9	1.1
Diotimite	8.3	86.0	2.3	1.8	–	0.6	0.4	-
Kayseri Poz.	2.6	63.1	18.6	5.6	5.1	1.6	-	-

The rate at which a finely divided siliceous material combines with $Ca(OH)_2$ apparently depends on a number of factors, most of which are not clearly understood. Any siliceous material, regardless of its mineral structure or composition, if of sufficiently high fineness will combine with $Ca(OH)_2$ at normal temperatures, though the rate of combination may be slow for some materials. K.M. Alexander(10), working with ultrafine powders (with surface areas up to 140,000 cm^2/gr) of various sliceous materials comes to a conclusion that an upper limit of activity can be attained by grinding, which is the same for all materials, regardless of whether they would be classed as pozzolanic, weakly pozzolanic or inert when ground to the usual fineness specified for pozzolans.

Generally speaking, however, silica in the amorphous form reacts with $Ca(OH)_2$ much more rapidly than does silica in the crystal forms, and pozzolans high in alumina have a much higher reaction rate.(8) Therefore we may say that active pozzolans are those which have a high alumina and amorphous silica content.

The rate of pozzolanic reaction is also determined by the prevaling temperatures. Examinations with D.T.A. have shown the pozzolanic reaction to be endothermic. Hence, pozzolanic reaction is accellerated at high temperatures and retarded at lower ones.

PROPERTIES OF POZZOLAN-PORTLAND CEMENT MIXES

Pozzolans are used with portland cement on account of their property of combining with lime and thereby removing the $Ca(OH)_2$ liberated during the setting of the portland cement. Calcium hydroxide which makes little or no contribution to the strength of the set cement is thus removed and a lime-pozzolan compound of cementitious value is formed.

The original use of pozzolans with portland cement was the improved durability, combined with some economy obtained in marine and hydraulic structures. The reduction of heat of hydration provided another reason, and finally it was found that alkali-aggregate reaction could be prevented with pozzolanic use. In the last score pozzolanic cements have been developed as constructional elements. Thus in countries such as Italy, Germany and the U.S.A. it is possible to buy 30-40% pozzolan containing cements and use them for general building construction.

Pozzolans are used with portland cement as admixtures or substitutes. For reasons of economy there is a tendency to use them as substitutes, though it is beyond doubt that their use as admixtures will result in much better concretes.

Since the composition and the amount and character of active substance is different for every pozzolan, what the properties of a certain mix will be, can never be predicted unless tests are run on the specific materials in use. But all portland-pozzolan cements show a general tendency in concrete properties which will be discussed below.

A. STRENGTH PROPERTIES

1. Compressive Strength

The substitution of pozzolans for portland cement always reduces the strength obtained at the early ages, though the ultimate strength attained may be increased. The difference between good and indifferent pozzolans is much more marked at long than in short ages when in any case most of the strength comes from the portland cement constituent. Hence the greater the substitution the less is the early age strength.

Figure I. shows the effect of replacement, tested on 6-12 inch cylinders cured under moist conditions. The values are the averages of ten to twenty types of portland-pozzolan mixes, that is pumicites, diatomaceous shales and earths, volcanic ashes, raw and burnt clays, hence show the general tendency of pozzolans. (1)

FIG. I

COMPRESSIVE STRENGTHS OF PORTLAND & PORTLAND-POZZOLAN CEMENTS

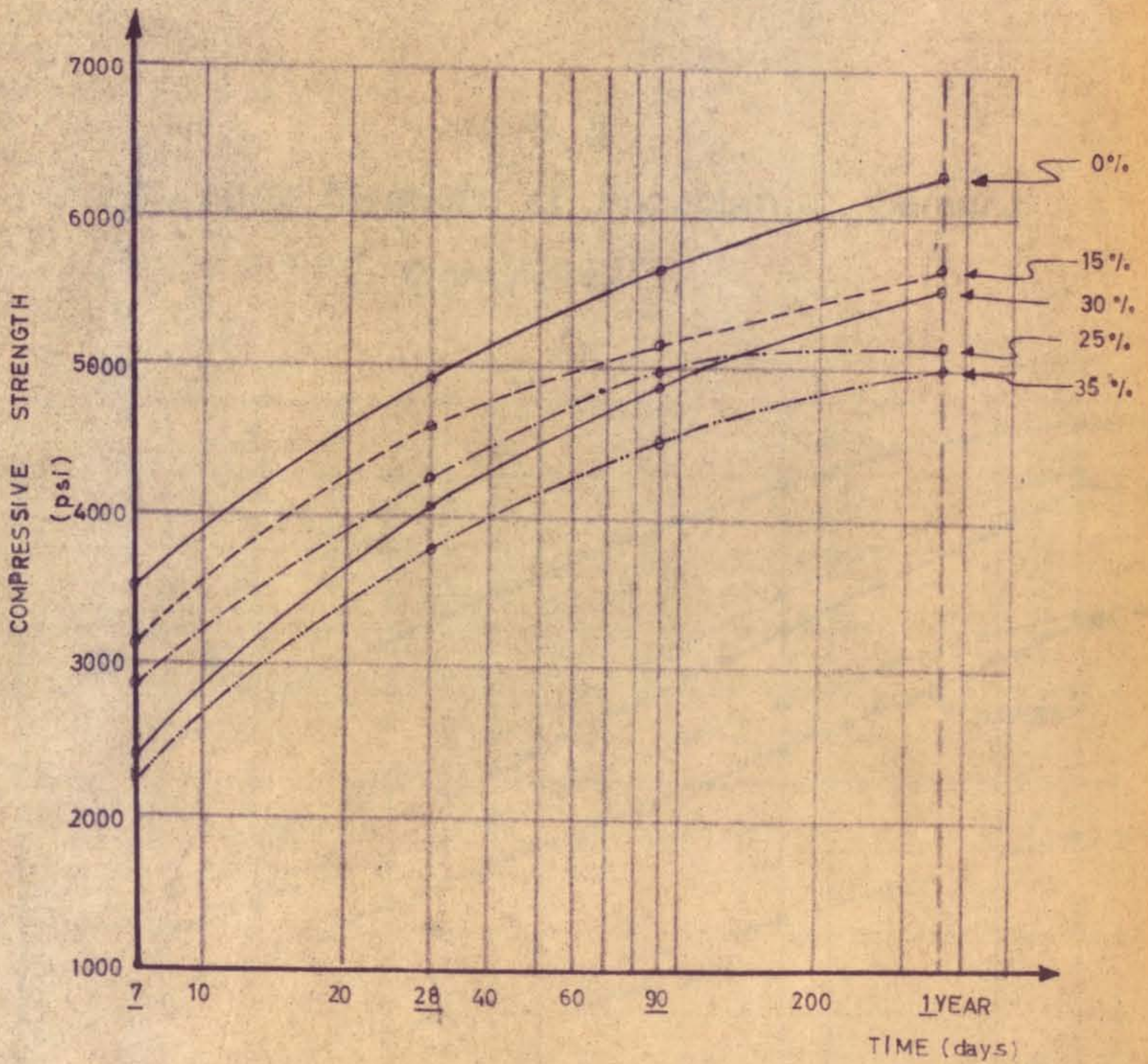
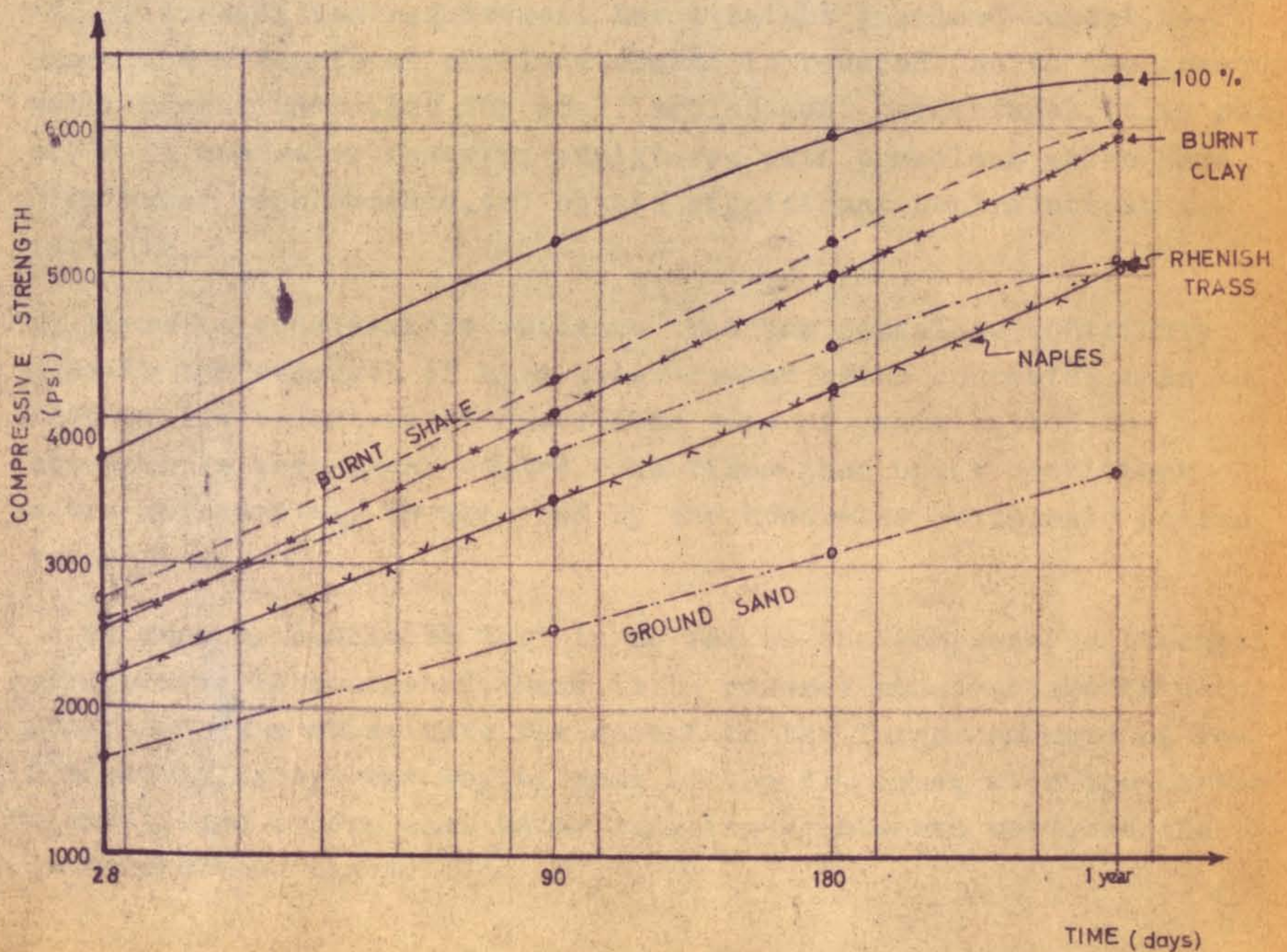


Fig.II shows the compressive strengths of pozzolanic cement concretes.The tests were run on 4-inch cubes stored in water at 20°C.Cement : sand : aggregate ratio is 1:2:4,water : cement ratio is 0.60.Pozzolan substitution is 40% on volume basis.(2,pg.381)

FIG. II

Compressive Strength of Pozzolanic Cement Concretes



For the richer mixes, under conditions of moist curing, concretes containing pozzolans in the order of 20 per cent or more, generally exhibit a later-age strength which is lower. In some cases the later age strength may approach or slightly exceed that of corresponding concretes containing straight portland-cement. Fly ashes of high fineness and low carbon content, used in 20-30 per cent replacement reach equal strenght at three months and show higher strengths at the age of one year. (8)

In general, pozzolans contribute more to the strength of lean mixes than rich ones, and under moist curing this contribution may exceed that of replaced portland-cement at the later ages. This is not true if the water requirement for a given consistency substantially exceeds the requirement for straight portland-cement, because the strength of portland-cement is reduced due to the greater water-cement ratio. But for small replacement percentages, it is possible to use water-reducing admixtures with pozzolans which have high water requirements, and obtain significant contributions to strength.

There is considerable evidence that the pozzolans contribute more to the strength of high water-cement ratio concretes than to that of low cement-ratio ones. Their rate of contribution to strength is less under sealed conditions than under conditions where moisture may be absorbed by the concretes pozzolanic action takes place.

It must be concluded that in so far as the compressive strength of concrete is concerned, there is in general no advantage in using pozzolans as a substitute for cement in the larger amounts of replacements. Exceptions may be some of the fly ashes with low carbon content, some others when water reducing agents are used, and the leaner, harsher mixes.

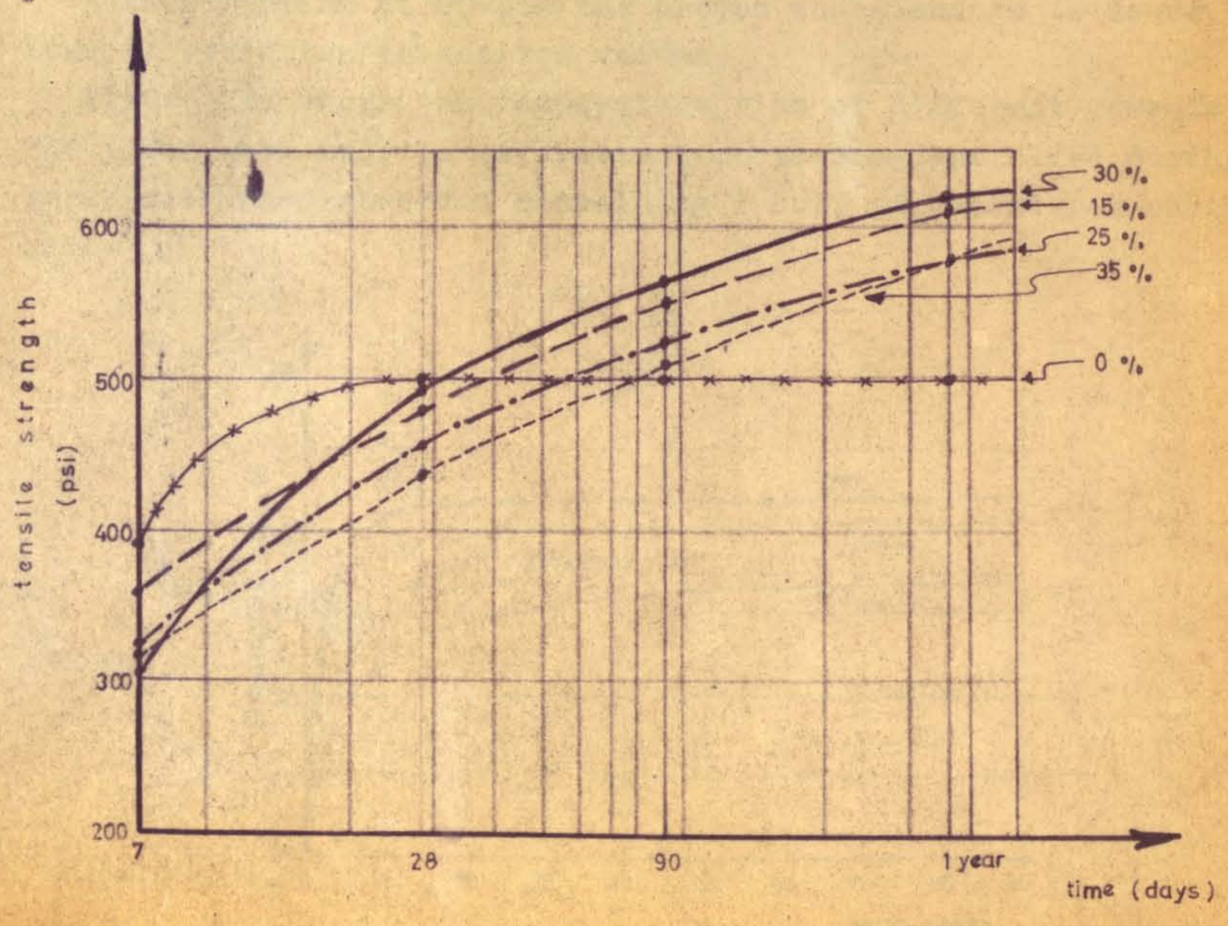
2. Tensile Strength

The tensile strength of portland-pozzolan mixes are almost always higher than straight portland cements. With only a 20% substitution the tensile strength often equals that of portland cement at 90 days and exceeds it at later ages.

Figure III. shows the effect of replacement tested on briquettes which were cured under moist conditions. The values are the averages of ten to twenty types of portland-pozzolan mixes, that is pumicite, diatomaceous shales and earths, volcanic tuffs, raw and burnt clays, hence show the general tendency of pozzolans.

FIG. III

TENSILE STRENGTHS OF PORTLAND & PORTLAND POZZOLAN CEMENTS



B. HEAT OF HYDRATION

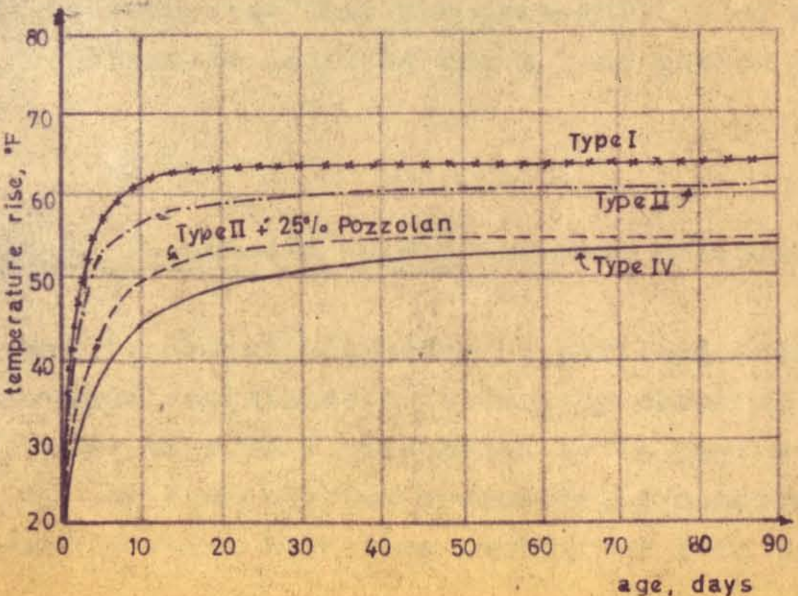
If pozzolans are used as a substitute, the heat of hydration is reduced, though not proportional to the degree of substitution since the pozzolanic reaction is also involved. For some pozzolans it has been observed that the rate of hydration is quite greater for the mix than for portland cement alone. This is a desirable property in mass construction since more heat will be liberated before the next lift is poured.

Heat of hydration at 28 days is higher for the more active pozzolans such as diatomaceous earths and opaline shales than for the less active ones, that is, pumicite and volcanic tuffs. As a rough approximation the percentage of reduction in the 28-day heat of hydration can be taken as about one half the percentage of replacement. (8)

A substitution of 20-30% has proven to be enough to lower the heat of hydration to desired values.

Figure IV. shows the temperature rise of different cements. The tests were made in adiabatic temperature-controlled curing rooms with mass concrete containing 1 bbl. of cement per cubic yard. (1)

FIG. IV



C. PERMEABILITY

One of the most important properties of pozzolans, whether used as additives or as substitutes, is their ability to reduce the permeability of the concrete mix. This property is not so pronounced in early ages, but at later ages particularly under wet curing conditions it becomes very obvious.

Pozzolans of opaline character are more effective in reducing the permeability at the early ages than the glassy pozzolans such as pumicite and fly ash, and the leaner the concrete the more beneficial is the effect of pozzolan. For example, a calcined opaline shale used as 25% replacement for a 4-sack mix may reduce permeability by one half in 28 days, and a 3-sack mix by three fourths, whereas a glassy pozzolan replacement may show no change. (8)

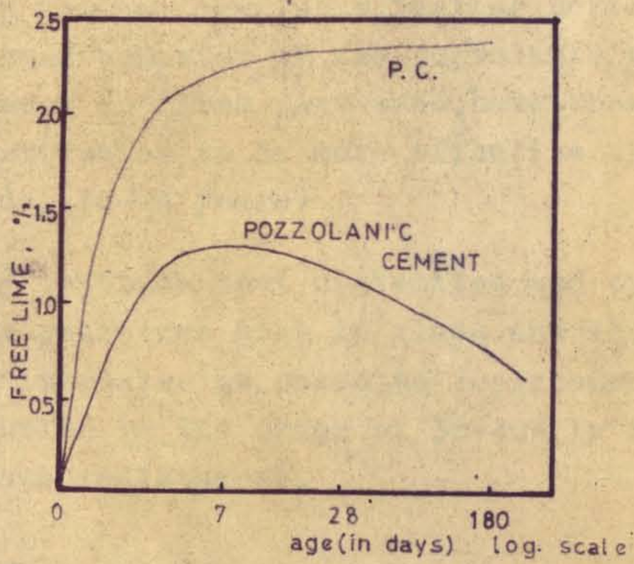
However, the permeabilities of concretes containing replacements are generally just a fraction of the straight portland cement mixes at later ages. At the age of six months, for concretes of equal water content (corresponding to about 0.75 water-cement ratio for portland cement cocrete) the effect of a 30% replacement of a pumicite or fly-ash is to produce a permeability which is only $^1/_3$ to $^1/_5$ of the straight mix. Though tests for later ages is not available, it is suspected that the permeability of replaced concretes will continue to decrease for a long period under moist conditions.

D. RESISTANCE TO AGGRESSIVE WATERS (SULFATE RESISTANCE)

Another very important character of portland-pozzolan cements is their increased resistance to attack by chemical agencies, particularly sea-water. This phenomenon is in part attributed to the removal of the free calcium hydroxide, by combination with pozzolan. Figure 5 shows free lime content of 1 to 3, cement: sand mortars,one straight portland cement,the other 60% portland cement

FIG. V

FREE LIME CONTENT OF MORTARS



plus 40% burnt clay.(2)

Lafuma has suggested that the combination between an insoluble set cement compound in the solid state and a substance in solution always causes expansion,but if the cement compound passes into solution,reacts,and then precipitates as a solid,no expansion occurs.(2).It is known that the solubility of the hydrated calcium aluminates increases as the lime percent in solution falls.Hence Lafuma's theory can be used to explain why the sulfate reaction occurs without expansion in portland-pozzolan cements,whereas expansion takes place in straight portland cement.

Turriziani and Rio have given a different explanation.They suggest that ettringite,($3CaO{\cdot}Al_2O_3{\cdot}3CaSO_4{\cdot}31H_2O$,the compound formed upon sulfate attack,which causes the swelling)formation is slowed down because of the higher sulfate concentration is lowered.

These explanations are not the sole reasons to resistance of pozzolanic cements.We may add the increased impermeability and formation of protective silica films over the more vulnerable alumina compounds.

Accelerated tests for determining the sulfate resistance of pozzolanic cements are not available.Testing periods in the order of months do not show behavior of the pozzolanic cements.Feret's tests on one part cement to three part sand,have shown burnt gaize and burnt clay substitution to be more effective than volcanic tuffs, for long periods.(10-24 years)

Hence we may conclude that diatomites and opaline materials are superior to the pozzolans high in glass and that the resistance to sulfate action increases as pozzolán replacement increases.In general,a substitution in the order of 30-40% is required to obtain desirable sulfate resistances.

E. ALKALI-AGGREGATE REACTION

In regions where reactive aggregates are encountered,pozzolans are successfully employed in counteracting the delayed excessive expansion of these aggregates due to the action of alkali coming from the cement or other sources.How pozzolans prevent,this is not clearly understood,though it is suspected that the finely divided silica in pozzolanic materials is readily available for reaction with the alkali ,and most of the deleterious reaction takes place before the concrete hardens,thus reducing or eliminating the excessive expansion.

Some of the pozzolans high in opal,when used as 15-20% replacements prevent excessive expansion even though the cement may be very high in alkali.The glassy pozzolans are not as effective , hence greater replacements are required to achieve the same end. Some clays,opalines shales and diatomites can be improved to prevent alkali-aggregate reaction by calcination.

F. VOLUME CHANGES

In general portland-pozzolan cement concretes expand slightly more under continuously wet conditions and shrink substantially more under continuously dry conditions than do straight portland cement mixes.The drying shrinkage is roughly proportional to the magnitude of replacement.The pozzolans high in opal show great drying shrinkages.The pozzolans high in volcanic glass show an intermediary trend.

In some cases,though the drying shrinkages are high,portland-pozzolan mixes show a crack resistance not very different from straight portland cement.This is not the general case however,and with the exception of some fly ashes,pozzolans should not be employed in thin concrete structures subject to continuous drying conditions,unless precautions against drying shrinkage is taken.(8)

G. WEATHERING RESISTANCE

The weathering resistance,as determined from freezing and thawing tests is less for portland-pozzolan concretes.The substitution of pozzolans naturally leads to less air entrainment.If air-entraining agents are employed the resistance of portland-pozzolan cements may be substantially increased,sometimes being greater than straight air-entraining portland cement.

Freezing and thawing tests on concretes moist cured up to four or five months show resistance,as measured both by losses and changes in length,quite near to straight portland cement,though the tests on 28-day specimens may show poor properties.

Therefore,if air is entrained,and the concrete protected long enough for the pozzolanic reaction to take place,no adverse affects of weathering will be seen.

H. OTHER PROPERTIES

1. The creep of concrete in both tension and compression is greater when pozzolans are employed. Other things being equal, the larger the percentage replaced, the higher is the creep.
2. The substitution of pozzolans generally improves the workability of the mixes.
3. Use of pozzolans in the order of two percent may prevent segregation of the concrete.(8)

I. LOWER COSTS

Pozzolans are much cheaper to obtain than portland cement. Save the clays and some shales which usually need calcination, most pozzolans require only grinding the material which generally consists of loosely bound small particles. Hence great economy can be achieved through pozzolan substitution. In a project in the U.S.A., $ 1,976,250 were saved on pozzolan substitution, for which the pozzolan was delivered well over 1000 miles distance.(1)

PROPERTIES OF LIME-POZZOLAN MORTARS

Lime-pozzolan mortars have been used by the earlier civilizations as a cementing material, and their behavior in time is a good indication of their durability and strength carrying properties. Today lime-pozzolan mortars enjoy a good reputation in Europe particularly in Italy, for sea-water work.

The traditional mortar is one volume slaked lime putty to two volumes unground pozzolan and three to four volumes of aggregate, but there is a tendency to use one to three lime:pozzolan ratio while holding the cement:aggregate ratio one to two.(2) The rate of hardening is slow, but it can be increased by grinding 15-20% of the pozzolan to cement fineness, or adding some portland cement to the mix. With some of the more active pozzolans it becomes possible to expose the structure to the wash of the wawes within a day of placing. Lime-pozzolan mixes are not favored in Northern Europe due to the slow rate of hardening because of low temperatures.

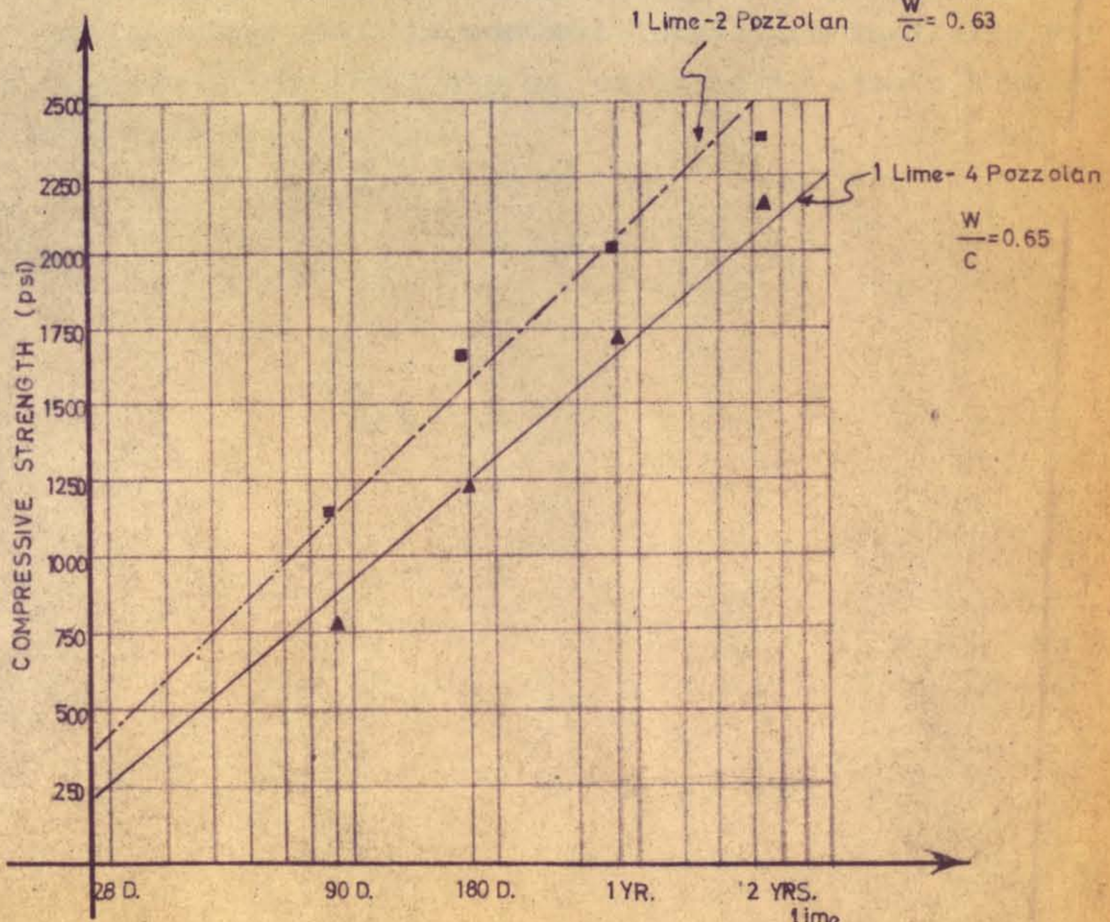
High calcium limes are normally used in lime-pozzolan mixes, though the use of hydraulic limes is also possible. The strength developed varies with the lime:pozzolan ratio as well as the other factors such as specific area, water available and environmental temperature. Since the reaction is of complex nature involving silicates, aluminates and calcium hydroxide, the amount of active substance in the pozzolan and calcium hydroxide in the lime putty is of main importance. A general tendency has been observed that higher early strengths are obtained with a low lime:pozzolan ratio such as 1:4, and higher later age strengths are obtained with higher lime:pozzolan ratios such as 1:3 or 1:2.

Feret has obtained copresive strengths of 1640 psi and 1850 psi for German Trass and Roman Pozzolan respectively at the age of one year for plastic mortars containing 1:3 cement:aggregate ratio in which the lime:pozzolan ratio is approximately 1:3.(2)

The 8x4 inch cylinder strengths of lime-pozzolan mortars of two-inch slump are given below, Fig. 6. The specimens were stored in water at 18°C after an initial storage of 14 days in moist air. Cement:sand:gravel ratio is 1:1.5:2.67 by weight.(2)

FIG. VI

COMPRESSIVE STRENGTHS OF LIME-POZZOLAN MORTARS



Small additions of gypsum,1-3%,to the lime-pozzolan mix sometimes has a favorable effect on the strength at early ages,but the effect is erratic and can not be predicted.In Italy larger percentages such as 5% have been employed,and are stated to accellerate setting and hardening of volcanic ash pozzolans and give a high resistance to attack by sea-water.(2)

Lime-pozzolan mortars attain much higher ultimate strength when cured in water than air,though the initial effect is normally the reverse.As a rule,a long period of moist curing is essential to the development of higher strengths,and rapid drying has most injurious effects.

Pozzolanic reaction also the forms the basis of soil stabilization with lime.Lime,usually in the percentages of 5-12,is added to clay type pozzolans such as montmorillonite and kaolinite.For economic considerations clays are not calcined to obtain higher strength properties.

PART II

EVALUATION OF POZZOLANS

Scientists have been working on methods to determine the pozzolanic characteristics of materials over a hundred years, and there seems to be no satisfactory method yet developed to apply to all materials to be used in any construction. The difficulties arise from three sources:

1. Pozzolanic materials as found, have different chemical composition as can be seen from table 1, different histories, and hence different amounts of active substance that plays part in pozzolanic reaction.

2. Pozzolans having no cementitious value themselves, must be tested with lime or portland-cement to demonstrate their cementing qualities. The pitfalls involved in trying to use commercial lime or portland-cement as a reagent in a standardized test procedure are obvious.

3. Since pozzolans are generally employed for specific purposes, it is hard to make a general test which will predict all the specific properties to be obtained.

In spite of the above listed difficulties, investigators have not been easily discouraged; methods have been developed, and national standards have been accepted, even though they may be very different from each other.

A. Tests on Pozzolan Alone

Chemical Composition:

Although it is generally agreed that the silica and alumina are the active portions of a pozzolan, no correlation has been shown between the analysis and the activity. This arises because there is no indication of the amount of the more active amorphous substance. The results of chemical composition can be used tentatively by comparison with other known pozzolans.

Lime Absorption Test:

The oldest test for pozzolans is the one proposed by Vicat in 1837, in which the rate of absorption of lime from a calcium hydroxide solution is measured. This test both in its original and modified forms has some limited value for distinguishing between active and inert materials, but affords no adequate guide to the value of a pozzolan in use. A correlation between the lime absorbed and the strength of portland-pozzolan cement mortar cubes has been shown for 90-Day testing. Réference 8, page 113 can be consulted for the details of a method used by the U.S.B.R.

Petrographic Analysis:

Petrographic examination and analysis of pozzolans provide valuable information supplementary to that obtained from standard physical and chemical tests. Through microscopical observation, the mineralogie composition, petrographic identity and the particle size distribution may be established, and by this means, the constituents known to contribute to pozzolanic activity are identified and their amounts estimated. Thus, the potential activity of the material and the need for preliminary treatment or grinding can be established prior to initiation of time-consuming tests.

Microscopical study is particularly useful for pozzolans containing amorphous materials, such as opal and volcanic glass. Weathering and alteration, factors which affect the chemical activity of pozzolans, are recognizable when the materials are examined petrographically.

Pozzolans of volcanic origin hardly benefit from calcination, whereas clays of kaolinite and montmorillonite groups are activated by calcination in the temperature range of 900-1800°F. Therefore petrographic study serves as a guide to expected behavior upon calcination.

Petrographic analysis, coupled with X-Ray diffraction, is also a useful technique for evaluating the effectiveness of pozzolans in controlling alkali-aggregate reaction.

Petrographic investigation requires expensive equipment and a skilled petrographer experienced in the study of pozzolanic materials.

B. Tests on Pozzolan-Lime Mixtures:

Time of Set Test: (8)

This test is conducted by preparing a paste of pozzolan and a commercial grade of hydrated lime in the ratio of 4 to 1 by weight. The mixture is gaged with sufficient water and mixed by hand to produce a paste of normal consistency. (6) The resulting paste is then placed in a small cylindrical glass Jar, covered with a layer of saturated lime water, which is in turn covered with a film of karosene or transparent oil in order to prevent ingress of carbon monoxide from the atmosphere and any excessive evaporation. A intermittent time intervals, the paste is tested by means of the standard Vicat needle to determine when initial and final set occurs

Initial test is considered to have occured when the needle is retarded 35mm. from the upper surface of the paste in 30 seconds. When the needle shows no appreciable indentation on the specimen surface, the final set is considered to have occured.

The degree of rapidity of both the initial and final set is taken as a measure of the activity of the particular material under investigation. On the average, active pozzolans will show an initial set in less than 50 hours, and a final set in less than 100 hours, whereas poor or intermediate material will range from these values to no set. Inactive materials will not set under this procedure. This method is limited in that it does not afford a direct measure of the relative degrees of activity between various pozzolans. It is of value only in differentiating, qualitatively, the efficiency of different materials.

Compressive and Tensile Strength Tests:

Compression and tension tests of sand mortars are the methods most commanly accepted universally for evaluating the efficiencies of natural or artificial pozzolans.

1. National Standards

Each country has its own method according to the character of the most abundant type of pozzolan and the climatic and industrial conditions. Some of the typical test requirement and methods are given below:

U.S.A.:

A.S.T.M. makes a distinction between pozzolans used with lime and pozzolans used with portland cement, and gives different methods for testing the materials. In general better physical and chemical properties are required for the pozzolans to be used with portland cement.

a. Pozzolans for Use with Portland Cement (ASTM C 340-64 T)

In addition to the requirements of the portland-pozzolan cement, the standard asks for the the pozzolanic activity of the material to be confirmed by the 'Pozzolanic Activity Test'.

-Standard Materials:

Pozzolan: Percentage retained when wet sieved on a No:325 (44μ) sieve........... max. 12%

Lime (ASTM C-6): The chemical composition should be such that;

Calcium and magnesium oxides....... min. 95%
Carbon dioxide..................... max. 5%
Magnesium oxide.................... max. 5%

Percentage retained on No:325 sieve max. 5%

Sand (ASTM C-109): Natural silica sand from Ottowa, graded as;

Sieve No.	% Retained
100	98 ± 2
50	72 ± 2
30	2 ± 2
16	None

-Proportioning: 1 part lime : 2N parts pozzolan, where N is a factor obtained by dividing the specific gravity of pozzolan by the specific gravity of lime : 9 parts sand : water to give a flow of 110 ± 5. (Flow table dropped 25 times in 15 seconds)

-Molds: Cylindrical molds 2 in. in diameter, 4 in. high.

-Storage: Molds are sealed by soldering or some other means and the specimens are kept in the molds at 23 ± 1.7°C the first day, at 55 ± 1.7°C the next six days, and cooled to 23 ± 1.7°C before testing.

-Requirement: Pozzolanic strength at 7 days.... min. 600 psi

b. Pozzolans for Use with Lime (ASTM C 432-65 T)

This specification asks for two different tests to be run. One test is to determine pozzolanic activity, whereas the other ascertains that the material does not posses cementitious properties in itself.

1. Lime-Pozzolan Strength Development

-Standard Materials:

Pozzolan: Moisture content............ max. 10%
Loss on ignition............ max. 10%
Amount retained when wet sieved on... No.30 sieve.... max. 2%
No.200 sieve... max. 10%

Lime: Shall be the same as that to be used on the job, or contain; (ASTM C-207)

Calcium and magnesium oxides.......... min. 95%
Carbon dioxide........................ max. 5%

Percentage retained on No.30 sieve.... max. 0.5%

Sand: Natural silica sand from Ottowa, graded as previously noted, ASTM C-109.

Proportioning: 1 part lime : 2 parts pozzolan 8.22 parts sand : water to give a flow of 70 ± 5. (Dropped 10 times in 6 seconds)

Molds: 2 inch cube molds.

Storage: Specimens are placed in a closed vapor oven at 55 ± 1.7°C upon preparation, and left to stay there two days. They are removed from the molds and kept in water at 55 ± 1.7°C for the next five days, and in a moist room of 95-100% relative humidity for the next 28 days.

Requirement: Compressive strength;

After 7 days at 55 ± 1.7°C..........min. 600 psi
After additional 28 days.......... min. 600 psi

2. Hydraulic Strength Development

Test as the previous except that for proportioning use 1 part pozzolan : 2.74 parts sand.

Requirement: Compressive strength;

After 7 days at 55 ± 1.7°C......... max. 100 psi
After additional 28 days.......... max. 150 psi

If specimens too weak for removal from the molds at 48 hours, no further testing is required and the strength is reported as 'no strength'.

GERMANY (2,5,16)

Standard Materials:

Trass: Percentage retained on a 0.18 mm sieve(No.900 of the German Standards corresponding to No.80 of the ASTM) .... max. 20%

Combined water..................... min. 7%

Lime: The source and the manner of its hydration is specified. Limestone, containing a minimum of 99.5% $CaCO_3$, will be burnt at 900°C minimum temperature. The better portions will slaked and kept sealed. Prior to usage, lime will be hydrated at 90-95°C, and ground to pass a 0.18 mm sieve.

Proportioning: 0.8 parts lime : 1 part trass : 1.5 parts sand : 16-17.5 % of the total dry mix of water.(2) This gives a dry mix and a Boehme Hammer Machine is employed to compact the specimens.

Storage: The specimens are stored at 17-20°C in humid chambers for the first three days, and in water till the time of test at the same temperature.

Requirement:

	7 Day	28 Day
Tensile Strength, psi	71	228
Compressive Strength, psi	640	1990

ITALY (2)

Standard Materials:

Pozzolan: The pozzalan should be of such fineness that it pass a 3mm sieve. This sieve is approximately equivalent to No.7 of the ASTM.

Lime: Of such fineness to pass a 0,18 mm sieve. Contain 94 % calcium oxide, min.

Proportioning: 1 part Lime : 3 parts pozzolan : Water to give a consistence such the mix will agglomerate under hand pressure.

Storage: The specimens are kept in moist air at 15-20°C for the first seven days, and in water at the same temperature for the next 21 days.

Requirement:

28-day Tensile Strength, psi.......71
28-day Compressive Strength, psi..355

TURKEY- T.S.25-26-27-28-29

In the Turkish Standards pozzolans are defined as;

''From the view point of building tecnique, tras is a volcanic tuff which, in finely divided form can strengthen in air or water when combined with slaked lime.'

The standards follow the procedure of the German Standards, except that there is no mention of the combined water and the strength requirements are lowered as;

	7 Day	28 Day
Tensile Strength, psi	71	199
Compressive strength, psi	640	1280

2. Accellerated Test for Research Purposes (2)

Lea proposes an accellerated test for determining the later age strengths of pozzolans. In this test 1:2:9 lime : pozzolan : standard sand briquettes are cured in moist air at 18^{o}C for seven days, then immersed in water in a container which can reach 50^{o}C within 1.5 hours. The briquettes are kept at 50^{o}C for 46 or 94 hours and placed in water at 18^{o}C for two hours prior to testing. Both of these curing treatments give strengths that show a fair correlation with the strength developed at 90 days at normal temperatures, but the 94 hour curing gives the better correlation with the strength at 180 days.

Table II. shows the tensile strengths of 1:2:9 hydrated lime : pozzolan : standard sand plastic mortars. (2,pg 389)

POZZOLAN	% WATER IN MORTAR	TENSILE STRENGTH (psi)					
		STORED AT 18°C			CURED AT 50°C		
		14-D	28-D	90-D	14-D	28-D	90-D
Good Burnt Clay	13.5	173	294	414	445	404	405
Good Burnt Clay	13.5	173	294	414	445	404	405
Good Burnt Clay	15.1	57	164	300	312	313	355
Poor Burnt Clay	15.5	34	67	119	143	66	91
Good Burnt Shale	14.1	41	105	303	351	204	395
Trass	13.7	92	184	257	275	285	317
Bacoli(Naples)	12.8	56	122	300	300	269	315
Santorin Earth	13.0	0	63	284	361	181	283
Burnt Brick	12.8	0	0	98	233	37	147

Longer periods of curing at 50°C, or curing at 100°C, are not suitable, since relatively inert materials then develop strength.

3. Tests on Portland-Pozzolan Çements:

Most of the tests on portland-pozzolan cements are aimed at finding a correlation between the strength and the $Ca(OH)_2$ content of the mix. Among them we can mention methods for determining insoluble residue and uncombined lime, resistance to leaching and lime solubility. (8)

Lea (2, pg. 393) has proposed an accelerated test based on strength property. The method takes advantage of the difference between the acceleration of hardening of portland cement and pozzolanic cements when cured at 50^o. At ages up to 7 days the pozzolan contributes very little to strength at ordinary temperatures, but at 50^o it makes a substantial contribution depending in magnitude on the proportion and activity of the pozzolan present. This increase in strength from the pozzolan is considerably greater than any change in the portland cement strength between the two conditions so that the difference between the strengths developed at 18^o and 50^o affords a measure of the value of the pozzolan present. Either tensile or compressive tests can be made, using a 1:3 cement:standard sand mortar of a standard plastic consistence or at a fixed water:cement ratio of 0:40. One set of specimens (6 for tensile briquettes, 3 for vibrated mortar cubes) is cured at 18^o for 7 days (1 day moist air, 6 days water) and another set for 1 day in moist air and 4 days in water at 18^o, then 46 hours in water at 50^o, followed by a final 2 hours in water at 18^o.

The strength difference increases with the proportion of pozzolan and is considerably greater for good pozzolans than for a poor one or an inert material.

For cements with a fixed pozzolan content, the strength difference shows a correlation with the contribution the pozzolan will make to the strength of concrete at an age of 6 months or a year. The strength difference is not, of course, a measure of the absolute strength for this depends also on the portland cement. For a 40 per cent pozzolan content, the strength difference for this particular form of strength test should not be less than about 2000 lb. per sq. in., and for a 20 per cent content about 1500 lb.

PART III

POZZOLAN OF ÇANAKKALE

General Information:

The information on the pozzolan deposit was obtained from Halim Türkmen, ex-director of the Kartal Cement Factory Chemistry Laboratories. He had done some research on the material ten years ago, and found it to be suitable, though no data of his work was existing.

No geological survey was made of the deposit, but the material was observed at points approximately three kilometers apart. A thin earth layer had covered the pozzolan. The sample was taken from the flanks of a small hill, after removing a 50 cm. layer which looked weathered.

The pozzolan is gray in color, compacted to a rock-like form which could easily be broken by a pickaxe. Some 100 klg. was taken and transported to the laboratory.

Figure VII. shows the location of the pozzolan deposit.

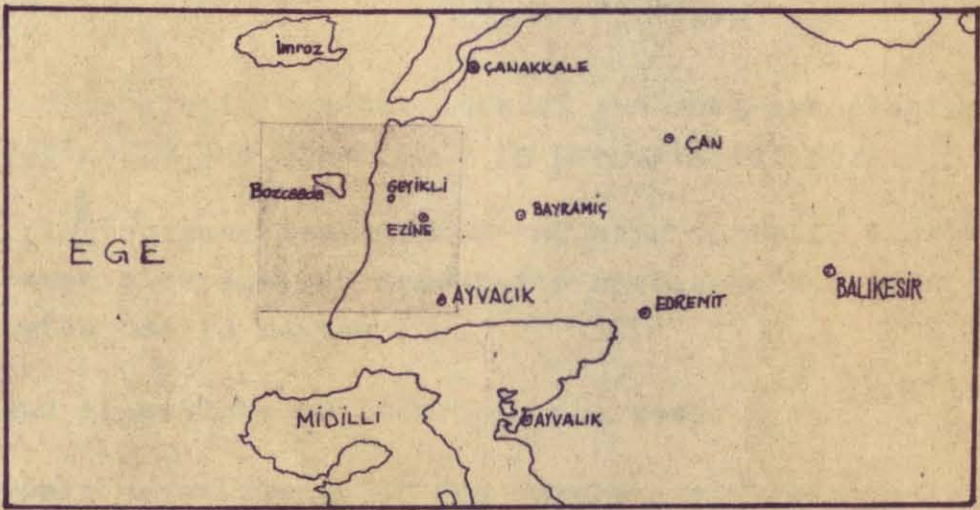
Chemical Composition:

A chemical analysis was run in R.C. Chemistry Laboratories and the following composition was found.

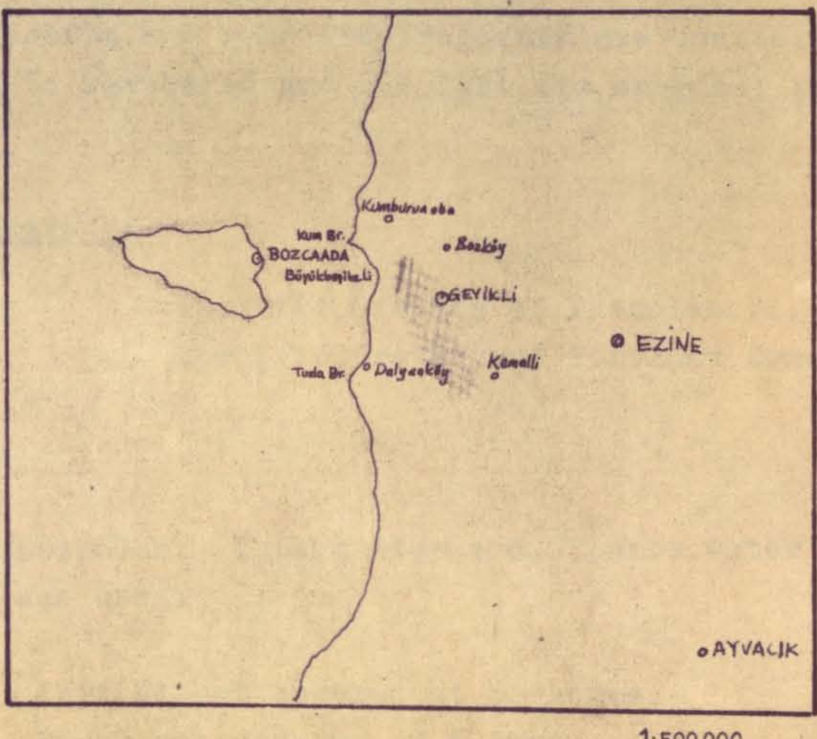
SiO_2....................87.2%	MgO...............Not traced
Al_2O_3-Fe_2O_3.............3.6%	SO_3...............Not traced
Loss on Ignition.........7.6%	CaO...............0.7%

FIG. VII

LOCATION OF THE DEPOSIT



1:2 000 000



1:500 000

Petrographic Analysis:

A petrographic analysis was made by the D.S.I. Laboratories in Ankara. The material was classified as "Andesitic Tuff". The report reads:

"The mineralogic constituents of the rock are plagioclas(Labrodorite), biotite and hornblende in phenocrystal form.

The plagioclases are twinned and show serizite. Biotite and hornblende show cleavage, and some parts have been hydrated and turned to chloride due to weathering.

Opaque mineral is scattered in the rock.

The main constituents of the sample are plagioclas(partly microline), biotite, hornblende and volcanic glass.

Some trachite and ryholite fragments are scattered in the sample. The sample is weathered and has lost its original form."

Specific Gravity:

Specific Gravity of Pozzolan...........2.4
Specific Gravity of Portland Cement....3.2

Time of Set:

4 parts pozzolan : 1 part lime : 3.2 parts water (64% of total dry weight) was used.

Initial set occured at 68 hours.
Final set occured at 5 days.

Standard Tests: [1]

Pozzolanic activity test: ASTM C 340-64 T

-Materials: 1 part lime : 2 parts pozzolan : 9 parts commercial sand : 2.1 parts water (water : cement ratio is 0.71)

-Procedure: Molds were not soldered,instead they were placed on a glass and were covered with a glass cover. Water in containers were placed near the molds.Heavy oil was used to seal the sides of the glass cover.After the specified period,drying and shrinkage was observed on the specimens.

-Results: Seven day compressive strength is 480 psi.

Lime-Pozzolan Strength Development: ASTM C 432-65 T

-Materials: 1 part lime : 2 parts pozzolan : 8.22 parts standard sand : 2 parts water (water : cement ratio is 0.67)

-Results: -Seven day compressive strength is 500 psi.
-Seven plus twenty-eight day compressive strength is.......... 910 psi.

1- Refer to'Appendix A' for the description of materials and laboratory conditions.Unless otherwise stated the tests were run according to the standard procedures.
Data of the test results are given in 'Appendix B'.

Hydraulic Strength Development: ASTM C 432-65 T

-Materials: 1 part pozzolan : 2.74 parts standard sand : 0.445 parts water (water : cement ratio is 0.445)

-Results: No strength.

Turkish Standard Tests: TS. 29

-Materials: 1 part pozzolan : 0.8 parts lime : 1.5 parts standard sand : 0.4 parts water (water : cement ratio is 0.222)

-Procedure: The standard procedure was followed, except that the storage temperature was higher and compaction was done by hand. Each specimen was compacted by 150 blows of a 2 klg. hammer falling through a height of approximately 30 cm.

-Results:

	7-day	28-day
Tensile Strength, psi	None	Negligible
Compressive strength, psi ..	None	Not performed

Comparative Tests with Portland-Pozzolan Cement Mixes

A. Strength Tests

1. Portland Cement Replacement on Weight Basis

The compressive and tensile strengths of portland-pozzolan mixes, in which portland cement was replaced by an equivalent weight of pozzolan, were determined. Compression tests were run according to ASTM C-109. Tension tests were run according to ASTM C-190. The same batch was used in both sets, hence the grading of sand and the cement:aggregate ratio did not conform to ASTM C-190.

-Materials : Pozzolan
Portland Cement
Commercial Sand

-Proportioning: 1 part cement : 2.75 parts sand : 46 % water by weight of cement.

-Molds: 2-inch cube molds
8-shaped standard briquettes

-Storage: One day in humid chamber at $22 \pm 1^{o}C$, the next 6 or 27 days in water at $21^{o}C$.

One set special curing of one day in humid chamber, 6 days in water at $21^{o}C$ and 4 days in water bath at $50 \pm 2^{o}C$. The results of this test are referred to as the 'accelerated test'.

-Results:

% REPLACEMENT	COMPRESSIVE STRENGTH (psi)			TENSILE STRENGTH (psi)		
	7-Day	28-Day	Accelerated	7-Day	28-Day	Accelerated
0	2180	2890	2920	187	283	242
10	2120	2690	2770	-	-	-
40	717	1190	1660	116	159	202
50	555	725	1200	110	135	207

2. Portland Cement Replacement on Volume Basis

This set of tests were run as the previous set, with the exception that portland cement was replaced by an equivalent volume of pozzolan. Since the specific gravity of portland cement is 1.33 times that of pozzolan, the weight of pozzolan added is less than the weight of portland cement taken out.

-Proportioning: Proportioning of initial batch(straight portland cement was;

1 part cement : 2.75 parts commercial sand : 50.5% water by weight of cement.

In other batches replacements were done on a volume basis. Water content was kept constant. The resulting flows determined by dropping the flow-table 25 times in

15 seconds for different ratios are;

Mix	Flow
Straight portland cement	107
90% portland cement 10% pozzolan........	80
70% portland cement 30% pozzolan	62

-Results:

% REPLACEMENT	COMPESSIVE STRENGTH (psi)			TENSILE STRENGTH (psi)		
	7-DAY	28-DAY	ACC.	7-DAY	28-DAY	ACC.
0	2010	2750	2800	312	355	341
10	1860	2300	2360	312	297	320
30	1190	1870	2170	166	223	303

B. Permeability Test

-Materials: Pozzolan; 1.Çanakkale Pozzolan
2.Kayseri Pozzolan 'H' (5,pg.13)
Portland Cement
Turkish Standard Sand

-Proportioning: Proportioning of the initial batch (straight portland cement) was; 1 part cement : 5 parts sand : 75 % water by weight of cement.

Replacements were done on volume basis.Water content was kept constant.

-Molds: Conical rings 6 cm. high.Inside diameters are 6 cm. at the bottom,5 cm. at the top.

-Storage: The specimens were stored in humidity chamber at 22 ± 1°C the first day,in water at 21°C the next 27 days,and cured in 50°C water bath for 4 days.

-Testing: The specimens were mounted on a permeability test apparatus.A head of 8 atmospheric pressure was applied in successive steps.A constant pressure of 8 atmospheres was applied for 24 hours before measurements were taken.The amounts of flow through the specimens for a duration of 1 hour were recorded.

-Results:

Mix	K (cm/sec)
Straight portland cement	17.2×10^{-6}
70% portland cement 30% Kayseri Pozzolan'H'	3.2×10^{-6}
70% portland cement 30% Çanakkale Pozzolan	11.5×10^{-6}

INTERPRETATION OF THE RESULTS AND TEST METHODS

A-General and Standard Testing Methods

The chemical composition showed a very high silica and a low alumina content compared to the other volcanic tuffs. Hence we are to expect pozzolanic activity, but the process will be slow due to the shortage of alumina.

Petrographic analysis showed that the material is a volcanic tuff containing a considerable amount of glass. Plagioclase, biotite and hornblende are also present. It was previously indicated that petrographic analysis is essential to determine the nature of the substance and the possible alterations that might have occured. The sample is weathered and hence altered. Pozzolanic activity might have been reduced due to the weathering, but the weathering was not to an extent such that the glassy portion had lost its characteritics. Therefore the sample under investigation will closely reveal the behavior of nonweathered parts.

The specific gravity of the pozzolan is 2.4 and it falls within the limits of the specific gravity of well known pozzolans.

Time of set test showed an initial set at 68 hours which indicates that a pozzolanic reaction takes place to harden the material at a moderate rate.

Pozzolanic activity tests gave a compressive strength of 480 psi which is less than the specified 600 psi. Three handicaps were encountered while running this experiment. The first was the composition of the lime used, which had 91.6% CaO, highest of the three samples which were analysed, but still not comforming to the standards. The second was the fineness of the pozzolan and the lime, which as used was passing No.200 sieve rather than the specified No.325. Keeping the specimens' moisture content constant during the experiments was the last difficulty. Soldering was found to be inconvinient therefore covering was tried which was not as effective.

The test run for pozzolans for use with lime gave quite good results. All the requirements except chemical composition of lime were met. Though the seven day strength was lower than the specified, a much higher strength was obtained at the later age. After additional 28-day storage 910 psi strength developed as compared to the specified 600 psi.

B-Comparative Tests

These tests were run to get an idea of how the pozzolans would behave in portland-pozzolan cement mixes. The consistencies of the mixes could be kept constant by changing the water:cement ratio for each replacement, or the water:cement ratio be kept constant and let the consistencies change. The second procedure was adopted and replacements were made both on volume and weight basis. Replacement by weight gives rise to bigger differences in consistency as the volume of pozzolan introduced is greater than the cement taken out.

It was not possible to run tests for a longer period than 28 days, hence an accelerated test was run. Lea states that the strength of the portland-pozzolan mixes at the age of 7 or 28 days is determined entirely by the portland cement present, for it is only at later ages that the pozzolan-lime reaction contributes to to the strength. The strengths of portland-pozzolan cement concretes cured at 50°C are higher than the strengths of the same mixes cured at normal temperatures. This gain in strength comes partly from the portland cement, but mostly from the pozzolan constituent. Therefore if concretes containing different percentages of pozzolan are cured at 50°C for four days, the relation between the strength gain of each mix will be an indication of the degree of pozzolanic activity. The strength gain will be higher for the mixes containing higher percentages of pozzolan.

The results of the comparative strength tests are reproduced in Fig.s VIII. and IX. An examination of the curves shows that;

1. The compressive strengths of the mixes decreased as the per cent replacement of pozzolan increased.

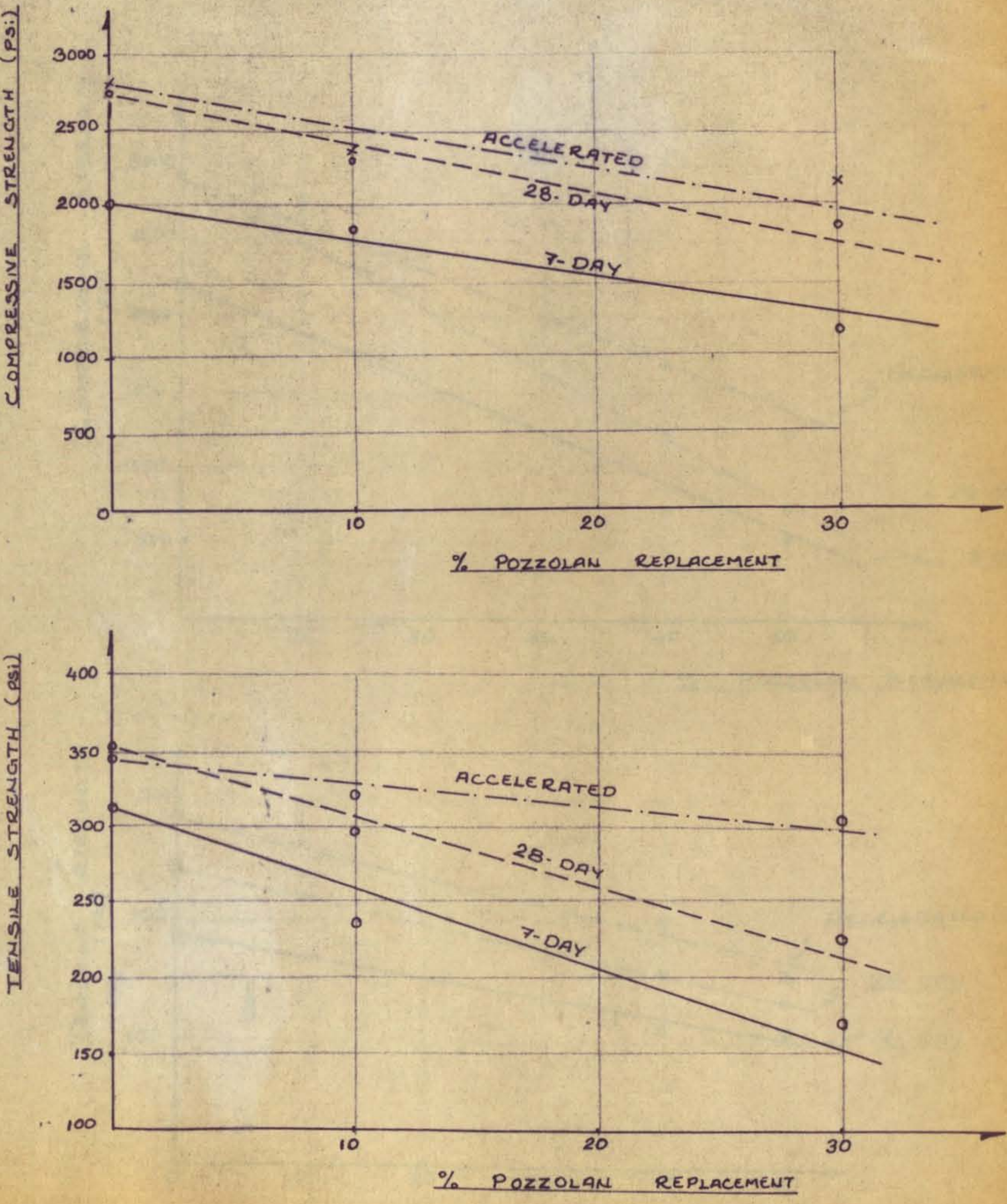
2. The tensile strengths of the mixes decreased as the per cent replacement of the pozzolan increased, but this decrease is less compared to the decrease in compressive strength.

3. The rate of contribution to strength of the portland cement constituent is higher than the rate of contribution of the pozzolan.

4. The strength gain obtained upon heat treatment is higher for higher pozzolan containing mixes. Therefore pozzolanic activity is accelerated by heat-treatment.

FIG. VIII.

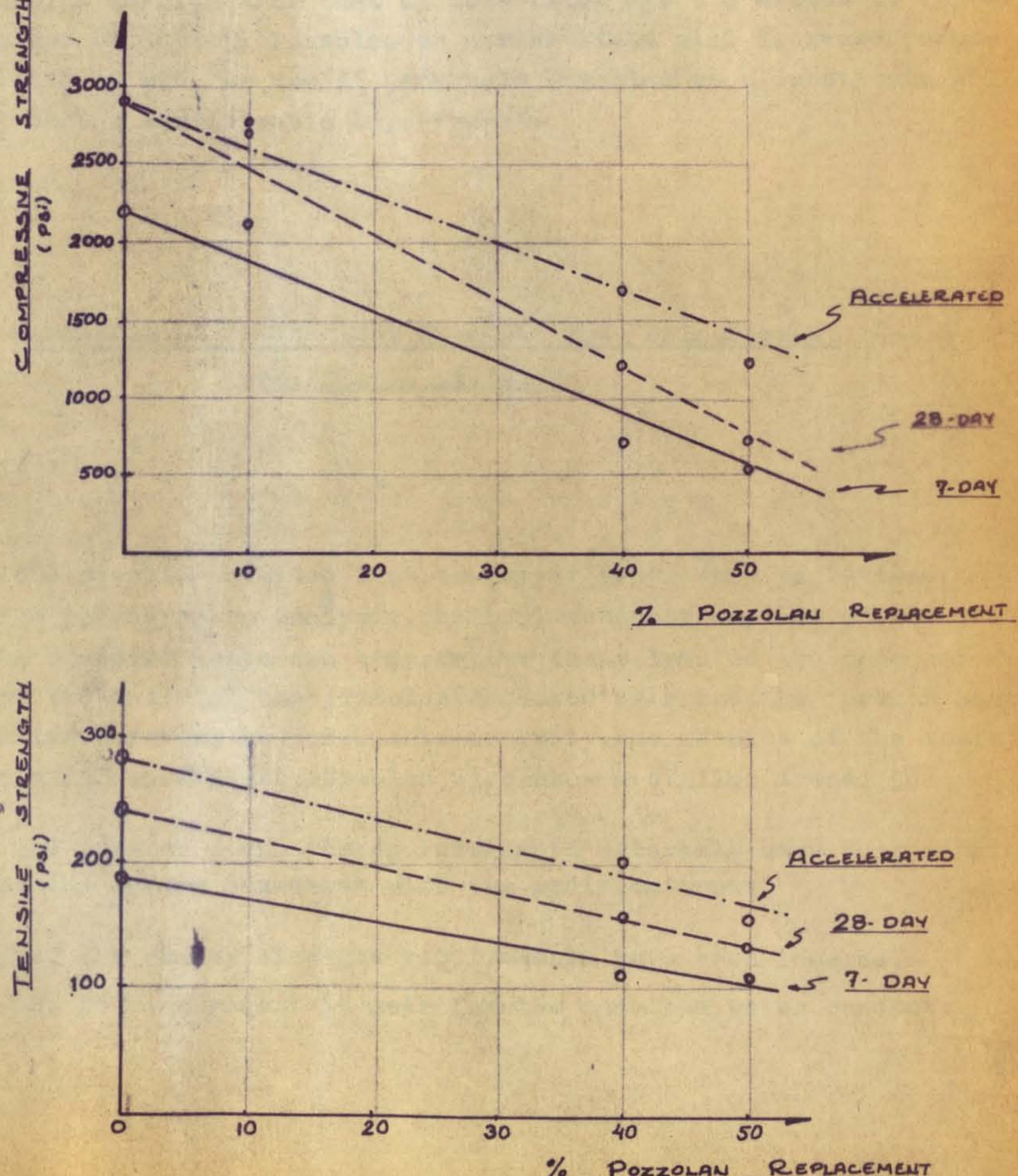
EFFECT OF POZZOLAN REPLACEMENT ON CONCRETE STRENGTH *



* REPLACEMENT BY VOLUME

FIG. IX.

EFFECT OF POZZOLAN REPLACEMENT ON CONCRETE STRENGTH *



* REPLACEMENT BY WEIGHT

The results of comparative permeability tests must be interpreted tentatively because only two specimens for each mix were tested. At 28 days portland cement acquires most of its later age properties. Curing at 50°C was done to accelarate pozzolanic reaction. The results show that at some later age (6 months to 1 year) the use of Kayseri Pozzolan as a substitute will decrease permeability by 80%. The use of Çanakkale Pozzolan as a substitute will not show a considerable improvement.

DISCUSSION OF THE TEST METHODS FOR DETERMINING POZZOLANIC ACTIVITY

The results obtained from the experiments show variations. while petrographic analysis, chemical composition, time of set test, ASTM Standard tests and comparative tests lead to the conclusion that the material has pozzolanic characteristics, the Turkish Standard tests reveal no pozzolanic activity. The results of the tests performed on Kayseri Pozzolan also show a similar trend. (5)

The Turkish Standards on Pozzolanic Materials have been adopted from the German Standards with two modifications:

1. The 28-day strength requirements have been lowered,
2. No requirement is made for the combined water content.

The German Standards are prepared for only one kind of pozzolanic material, namely Trass. Trass is an altered form of volcanic tuffs and occurs only in Germany, Rumania and Crimea.(8) Literature on Turkish volcanic tuffs reveal that they are incoherent like the Italian pozzolans. Therefore the present standards are drawn for a material which is nonexisting in Turkey.

Using the standards drawn for trass creates the following problems. The first is the definition of the pozzolanic material. The Turkish Standards define pozzolan as a volcanic tuff which can combine with lime. In general pozzolans are defined according to the activity they show. Clays, diatomites and shales also show pozzolanic properties, and are used in many countries as pozzolanic materials. The Turkish Standards definition should be changed to permit the use of such materials.

The second problem arises from the characteristics of trass. Trass is more reactive to calcium hydroxide due to the zeolitization process that it has undergone. Therefore the strength and properties obtained with trass are higher than those obtained with pozzolan. The Turkish Standards require lower 28-day strengths, but the 7-day strength is the same as the German Standards. It is quite improbable that an incoherent volcanic tuff will acquire early age strengths comparable to trass. Hence using the standards drawn for trass will rule out the use of many pozzolanic materials which are inferior to it but all the same give reasonable strength and properties.

CONCLUSION

The results of the tests show that the material is a volcanic tuff which has pozzolanic activity.The reaction rate is slow due to the low alimuna content.It is possible to classify it as a material having low pozzolanic activity according to the ASTM Standards.

As the material is slow-reacting,it is not advisable to use it with portland cement in engineering works.It might be employed regionally for tile making or as a soil stabilizing agent in highway construction.

Though the investigations are limited,better pozzolan deposits have been found in Turkey.(5,13,16) The need of such material for economic and technologic reasons are obvious.An extensive investigation has to be carried out to make use of this potential source of cement.

The present Turkish Standards will be hindering any use of pozzolans,because they are prepared for another economy using a different material.Therefore the Turkish Standards should be withdrawn and investigations should be made in such an order;

1. Microscopic Examination.Magnification in the order of 100 will reveal volcanic glass present.
2. Chemical Analysis
3. Petrographic Analysis
4. Time of Set Test
5. Strength tests for determining pozzolanic activity similar to those of Italy.

When the pozzolanic activity of the material is confirmed, detailed tests for its possible use in lime-pozzolona mortars and its contribution to the concrete properties should be investigated.

Turkish Standards on pozzolanic materials should be prepared upon the results of a nationwide investigation.

APPENDIX

A. Laboratory Conditions and Materials Used

1. Materials:

a. Pozzolan: Çanakkale Pozzolan, ground to pass No.100 sieve for Turkish Standard tests, No.200 sieve for all other tests.

b. Lime: Commercial slaked lime, dried in an oven at 95 5°C, kept in closed containers. It was ground to pass No.200 sieve for Pozzolanic Activity Test, ASTM C 340-64 T, No.100 sieve for all other tests. Calcium oxide content of the lime is 91.6 %.

c. Portland Cement: Zeytinburnu Fabrikası, T.S. 19 NPÇ 350. Date of production: 1966

d. Sand: 1. Ottowa Sand conforming to ASTM C-109
2. 'Sultanköyü Kumu' conforming to T.S.33
3. Commercial washed sand conforming to ASTM C-109

2. Apparatus:

a. Molds: Molds conforming to ASTM and Turkish Standards

b. Humid Chamber: Humid chamber with a relative humidity of 90%. Temperature in the chamber was 22 ± 1°C.

c. Water Bath: Electric water bath equipped with a thermostat to keep the required temperature within ± 2°C.

d. Storage Water: Tap water at a constant temperature of 21°C.

e. Compression Testing Device: A proving ring apparatus capable of carrying 14,000 lb. Approximate rate of loading was 6000 lb. per minute. Fig. X.

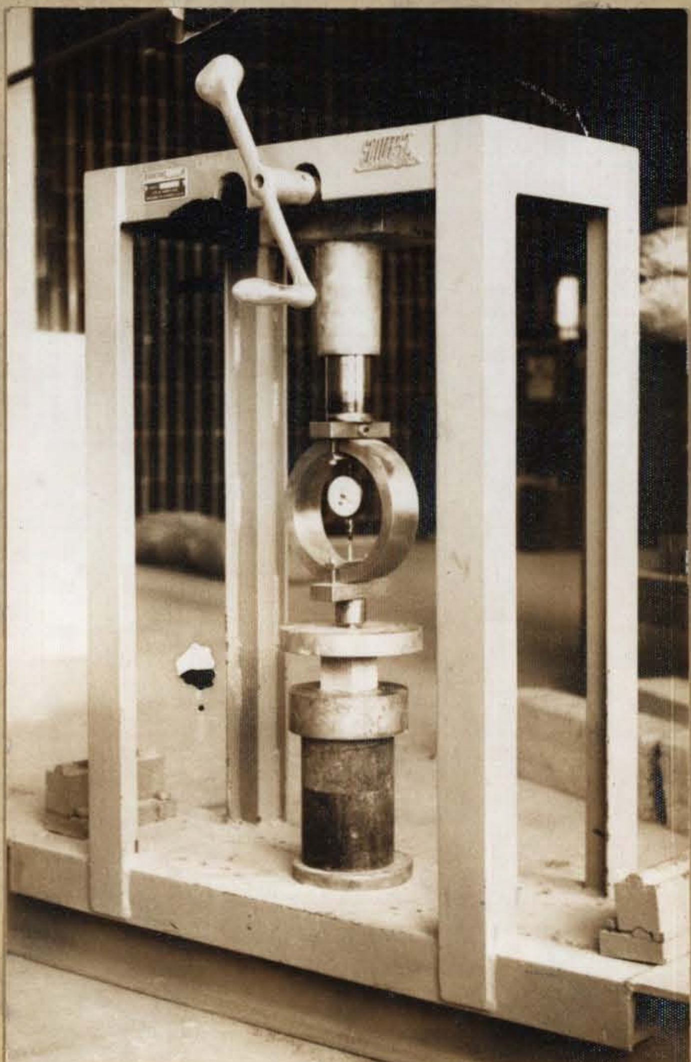


Fig. X.

f. Tension Testing Machine: Soil-Test Tension Testing Machine conforming to the ASTM.Fig.XI.

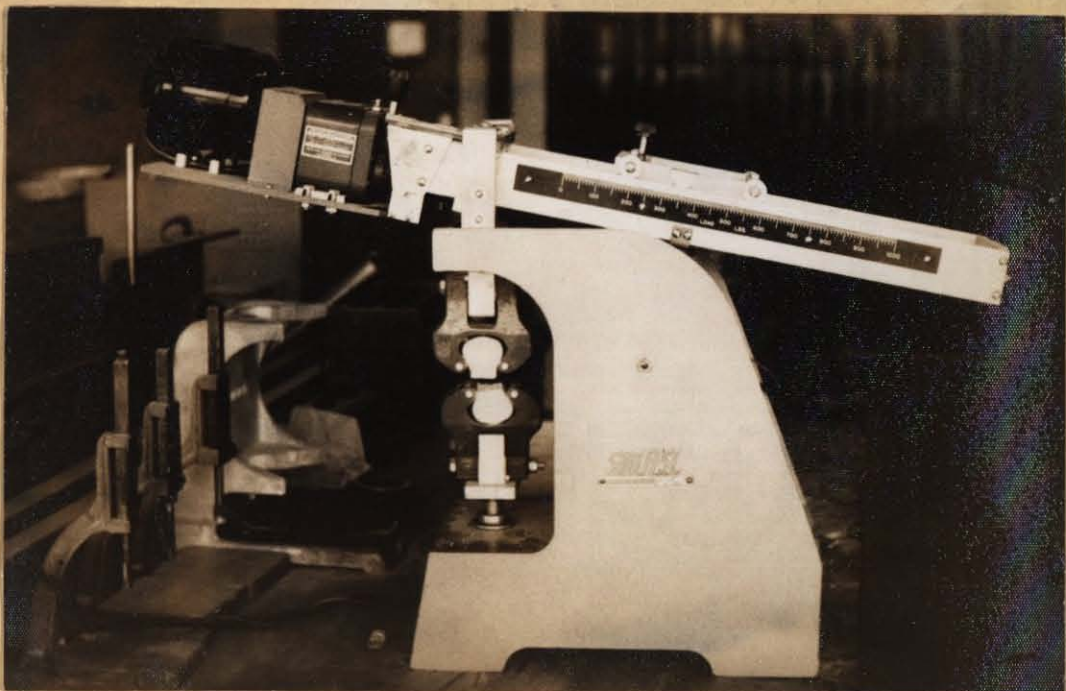


Fig. XI.

B. Laboratory Results:

Pozzolanic Activity Test; 7 Day Strength(psi)....460-485-500

Lime-Pozzolan Strength Development
7 Day Strength(psi)....490-495-520
Additional 28 Day Strength(psi)....880-925-930

Portland-Pozzolan Mixes, replacement by weight:

COMPRESSIVE STRENGTHS

%Replacement	7 Day	28 Day	Accelerated Test
0	2170-2200-2200	2820-2900-2950	2800-2950-3000
10	2050-2120-2180	2600-2650-2820	2700-2740-2880
30	562- 750- 750	575- 875- 900	650-1075-1330
40	700- 700- 750	1125-1170-1275	1600-1610-1760
50	440- 575- 650	700- 800- 825	1140-1140-1320

TENSILE STRENGTHS

%Replacement	7 Day	28 Day	Accelerated Test
0	121-184-191	265-290-295	219-240-268
30	103-105-110	137-140-140	185-187-190
40	110-115-122	145-155-175	99-183-222
50	99-110-121	110-120-135	198-198-226

Portland-Pozzolan Mixes, replacement by volume:

COMPRESSIVE STRENGTHS

%Replacement	7 Day	28 Day	Accelerated Test
0	1820-2050-2150	2650-2775-2830	2790-2810- -
10	1790-1840-1950	2250-2320-2340	2320-2350-2410
30	1190-1160-1210	1800-1900-1910	2100-2170-2250

TENSILE STRENGTHS

%Replacement	7 Day	28 Day	Accelerated Test
0	303-316-316	330-365-370	325-345-353
10	213-232-266	287-300-305	308-320-333
30	153-180- -	215-218-240	290-300-320

Comparative Permeability Test:

Pressure ....8 atmospheres
Time..............1 hour

Sample No.	Amount of Water Passed, cm^3		
	Straight Portland Cement	70% P.C. 30% Kayseri P.	70% P.C. 30% Çanakkale
1	6.0	1.0	3.5
2	7.5	1.5	Leaked

DSİ UMUM MÜDÜRLÜĞÜ
ARAŞTIRMA DAİRESİ REİSLİĞİ
MALZEME LABORATUARI FEN HEYETİ MÜDÜRLÜĞÜ
PETROGRAFİ LABORATUARI

PETROĞRAFİK RAPOR

Numunenin geldiği yer : Araştırma Da.Bşk.
Numunenin geldiği Tarih : 28/3/1966
Numuneyi alan : Araştırma Da.Bşk.
Laboratuvar sıra No. : 549

Raporu hazırlayan : Gülsevim Akın
Lab. rapor Tarihi : 29/3/1966
Lab. rapor No. : 2023

Numune Geliş No.	Numune Sıra No.	Müşahade	Petrografik Tayin
1	24295	Andezitik Tüf	Taşın minerolojik terkibi: Plağioklas(Labrodorit),biotit ve hornblend fenokristal halindedir. Plagioklaslar ikizli olup serizitleşme göstermektedir. Biotit ve hornblendin bir kısmı dilinimli bir kısmı sekonder olarak kloritleşmiş, esas bünyesini kaybetmiştir. Opak mineral taşın her tarafına dağılmıştır. Ayrıca numune içerisinde plagioklas(kısmen mikrolit halinde),biotit,hornblend ve volkanik camdan ibaret esas kısım mevcuttur. Numunenin içerisine trakit ve riyolit fragmentleri yer yer dağılmıştır.Numune tahallül ve tahavvül etmiş olup esas bünyesini kaybetmiştir.

İmza

REFERENCES

1. Blanks, R.F., and Kennedy, H.L., 'The Technology of Cement and Concrete', New York, John Wiley and Sons, 1955.

2. Lea, F.M., 'The Chemistry of Cement and Concrete', London, Edward Arnold Ltd., 1956.

3. Alaydın, Sevim, 'Betonlarda Alkali-Agrega Reaktivitesi (Türk Portland Çimento Alkaliniteleri)', Ankara, D.S.İ. Yayınları, 1965.

4. 'Türk Standardları 19-33', Türk Standardları Enstitüsü, Ankara, 1959.

5. Postacıoğlu, B., Çakıroğlu, N., Ortabaşı, N., 'Kayseri Puzolanları', I.T.Ü. Yapı Araştırma Kurumu, 1960.

6. '1965 Book of ASTM Standards', Philedelphia, ASTM, 1965, Vol.9.

8. 'Symposium on Use of Pozzolanic Materials in Mortars and Concretes', ASTM Special Technical Publication No.99, Philedelphia, ASTM, 1949.

9. Malquori, G., 'Portland-Pozzolan Cement', Chemistry of Cement, Proceedings of the 4th International Symposium, Washington, 1960, U.S. Dep't of Commerce-Monograph 43, Washington D.C., 1962.

10. Alexander,K.M.,'Reactivity of Ultrafine Powders Produced from Siliceous Rocks',ACI Journal,Vol.32,No.5,Nov. 1960, pp.557-69.

11. Kocataşkın,Ferruh,'Çimento ve Özellikleri Hakkında Ne Biliyorsunuz?',Istanbul,I.T.Ü. Matbaası,1965.

12. Akın,Gülsevin,'Türkiye Trasları',DSİ Teknik Bülten,No.3 June 1965,pp.17-31.

13. Yarar,Güler,'Tras ve Kullanma Yerleri',İmar ve Iskân Bakanlığı,Yapı Malzemesi Genel Md.lüğü,No.2.00.88.12, Ankara,1963.

14. Ruiz,A.L.,'Strength Contribution of a Pozzolan to Concrete', ACI Journal,Vol.62,No.3,March 1965,pp.315-26.

15. Dikmen,Fikri,'Termik Santral Küllerinden Neden Istifade Etmiyoruz?',Türkiye Mühendislik Haberleri,Vol.11,No.132 pp.11-13.

16. Dener,D.,'Traslı Çimento ve Beton Araştırması',Ankara, DSİ Yayınları,1963.