CONTENTS ENVELOPE 2420 — E.L. 123

TENEMENT: Exploration Licence No. 123

TENEMENT HOLDER: R.M.C. Minerals Pty. Ltd.

REPORT: Report AN 4802/74 (Pgs. 3-4)

REPORT: Final Report on E.L. No. 123 (Pgs. 5-60)

PLAN: Lake Leake Topographic Plan (including Geology) 2420-1

P. Cleary

003

amdel
The Australian Mineral Development Laboratories

Flemington Street, Frewville, South Australia 5063
Phone 79 1662, telex AA82520

Please address all correspondence to the Director
In reply quote: AN3/115/1/0 - 4802/74

NATA CERTIFICATE

15 July 1974

The Exploration Officer
RMC Minerals Pty Limited
GPO Box 1798
ADELAIDE SA 5001

REPORT AN 4802/74

YOUR REFERENCE: Letter dated 18/6/74 Order A.77434

IDENTIFICATION: X-103

DATE RECEIVED: 19/6/74

Enquiries quoting AN 4802/74 to Officer in Charge please

Officer in Charge, Analytical Section: A.B. Timms

for F.R. Hartley
Director

pkm

AN 4802/74

ANALYSIS

%

Sample:	X-103	
Silica	SiO_2	39.3
Aluminium oxide	Al_2O_3	7.50
Ferric oxide	Fe_2O_3	8.80
Ferrous oxide	FeO	2.55
Magnesium oxide	MgO	12.4
Calcium oxide	CaO	4.90
Sodium oxide	Na_2O	0.55
Potassium oxide	K_2O	1.30
Water over 105°C	H_2O^+	7.25
Water at 105°C	H_2O^-	11.8
Carbon dioxide	CO_2	0.10
Titanium oxide	TiO_2	2.55
Phosphorus pentoxide	P_2O_5	0.80
Manganese oxide	MnO	0.15

005

FINAL REPORT

EXPLORATION LICENSE NO 123

SOUTH EASTERN SOUTH AUSTRALIA

B.C. PARAM

P.R. GRAY

RECEIVED
2 AUG 1974
DEPT. OF MINES
SECURITY
2410

July 1974.

LOCATION

Exploration License No 123.

Situated approximately 30 kilometres northwest from Mt. Gambier, within the Hundreds of Riddoch, and Hindmarsh, covering an area of 11 square kilometres within the following boundaries:-

i.e. Commencing at a point being the intersection of Latitude 37° 36' S and Longitude 140° 34' E; thence east to Longitude 140° 36' E; south to Latitude 37° 38' S; west to Longitude 140° 34' E; and continuing northwards to the point of commencement.

CONTENTS

	PAGE NO.
ABSTRACT	
INTRODUCTION	3
POZZOLANS	
Definition	5
Application	5
Natural Types	6
History of Use	7
GEOLOGY	
Regional	11
Lake Leake Physiography	12
Lake Leake Geology	13
EXPERIMENTAL PROCEDURES	
Sample Origin	15
Sample Preparation	15
Equipment	16
Concrete Trials	16
X-RAY DIFFRACTION/PETROGRAPHY	18
BLAINE SURFACE AREA DETERMINATIONS	22
RESULTS OF CONCRETE TRIALS	
Report No 1	26
Report No 2	30
EXPENDITURE	38
CONCLUSIONS	39

APPENDIX I

"Proportioning Fly-ash concrete mixes for strength and economy" by Robert W. Cannon.

APPENDIX II

Topographic Plan (Including Geology)

ABSTRACT E - 008

Investigation of naturally occurring volcanic ash deposits displaying potential as a source of pozzolan for use within Concrete Manufacture began by this Company during 1972 and has continued throughout the duration of three separate Licenses held over certain portions of south-eastern South Australia.

Preliminary drilling and associated geological mapping has indicated quite large reserves of consolidated and semi-consolidated volcanic ash surrounding Lake Leake. This volcanic occurrence consists of a partially subsided Caldera with assymetrical distribution of ejectamenta along the northern and eastern margins.

The ash-beds appear to have evolved from periodic ejections during a single explosive type eruption, with the material becoming sorted during its descent. Cross bedding visible within exposures, and outcrop suggests a direct influence of prevalent winds during deposition. Ash within the vicinity of the Lake is in an advanced state of consolidation due to environmental influences and the cementiteous properties of secondary mineralization.

Basically the ejectamenta is composed of a mixture of silicates and contains both glass and crystalline material. At the time of volcanism the ejectamenta has undergone rapid cooling and in some instances has suffered considerable chemical alteration, the effect of which is a conversion of the original material to a more chemically reactive modification.

Exploratory field work has been confined to the perimeter of the Lake only, where considerable accumulations of ash with little soil cover are encountered. Outcrop of bedding is prominent in this area, together with one quite large excavation on the north side from which road building materials have been extracted.

Initially, sample material gained for testing from drill holes, proved to be consistent with that taken from existing exposures present within the formations, and therefore samples for final test-work were gained exclusively from such exposures.

Preparation of samples for test-work included drying, crushing and milling in the laboratory of R.M.C. Minerals, prior to submission for concrete mix/strength trials at the laboratory of Ready Mixed Concrete (S.A.) Pty. Ltd. A small parcel from each of the individual samples was retained and forwarded to AMDEL for Blaine Sizing determination. Further work completed by AMDEL included petrographic examination and X-ray diffraction.

Physical testing by Ready Mixed Concrete (S.A.) Pty. Ltd., has confirmed conclusively that the pozzolanic properties of this ground volcanic ash have had a detrimental effect upon early strength of concrete test specimens. However, test specimens retained for a greater period of time than the appropriate Specification allows, have proved to equal the strength of the accompanying control specimen, and in some instances their strength succeeded in surpassing that of the control.

Although the long term strength benefit of the pozzolan has proved equal to, or better than, the control specimen, the pozzolans will not meet the required strength within the maximum period of 28 days described within the Specification, and therefore further evaluation of the material using the currently applied economic methods would be futile.

INTRODUCTION

The use of Pozzolanic Materials within Concrete Manufacture has long been recognised as advantageous both to the promotion of high strength of the concrete, and the durability of the product against harsh environmental conditions.

Initial use of pozzolans must be credited to the Early Romans who found the material to be an excellent cementing substance if crushed down to a powder and mixed with lime and water, which thus assisted in construction of many of the buildings which today are still recognised as masterpieces.

Pozzolans gained for this use came from naturally occurring volcanic sources containing mostly ash and loose scoriaceous material derived from explosive type volcanoes present in Italy and Greece.

During the rise of the Roman Empire, and until the decline of that same Empire, the Romans invaded a number of countries in which pozzolans could not be gained from natural sources, which therefore led to a rapid advance in technology by experimentation of other materials for this same use. It was found during this period that clays, and like materials which had been utilized in brick and tile manufacture,also contained pozzolanic properties after they had been kiln-fired and roasted, and with crushing to a relatively fine consistency were used as a synthetic form of pozzolan.

Further advances since that period of time, have resulted in the use of other substances again. For example, we now find that probably the most commonly used material of this nature is derived from residue products precipitated from burned coals produced as waste material from Power Stations.

During the past few years, however, emphasis has once again been directed toward the use of naturally occurring pozzolans, basically because of the consistency of their desirable properties when compared to synthetic materials. This, together with today's low cost of crushing and milling substances of this nature, once again made volcanic sources attractive.

R.M.C. Minerals Pty. Ltd., became involved in the testing of volcanic sources on behalf of its parent Company, The Readymix Group (S.A.), during 1972, when it was decided to apply for suitable areas in the south-east of South Australia for exploration and investigational purposes. The first area held under Special Mining Lease No 655, included most of the volcanic province within the South East when emphasis was placed mainly on test-work carried out on samples gained from areas containing volcanic ash only.

After the expiry of Special Mining Lease No 655, the Company decided to apply for a smaller area covering the two most promising volcanoes, which are known as Lake Leake, and Lake Edward. Test-work on material derived from Lake Leake displayed some promising results during the tenancy of the Exploration License. At the time of expiry of the License (No 13) this Company had not completed the whole of its desired analytical and physical experimentation of sample material, which, together with some neglect by this Company in failing to notify the Director of Mines of its wish to renew the License during the appropriate period, we thus could no longer hold the area. Therefore, a new application was made for the area immediately surrounding Lake Leake only. The resultant Exploration License No 123, taken out for a period of six months, has enabled a continuation of the work commenced previously.

Because of the circumstances involved in continuous work during the Tenancy of this, and the previous Exploration License, we therefore contain here selected extracts from the Reports of the previous License, together with the results derived from work completed during the current License period.

POZZOLANS 012

DEFINITION

Pozzolans are usually defined as materials which though not cementitious in themselves, contain constituents which will combine with lime at ordinary temperatures in the presence of water to form stable insoluble compounds possessing cementing properties.

Pozzolans can be divided into two groups containing the natural and artificial products respectively. The natural pozzolans are for the most part materials of volcanic origin, but include also certain diatomaceous earths. The artificial pozzolans are mainly products obtained by the heat treatment of natural materials, such as, clays and shales and certain siliceous rocks.

Pozzolans of volcanic origin consist of tuffs arising from the deposition of volcanic dust and ash. They may occur, as does the Rhenish Trass, in a consolidated rock-like form underlying material deposited subsequently, or in a more fragmentary and unconsolidated state like some of the Italian pozzolans.

In Europe the materials which have been most exploited are the Italian Pozzolans, Santorin Earth obtained from the Grecian Isle of Santorin, and the German Trass, which is found in the neighbourhood of Coblenz on the Rhine.

Deposits of unconsolidated and semi-consolidated volcanic ash are distributed sparingly throughout the world, however, until recently this natural resource has been largely untapped due to the high costs involved in processing the material, although much attention has been given to utilizing artificial or synthetic pozzolans in the form of fly-ash produced as waste product from precipitation of fired brown coal.

APPLICATION

Pozzolans are used in lime/pozzolan mortars, in blended pozzolanic/ Portland Cement's, and as a direct addition to a concrete mix.

APPLICATION (Cont'd) F- 013

The addition of pozzolanic materials derived both from natural and artificial sources, and blended with Portland Cement concrete mixes has been a common practice for many years in European countries, where, because of its desirable resistance to water, whether saline or fresh, it has been used for such complexes as docks, harbours, inland waterways and bridges.

Formerly, the method of application was to add the pozzolan as a separate constituent to the concrete mix, but in more recent years it has become the practice to pre-mix the pozzolan with Portland Cement in suitable dry mixers before transferring to the concrete batch-mixer.

In the past, considerable attention has been given to developing methods for evaluating the activity of pozzolans by means which are more rapid than the direct testing of the rate of development of strength in concrete or mortar mixes. However, the nature of the constituents to which the pozzolanic properties of natrual pozzolans is due, has been a controversial matter which is not yet entirely solved.

In the history of testing of pozzolanic materials, many difficulties are presented by the fact that pozzolans have no basic cementitious properties in themselves, and only develop these desirable qualities when mixed with lime or cement, therefore, physical strength tests must be carried out to evaluate the durability of pozzolan-lime or pozzolan-cement concretes.

NATURAL TYPES

1. <u>Tuff</u> pozzolans are composed of a mixture of silicates and contain both glass and crystalline particles formed by rapid cooling and in some instances may have undergone considerable chemical alteration attributed to the action of super-heated steam and carbon-dioxide below the earth's surface.

2. Trass is a trachytic tuff which has been subjected to the action of carbon-dioxide bearing waters for such a long period of time, that a large part of the minerals originally present, have become hydrated and decomposed. When altered as such, the development of zeolitic characteristics is not uncommon.

3. Zeolites are a group of insoluble hydrated alumino-silicates of the alkalis and alkaline earths. These compounds have the property of exchanging some of their base constituents for other bases when in contact with salt solutions.

HISTORY OF USE

The use of cements in building is not met with below a relatively advanced stage of civilization, where the earliest structures are composed of earth, sometimes raised in the form of walls or domes by ramming successive layers, or of stone blocks set one above another without the aid of any cementing material as in prehistoric megalithic structures, such as the Cyclopean masonary of Greece. Although remarkable works have been accomplished by such a method of construction, notably in the domed chambers of Mycenae, where stone wedges are driven between the large blocks in order to tighten the joints, Cyclopean work has always given way in later times to masonry or brickwork erected with the aid of some plastic jointing material.

Both the Greeks and the Romans were aware that certain volcanic deposits, which if finely ground and then mixed with sand and lime, yielded a cementing agent with advantageous properties if mixed into a mortar and placed between the building blocks or rough-hewn stone. This mortar also had the superior properties of high strength and durability in resisting the action of water, whether fresh or salt.

The Greeks employed for this purpose the volcanic Tuff from the island of Thera (now known as Santorin) and this material now called Santorin Earth, still enjoys a high reputation as a natural cement in the Mediterranean area. The mortar used at the present day by the peasants of Santorin (an island destitute of timber for building) is identical in its composition and preparation with that of ancient times.

The corresponding material of the Roman builders was the red or purple volcanic tuff found at different points on and near the Bay of Naples. As the best of this material was found in the neighbourhood of Pozzoli (or Pozzouli) the material acquired the name of "Pozzolanna" (now referred to as Pozzolan) and this designation has been extended to the whole class of mineral matters of which it is a type.

In testament of the desirable qualities within the early Roman pozzolanic concretes, is the famous Roman building, the "Pantheon", with walls some twenty feet in thickness, consisting of both tuff and pozzolan concrete thinly faced with brick, whilst the dome, one hundred and forty two feet in span is cast solid in concrete containing pumice and pozzolan. Wooden boards were used as moulds and the concrete was filled in, in a semi-fluid condition. The present condition of many Roman buildings of this class is a sufficient testimony to the excellence of the material.

If volcanic materials did not happen to be available in certain areas, the Romans made use of powdered tiles or pottery, which produced artificial pozzolan.

The Romans carried their knowledge of the preparation of pozzolanic mortars and cements with them to the more remote parts of the Empire, and the Roman brickwork found in England for example, is equal to the best of that in Italy. Ground or pulverised tiles were the most commonly used artificial pozzolan in England. However, in a few districts, deposits bearing some resemblance to the natural pozzolans of the Bay of Naples were found and utilized. The use of Rhenish volcanic tuffs known as "Trass" was probably introduced at this time and like pozzolan, is still largely employed at the present day.

A gradual decline in the quality of the mortar used in buildings set in after the collapse of the Roman Empire and continued throughout the Middle Ages. Saxon and Norman buildings for instance, constantly exhibit evidence of badly mixed mortars consisting primarily of imperfectly burnt lime with little or no pozzolanic content. It is apparent that during the ninth, tenth and eleventh centuries, the art of burning lime was almost completely lost, with the lime being used in badly burned lumps, without the addition of ground tiles or naturally occurring pozzolans.

From the twelth century onwards, the quality improved due to consistant experimental work carried out in both England and Europe, by blending and upgrading the various materials used. The Roman mixture of lime and natural or artificial pozzolans long retained its supremacy as the only suitable material for use under or exposed to water.

When we come to more recent times, the use of natural pozzolans of volcanic origin became obsolete and with improvements in burning kilns and mechanical equipment, together with new discoveries in the blending of calcined materials, synthetic or artificial cements were produced.

This newly developed synthetic material was given the name "Portland Cement" the name being derived from the resemblance of the cement colour after drying, to that of Portland Stone.

Portland Cement, in spite of its great cost of production during the early stages, gradually superseded the use of naturally occurring cements, mainly because quality is easily controlled by blending of the ingredients within the artificial mixture.

The development of hydraulic cements of various types has proceeded in a series of stages throughout the past years, however in this gradual evolution there have arisen some cements, which attained at one time a considerable degree of importance, but have now fallen partly or entirely into disuse. The natural cements from volcanic sources are perhaps the best example of this group.

The growth of new varieties of cement has however far outweighed any decrease due to the disappearance of former products until today; their number is apt to become bewildering. Many of these cements are used only for certain limited purposes and their output is only a very small fraction of that of ordinary Portland Cement, which still represents the greater part of world production.

During the early part of this century, systematic work in development and improvement of Portland Cements led to new investigations into once again utilizing pozzolans, including both artificial and natural, within concrete manufacture.

During the post-war years, pozzolans have become a standard component of raw materials used in the manufacture of concrete throughout the world where the common method for utilization is to proportionally replace up to twenty five percent of the total Portland Cement content with an equal or greater volume of natural or artificial pozzolan.

REGIONAL

South Eastern South Australia comprises mainly Tertiary to Recent materials. The most prominent rock-type visible in outcrop is the Mid-Tertiary marine bryozoal limestone. Lower Tertiary fluviatile and paralic clays are restricted in outcrop whilst outcropping Pre-Tertiary rocks are rare.

The area is essentially a sub-coastal plain with minor seaward slope. The greater part is less than 90 metres above sea level and is practically devoid of any obvious surface drainage features.

Superimposed upon this depressed terrain there exists a well developed system of sub-parallel ranges aligned in sympathy with the modern coast. These ranges consist of stranded ocean coastal dunes of the Quaternary period, which rarely exceed 30 metres in elevation above the inter-dune and surrounding flats. Marshes, swamps and lagoons are prominent features of the inter-dune areas over which extensive flooding normally takes place during the winter months.

Although the area as a whole is underlain with porous Tertiary limestone, downward percolation of surface waters is impeded by the proximity of static groundwater levels, and also by a usually thin veneer of impervious soil, travertine, and swamp clays.

Fissure eruptive volcanics of the late Tertiary period occurring extensively throughout Western Victoria, and to a lesser extent in South Eastern South Australia, form the areas of greatest topographic relief, and although rising to a maximum of 244 metres above sea level within South Australia, they constitute promient landmarks. Among these, Mt. Burr attains the greatest elevation (244m) whilst the better known areas such as Mt. Graham, Mt. Gambier and Mt. Schank are respectively elevated to 206m; 192m; and 158m. At each of these locations and others less prominent, volcanicity during the latter Cainozoic Period has produced massive accumulations of basalt as at Mt. Burr and The Bluff, and also the building of several basaltic and ash cones at Mt. Schank and Mt. Gambier.

Fissure eruption played a major role in the volcanicity of South Eastern Australia with the development of basaltic sheets covering some 25,000 square kilometres derived from more than 150 known vents within the State of Victoria alone. Within South Australia, approximately sixteen recognised areas of fissure eruption are present, which consist of a westerly extension of the wider regional phenomenon. The outbursts here, although spectacular were of short duration, with minor flows apparently preceding cone formation in most cases, which with later rapid accumulations of steam led to the development of explosion craters.

The various volcanoes and fissure eruptives, although restricted to only a small portion of South Australia extending from Mt. Schank to Mt. Graham (a distance of some sixty kilometres), have since occurrence become extensively modified by erosion, and also masked by ocean beach sand drift. Ocean coastal erosion, resulting from the migratory coastal belt during mid/late Pliestocene time, has made considerable inroads on the seaward margins of a number of these volcanic accumulations, where erosion in some instances has eliminated the true form of the vents.

Lake Leake, the subject of this Report, consists basically of initial fissure eruption followed closely by explosive cratering and resultant accumulation of scoreacious and basaltic ash.

Lake Leake - Physiography

The lake forms a sub-circular depression approximately ½ kilometre in diameter and is bounded along the western and southern margins by swamp. The eastern banks are low and rise gradually to form the saddle present between this lake, and the crater of nearby Lake Edward. Along the northern perimeter, and to a less extent the north-eastern portion, the relief is broken by the existence of a near vertical face abutting the lake where there exists a difference of some 27 metres in elevation from that of the lake. From this location (known as Lake Leake Hill) the country slopes away gently towards north.

The fissure eruptive volcanics at both Lake Leake, and Edward, consist of Calderas of minor Subsidence, with assymetrical distribution of ejectamenta in the areas immediately surrounding the northern and eastern crater margins. The pyroclastic material shows distinct bedding alignment in sympathy with the surface enlarged fissure vent, and the surrounding land surface. Distribution of ejectamenta, composed principally of scoriaceous, basaltic, and olivene rich ash, laid down in successive horizons of varying particle size originated from periodic ejections during a single eruption with the material becoming sorted during descent from spasmodic explosive eruption. Exposures of consolidated ash visible in the area, suggest that minor cross-bedding of the ash beds resulted from the influence of prevailing atmospheric conditions during the volcanism of the region, when surface winds have assisted sorting and deposition of individual particle sizes.

Ejectamenta present in the area of Lake Leake is mainly pyroclastic in the upper levels of deposition, however near the base of the almost vertical face abutting the lakes northern perimeter, there is a considerable amount of country rock contained within the ejectamenta, and in one location a distinct sequence attaining a thickness of approximately one metre exposes the original displaced country rock re-deposited during the initial eruptive phase. Ash resulting from this phase of volcanism is now in an advanced state of consolidation, and often underlies a shallow depth of paralic clays and sandy soil. Transformation of this consolidated material, by direct weathering to volcanic soil, is minimal as a result of the protective nature of the overlying clayey materials. The presence of volcanic soil profiles, although obscure beneath the more recently deposited sediments, appears to be confined to the area immediately surrounding that of consolidated ash deposition towards north and east.

Research into composition of the pyroclastic ash has indicated an abundance of glass, and to a lesser extent olivine and associated minerals rich in zeolitic substances.

In summary, the materials present here, together with the nature of distribution, suggest an extremely violent ejection period during the eruptive cycle, when ejectamenta underwent rapid cooling which has in part caused a considerable alteration to the material.

EXPERIMENTAL PROCEDURES

SAMPLE ORIGIN

Previous evaluation of volcanic ash, during the tenancy of other Exploration Licenses, had indicated that sample material obtained from drill-holes in the vicinity of Lake Leake, is representative of bulk sample material derived from a disused quarry located on Lake Leake Hill. Therefore, material for inclusion in final evaluation trials was obtained from the quarry, where past extraction of road-making material has exposed a depth of consolidated ash some ten metres in depth. This exposure contains coarse granular ash, with remnant fragmental limestone country-rock inclusions, and accesory minor olivine and bomb fragments. Noticeable within the formation is the cementiteous nature of the finer scoriaceous laminated beds, and rich zeolitic development within the intermediate coarse ash beds. Sample material obtained for analytical purposes consisted of a cross-section of these strata, and is regarded as representative of the mass.

SAMPLE PREPARATION

(1) The original sample consisting of approximately 130 kilograms of Lake Leake volcanic ash in large aggregates of approximately 5 kilograms each, was dried in small batches each for a period of 24 hours at 300^{o}F.

(2) When dry, the material was passed through a large jaw crusher, after which another crushing followed, reducing particle size to ¼" maximum diameter.

(3) The total material was then oven dried again for a period of 4 hours to eliminate all moisture, and then thoroughly homogenized with a shovel.

(4) The sample was then split into five batches, each consisting of approximately 20 kilograms, and the residue was stored.

(5) Each individual batch was then passed through a disc pulverizer.

(6) Of the five remaining 20 Kilogram batches, each batch was then split, and a 10.5 kilogram parcel from each prepared as ball mill feed charge, with the surplus of each, remaining for storage pruposes.

(7) The five 10.5 Kilogram parcels were then milled for different respective periods, beginning initially with a two hour grind for sample No. P.60 and increasing the milling period by 1 hour for each individual parcel, thus the final sample (No. P.64) had a total grinding period of six hours.

(8) From each milled sample, 10 Kilograms were then weighed out for submission to the concrete-testing laboratory, and the surplus was bagged for submission to A.M.D.E.L. for partical sizing determination.

EQUIPMENT

(1) Drying Oven 15 cubic feet x 300°F.
(2) 9" x 6" Jaw Crusher - product -3/4" agg.
(3) 3" Jaw Crusher - product -1/4" agg.
(4) Disc Pulverizer
(5) Ball Mill - Dimensions: diameter - 10"
length - 20"
ball discharge - 40% by volume
speed - 73 R.P.M.
(6) 50 kg (max) Spring balance
(7) 10 kg (max) Beam balance (correct to 5gm)
(8) Ball Mill discharge screen and collector receptical.
(9) Various containers, shovel, etc.

CONCRETE TRIALS

Standard Concrete Mix Designs were used in all instances, with a selected content equivalent to 400 lbs.Adelaide Portland Cement per cubic yard of concrete.

The individual trials were mixed in a standard 1 c. ft. capacity tilting bowl mixer of the type used for domestic purposes.

Specific mixes and blend ratios were as outlined and described in the results for initial trials (Report No 1).

Sampling, curing, and strength tests, of mix specimens were completed under the Standard Code of Practice outlined in Australian Standards, including, AS100 - 104, AS108 - 109 and amendments.

025

X-RAY DIFFRACTION & PETROGRAPHIC

EXAMINATION OF MILLED VOLCANIC ASH

(REPORT BY A.M.D.E.L.)

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026

Please address all correspondence to Frewville.
In reply quote: MP 3/115/1/0

1 July 1974

R.M.C. Minerals Pty. Ltd.,
Box 1798 GPO,
ADELAIDE, SA 5001

Attention: Mr P.R. Gray

PART REPORT MP 4802/74

YOUR REFERENCE:	Letter of 18 June 1974
MATERIAL:	One rock
IDENTIFICATION:	X-104
DATE RECEIVED:	19-6-74
WORK REQUIRED:	X-ray diffraction and petrography

Investigation and report by: Dr R.N. Brown and Dr B.G. Steveson

Officer in Charge, Mineralogy & Petrology Section: Dr K.J. Henley

K.J. Henley

for F.R. Hartley
Director

mhb

REC. 3 JUL 19

Pilot Plant: Osman Place, Thebarton, South Australia, phone Adelaide 43 8053 Branch Offices: Perth and Sydney

EXAMINATION OF VOLCANIC GLASS

1. INTRODUCTION AND PROCEDURES

This part-report describes work carried out on a sample (X-104) submitted by R.M.C. Minerals Pty. Ltd.

One chip of the rock was crushed and was analysed by X-ray diffractometry and a thin section was prepared from another sub-sample.

2. RESULTS

2.1 X-ray diffraction results

The minerals in the rock, in decreasing order of abundance are:

Montmorillonite

Forsterite

Phillipsite

There is a considerable amount of amorphous material in the sample which gives no X-ray diffraction pattern.

2.2 Petrographic description (TS 32540)

An optical estimate of the constituents gives the following:-

	%
Glass	65
Olivine (forsterite)	15
Clay and zeolite	20
?Plagioclase	<5

Most of the sample consists of a brown volcanic glass which is completely isotropic. Numerous minute needles of ?plagioclase (? clinopyroxene) are present in the glass and have the glass's overall orange-brown colour.

Crystals of olivine are commonly 0.1-0.6 mm in size and show subhedral shapes. Some of the olivine shows a little brown, dusty alteration but, for the most part, the olivine, like the glass, is completely fresh.

The sample contains a wide variety of vugs and cavities; the smallest and most abundant are circular features as little as 0.05 mm in diameter. A radially arranged clay or zeolite fills these cavities. In some parts of the thin section these cavities occupy up to 50% of the rock. Larger vugs are several millimetres in size and have irregular shapes. A lining of elongate ?zeolite crystals characterises most of these large vugs and there is generally a central area of extremely fine-grained granular material (?zeolite, ?clay).

In summary, therefore, the rock is a vitric olivine basalt containing numerous vugs now filled with secondary minerals. The glass has not devitrified and the olivine is fresh.

029

BLAINE SURFACE AREA DETERMINATIONS

OF MILLED VOLCANIC ASH

(REPORT BY A.M.D.E.L.)

F.C (P.G)

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030

Please address all correspondence to the Director
In reply quote: ME 3/115/1/0

27 June 1974

Mr P.R. Gray
RMC Minerals Pty Limited
G.P.O. Box 1798
ADELAIDE SA 5001

REPORT: ME 4802/74

YOUR REFERENCE:	Letter dated 18 June 1974
MATERIAL:	Volcanic Ash
IDENTIFICATION:	Samples No. P60 - P64
DATE RECEIVED:	19 June 1974
WORK REQUIRED:	Blaine surface area determinations

28 JUN 1974

Investigation and Report by:	D.W. Fox and H. Mowinkel
Officer in Charge, Mineral Engineering Section:	G.A. Dunlop

for F.R. Hartley
Director

ha

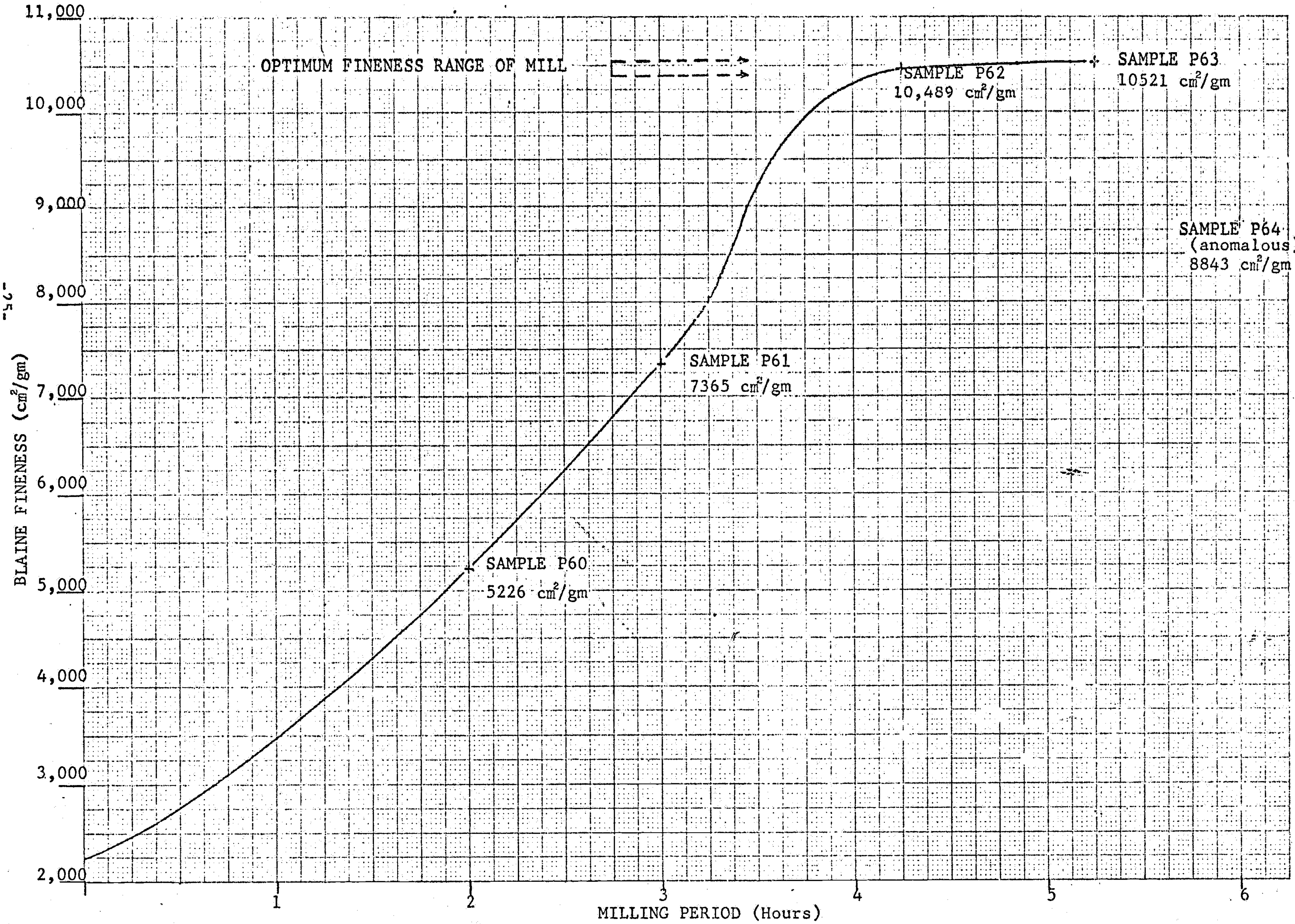
In a letter dated 18 June 1974, R.M.C. Minerals Pty Limited requested that Amdel undertake a Blaine sizing determination on each of five samples of volcanic ash, the results of which work are reported below. The chemical analysis and the petrographic examination of two further samples as requested in the same letter, will be reported separately by the relevant Amdel sections.

The Blaine surface area determinations were carried out in accordance with the SAA standard procedure AS A2-1963 and amendments, Section 3, Method of Test for Fineness of Portland Cement by Air Permeability Method. Briefly, this involves drawing a fixed volume of air under a varying head through a prepared bed of sample of known dimensions and porosity. The number and size of the pores in such a bed is a function of the particle sizing and thus determines the air flow-rate through the bed. The surface area of the material is in turn proportional to the square root of the time taken for the fixed volume of air to pass through the bed. A complete description of the apparatus required and the method of determination may be found in the SAA publication cited above.

The results of the testwork are as follows:-

Sample	S.G.	Blaine Surface Area (cm^2/gm)
P60	2.38	5226
P61	2.53	7365
P62	2.64	10489
P63	2.62	10521
P64	2.72	8843

The Blaine surface areas of samples P60 - P63 are each the average of two determinations, the results of which did not differ by more than 1%. The result recorded for sample P64 did not follow the expected trend and so a further three determinations were performed. The result shown is the average of three determinations, the values for which did not differ by more than 0.5%. The closeness in results for samples P62 and P63 is due to the similarity in their S.G.'s. Both the S.G. determinations were repeated, confirming the initial results.



OPTIMUM FINENESS RANGE OF MILL
SAMPLE P60
5226 cm²/gm
SAMPLE P61
7365 cm²/gm
SAMPLE P62
10,489 cm²/gm
SAMPLE P63
10521 cm²/gm
SAMPLE P64
(anomalous)
8843 cm²/gm
BLAINE FINENESS (cm²/gm)
MILLING PERIOD (Hours)
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
11,000
1
2
3
4
5
6

RESULTS OF CONCRETE TRIALS 033

THE READYMIX GROUP (S.A.) 034

REPORT NO 1 - EXPLORATION LICENSE NO 123 5.4.74

EVALUATION OF GROUND VOLCANIC ASH IN CONCRETE MIX TRIALS

INTRODUCTION

Five volcanic ash samples forwarded by R.M.C. Minerals Pty. Ltd., were received at the Brompton Laboratory during February 1974 for evaluation in physical concrete trials.

Methods of evaluation were to conform with those previously used in test-work carried out on materials from the same source, whereby the ratio of pozzolanic volcanic ash added to a given mix must exceed the volume or weight of cement removed. This system, although not conforming with standard procedure for the use of pozzolans, has been used widely throughout the U.S.A. in recent years.

METHOD

As outlined within the accompanying text by Robert W. Cannon, and titled "Proportioning Fly Ash Concrete Mixes for Strength and Economy".

BLEND RATIO

Selected ratios of contained pozzolan, were chosen from the most promising results of past trials. These included 15% and 25% of the total weight of Normal Portland Cement used in a standard mix containing 400 lbs of cement per cubic yard of concrete. The corresponding removal of Normal Portland Cement was 7.7% and 13.1% (by weight) respectively.

RESULTS

MIX	SLUMP (inches)	COMPRESSIVE STRENGTH (P.S.I) 7 days	28 days	28 days (Av)	28 days Equiv 3" Slump	Variation from Control	ACTUAL YIELD (c.ft)	ACTUAL TOTAL WATER (galls/c.yd)
ple P. 60 (2 .2.74)								
trol 400 lbs A el. N.P.	2.75	2050	3250	3225	3175		27.0	37.9
			3200					
% ash/cement	3.00	1600	3000	2975	2975	-200(-6%)	27.0	37.0
			2950					
% ash/cement	3.00	1600	2750	2775	2775	-400(-13%)	27.0	36.5
			2800					
ple P.61 (27.2.74)								
ntrol 400 lbs el. N.P.	3.00	1750	3050	3125	3125		27.0	37.9
			3200					
% ash/cement	3.00	1650	2500	2475	2475	-650(-21%)	27.0	37.0
			2450					
% ash/cement	2.50	1800	2550	2700	2600	-525(-17%)	27.0	36.5
			2850					
mple P. 62 28.2.74)								
Control 400 lbs el N.P.	4.25	1550	2800	2750	3000		27.1	37.9
			2700					
% ash/cement	Insufficient Sample Material							
25% ash/cement	3.00	1400	2800	2800	2800	-200(-7%)	27.0	36.5
			2800					
Sample P. 63 (8.2.74)								
ontrol 400 lbs Adel. N.P.	2.75	1700	3200	3150	3100		27.0	37.9
			3100					
15% ash/cement	3.00	1600	2850	2875	2875	-225(-7%)	27.0	37.0
			2900					
25% ash/cement	2.50	1650	2850	2775	2675	-425(-14%)	27.0	36.5
			2700					

MIX	SLUMP (inches)	COMPRESSIVE STRENGTH (P.S.I.)					ACTUAL YIELD (C. Ft)	ACTUAL TOTAL WATER (galls/c.yd)
		7 days	28 days	28 days (Av)	28 days Equiv 3" Slump	Variation from Control		
mple P. 64 (4.3.74)								
ntrol 400 lbs Adel. N.P.	3.00	1600	2850 2900	2875	2875		27.0	37.9
% ash/cement	2.75	1800	2800 2850	2825	2775	-100(-3%)	27.0	37.0
% ash/cement	3.50	1450	2600 2700	2650	2750	-125(-4%)	27.0	36.5

CONCLUSIONS

(a) Results from the current series of trials have proved conclusively that the addition of these pozzolans to a concrete mix, at the blend ratios used here, would not benefit the resultant product strength in any way.

(b) Economically, the use of a blend ratio of less than 15% (pozzolan) would be extremely difficult to justify.

THE READYMIX GROUP (S.A.)

REPORT NO 2 - EXPLORATION LICENSE NO 123 5.6.74

LONG TERM EVALUATION OF GROUND VOLCANIC ASH IN CONCRETE MANUFACTURE

INTRODUCTION

This Report concerns long-term evaluation of pozzolanic volcanic ash, when used as a part substitute for cement in concrete manufacture.

Preliminary test-work, completed on behalf of R.M.C. Minerals Pty. Ltd., included initial trials upon the same five samples, number P.60 - P. 64 respectively, as are outlined in the results hereof. Reference to the results of previous trials were the subject of Report No 1.

WORK REQUIRED

Previous work had entailed strength tests after the duration of both 7 days, and 28 days, from the time of mixing and casting of test specimens.

R.M.C. Minerals requested initially that strength tests also be completed after 90 days duration, to enable further interpretation of respective rates of increase in strength of Blended, and Control specimens.

SCOPE

Although current Australian Standards require a maximum specified strength for a given concrete mix at the duration of a 28 day curing period, previous test-work had indicated a greater progressive strength increase in the Blended Concrete than the Control specimen, during the period terminating at 90 days. Previous work of this nature, during the tenancy of former Exploration Licenses, has shown that this resultant increase can only be obtained from concrete mixes containing blended Pozzolans with a fineness in excess of that of normal cements. Among these more promising past results, the fineness was maintained at approximately 5000 cm^2/gm (Blaine Method of Fineness Determination). However, trial mixes represented here, and as reported upon in the Report No 1, had not at the time of the trial had a determination of fineness of the milled volcanic ash, and therefore it is difficult to correlate a number of the anomalous results of these current trials.

RESULTS

SAMPLE NO	MIX	COMPRESSIVE STRENGTH (P.S.I.)				
		28 days	28 days Av.	90 days	Total Gain/ Loss	Control Comparison
P. 60	Control 400lbs N.P.	3250	3225	4150	+925	
		3200				
	15% ash/cement	3000	2975	3700	+775	-450
		2950				
	25% ash/cement	2750	2775	3900	+1125	-250
		2800				
P. 61	Control 400 lbs N.P.	3050	3125	3700	+575	
		3200				
	15% ash/cement	2500	2475	3100	+725	-600
		2450				
	25% ash/cement	2550	2700	3450	+750	-250
		2850				
P. 62	Control 400 lbs N.P.	2800	2750	3250	+500	
		2700				
	25% ash/cement	2800	2800	3650	+850	+400
		2800				
P. 63	Control 400 lbs N.P.	3200	3150	3750	+600	
		3100				
	15% ash/cement	2850	2875	3550	+675	-200
		2900				
	25% ash/cement	2850	2775	3600	+825	-150
		2700				
P. 64	Control 400 lbs N.P.	2850	2875	3550	+675	
		2900				
	15% ash/cement	2800	2825	3450	+625	-100
		2850				
	25% ash/cement	2600	2650	3200	+550	-350
		2700				

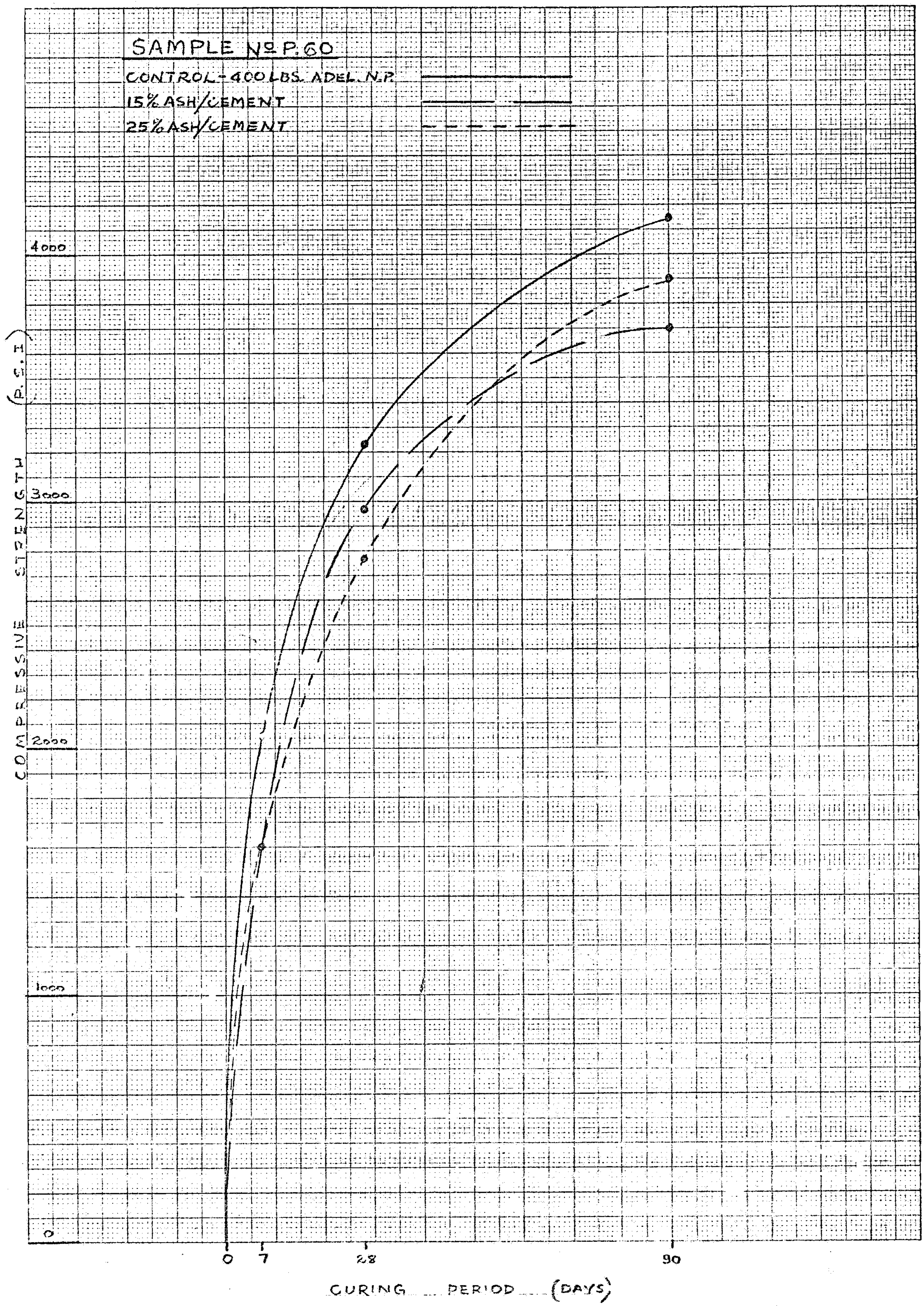
NOTE: 15% ash/cement corresponds to 7.7% and 13.1% respectively of actual cement removed

CONCLUSIONS

(a) The results represented above, with the exception of Sample P. 62 have failed to obtain strengths comparable to both 28 day and 90 day Control tests.

(b) Fineness of the samples submitted appeared to vary and this probably had considerable influence on resultant strengths.

07A88
1 millimetre squares
.039



07A88
1 millimetre squares
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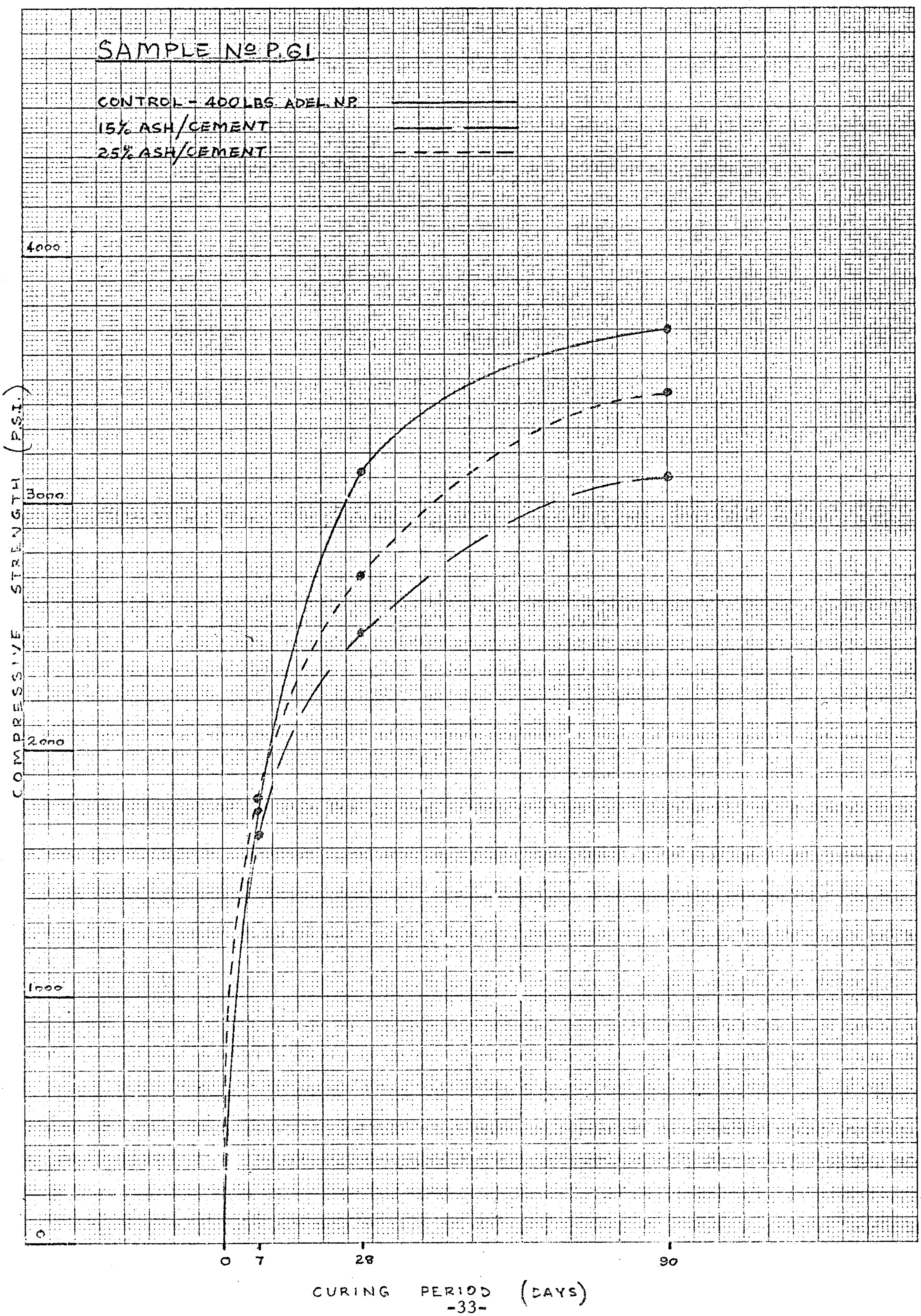

07A88
1 millimetre squares

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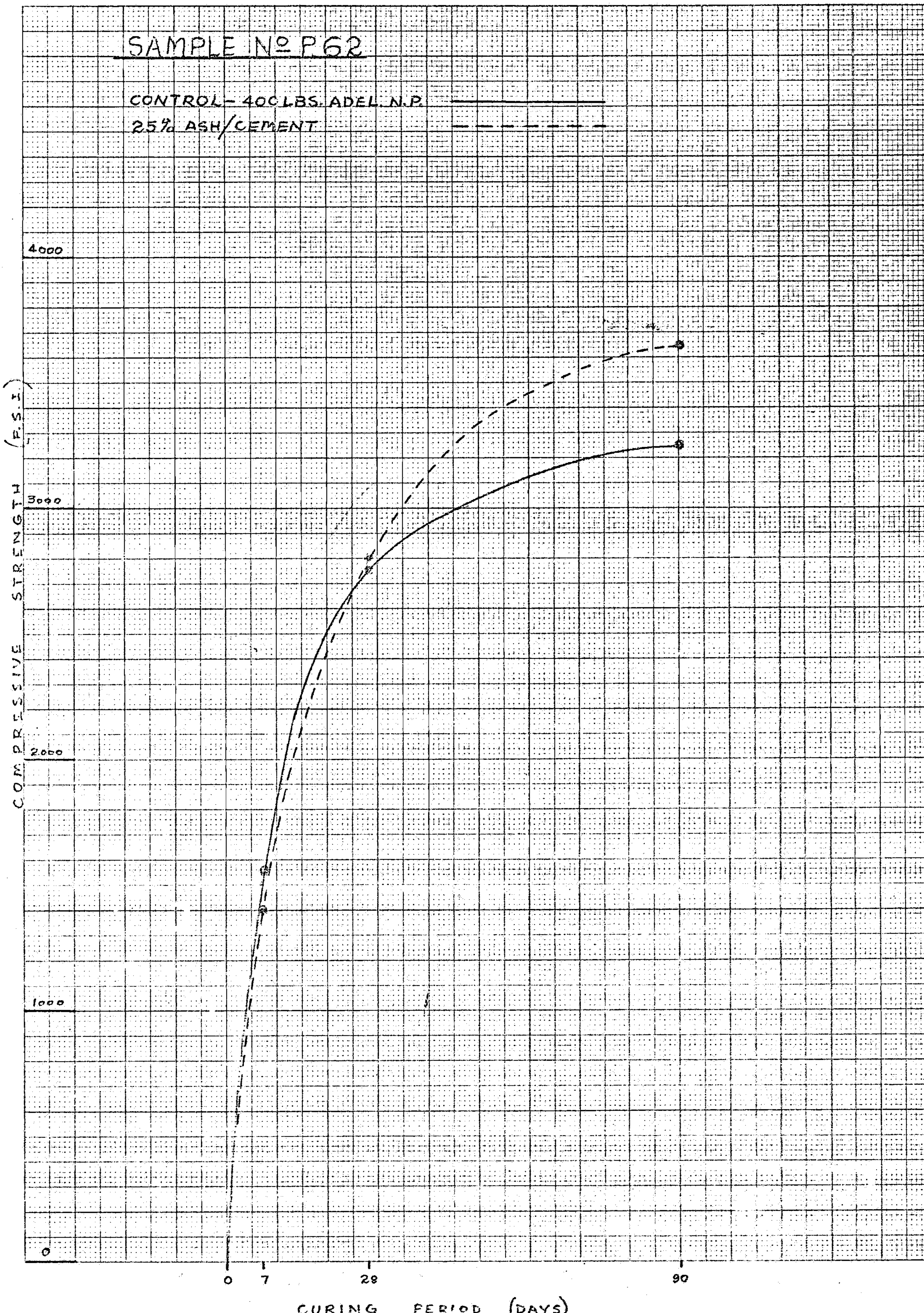
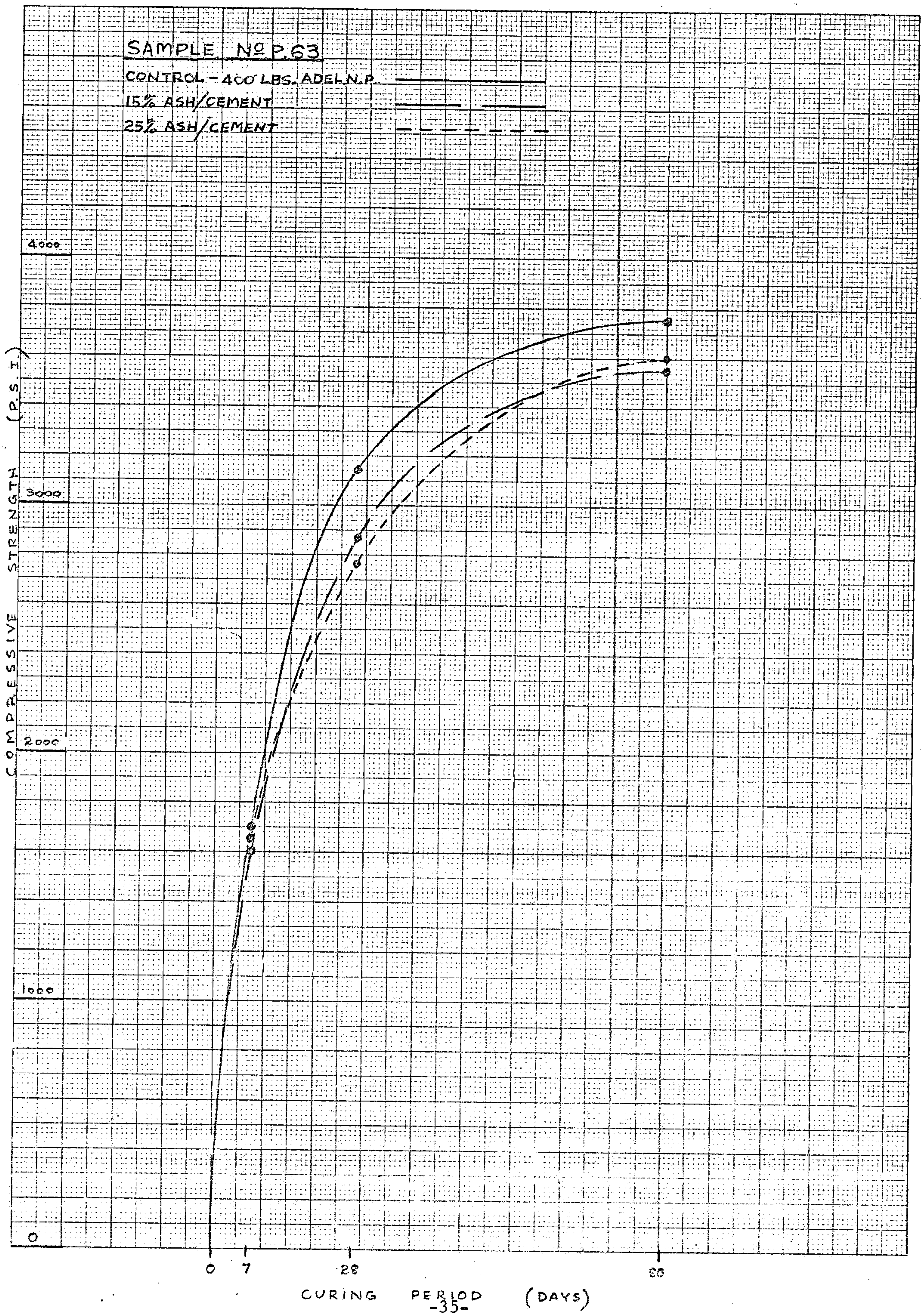
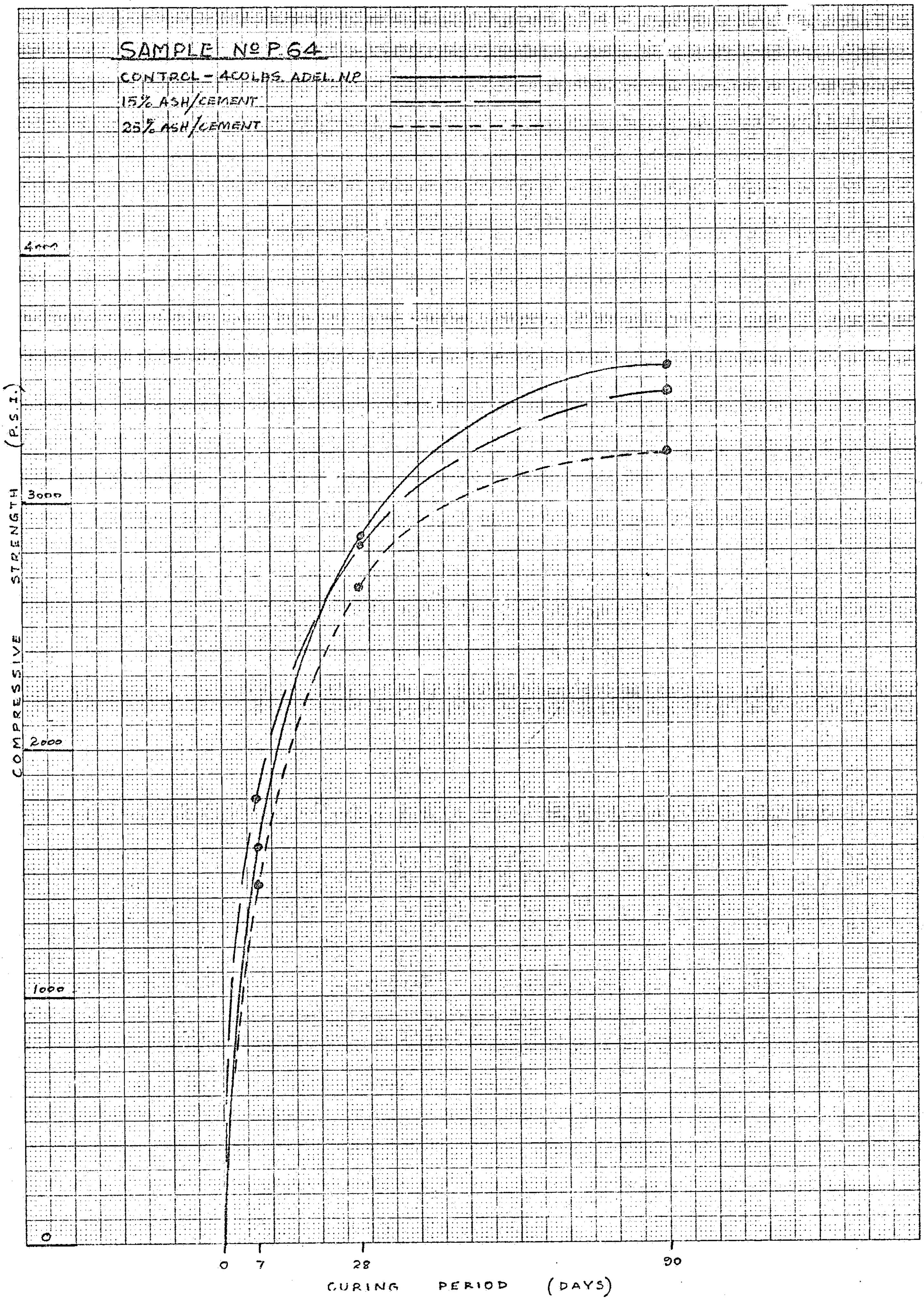
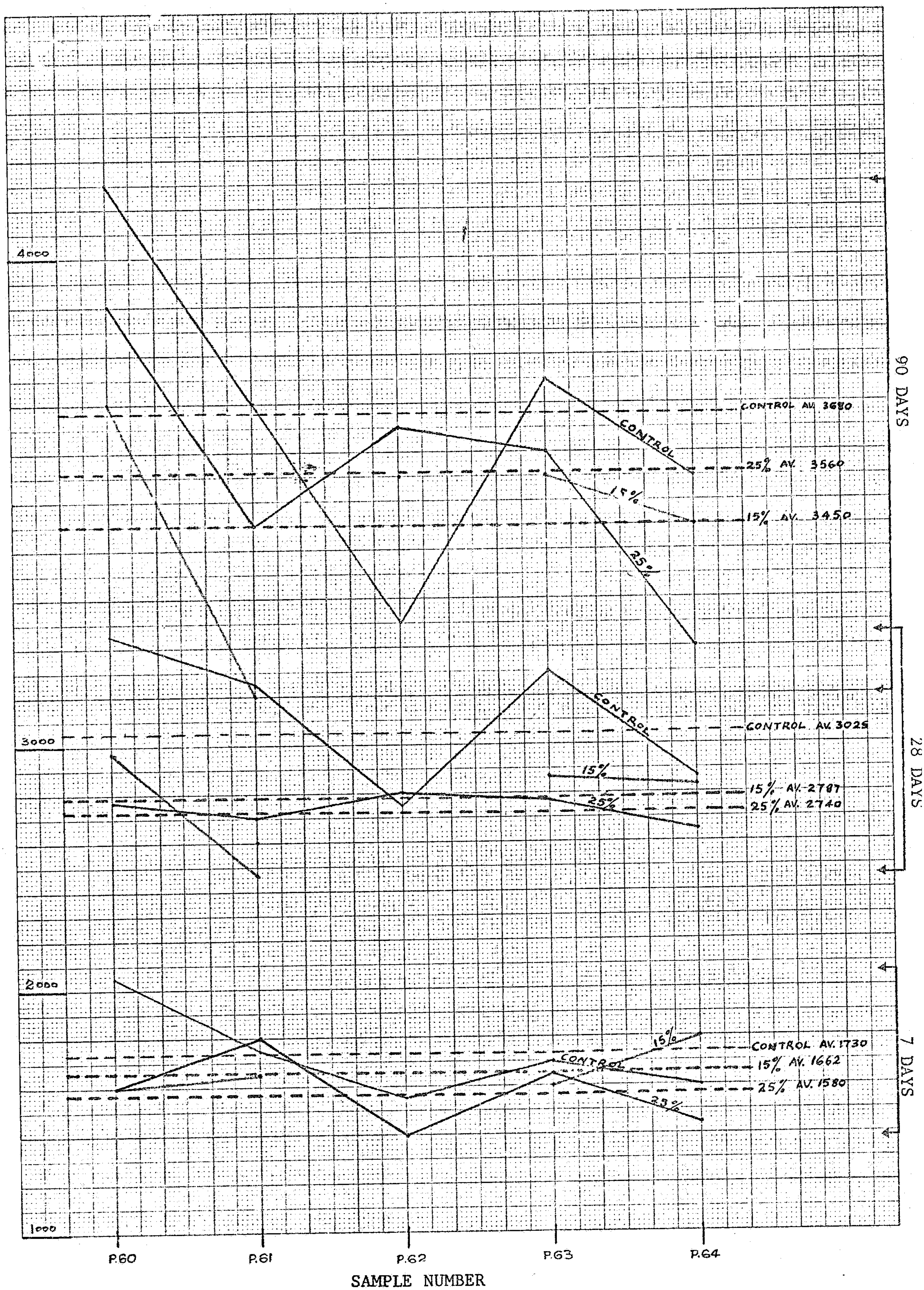



SAMPLE Nº P.63
CONTROL - 400 LBS. ADEL N.P.
15% ASH/CEMENT
25% ASH/CEMENT
COMPRESSIVE STRENGTH (P.S.I.)
4000
3000
2000
1000
0
0
7
28
90
CURING PERIOD (DAYS)


SAMPLE Nº P 64
CONTROL - 400 LBS. ADEL. N.P.
15% ASH/CEMENT
25% ASH/CEMENT
4000
3000
2000
1000
0
COMPRESSIVE STRENGTH (P.S.I.)
0
7
28
90
CURING PERIOD (DAYS)

STRENGTH COMPARISONS



EXPENDITURE

F~ 045

	$
Geological & Technical Supervision	900.00
Field work - including labour, accomodation travel sampling etc.	820.00
Sample preparation	395.00
Laboratory Trials @ $11.00 per specimen	616.00
A.M.D.E.L. (Approx)	100.00
Administration and other overhead costs	575.00
TOTAL	$3,406.00

CONCLUSIONS

The interest originally displayed by R.M.C. Minerals Pty. Ltd. in the investigation of South Australian Volcanics, stemmed from previous interest shown by its parent Company in development of pozzolanic cements from naturally occuring volcanic resources.

During the tenancy of three individual Exploration Licenses held by R.M.C. Minerals Pty. Ltd., since 1972, over volcanic areas within the South Eastern Province, much has been learned of the pozzolanic properties characteristic of ash ejectamenta resulting from explosive volcanic eruptions of the Late Tertiary and Recent Periods.

Investigation of mode of deposition within the ash beds, and the properties of the ash, have indicated that although there exists a considerable variation in age between the older volcanics of the South-East, and the more recent occurrences such as Mt. Schank, there is a remarkable similarity in the nature of pozzolanic properties of ash present at the respective locations.

Original exploration was directed toward deposits containing sizeable reserves which could be extracted with minimum effect upon the environment concerned. Initial investigations during the tenancy of Special Mining Lease No 655, were restricted to the material present at Mt. Schank, when extensive tests indicated that the material, if milled to a fineness in excess of that for Normal Portland Cement, would react with cement in a concrete-mix, and thus promote a long-term strength gain in the concrete. It was also noticed during this stage that although long-term benefit was promoted, the reverse effect was present at relatively early periods, and because of the requirements of Specifications controlling structural concretes, the strength gain of the test specimens were in all instances below that of the Specification at the duration of the test period.

Variations in fineness of the milled pozzolan were noticed to effect the resultant strength of manufactured concrete specimens at this time, and trials were adjusted to include these variations, however, the expected goal was not reached.

Although these results were somewhat discouraging at the time, other associated tests upon lime/pozzolan mortars had indicated that materials derived from both Mt. Schank and Lake Leake were equivalent to commercially used pozzolans of the Eastern States.

After the expiry of Special Mining Lease No 655, an area comprising the twin volcanic vents of Lakes Edward and Leake was taken up by this Company. Work, centred principally around Lake Leake material, continued throughout the duration of firstly, Exploration License No 13, and proceeded again during the tenancy of Exploration License No 123, of which this Report is concerned.

Initial strength trials on pozzolan/cement concretes during Exploration License No 13 displayed considerable promise of fulfilling requirements of the Specification provided that the milled fineness of Lake Leake ash was in excess of 5000 cm^2/gm. However, with further evaluation, it was found that where some samples of consistant fineness may yield promising results, there were others of the same fineness with anomalous values which were detrimental to product strength. These anomalous values therefore, were not attributable to material fineness, but some other criteria of which we were not fully aware.

Further work since that time has included a much broader scope of experimentation, whereby combinations of various fineness, rates of pozzolan/cement blend, and mix adjustments have been tried. Early in the program considerable work was also completed in trials using different specific mix designs, however, this was found to be of no positive advantage, and therefore, in recent times, all experiments have been based upon a specific concrete mix containing the standard equivalent of 400 lbs of Normal Portland Cement per cubic yard.

Results derived from the final experimental procedures outlined herein, have shown, as with all previous results, that all samples used within concrete trials have contained definite pozzolanic properties, but unfortunately the ability of the material to react with cement in a rigidly controlled concrete mix, is in no way consistent. Moreover, the rate of milled fineness of the pozzolan cannot in all instances be directly related to the resultant product strength, and therefore the ability to utilize the material within the Concrete Manufacturing Industry, without further extensive research, appears impractical.

APPENDIX I

~ ~ 048

PROPORTIONING FLY-ASH CONCRETE MIXES FOR STRENGTH AND ECONOMY.

by Robert W. Cannon.

TITLE NO. 65-75

Proportioning Fly Ash Concrete Mixes for Strength and Economy

By ROBERT W. CANNON

A method is presented for proportioning fly ash with cement to produce concrete of equal strengths at 28 and 90 days to concrete without fly ash. The method was developed by the Tennessee Valley Authority (TVA) as a result of using fly ash in all classes of concrete for the past 12 years. Effects of differing proportions of fly ash on water requirements, strength, and economy are given along with a discussion of the effects of fineness and carbon content of fly ash and variations in strength of cements on cement requirements. Comparisons are made between the cement requirements as determined by this method with the cement actually required by tests from the Corps of Engineers, TVA, and Bays Mountain Construction Company using at least nine different suppliers of cement and eight different fly ashes, four of which would not meet Federal and ASTM specifications.

Keywords: air content; carbon analysis; cement content; cements; compressive strength; concretes; costs; fineness; fly ash; mix proportioning; slump tests; specific surface; water-cement ratio; water content; water reducing agents.

THE PRINCIPAL METHOD USED by most mix designers to proportion fly ash in concrete is to substitute fly ash for cement. This substitution is generally made on a one-for-one basis either by weight or by volume in order to make sense out of the existing water-cement ratio requirements of specifications. Fly ash concrete mixes proportioned by this method will nearly always have lower strengths than their control mixes at ages up to 28 days, but frequently equal or higher at 90 days and beyond. These lower early strengths have led many designers to conclude that fly ash is only desirable or economical in mass concrete where strength is not the principal requirement. An exception to this approach is the method developed by Lovewell and Washa[1] based on proportioning fly ash mixes for equal 28-day strength to control mixes. In their method the amount of fly ash added always exceeded the amount of cement removed.

Initial investigation by TVA into the potential use of fly ash from TVA steam plants prompted TVA to substitute 2 lb of fly ash for each pound of cement replaced in an effort to utilize a coarser fly ash than was acceptable under Federal and ASTM specifications.[2] TVA found that its fly ash mixes when proportioned by this method had strengths equal to the strength of control mixes at about 60 days. Today with the addition of electrostatic precipitators, some TVA steam plants produce fly ash which meets or exceeds the fineness requirements of Federal and ASTM specifications. During the past 5 years TVA has conducted extensive investigations into the proportioning of fly ash mixes for equal strength concrete at 7, 28, and 90 days using both specification and nonspecification fly ash. Present TVA policy is to use the source of fly ash which offers the greatest economy in the concrete for each particular construction project regardless of whether or not the fly ash meets Federal and ASTM specifications.

The following procedure for proportioning fly ash mixes has evolved from TVA investigations. It is readily adaptable to different strengths of Types I and II cement and to different qualities of fly ash. This method is intended only for porportioning cement and fly ash and does not

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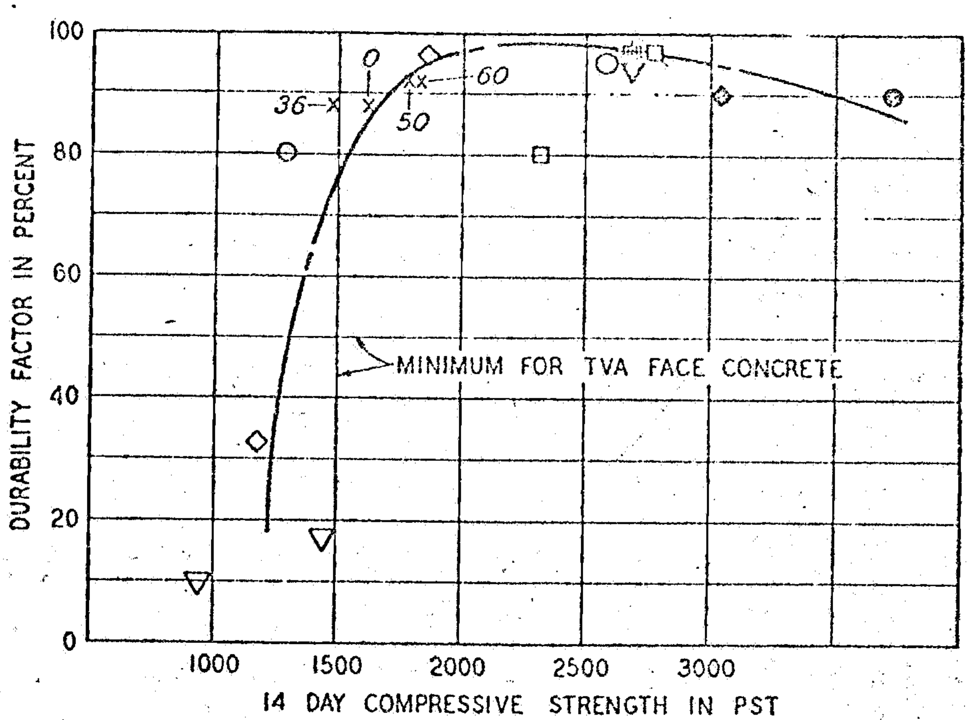
deal with the proportioning of aggregates or the determination of the basic water requirements. The procedure is applicable regardless of the efficiency and inefficiency of proportioning aggregates. It does assume that the quantity and gradation of the coarse aggregate is the same in comparable mixes and that the difference in yield due to the larger volume of cementitious material in the fly ash mix is balanced by a reduction of the sand content. When the quantity of coarse aggregate differs in comparable mixes adjustments will be required to account for this difference as will be shown later.

TVA has also conducted extensive investigations into the freezing and thawing resistance of concretes containing various proportions of fly ash to cement. These investigations reveal that freezing and thawing resistance is independent of fly ash proportions for concrete proportioned for equal strength and air contents. Fig. 1 shows the results of TVA tests with limestone aggregates. With good aggregate and proper air contents, concrete having 14-day strengths greater than 1500 psi should have good freezing and thawing resistance irrespective of the makeup of the cementitious material.

VARIATION IN CEMENT STRENGTH

The water-cement ratio curves of Fig. 2 represent the average of tests from seven different cement manufacturers in the TVA region using Type II cement with 7.5 percent ± air content by volume of mortar in the compacted test specimen. The variation in strength of the cement from the different mills from these 28- 90-day averages was 10 percent ± of any given water-cement ratio. Corrections should be made for the difference between Fig. 2 strengths and the actual strengths



SYMBOLS	FLY ASH % CMT BY WT	FLY ASH % TOTAL BY VOL	TYPE II CEMENT MILL	LIMESTONE AGG. SOURCE
▽	80	50	VII	NICKAJACK
▼	60	43	"	"
◇	80	50	PII	"
◈	60	43	"	"
○	80	50	"	BULL RUN
⊙	60	43	"	"
□	40	33	"	MARYVILLE
⊟	40	33	LII	"
⊞	40	33	SII	"
⌑	40	33	SMII	"
x – 0	0	0	SII	BROWNS FERRY
x – 36	40	36	"	"
x – 50	80	50	"	"
x – 60	120	60	"	"

Fig. 1—Freezing and thawing resistance of concrete containing fly ash of varying proportions.

of the cement to be used on the job as indicated in the procedure.

VARIATION IN STRENGTH DUE TO FLY ASH

The fineness of fly ash is generally recognized as one of the principal factors affecting the quality of fly ash. To the author's knowledge no one has succeeded in attaching any particular significance to the chemical makeup of fly ash other than to loss on ignition normally considered herein as carbon content, which does appear to be a definite factor affecting ash quality. We have found that a decrease in fineness of 1000 cm²/gm in specific surface area of the fly ash as measured by the modified Blaine method[3] will require an increase in cement content of 5 to 6 percent for ashes of equal carbon content to maintain the same concrete strength. TVA fly ashes generally have very little variation in carbon content and although we have conducted no experiments on the effect of variations in carbon content, we feel that variations will have a more pronounced effect on cement requirements in the lower ranges of carbon content than equal variations in the upper ranges.

In general, the variation in fineness and carbon content will be small from a modern steady load and efficiently operated powerplant. Based on TVA's experience, variations in strength of approximately 4 percent may be expected due to variations in the fly ash. The addition of fly ash as another variable in the concrete does not normally mean an increase in the coefficient of variation of the concrete as produced since fly ash concrete at a given concrete plant will almost always have an equal or lower coefficient of variation for a properly designed mix than a comparable mix without fly ash. Tests conducted by TVA using a single source of fly ash and cements from seven different sources consistently showed lower coefficients of variation in the fly ash mixes at all proportions and strength levels than in the control mixes without fly ash.

In the author's opinion, fly ash can contribute to the strength of concrete in three distinct ways; first, by direct water reduction; second, by increasing the effective volume of paste in the mix; and, third, by pozzolanic reaction. The first two ways contribute to the immediate or early strength of the concrete and the third way contributes to the long range strength gain of fly ash concrete. Direct water reduction can be measured and is considered in the following paragraph. By partially filling the sand voids of the mortar with solid particles of fly ash (the fine fly ash particles may be securely held in the paste by molecular attraction thus increasing the volume of paste without loss of paste strength) the average thickness of paste surrounding the sand particle is increased providing a stronger bond of paste to sand particles thereby increasing mortar strength particularly in leaner concrete mixes having a deficiency of paste without fly ash. This

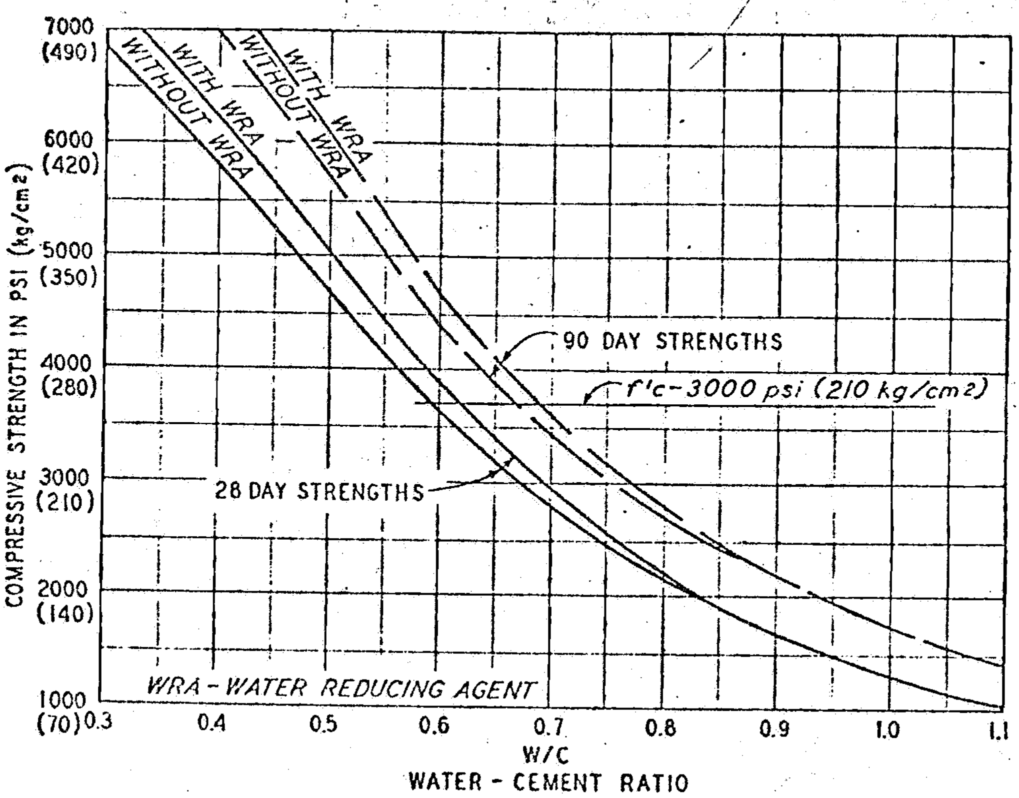


Fig. 2—Water-cement ratios strengths of control mixes for an average Type II cement, limestone sand, and 7.5 percent ± mortar air content

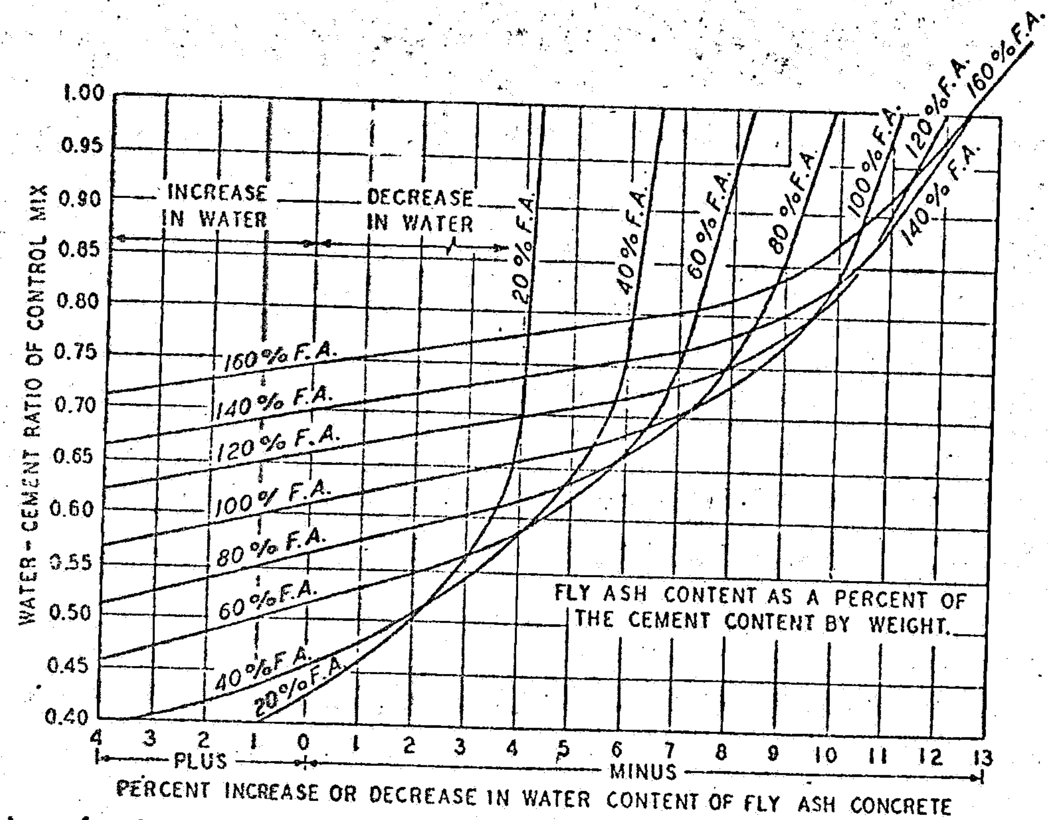


Fig. 3—Comparison of water requirements of concrete with and without fly ash equally proportioned for 28-day strength, identical slump, and air contents

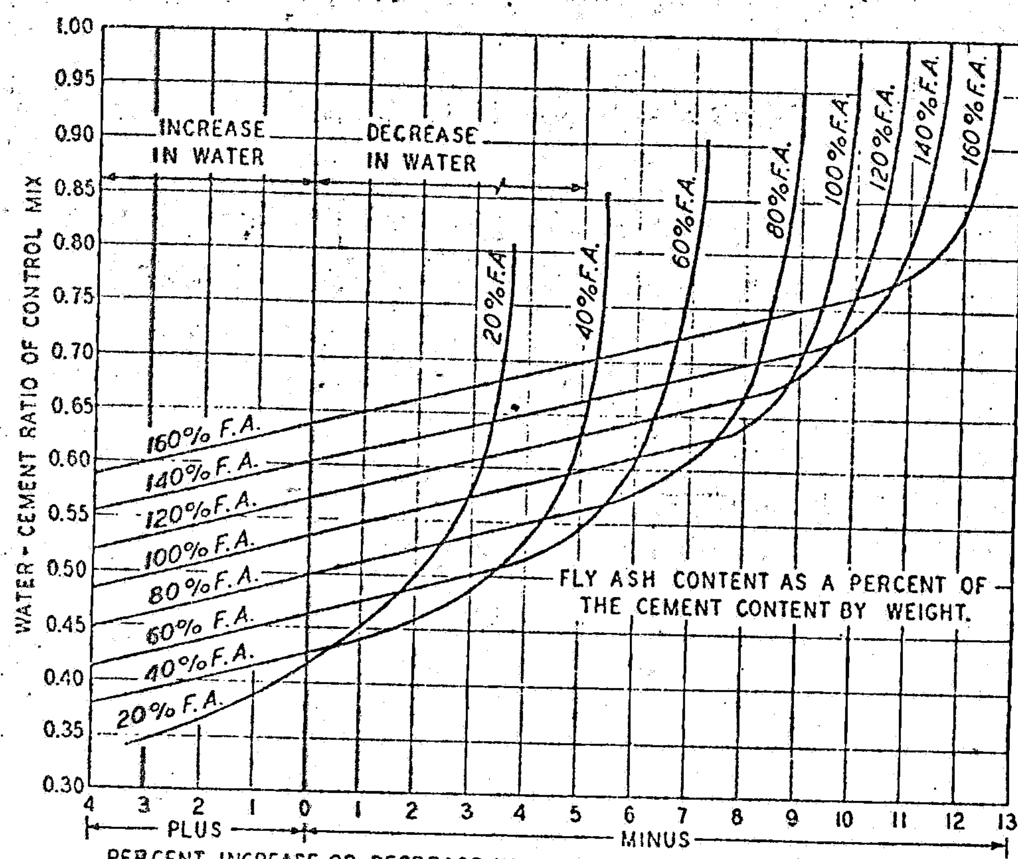


Fig. 4—Comparison of water requirement of concrete with and without fly ash equally proportioned for 90-day strength, identical slump, and air contents

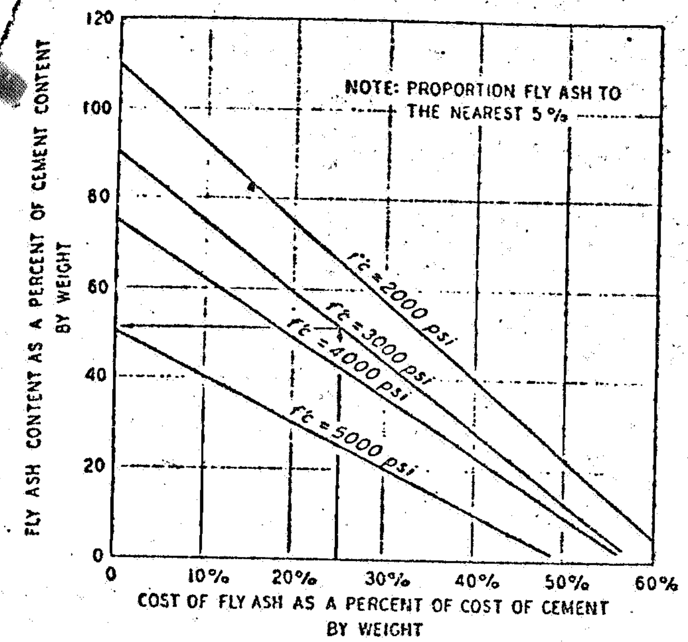


Fig. 5—Economic proportions of fly ash for 28-day strength concrete

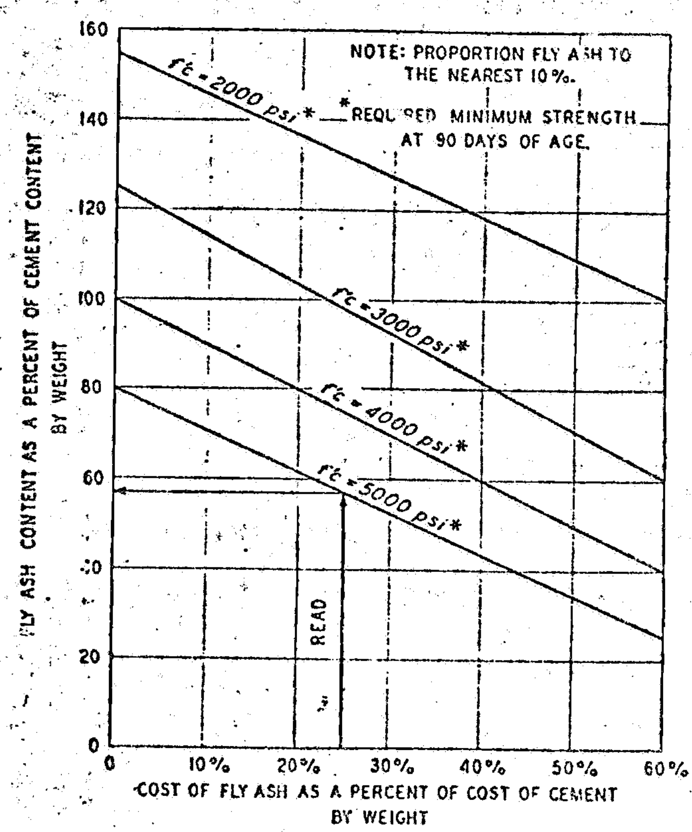


Fig. 6—Economic proportions of fly ash concrete for 90-day strength concrete

is the only logical explanation which the author can offer for the concrete strengths of very high proportions of fly ash with a given cement content since there is neither enough calcium hydroxide available from the cement for complete pozzolanic reaction with all of the fly ash or enough direct water reduction to account for the strengths.

EFFECT OF FLY ASH ON WATER CONTENTS

For a given set of concrete materials, the water required to produce a uniform consistency for a given mortar volume and air content is dependent entirely on the quantities of cement and fly ash. Fig. 3 (28-day strengths) and Fig. 4 (90-day strengths) show the comparison of water requirements for equal strength concrete in terms of the proportions of fly ash to cement used and the water-cement ratio of control mixes. These curves are based on an average TVA fly ash having approximately 2 percent loss on ignition and a specific surface area of 2500 cm^2/gm. They are also based on the average results of Type II cements from seven different mills.

Another fly ash with differing specific surface area and ignition loss may differ in water requirements from Fig. 3 and 4. The effect of differences in water requirements is minimized, however, in using these curves for proportioning mixes when the mix is checked for actual water requirements as in Step 10 of the procedure which follows. Fly ashes do not produce the same water reduction with all cements, but fortunately fly ash effects a greater water reduction in the cements which require higher water contents themselves. This leveling effect on water requirements at a given slump level is, we believe, the principal reason for lower coefficients of variation of fly ash concrete. The reason for differences in water requirements for comparative 90-day strengths (Fig. 4) over that of comparative 28-day strengths (Fig. 3) for given control mix water-cement ratios is the much greater reduction in cement requirements for 90-day strengths in fly ash mixes.

ECONOMIC PROPORTIONS

The economy of using fly ash depends entirely on the relative cost of fly ash to cement, the quality of ash, and the strength requirements of the concrete. Fig. 5 (28-day strengths) and Fig. 6 (90-day strengths) show the economic proportions for an average fly ash to provide the minimum combined cost of cement and fly ash in the mix. They are based on recommended average concrete strengths normally required to provide the minimum strength concrete indicated.

REDUCTION IN CEMENT CONTENT

Fig. 7 and 8 give the comparative cement requirements of various fly ash proportions to produce concrete of equal strengths at 28 and 90 days of age to mixes without fly ash. These curves are developed from a series of strength versus water-cement plus fly ash curves by making allowances for the differences in water requirements at the various levels of strength using Fig. 3 and 4.

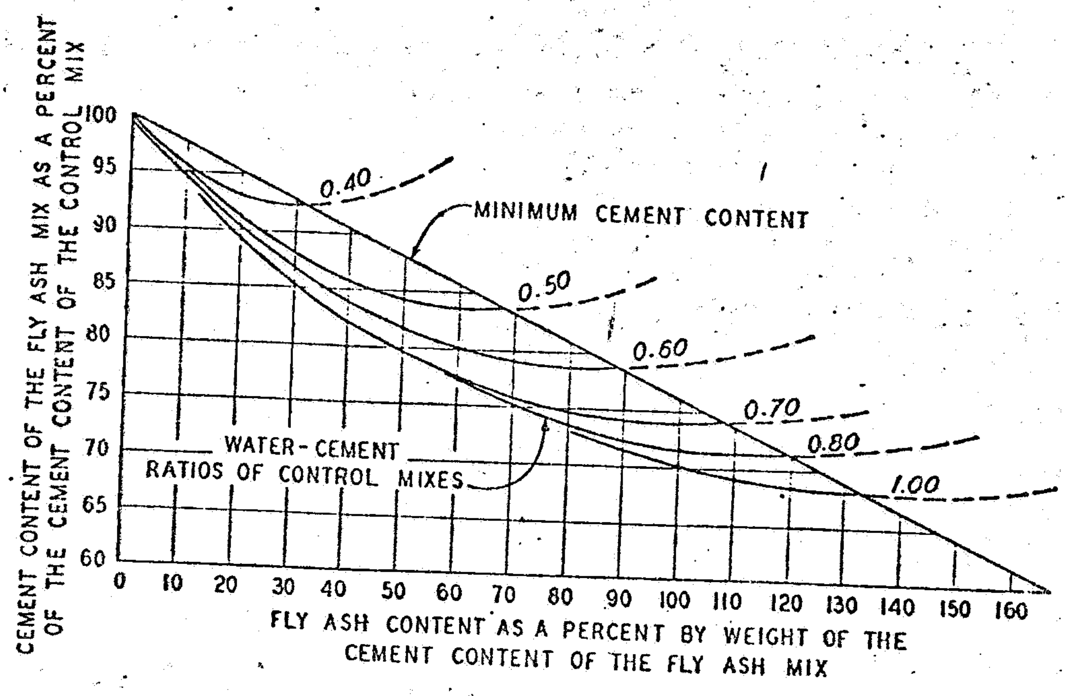
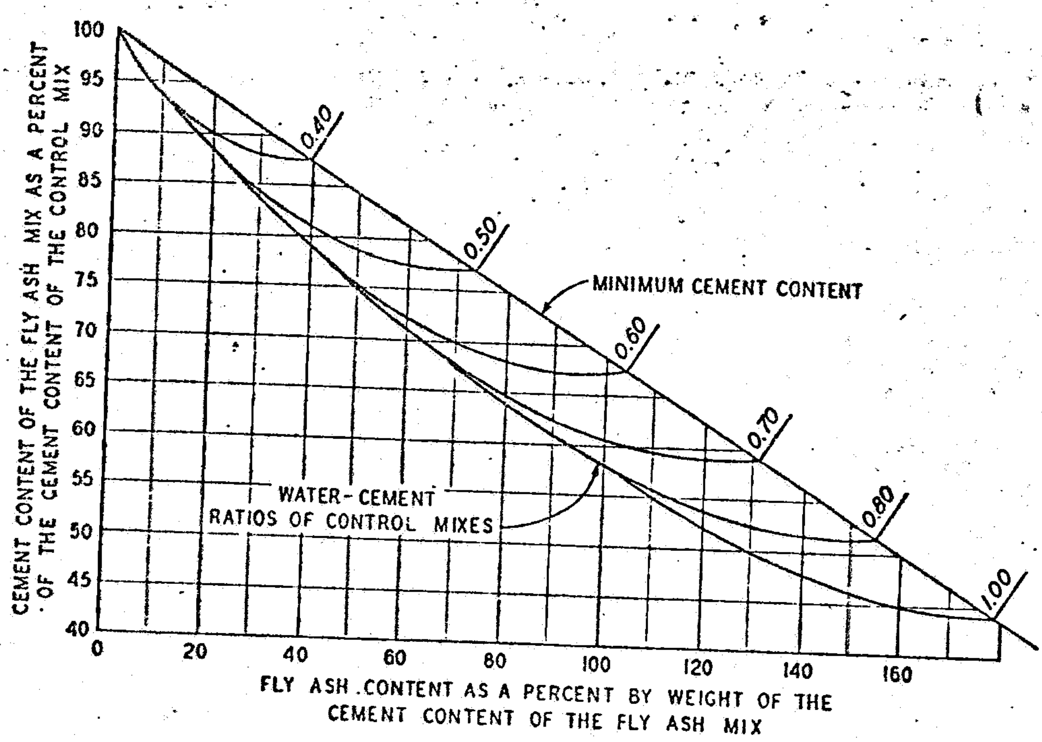


Fig. 7—Relative cement requirements for various fly ash proportions of concrete equally proportioned for 28-day strength, identical slump, and air contents



8—Relative cement requirement for various fly ash proportions of concrete equally proportioned for 90-day strength, identical slump, and air contents

PROCEDURE FOR PROPORTIONING MIXES

Designing for a required strength

Step 1 — Select the volume of coarse aggregate per unit volume of concrete from Table 6 of ACI 613-54. (In making this selection the fineness modulus of the sand should be reduced by 0.20 to allow for the effect of the larger volume of cementitious material in the fly ash mix.)

Step 2 — Estimate the water requirements for the maximum size of aggregate to be used and the required slump (use ACI 613-54 as a guide).

Step 3 — Select from Fig. 2 the water-cement ratio required for a given strength concrete.

Step 4 — Select the fly ash proportion to be used (for economic considerations, use either Fig. 5 or 6 using the appropriate relative cost of fly ash and required strength to select the fly ash proportion).

Step 5 — Using the water-cement ratio of Step 3 and fly ash proportion of Step 4, determine the water reduction from Fig. 3 or 4.

Step 6 — Using the estimated water requirements of Step 2 for the control mix, determine the water requirements of the fly ash mix by using the water reduction of Step 5.

Step 7 — Determine the cement requirements of the control mix by dividing the control mix water requirements by the water-cement ratio of Step 3.

Step 8 — Select the proportionate cement requirement of the fly ash mix from Fig. 7 or 8 (depending on the age-strength requirements) using the water-cement ratio of Step 3 and the fly ash proportion of Step 4.

Step 9 — Using methods in ACI 613-54 determine the solid volume of sand for the mix by subtracting the solid volumes of coarse aggregate, cement, fly ash, and water plus the required volume of air from the unit volume of concrete in the mix.

Step 10 — Check the mix for slump and air content and repeat the procedure for the actual water required to provide the desired slump and air contents.

Step 11 — If trial mix strengths differ significantly from the required strength an adjustment in cement and fly ash contents will be required in the final mix. This adjustment is in direct proportion to the water-cement ratio in Fig. 2 corresponding to the trial mix strength divided by the original water-cement ratio used in design.

Example problem

Design a 28-day, 3000-psi (210 kg/cm²) concrete with 1-½-in. (38 mm) maximum size aggregate, 5 percent air content, 2-½-in. (64 mm) slump, no water reducing agent, fly ash cost at 25 percent of cement cost.

Step 1 — Assume Table 6 requires 12 cu. ft (0.34 m³) of coarse aggregate or 2000 lb (905 kg) for specific gravity of 2.67.

Step 2 — From Table 3 of ACI 613-54, approximately 30 gal. or 250 lb (113 kg) of water are required in the control mix.

Step 3 — From Fig. 2, water-cement ratio = 0.59 for 3700-psi (260 kg/cm²) strength.

Step 4 — From Fig. 5, for fly ash cost at 25 percent of cement the economical proportion of fly ash is 50 percent of the cement content by weight.

Step 5 — From Fig. 3, the water reduction is 4 percent for a water-cement ratio = 0.59 and fly ash at 50 percent.

Step 6 — Water content of fly ash mix is 250 (0.96) = 240 lb. 113 (0.96) = 108 kg.

Step 7 — Control mix cement = $\frac{250}{0.59} = 425$ lb

$$\frac{113}{0.59} = 192 \text{ kg}$$

Step 8 — From Fig. 7, the fly ash mix cement content = 82 percent for water-cement ratio = 0.59 and 50 percent fly ash.

Fly ash mix cement = 0.82 (425) = 348 lb
0.82 (192) = 157 kg

Fly ash content = 0.5 (348) = 174 lb
0.5 (157) = 79 kg

Step 9 — Calculate weights and volumes of concrete ingredients

Ingredient	Weight		Volume	
	lb	kg	cu ft	m³
Coarse aggregate	2000	905	12.0	0.340
Cement	348	158	1.76	0.050
Fly ash	174	79	1.16	0.033
Water	240	109	3.48	0.098
Air	—	—	1.35	0.038
Subtotal	—	—	19.75	0.560
Sand (Specific gravity = 2.65)	1200	545	7.25	0.205
Total	3962	1796	27.00	0.765

COMPARISON OF DIFFERENCES

Ingredient	Fly ash mix				Control mix			
	Weight, lb	Volume, cu ft	Cost		Weight, lb	Volume, cu ft	Cost	
			Unit	Total			Unit	Total
Cement	330	1.67	$1.15/100 lb	$3.80	404	2.04	$1.15/100 lb	$4.63
Fly ash	165	1.10	$0.29/100 lb	0.48	—	0	—	—
Water	240	3.84	—	—	250	4.00	—	—
Added sand	0	—	—	—	94	0.57	$0.10/100 lb	0.09
Total	735	6.61	—	$4.28	748	6.61	—	$4.72

Difference in cost = $0.44/yd ($0.57/m³)

Step 10 — Assume actual slump is within ± ¼ in. of design slump. No adjustment necessary.

Step 11 — Assume trial mixes had an average strength of 4000 psi. (280 kg/cm²) instead of 3700 psi (210 kg/cm²)

From Fig. 2, 4000 psi (280 kg/cm²) corresponds to a water-cement ratio of 0.56. Adjustment = $\frac{0.56}{0.59}$ = 0.95 for trial mix strength

Or control mix requires:
0.95 (425) = 404 lb cement
0.95 (192) = 182 kg cement

Final fly ash requires 0.95 (348) = 330 lb cement and 165-lb fly ash
0.95 (157) = 149 kg cement and 75 kg fly ash

Sand adjustment = + 0.15 cu ft (0.004 m³)

COMPARISON WITH ACTUAL TESTS

When control mixes are run in conjunction with fly ash mixes, as was done in Reference 1, Steps 2, 3, and 7 of the above procedure are eliminated and actual values from the control mix should be used. With the water-cement ratio and cement content of the control mix known, the cement content of the fly ash mix can be determined directly from Fig. 7 or 8 for any given ratio of fly ash to cement in the fly ash mix. Since the above procedures are based on identical quantities of coarse aggregate in the control mix and fly ash mix, any difference in coarse aggregate quantities must be accounted for in determining the quantities of cement and water in the fly ash mix. This is simply done by proportioning the volume of mortar in the fly ash mix to the volume of mortar in the control mix as shown in the following comparison of mix proportions using the above procedure and Mixes "M" and "S" of Table 5 in Reference 1.

Example 1

Control mix "M", cement content = 470 lb per cu yd (279 kg/m³); water-cement ratio = 0.63; net water = 296 lb per cu yd (176 kg/m³)

Fly ash mix "S", fly ash as percent of cement content = 32 percent (for comparison purposes the percent of fly ash must be the same in comparable mixes).

From Fig. 7, the fly ash mix cement content = 86 percent for water-cement ratio = 0.63 and 32 percent fly ash.

Correction for aggregate (using coarse aggregates of Mixes "M" (1910 lb or 865 kg) and "S" (1990 lb or 904 kg) and assuming specific gravity of 2.72 for aggregate.

$$\text{Correction} = \frac{27(62.5)(2.72) - 1990}{4600 - 1910} = 0.97$$

$$\frac{0.765(2720) - 904}{2080 - 865} = 0.97$$

Fly ash mix cement = 470 (0.86) (0.97) = 391 lb per cu yd. 279 (0.86) (0.97) = 233 kg/m³

Fly ash content = 391 (0.32) = 125 lb per cu yd. (233) (0.32) = 75 kg/m³

From Fig. 4 the water reduction is 4½ percent for Water-cement ratio = 0.63 and 32 percent fly ash.

Fly ash mix water content = 296 (0.955) (0.97) = 274 lb per cu yd. (176) (0.955) (0.97) = 163 kg/m³

A comparison of all mixes reported in Table 5 of Reference 1 is given in Table 1.

For purposes of comparing this fly ash mix design procedure with fly ash mix test data where control mixes were not used the strength of cement, quality of fly ash, and air content of the concrete must all be considered. This is necessary since this procedure is based on cement and water contents of control mixes and any error in estimating control mix requirements from 28- or 90-day compressive strength test data will reflect directly on the accuracy of calculating the fly ash mix requirements.

Air content affects strength approximately 5 percent for each percent change in air content for a given water-cement ratio and the difference in air contents between plain and air-entrained concrete is approximately 3-½ percent for 1-½-in. (38 mm) maximum size aggregate mixes and 4

TABLE 1—COMPARISON OF ACTUAL AND DESIGN CEMENT AND WATER REQUIREMENTS OF FLY ASH MIXES BASED ON CONTROL MIXES

Mix	Fly ash, percent ±	Cement content: Fig. 7* (design) lb per cu yd	Fig. 7* (design) kg/m³	Table 5[1] (actual) lb per cu yd	Table 5[1] (actual) kg/m³	Actual/Design	Water content: Fig. 3* (design) lb per cu yd	Fig. 3* (design) kg/m³	Table 5[1] (actual) lb per cu yd	Table 5[1] (actual) kg/m³	Actual/Design
F	62	276	164	281	167	1.020	276	164	292	173	1.055
G	47	325	193	335	199	1.030	293	174	288	171	0.985
H	35	372	221	385	228	1.035	296	176	297	176	1.000
I	27	428	254	438	260	1.020	298	177	295	175	0.990
J	20	488	289	490	291	1.005	305	181	301	179	0.985
P	54	286	170	283	168	0.990	277	164	269	160	0.975
R	41	335	199	336	200	1.000	271	161	270	160	1.000
S	32	391	232	388	230	0.995	274	163	272	161	0.990
T	26	442	262	442	262	1.000	281	167	272	161	0.970
U	20	495	294	494	293	1.000	276	170	278	171	1.010
Average of ratios						1.010					0.995

*Calculated using charts as per above example.

± Fly ash in percent of cement content by weight.

percent for ¾-in. (19 mm) aggregates. In using Fig. 2 the strengths of non-air-entrained concrete should be multiplied by 0.825 for 1½-in. aggregate mixes and 0.80 for ¾-in. aggregate mixes in estimating the water-cement ratio of non-air-entrained control mixes.

In comparisons of this sort it is likely that no information will be available on the strength of cement or quality of ash used in the test data. However, the difference between estimated and actual quantities for a number of tests should be fairly constant for a given cement or fly ash.

To illustrate this procedure the same fly ash Mix "S" of Reference 1 is estimated without regard to control Mix "M."

Example 2

Given — 28-day strength of non-air-entrained concrete = 4345 psi (304 kg/cm²) for 1½-in. (38 mm) aggregate, air-entrained concrete at the same water-cement ratio $f_c' = 4345\ (0.825) = 3590$ psi or (251 kg/cm²)

From Fig. 2, water-cement ratio = 0.61.

Net water content of Mix "S" = 272 lb per cu yd (161 kg/m³).

From Fig. 3, water reduction for water-cement ratio = 0.61 and 32 percent fly ash = 4 percent.

$$\text{Cement content of control mix} = \frac{272}{(0.61)(0.96)} = 465 \text{ lb per cu yd}$$

$$\frac{161}{(0.61)(0.96)} = 276 \text{ kg/m}^3$$

From Fig. 7, the fly ash mix cement content = 86 percent for water-cement ratio = 0.61 and 32 percent fly ash.

Fly ash mix cement content = 0.86(465) = 400 lb per cu yd. 0.86(276) = 238 kg/m³

$$\frac{\text{Actual}}{\text{Design}} = \frac{388}{400} = 0.97$$

Fig. 9 and 10 show comparisons of cement contents required by design using the above procedure and actual cement contents used in various tests at different levels of control water-cement ratio. Fig. 9 is a comparison with tests reported in Reference 4, and Fig. 10 is a comparison with other laboratory tests. The average of all ratios of actual cement required to design cement required based on 28-day strengths (similar to that shown in Table 1) was 0.98 irrespective of the differences in cements and fly ashes. For 90-day strengths the average of all ratios was 1.00. The coefficient of variation of all ratios with respect to these averages was 9.2 percent for 28-day comparisons and 8.0 percent for 90 days. Accounting for the average differences in cement and fly ash the coefficient of variation of all ratios was 4.5 and 3.6 percent for 28- and 90-day designs, respectively.

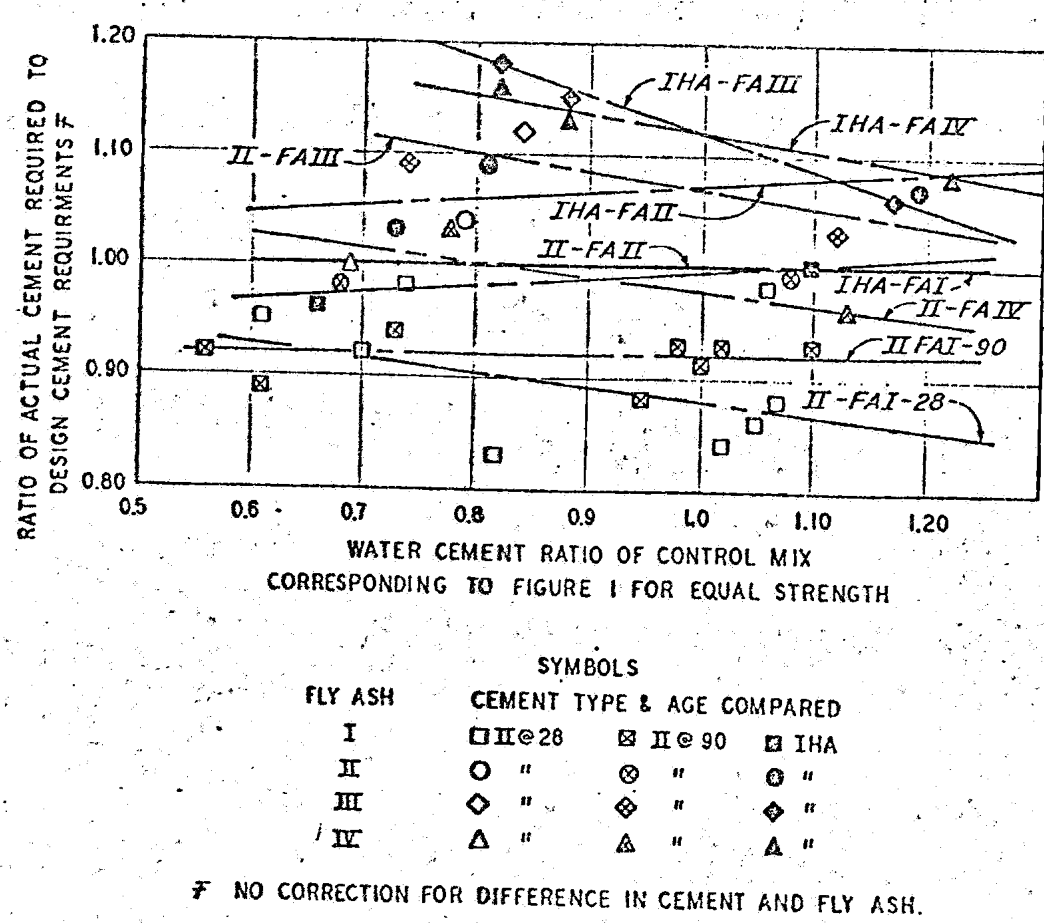


Fig. 9—Comparison of design cement requirements with actual cement requirements in tests reported in Reference 4

It is evident in Fig. 9 and 10 that differences in cement and fly ash do not affect the ratio of actual cement required to design cement requirements uniformly at all levels of control water-cement ratio. The strength contribution of fly ash in the high range of cement contents generally decreases with cements requiring lower than average water content for consistency and increases with cements requiring higher than average water contents.

The quality of fly ash is also more significant in the high range of cement contents such that effectiveness in reducing cement requirements in this range is related directly to ash quality. In lower range of cement contents the quality of ash is not so significant especially at 90 days and later ages.

CONCLUSIONS

1. Abram's law concerning water-cement ratio, if used correctly, refers only to adjusting a concrete of a given set of materials from one strength level to another. Used in this manner the law is valid for fly ash concrete provided the proportions of fly ash to cement remain in a fixed relationship with each other. The normal license taken with Abram's law is to associate water-cement ratio with a given level of strength. Used in this manner the law completely loses its meaning with fly ash or other pozzolans since it is possible to arrive at the same general level of strength using many different proportions of cement and fly ash or pozzolan.

2. Fig. 2 through 8 can be used to proportion any fly ash concrete mix for strength and economy.

3. Fly ash can and should be proportioned in concrete on the basis of economy and equal strength requirements and not as a straight substitution for cement either on a weight or volume basis.

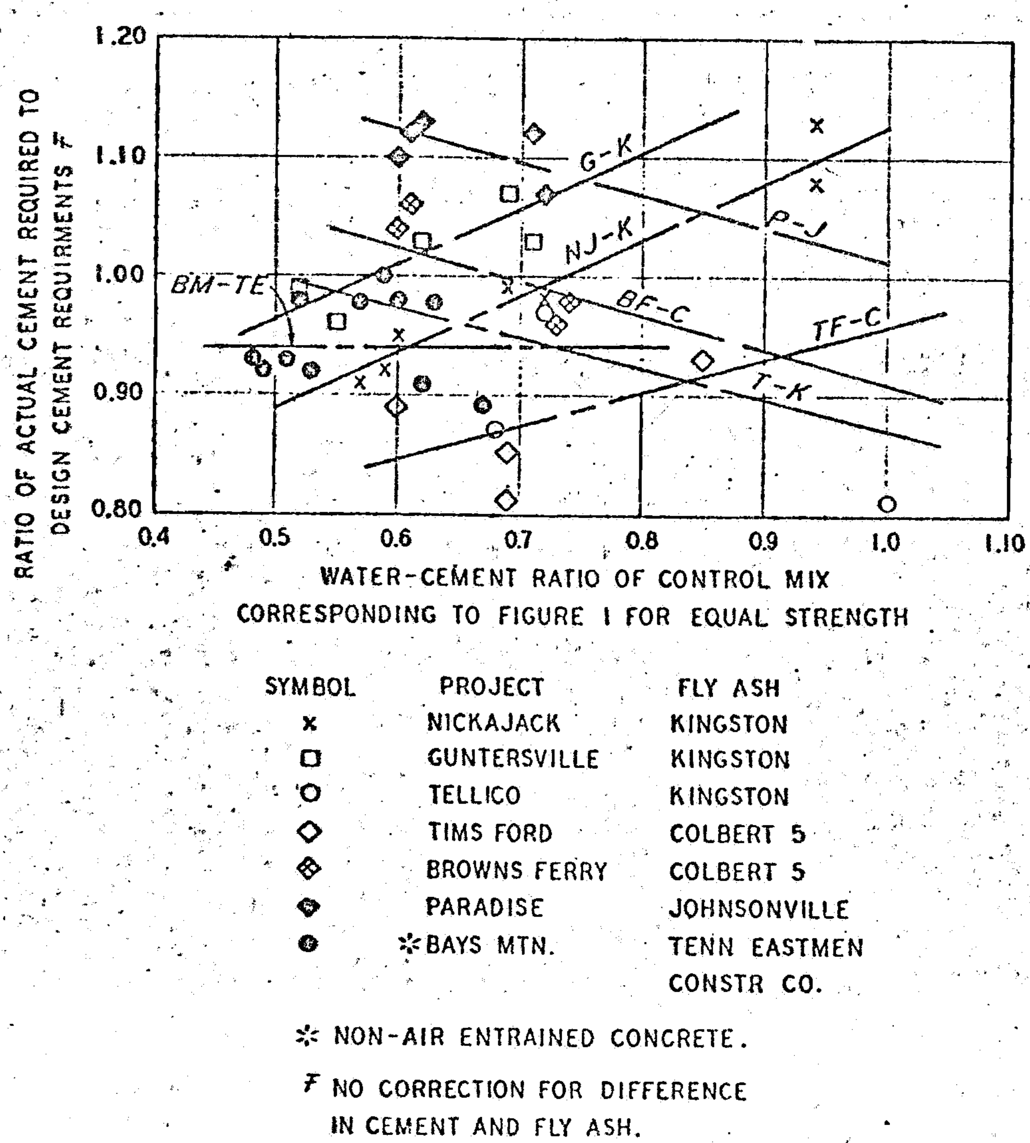


Fig. 10—Comparison of design cement requirements with actual cement requirements in tests conducted by TVA and Bays Mountain Construction Company

4. In proportioning concrete mixes, economy should be the only restriction placed on the proportions of fly ash to cement used.

5. Although fly ash becomes more economical as the strength requirements decrease, savings in material costs may be realized even in concrete requiring 5000 psi in 28 days.

6. In general, fly ash concrete will have a lower coefficient of variation than nonfly ash concrete for the same control efforts and for equal strength concrete.

7. The significance of the quality of fly ash increases with increased strength requirements of the concrete. Fly ashes in the low ranges of loss on ignition which do not presently meet Federal and ASTM specifications for fineness can be used economically in many concrete operations. The principal factors to be used in selecting a fly ash for use in concrete should be: the delivered cost of the ash, the quality of the ash, and the strength requirements of the concrete.

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4. Mather, Bryant, "Investigation of Cement-Replacement Materials," *Miscellaneous Paper* No. 6-123, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Apr. 1965.

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This paper was received by the Institute Mar. 15, 1968.

Sinopsis — Résumé — Zusammenfassung

Proporcionamiento de Mezclas de Concreto con Ceniza Volante para Resistencia y Economia

Se presenta un método para proporcionar ceniza volante con el cemento y producir concreto de igual resistencia a los 28 y 90 días que los concretos sin ceniza volante. El método fué desarrollado por la Autoridad del Valle de Tennesee (AVT) como resultado de usar ceniza volante en todas las clases de concreto durante los últimos 12 años. Se presentan los efectos de las diferentes proporciones de ceniza volante en los requisitos de agua, resistencia y economía conjuntamente con una discusión de los efectos de finura y contenido de carbón de la ceniza volante, así como las variaciones en la resistencia de los cementos en los requisitos del cemento. Se comparan los requisitos del cemento determinados por este método con el cemento realmente requerido por los ensayos del cuerpo de Ingenieros, AVT y Base Mountain Construccion Co., usando por lo menos 9 diferentes suministradores de cemento y 8 cenizas volantes diferentes, cuatro de las cuales no satisfarían las especificaciones Federales y de la ASTM.

Proportion de Cendres Volantes dans les Mélanges de Béton pour Résistance et Economie

Une méthode est présentée pour proportionner les cendres volantes avec le ciment afin de produire un béton d'égale résistance après 28 et 90 jours à un béton sans cendres volantes. La méthode a été mise au point par le Tennessee Valley Authority (TVA) à la suite des résultats obtenus en utilisant des cendres volantes dans toutes classes de béton durant les 12 dernières années. Les effets de changement des proportions de cendres volantes selon les proportions d'eau, la résistance et l'économie, sont donnés en même temps qu'une discussion des effets de finesse et de proportion de carbone de cendres volantes et les variations de résistance des ciments sur les impératifs de qualité des ciments. Des comparaisons sont faites entre les impératifs de qualité des ciments qui sont déterminés par cette méthode avec les ciments effectivement exigés par les essais par le corps des Ingénieurs TVA et la compagnie de construction de Bays Mountain utilisant au moins neuf différents fournisseurs de ciment et huit différentes cendres volantes, Quatre desquelles ne correspondant pas aux spécifications fédérales et de l'ASTM.

Der Entwurf von Betonmischungen mit Flugaschezusätzen in Hinblick auf Festigkeit und Wirtschaftlichkeit

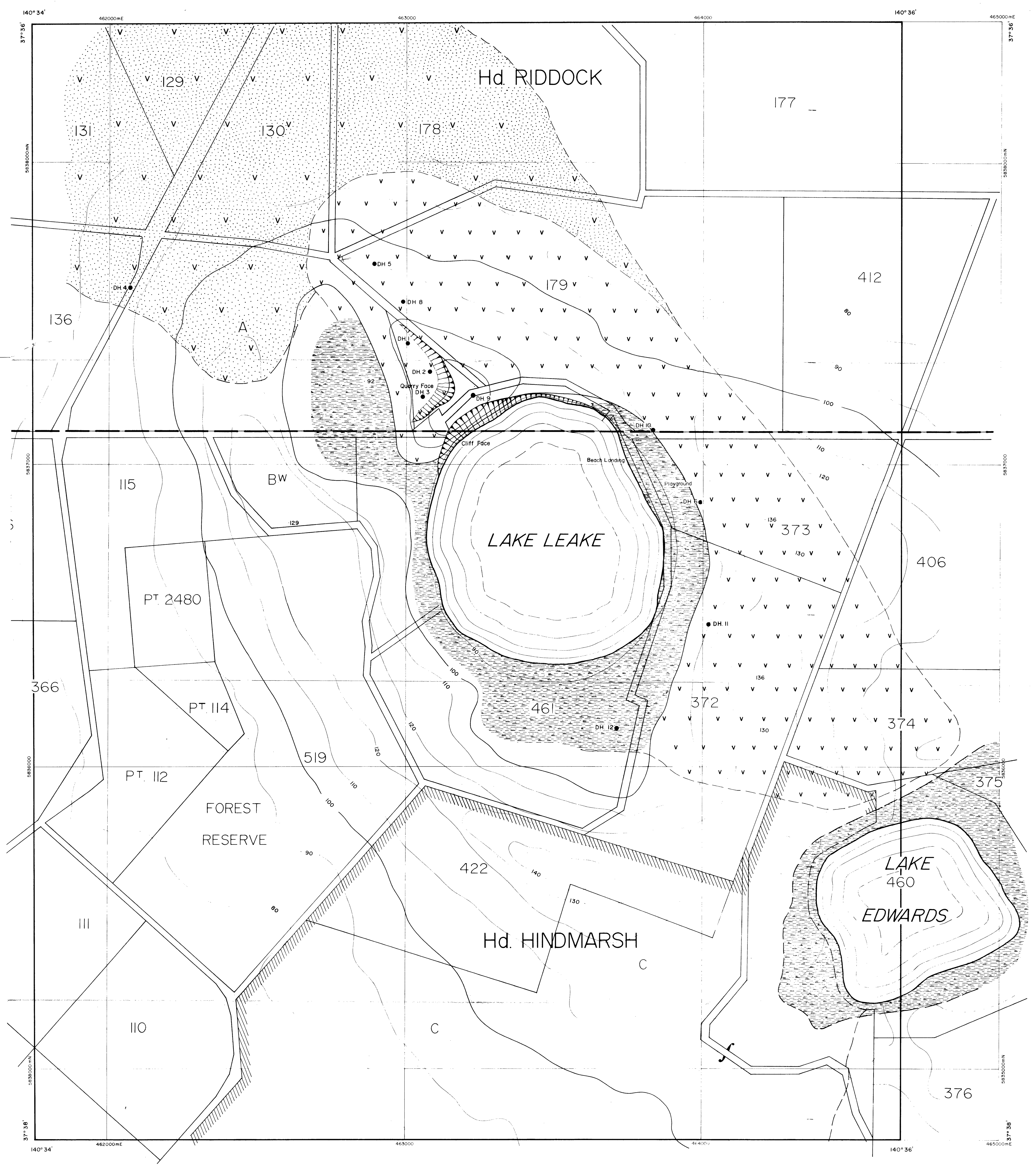
Eine Methode wird beschrieben, mit deren Hilfe Betonmischungen mit Flugaschezusätzen entworfen werden können, sodass die Festigkeit nach 28 und 90 Tagen ebenso gross wie die Festigkeit von Beton ohne Zusätze ist. Die Methode wurde von der Tennessee Valley Authority (TVA) entwickelt und baut auf Erfahrungen, die bei der Verwendung von Flugasche in Betonen aller Arten während der letzten 10 Jahre gewonnen wurden. Der Einfluss des Gehaltes an Flugasche auf Wasseranspruch, Festigkeit und Wirtschaftlichkeit werden gegeben, und die Wirkung des Feinheitsgrades und des Kohlegehaltes der Flugasche sowie der Festigkeit und Art des Zementes in Bezug auf die Auswahl eines geeigneten Zementes werden diskutiert. Vergleiche über die Anforderungen an den Zement nach dieser Methode und den Eigenschaften des Zementes, die auf Grund von Versuchen des Corps of Engineers, TVA und Bays Mountain Construction Company gefordert werden, wurden angestellt. Dabei wurden zumindest 9 Zementmarken und 8 Arten von Flugasche verwendet. In vier Fällen erfüllte die Flugasche nicht die staatlichen und die ASTM Anforderungen.

APPENDIX II

060

LAKE LEAKE TOPOGRAPHIC PLAN

(INCLUDING GEOLOGY)



REFERENCE

Volcanic soil	Hundred boundary
Consolidated volcanic ash	Section boundary
Marginal swamp land	Contour intervals at 10 metres (140, 130)
Forest reserve	Drill holes (DH 3)
Quarry face	Cliff face

R. M. C. MINERALS PTY. LIMITED

MAP TO ACCOMPANY FINAL REPORT

LAKE LEAKE VOLCANICS

E.L. 123

SCALE 1:5000

METRES 100 0 100 200 300 400 METRES

REVISIONS	GEOLOGY BY B. Param	DRAWN BY R. Newell
DATE	DATUM Mean Sea Level Pt Adelaide	DATE 9th July 1974
SCALE As shown above	CONTOUR INTERVAL 10 Metres	DRAWING No. B SR27 688

ENV 2420-1