ALKALI - AGGREGATE REACTION

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S252

THE USE OF FLY ASH IN CAPE TOWN RMC OPERATIONS

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SYNOPSIS

Fly ash of a quality suitable for use in concrete became available commercially in South Africa in 1978. A ready mixed concrete firm in Cape Town felt that a number of problems associated with local concrete could be overcome by the use of fly ash.

This paper sets out to cover in broad terms the nature of the material, its effect on the properties of concrete and its application in concrete using local materials.

SAMEVATTING

Poeierkoolas van geskikte gehalte vir gebruik in beton is vanaf 1978 kommersieel beskikbaar in Suid-Afrika. 'n Firma wat aangemaakte beton in Kaapstad lewer was van mening dat sekere probleme geassosieer met plaaslike beton oorkom kon word deur die gebruik van poeierkoolas.

Hierdie referaat gee in breë trekke die aard van die materiaal, die invloed daarvan op die eienskappe van beton en die gebruik daarvan in beton gemaak van plaaslike materiale.

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stance, and at that point the permeability should be higher.

(b) as the pozzolanic reaction takes place more gel will eventually be present than can arise from a similar mix which contains no pfa

(c) less reaction of the pfa is required to achieve a comparable position when the $C_3S:C_2S$ molar ratio is high than when it is low

(d) mixes can be designed in which very little, if any, reaction of the pfa is required to produce more gel between the aggregate particles than can occur in concretes containing no pfa.

'It is clear that the use of pfa can reduce the permeability to such a level that the movement of aggressive ions through the structure becomes very difficult, and the correct use of pfa can therefore make a major contribution to reducing the alkali-silica reaction. It should be emphasised that material of the correct quality should be used so that the pozzolanic reaction can occur at the desired rate and that the extent of the reaction is sufficient.'

1. INTRODUCTION

The cracking of concrete structures in the Western Cape as a result of expansive alkali-aggregate reaction has been under investigation by the National Building Research Institute for several years. Two finely divided pozzolanic mineral admixtures included in and giving positive results in the early stages of the investigation into the control of the problem by means of admixtures, are milled granulated blast furnace slag and fly ash.

The general properties of the first of these materials are well known after 25 years of experience in its use in South African concrete including some experience in the Western Cape. South African fly ashes on the other hand do not have an established record of performance in concrete.

Ready Mixed Concrete (Cape) therefore embarked on laboratory and field trials to evaluate the use of fly ash in concrete using local materials so that its performance as a concrete admixture could be established. These trials have shown that the available fly ash is suitable for use with local materials in addition to any benefits it may provide in controlling expansive alkali-aggregate reaction.

2. DESCRIPTION OF FLY ASH AS A MATERIAL

When South African bituminous coals are pulverised and used as the energy source at thermal power stations they produce approximately 30 per cent of their own mass in ash. This is called Pulverised Fuel Ash (PFA) and is made up of two ash types. The first, which constitutes approximately 20 per cent of the total ash, is formed from coarse particles which drop to the bottom of the furnace and are sluiced away for disposal in ash dams. The second and much finer type travels with the flue gases and must be removed before discharge of the gases into the atmosphere. This *fly* material is called fly ash and at present is mainly disposed of in ash dams. South Africa produces over 9 million tons of this ash per year and is the sixth largest producer in the world.

The fly ash is collected by passing the flue gases through a series of electrostatic precipitators whose magnetic fields remove up to 99 per cent by mass of the fly ash. This collection efficiency is achieved by passing the flue gases through two, three or four magnetic fields in series. The first field collects the coarsest fly ash which is unsuitable for use in concrete while the second and successive fields collect fly ashes which become progressively finer and can be used in concrete for their pozzolanic and other properties.

The magnetic field of each precipitator is periodically broken by rapper bars which allow the fly ash collected on the precipitator to fall into separate hoppers under each field. After quality checks it is transferred to storage silos for distribution by road or rail to users of fly ash. If the quality checks show that the fly ash is below the minimum acceptable standards it is sluiced away for disposal in ash dams.

A description of the major components of a typical coal-burning pulverised fuel power station is shown in Appendix 1.

Fly ash particles are generally light grey in colour, glassy in texture and spherical in shape ranging in size from 1 to 150 µm in diameter. They are thus finer than finely ground cement. Figures 1 and 2 show scanning electron micrographs of a combined field 2 and 3 fly ash and a local ordinary portland cement to the same scale.

The chemical composition of fly ash depends on the inorganic materials in the coal and is fairly constant for a given coal source or area. Fly ashes from different coal sources may vary widely in composition. More than 90 per cent of most fly ashes are composed of chemical compounds and glasses formed from the oxides of silica, alumina, calcium, magnesium and iron. Unburned coal collects with the fly ash in the form of carbon particles. The amount present depends on the rate of combustion, the air fuel ratios and the degree of pulverisation of the coal.

The assessment of the quality of fly ash is normally limited to the determination of particle size (percentage retained on a 45 µm sieve), of carbon content (loss on ignition) and of relative density. In the absence of a South African specification for fly ash, the accepted ASTM standards

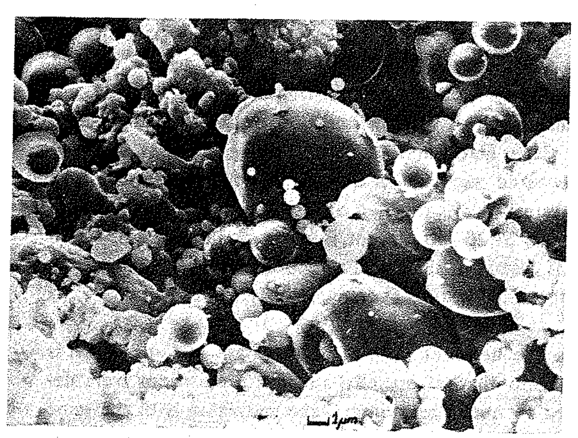

FIGURE 1: Scanning electron micrograph of fields 2 and 3 fly ash ex Grootvlei Power Station

FIGURE 2: Scanning electron micrograph of an opc produced in the Western Cape

are shown against a typical sample of South African fly ash.

	Precipitator Fields			
	1	2	3	4
% Of total fly ash	66	22	7	5
% Retained on 45 μm sieve	45	26	9	5
ASTM standard	– Not exceeding 34%–			
% Loss on ignition	2,1	2,0	1,9	1,7
ASTM standard	– Not exceeding 12%–			
Relative density	2,22	2,32	2,41	2,33

Standards adopted in other countries are shown in Appendix II.

3. POZZOLANIC PROPERTIES

Fly ash is an artificial pozzolan that displays pozzolanic properties when used in concrete.

A pozzolan is defined by ASTM as *siliceous and aluminous material which in itself possesses little or no cementitious value but which 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.* In general the finer ash the greater its pozzolanic properties.

When fly ash is used in concrete it reacts chemically with the calcium hydroxide liberated by the cement hydration process and becomes a part of the cementitious material. In so doing fly ash *fixes* or renders harmless a potentially troublesome by-product of cement hydration. Calcium hydroxide contributes nothing to concrete strength and is recognised as one of the vulnerable constituents of hardened concrete paste. It is liable to be leached out causing efflorescence and permeability to chemical attack by a number of agents, in particular, acid waters and sulphate waters. Prominent among the latter are those containing sodium, magnesium or calcium sulphate. In the presence of these salts, the reduced amount of calcium hydroxide in the hardened concrete as a result of interaction with the active silica in the pozzolan, delays or prevents the formation of calcium sulpho-aluminate, which is the chief cause of disintegration of concretes by sulphates.

Work in Cape Town has confirmed that South African fly ash has similar properties to overseas materials. Most publications on fly ash from the USA, Canada, Britain, France, Australia and Japan list the following benefits which can be obtained by using fly ash in concrete.

Reduced water demand	Improved workability
Reduced bleeding	Improved cohesion
Reduced segregation	Improved pumpability
Reduced heat of hydration	Improved compaction
Reduced thermal cracking	Improved off-shutter finish
Reduced shrinkage cracking	Improved durability
	Improved sulphate resistance
Reduced permeability	Improved resistance to severe exposure conditions including marine environments
Reduced thermal stress	Improved density
Extended setting times	Improved wear resistance
Extended long term compressive and flexural strength gain	
Improved modulus of elasticity	

Some of these characteristics of fly ash in concrete will be discussed later in the paper.

4. FLY ASH SOURCES IN SOUTH AFRICA

At present the Electricity Supply Commission (ESCOM) operates a number of major power stations in which pulverised coal is the energy source but none of these stations are situated in the Western Cape. Cape Town must therefore obtain its fly ash from the station at Grootvlei, 1500 km away in the Southern Transvaal. At this station commercial fly ash extraction equipment has been in use since 1978. During 1981 two additional Transvaal stations will start extracting fly ash for commercial purposes.

5. EARLY TESTS USING GROOTVLEI FLY ASH

Preliminary tests on samples of Grootvlei fly ash commenced in April, 1978.

A standard laboratory control mix of 27,5 MPa at 28 days was modified by replacing 20 per cent of the cement with 30 per cent fly ash by mass and the total water was reduced to maintain slump. At that time opc was supplied in Cape Town by two factories (Philippi and Riebeeck West) and parallel tests were run with samples from each source. These tests showed that the fly ash performed differently with each cement, but that in both cases the results were encouraging.

A further series of laboratory tests was performed using modified proportions for the fly ash mixes. Cement was replaced with a similar mass of fly ash for replacement levels of 10 per cent to 30 per cent in increments of 5 percent. Tests were also carried out to establish the performance of fly ash concrete which incorporated a water reducing admixture.

The coarse aggregate used in Cape Town area is a crushed Malmesbury hornfels which fractures to produce very angular particles with flakiness indices of 25–35 per cent. The Cape Flats sand used for fine aggregate is a largely single sized wind blown dune sand, which passes the 1,18 mm screen and is retained on a 150 μm screen. It has shell contents of 20–30 per cent, fineness modulus of 1,85–2,00 and is devoid of silt or clay fractions. This sand is available in substantial volume at comparatively low cost.

Since the delivered cost of bulk fly ash in Cape Town is similar to that of opc, fly ash mix proportions were designed to obtain maximum water reduction with the same workability and 28-day strengths as control mixes while

controlling material cost increases to a minimum.

As a result of this and additional work it was decided to utilize fly ash to replace 15 per cent of opc ex Philippi and 25 per cent of opc ex Riebeeck West, in a range of designs. Bulk samples of fly ash ex Grootvlei became available and field trials commenced in late June, 1978. (The Philippi factory was subsequently closed in October, 1980.)

In collaboration with consulting engineers and contractors, development was continued into 1979 with work on normal structural concrete in the range of 20 to 50 MPa, including pavement quality concretes and pumpable concretes.

Whilst this work was going on equipment was installed at Grootvlei to extract and blend selected fly ash from electrostatic fields 2 and 3 and a bulk depot was established at Paarden Eiland to handle rail tankers loaded at Grootvlei. The fly ash was pumped into storage silos and subsequently reloaded into road tankers for distribution to other depots in the Cape Town area.

The field trials had shown that fly ash mixes provided concretes which were more readily compactable on site than conventional mixes. The particular problem in Cape Town of the delamination of the surface of power-float-finished structural slabs on the ground (resulting from continued *bleeding* after initial trowelling), was overcome by the use of fly-ash modified mixes. It was found that trowelling could commence later and gave a high quality finish. In addition the trowelling in and finishing of an integral hard wearing material to the surface could more readily be achieved.

Some of the early contracts specifying the use of fly ash in concrete were drawn up on the recommendation of a supplier of floor hardeners in conjunction with a specialised concrete flooring contractor.

6. UNIFORMITY AND QUALITY CONTROL OF GROOTVLEI FLY ASH.

Grootvlei fly ash used in Cape Town is drawn only from precipitator fields 2 and 3 which together provide approximately 30 percent of the total fly ash produced by each boiler at the station. Samples of fly ash are taken for routine testing at half hourly intervals when precipitator hoppers are being emptied to ensure that minimum standards are maintained. The standards adopted and test methods used comply with the requirements of ASTM C613.

The routine tests consist of a colour check, loss on ignition, and percentage retained on a 45 μm sieve. The fly ash is

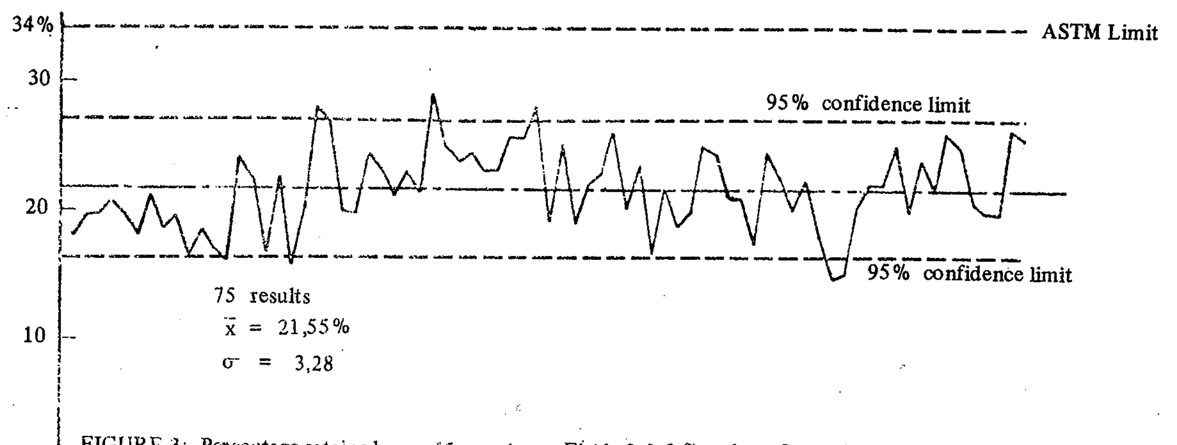

FIGURE 3: Percentage retained on a 45 μm sieve - Fields 2 & 3 fly ash ex Grootvlei

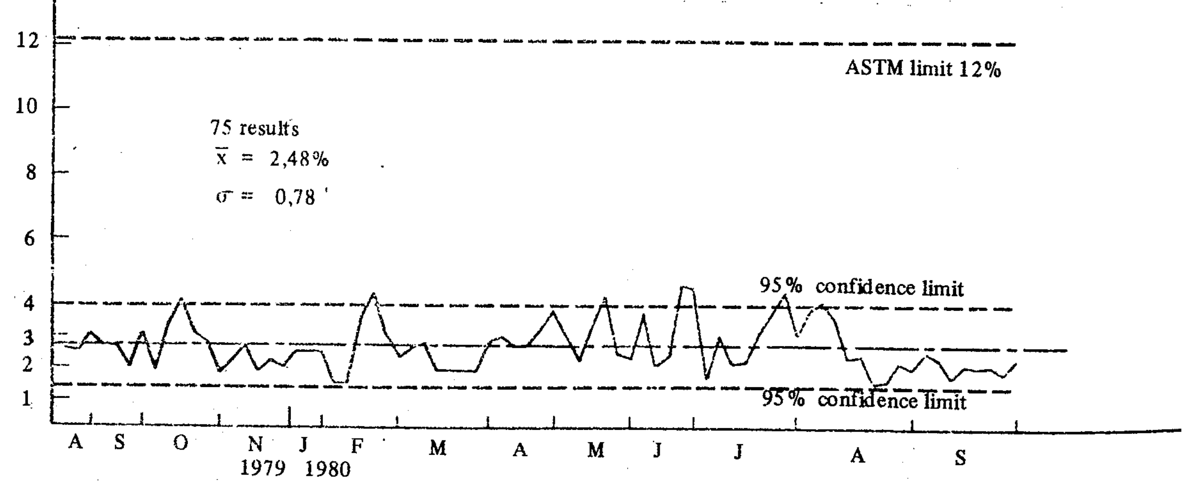

FIGURE 4: Percentage loss on ignition - Fields 2 & 3 fly ash ex Grootvlei

rejected and flushed to waste if it fails to meet the minimum requirements of the specification. The enormous volumes of fly ash available make it possible to use only the best quality fly ash and to keep quality variations to a minimum. The fact that Grootvlei is a base load power station and operates under continuous load conditions is another reason why the fly ash it produces tends to remain constant in quality.

On arrival in Cape Town the fly ash is again checked by an independent laboratory. The results of samples taken from bulk deliveries over the past year are shown in Figures 3 and 4 against the ASTM minimum requirements.

7. THE EFFECT OF GROOTVLEI FLY ASH ON THE PROPERTIES OF FRESH CONCRETE

(a) *Workability.* The glassy spherical shape and grading of fly ash particles have the effect of reducing the water demand of concrete owing to the so called *ball bearing* action. Water reductions of 6 per cent are possible on mixes where 25 per cent of cement by mass has been replaced by fly ash.

Concrete in which fly ash is used shows reduced segregation and bleeding and is more satisfactory when placed by pumping than plain concrete under similar circumstances. The same concrete gives a marked improvement in off-shutter finish which is attributed to the increase in cementitious volume and matrix density resulting from the use of fly ash.

It should be noted that concrete containing fly ash is deceptive in appearance as it looks less workable than a slump test would indicate. When judging workability, the addition of water should be metered so that the concrete appears to have 25mm less slump than its plain concrete counterpart.

Because the consequences of the prolonged agitation of concrete are of particular interest to the ready mixed concrete industry, tests were run to ascertain the effect on workability, temperature and strength of plain and fly ash concretes when agitated in a truckmixer drum for 5 hours. At the same time additional tests were run in which the concrete was retempered with water when necessary to maintain a reasonably constant slump. The results are shown in Figures 5 and 6.

It will be seen in Figure 5 that the concrete containing fly ash retains its workability for a longer period than the plain mix. Temperature rise was also less for the fly ash concrete while little difference in the rate of increase of 7 and 28 day strength development as a result of prolonged agitation, could be detected.

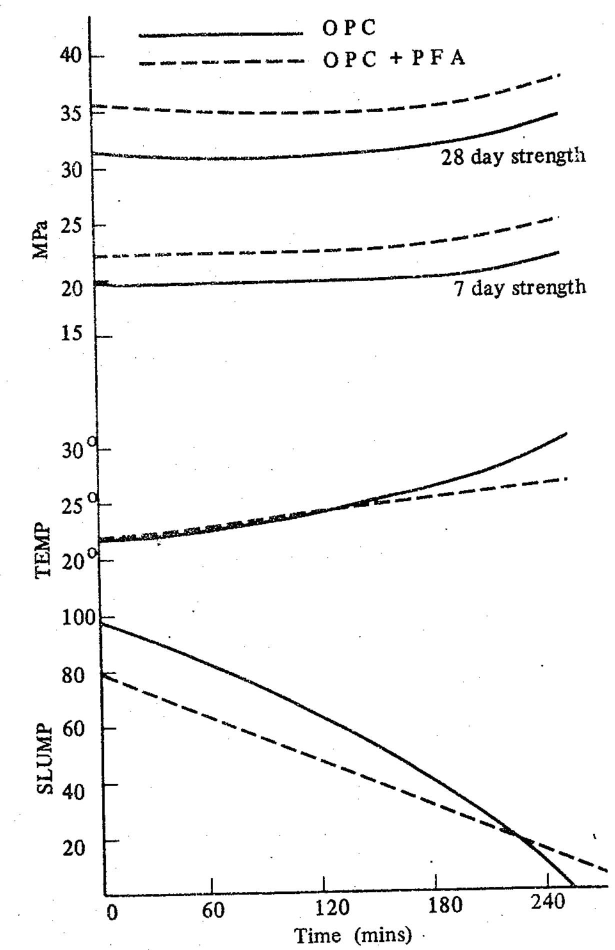

FIGURE 5: Prolonged agitation test

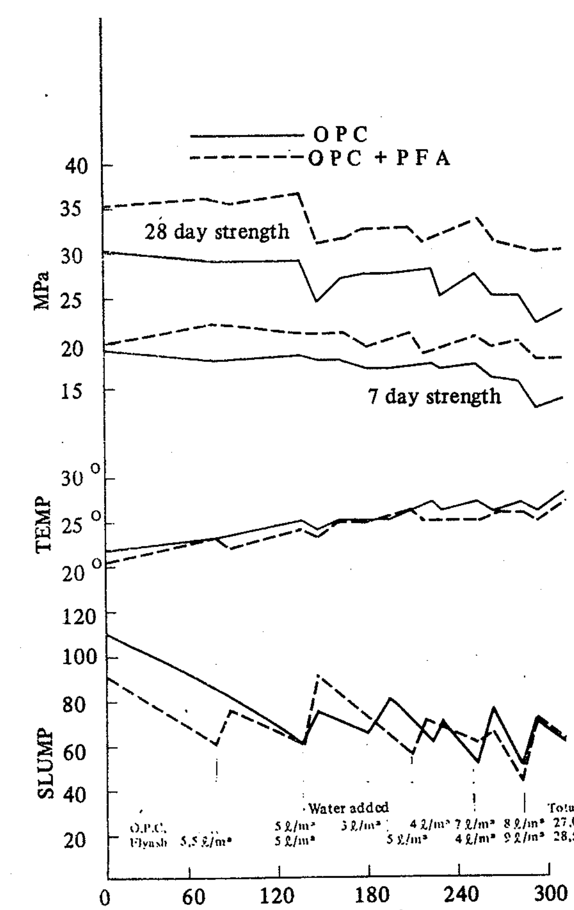

FIGURE 6: Prolonged agitation test – retempered mixes

The effects of retempering the two identical mixes are shown in Figure 6. It is interesting to note that the rapid drop in strength as a result of the addition of retempering water is partially offset by the increase in strength from extended agitation up to a period of 4 hours.

(b) *Bleeding.* The majority of concrete made in the Cape Town area suffers from the problem of excessive bleeding owing to the almost total lack of fine fractions in the dune sands available locally. This migration of bleed water leads to unsightly sand streaking on off-shutter finishes and delamination of high strength floor toppings. These problems can be overcome by increasing the overall paste volume by using fly ash in the concrete.

Figure 7 gives the comparative rates of bleeding for differing fly ash replacement rates.

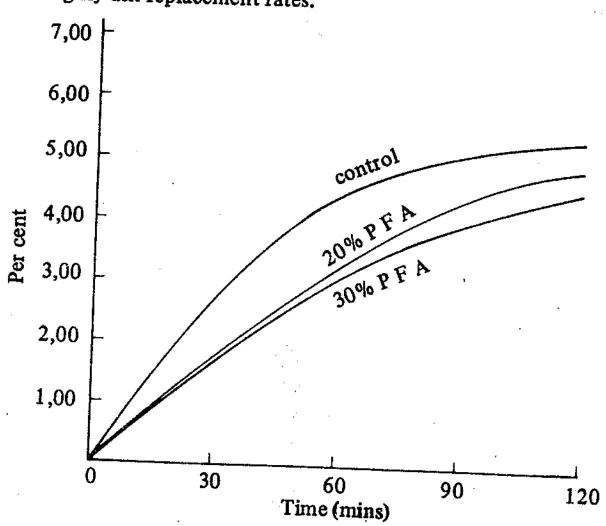

FIGURE 7: Bleed water expressed as a percentage of total mixing water

(c) *Admixtures.* Fly ash is compatible with water-reducing plasticisers and superplasticisers. Dosage rates should be based only on the cement content of the concrete mix and not on the total cementitious content if extended setting times are to be avoided.

Frequently the use of fly ash has an adverse affect on air entrainment in concrete and the dosage of air entraining agents has to be increased to produce the required result. This is caused by the vesicular nature of the carbon particles in fly ash and their ability to absorb air entraining agents and render them less effective in concrete. This is illustrated in Table 1 which shows the effect of deliberate overdoses of air entraining agents in concrete mixes containing varying percentages of fly ash.

(d) *Curing.* Tests carried out in Cape Town have confirmed that there is no significant difference in strength development at 28 days between plain concrete and mixes containing 30 per cent fly ash irrespective of the curing regime applied. The 7 day results however show a 10 per cent benefit in favour of plain concrete.

TABLE 1: Comparison of the performance of mixes with varying fly ash contents and air entrainer dosages.

Mix	Without admixtures	Single dose	Double dose	Treble dose
Control				
Air %	2,8	4,1	5,6	6,7
Slump (mm)	70	70	70	75
7 day strength (MPa)	16,0	16,0	15,0	14,5
28 day strength (MPa)	26,0	24,0	22,5	21,0
20% Fly ash				
Air %	1,8	1,8	2,3	3,1
Slump (mm)	70	70	70	75
7 day strength (MPa)	16,0	17,0	15,5	16,0
28 day strength (MPa)	27,5	24,5	23,5	24,0
30% Fly ash				
Air %	2,0	1,9	2,4	2,8
Slump (mm)	75	70	70	70
7 day strength (MPa)	16,0	16,5	14,5	14,0
28 day strength (MPa)	27,0	24,5	23,5	22,5

8. THE EFFECTS OF GROOTVLEI ASH ON THE PROPERTIES OF HARDENED CONCRETE

(a) *Heat of Hydration.* It has been found that for every 100 kg of opc in plain concrete, a temperature rise of up to 10°C can be expected using local cements. In mixes where a portion of cement has been replaced by fly ash however the total heat of hydration is reduced.

The temperature rise of a 35 MPa concrete using varying levels of fly ash replacement was tested [1] under laboratory conditions and the results are shown in Figure 8. The temperature rise of the 30 per cent and 15 per cent fly ash concrete was found to be 23 per cent and 11 per cent respectively less than in the control concrete.

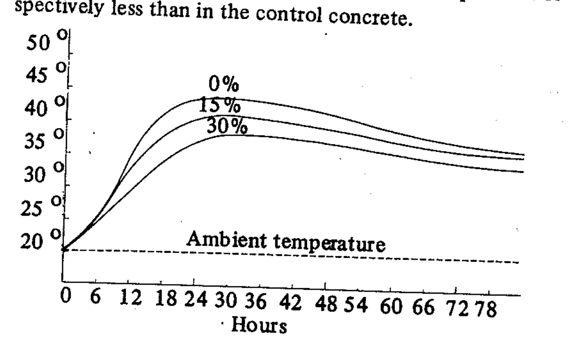

FIGURE 8: Heat of hydration of a 35 MPa concrete at three fly ash replacement levels

In mass concrete structures, portions of the interior may remain in an essentially adiabatic state for a period of weeks after the concrete is placed. This could result in excessive temperature differentials between the surface and the interior. If this differential exceeds 25°C the tensile stresses could exceed the tensile strength of the *green* concrete and cause subsequent cracking.

A recent example of fly ash being used to control temperature rise was at the construction of the National Accelerator near Cape Town where radiation shielding 4,3 metres thick had to be cast completely free of cracks. In this case a 50 per cent fly ash concrete was used in conjunction with 53mm aggregate and crushed ice and successfully kept the thermal gradient to a minimum.

(b) *Density.* A number of factors affect the density of fresh and hardened concrete but when using the same cement and aggregate under similar conditions, the major variables become the water content and the entrapped and entrained air. The higher the water content the more significant is the reduction in concrete density especially in the hardened condition owing to drying out and evaporation.

The addition of fly ash to a mix not only reduces the total mixing water but because of the improved workability also reduces the entrapped and entrained air. The cementitious matrix of a fly ash mix will therefore be more dense than a plain concrete equivalent.

An analysis of 195 cube masses of 30 per cent fly ash concrete over a period of one year in laboratory controlled tests has shown a 0,8 per cent increase in density when compared to a similar number of laboratory control cubes using plain concrete. This is considered significant as the relative density of fly ash is only 72% of that of cement which would suggest that the density of concrete containing fly ash would be lower.

The greater density of fly ash concrete leads to an improved off-shutter finish and a reduction in porosity and blow holes.

(c) *Durability.* As discussed earlier in the paper the pozzolanic properties of fly ash when used in concrete cause it to react with the calcium hydroxide produced by the hydration of cement to form less reactive calcium silicates and aluminates. In this way the permeability of fly ash concrete will be decreased and its durability to acid, sulphate and marine attack will be improved.

Tests are being conducted at present by the National Building Research Institute to determine the relative permeability of concrete at various levels of fly ash replacement using local materials and Grootvlei fly ash.

(d) *Shrinkage and Creep.* Comparitive tests [2] on plain and fly ash concrete of comparable workability and 28 day strength containing local materials have shown that shrinkage levels are similar while creep is significantly less in those mixes containing fly ash. These tests have been confirmed through to one year and are continuing.

9. MIX PROPORTIONING AND STRENGTH DEVELOPMENT OF FLY ASH CONCRETE

There are three methods in use for mix proportioning of concrete containing fly ash.

(a) *Replacement Method.* This method consists of part of the cement being replaced with an equal mass of fly ash. It results in an increased volume of cementitious material but reduced heat of hydration. Yield adjustments are made by a reduction in sand quantity. Compressive and flexural strengths are lower than plain concrete for up to three months but with the ultimate development of higher strengths.

This method is suitable for mass concrete structures where the reduction in early strength is not structurally significant when compared with the benefits of reduced temperature rise.

(b) *Addition Method.* Addition of fly ash while maintaining the cement content for a particular mix. Changes in aggregate content will depend on the particular job application while the yield is adjusted to accommodate the fly ash content. This method leads to a far greater cementitious content in the mix and compressive strengths will be greater at all ages.

(c) *Replacement Addition Method.* This is the most economical method of mix proportioning using fly ash. It involves the replacement of part of the cement with an excess amount of fly ash while yield adjustments are made by a reduction of sand in the mix. Concrete can be produced with compressive strengths equal to plain concrete, even at an early age, with the additional benefits of improved workability and reduced bleeding and permeability.

After a series of trials using the local materials and fly ash from Grootvlei, the third method was adopted for designing fly ash mixes in Cape Town.

Two years experience of fly ash concrete has shown that the following changes can be made to plain concrete proportions in order to produce a fly ash concrete of equal workability and 28 day strength.

Total cementitious content (opc and fly ash)	increased by	± 4%
Total water	reduced by	± 6%
Coarse aggregate	increased by	± 5%
Fine aggregate	reduced by	± 3%

These figures are consistent with the minimum fly ash proportions of approximately 15 per cent which appeared necessary in the early investigations to reduce the alkali-aggregate reaction to an acceptable level.

Figure 9 shows the typical strength development of fly ash concrete at different ages compared to standard control concrete.

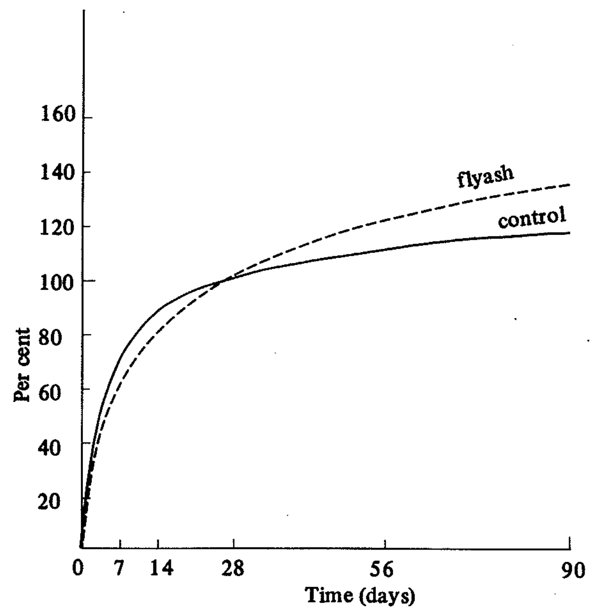

FIGURE 9: Strength development of fly ash concrete

10. PRACTICAL CONSIDERATIONS WHEN USING FLY ASH

The following points should be considered when using fly ash:–

(a) Ordinary Portland cement and fly ash are very similar in appearance and it is easy to confuse the two. In order to avoid accidental mixing of these materials extra precautions are necessary for handling and storing at a construction or plant site. The minimum requirement would be to mark the silo fill pipes and preferably provide locks on the pipes.

(b) As the bulk density of fly ash is two-thirds that of opc a silo which holds 50 tonnes of opc will only hold 33 tonnes of fly ash. In spite of the reduced dosage of fly ash per cubic metre of concrete it is still advisable to provide equal silo capacities for opc and fly ash.

(c) Silo filters need more regular maintenance because fly ash is both finer and more spherical than opc and will penetrate the filter cloth more deeply than opc. Filter cloth areas need to be double the area of opc filters in order to eliminate dust. As fly ash has a lower density than opc it will fly more easily and dust suppression becomes more important in mixing plants.

(d) Overseas experience indicates that fly ash tends to "pack" in a silo if left unaerated for a period, however no such difficulty has been experienced in Cape Town either in summer or winter.

11. APPLICATION OF FLY ASH CONCRETE IN CAPE TOWN

In addition to the use of fly ash in normal ready mixed concrete operations in Cape Town, it has also been used in a number of special applications as follows:–

(a) Contract – 10 Ml hospital reservoir at Atlantis.
Consultants – Liebenberg & Stander.

The original specifications called for a minimum cement content of 360 kg/m³. Mix proportions were altered to include 15 per cent fly ash by mass in order to provide more dense concrete with minimal shrinkage. The mean 28 day cube strength at completion of the contract was 50,8 MPa with a standard deviation of 3,56 MPa which is comparable to the variability normally achieved with plain concrete. The consultants specification for water retaining structures has since been altered to include the use of fly ash in this type of concrete.

(b) Contract – Construction of cold room floors.
Consultants – Hemingway & Coetzee.

These contracts called for pumpable concrete capable of withstanding freeze-thaw cycles with minimal shrinkage cracking. A number of cold stores have been completed using 15 per cent fly ash concrete with air entrainment.

(c) Contract – Shielding for the cyclotron at the national accelerator, Faure.
Consultants – Liebenberg & Stander.

After experimental work the consultants specified that a 50 per cent fly ash replacement level (together with 53mm aggregate and crushed ice) should be used to limit temperature rise and eliminate shrinkage cracking in the 4,3-metre-thick walls. A total of 6500 m³ of this concrete was supplied with a total cementitious content of 225 kg/m³. A mean 90 day strength of 43 MPa was achieved which represented 160 per cent of the 28 day strength obtained.

In addition the consultants specified a 30 per cent fly ash replacement for the class 30 nominal structural concrete on this contract to provide a dense concrete with a good off-shutter finish. A mean 28 day strength of 41,6 MPa was obtained with a standard deviation of 4,2 MPa.

(d) Contract – Construction of a tidal pool at Strandfontein.
Consultants – O'Connell Manthé & Partners.

The consultants required impermeable concrete of high durability to withstand the severe exposure of marine conditions. A dense concrete with very good off-shutter finish was obtained using a 15 per cent fly ash replacement level.

(e) Contract – Extensions to the University of Cape Town.
Consultants – Ninham Shand & Partners.

The consultants required a dense concrete with a board marked finish for a retaining wall at the Engineering Mall. This was achieved using a 15 per cent fly ash replacement concrete.

Other contracts where the unique properties of fly ash in concrete have been used include the base of the liquid ammonia vessel at Fedmis (to provide increased protection against chemical attack) and the radiation shielding for the cobalt bomb at Karl Bremer Hospital.

12. CONCLUSION

The use of fly ash in concrete is well established in other countries. In South Africa however it has been available for use in concrete for only two years although laboratory investigations have been under way for a much longer period.

Considerable pioneering work has been done in Cape Town in establishing fly ash as a concrete admixture. Its use is now gaining support from consulting engineers and contractors because of the advantages offered to concrete in terms of durability, impermeability, surface finish and other properties. Fly ash is currently being specified for use in 10 per cent of all ready mixed concrete produced in Cape Town. This will obviously increase if fly ash is accepted as a means of eliminating or reducing alkali-aggregate reactivity.

Whilst fly ash has many applications in fields other than concrete, it might well be true to say that once its use in concrete has become accepted practice it will be difficult to envisage how good quality concrete was ever made without it.

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APPENDIX I

Power generation

The following is a brief description of the major components of a typical coal-burning pulverised fuel power station.

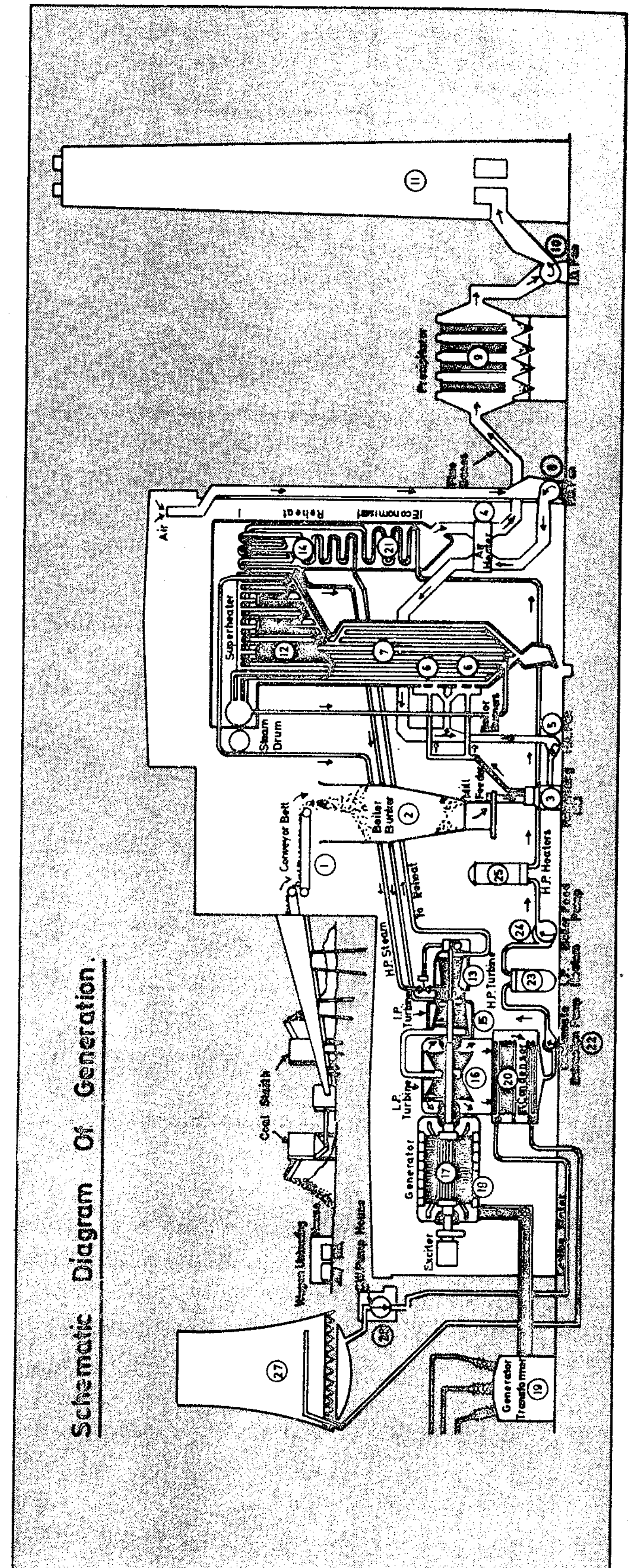
The coal travels by conveyor belt **(1)** from the coal-handling plant to the boiler bunkers **(2)** where it is fed into pulverising mills **(3)** which grind the coal into a dust which is as fine as face powder. This powdered coal is carried from the mill by a stream of air heated in the air heater **(4)** and driven by a primary air (P.A.) fan **(5)** to the boiler burners **(6)** where it is blown into the furnace **(7)** and burns like a gas. A forced draught (F.D.) fan **(8)** provides additional controllable air to the burners to assist combustion.

The products of this combustion are dust and ash in a ratio of 5 to 1. The ash falls to the bottom of the boiler and is periodically sluiced to the ash handling plant. The dust is carried in the flue gasses to the precipitator **(9)** where it is extracted by high voltage electrodes. The cleaned flue gasses pass on via an induced draught (I.D.) fan **(10)** to the chimney **(11)**.

The heat released by the burning coal is absorbed by the miles of tubing which form the boiler walls. Inside the tubes, extremely pure water, known as boiler feed water, is converted by the heat into steam at high pressure and temperature. The steam is superheated **(12)** in further tubes and passes to the high pressure (H.P.) turbine **(13)** where it is discharged onto the turbine blades. The energy of the steam striking the blades makes the turbine rotate. After passing through the high pressure turbine, the steam is returned to the boiler for reheating **(14)** before passing onto the intermediate pressure (I.P.) turbine **(15)** and from there to the low pressure (L.P.) turbine **(16)**. Coupled to the turbine shaft is the rotor of the generator **(17)**. This is a large cylindrical electro-magnet. The generator rotor is enclosed in the stator **(18)** which consists of large coils of copper bar in which electricity is produced by the rotation of the magnetic field created by the rotor. The electricity passes from the stator windings to a transformer **(19)** which increases its voltage so that it can be transmitted over the power lines into the Grid System.

After exhausting its useful energy in turning the turbine, the steam enters the condenser **(20)** to be used again in the boiler. Before entering the boiler at the economiser **(21)** the water is pumped by condensate pumps **(22)** heated in L.P. heaters **(23)**, increased in pressure by the boiler feed pump **(24)** and heated further in H.P. heaters **(25)**. The water passes through the economiser to the steam drum **(26)** then up through the furnace wall-tubing before returning to the steam drum for steam separation. The steam leaves the drum and is heated in the superheater on its way to the H.P. turbine. The condenser contains miles of tubing, through which the cold water from the cooling towers **(27)** is constantly pumped. The heat which the water extracts from the steam in the condenser is removed by passing the water through the cooling towers. The water is sprayed out at a low level in the towers and as it falls into the pond beneath is cooled by the upward draught of cold air. The cooled water in the pond is then recirculated by pumps **(28)** to the condensers. Inevitably, however, some of the water is drawn upwards by the draught and it is this water which forms the familiar white cloud emerging from the towers.

Schematic Diagram Of Generation.



DISCUSSION

Prof S Diamond (Purdue University, USA) commented that in regard to the plea to increase the curing time to beyond 28 days before taking strength measurements, a relatively large number of high rise structures using high strength Portland cement concrete (primarily in the columns) had been built in the United States and Canada over the last seven years, and the difficulty had been in achieving the high strengths specified (70 to 80 MPa) without causing heating, shrinkage, and other problems. The only way this could be done was by the careful selection of cements and aggregates as well as the use of fly ash and a superplasticizer so that they could get the water:cement ratio low enough. However, he added, this almost always left the strength at 28 days too low and a petition was usually granted, to allow the time at which the design strength was measured to be increased to 56 days. He suspected that South Africans might well follow suit before too long.

Dr P E Grattan-Bellew (NRC, Ottawa, Canada) found it very interesting that although there was a 6 per cent reduction in the water used and a 5 per cent increase in the coarse aggregate, workability seemed to be better than one would get without the pfa. He asked the author to explain why he was getting such good workability with this mix.

Mr B D G Johnson said he thought that this could be explained by the fact that the fly ash that they were using was well graded from 1 to 150 μm.

Prof S Diamond said he thought that in addition to the effect of grading, there was an additional benefit from the sphericity of many of the grains. There was also a sort of a quasi-chemical effect in that the floc structure of the cement paste had been modified significantly.

Dr D W Hobbs (C & CA, London, UK) added that if part of the cement were replaced by a pulverised fuel ash and the water content remained the same, then the workability would be increased because the water/OPC ratio had been increased. This reduced the yield value and plastic viscocity of the cement paste fraction but this was more than offset by the fact that these values had been increased by the presence of the pfa. If one replaced cement with fine sand one produced a similar effect. In order to achieve the same workability one had to reduce the water content. In his view it had nothing to do with the shape of the particles of pfa; if one replaced any part of the cement with any inert powder the same process applied. He asked Mr Johnson how, in the type of mix designs that he was suggesting, the blended cement content compared with the Portland cement content in a comparable concrete. His reason for asking this, was that in the UK a major drawback in the use of pfa was the fact that at a cement replacement level by pfa of 30 per cent, the blended cement content was approximately 7 per cent higher than that required by a comparable Portland cement concrete. Pfa in the UK he believed was a quarter the price of Portland cement.

Mr B D G Johnson replied that in Cape Town the figure varied but the blended cement content was about 4 per cent greater by mass than in the equivalent OPC concrete.

Mr G F Loedolff (Stellenbosch University, South Africa) asked how the bleeding was measured, and whether the amount of water retained in the concrete was more or less than with pfa concrete.

Mr B D G Johnson replied that the measurement of bleeding was a standard procedure which was used by the PCI and most concrete authorities in South Africa. They had noted that the rate of bleeding in fly ash concrete was slower and did not reach the same level as OPC concrete. The amount of water retained was slightly less but it was lost over a longer period.

APPENDIX II

APPENDIX II: OVERSEAS FLY ASH STANDARDS

		ASTM C618/72	ASTM C618/77	CORPS OF ENGINEERS	FEDERAL	BUREAU OF RECLAMATION	BS 3892	AUSTRALIAN 1129/1130/181	AUSTRIAN NORM B 3319
SiO_2	Min			)	)		NS)	NS)	NS
Al_2O_3	Min	70,0	70,0	70,0)	73,0)	75,0	NS)	NS)	NS
Fe_2O_3	Min			)	)		NS)	NS)	NS
SO_3	Max	5,0	5,0	4,0	4,0	4,0	2,5	2,5	3,5
Na_2O (alkali)	Max	1,5	1,5	1,5	2,0	2,0	NS	NS	NS
MgO	Max	NS	5,0	5,0	5,0	5,0	4,0	NS	NS
Moisture	Max	3,0	3,0	3,0	3,0	3,0	1,5	1,5	NS
Loss on Ignition	Max	12,0	12,0	6,0	6,0	3,0	7,0	8,0	7,0
S.G.	gm/cm^3	(2,25)	NS	(2,25)	(2,25)	(2,25)	NS	NS	NS
Surface Area	cm^2/cm^3	6 500	NS	6 500	6 500	6 500	1250–2750 2750–4250 4250–5780	NS	NS
Ave. Particle Size	microns	9,0	NS	NS	NS	NS	NS	Max 10% or 150	NS
Retained on 325 sieve	%	20,0	34,0	NS	NS	15,0	NS	50,0	NS
Strength of Cubes	p.s.i	100	NS	NS	NS	85	NS	NS	NS
Shrinkage	%	0,03	NS	NS	NS	0,04	NS	NS	NS
Autoclave Soundness	%	0,5	0,8	0,5	0,5	NS	NS	NS	NS
Pozzolanic Index	%	85,0	75,0	75,0	75,0	85,0	NS	NS	NS
Lime Reactivity	p.s.i	800	800	900	900	900	NS	NS	NS
Water Requirement	%	105	115	100	100	103	NS	NS	NS
Multiple factor (L.o.i. x retained on 325)	Max	150	NS	NS	NS	NS	NS	NS	NS
Hydraulic factor (comparison with powdered quartz)		NS	NS	NS	NS	NS	NS	NS	30,0