

## ALKALIES IN CEMENT & CONCRETE

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### ABSTRACT

Varying degrees of importance have been assigned to the effects of alkalis on a wide variety of cement and concrete characteristics. In some areas, notably in the United States, low alkali cements have come to be more favourably regarded than high alkali cements, while in other areas there is no comparable preference for low alkali cements. Such differences, however, suggest that there is a need to examine the behaviour of alkali in cement and concrete.

The presence of small amounts of alkalis may modify the compound composition of clinker and affect its behaviour while alkali compounds, which greatly exceed the solubility of other clinker compounds, may affect the physical properties and hydration characteristics of cement paste. Under appropriate exposure conditions, alkali may contribute to diverse phenomena such as surface staining, efflorescence, scaling and siliceous aggregate reaction and expansion in concrete. Despite the detrimental effects attributed to alkali, the general performance properties of cement can be suitably maintained provided raw material variations are anticipated and minimized and due attention is given to burning clinker, and to the fineness and gypsum content of cement.

## Introduction

Alkali metal compounds are minor constituents of portland cement. They are both readily and rapidly soluble in water. They may affect the behaviour and properties of both freshly-mixed and hardened cement paste and concrete and may contribute to the incidence of several problems which develop slowly in concrete.

All of the relevant characteristics of a cement are seldom identified or completely defined. The observed functions and performances of cement paste and concrete, on which experimental conclusions are based, may be influenced by many different interactions but are generally attributed to a relatively few factors such as compound compositions computed from chemical analyses and surface area measurements. However, other more significant characteristics are rarely stated. Examples of these deficiencies concern the actual compound compositions, crystallinity, heat treatment and production conditions of clinker, fineness characteristics such as particle size distribution, distribution skewness and particle shape of both clinker and gypsum, and the surface condition of particles when mixing with water commences. All of these factors are highly significant and may influence water requirement, setting time, stiffening tendencies, strength development, shrinkage and the sensitivity of cement to react with admixtures.

The present paper sets out to discuss the occurrence and behaviour of alkalis in cement and concrete, to indicate the effects of alkalis in cement reactions and in various phenomena which occur in freshly-mixed and hardened cement paste and concrete, and to comment on procedures that may be used to reduce the alkali content of cement and to modify some of the adverse effects produced by alkalis in concrete.

## Alkalis in Clinker

Alkali compounds in concrete are derived principally from cement, with aggregate and water as minor contributors, and from secondary external sources such as ground-water and air-borne spray. The common alkali metal ions, sodium and potassium, are present in variable but minor amounts in clinker generally within the range 0.1 - 1.5%  $\text{Na}_2\text{O} + \text{K}_2\text{O}$ . They are generally derived from the argillaceous fraction (clay or shale) of the raw meal or from coal ash. Other fuels may also indirectly affect the composition of clinker. Residual fuel oil usually contains large amounts of sulphur, while natural gas contains neither alkalis nor

sulphur compounds. The amount of sulphate in clinker affects not only the mode of occurrence of alkalis, but also the amounts of some of the other clinker compounds.

Newkirk (1951,1952)<sup>6,7</sup> has discussed alkali-clinker systems and described the occurrence of alkali phases and accompanying compound compositional changes in clinker. Alkalies combine preferentially with sulphate to form a solid solution of roughly constant composition, and consisting of potassium sulphate and sodium sulphate in an approximate 3:1 molecular ratio. Alkalies, in excess of the amounts combined with sulphate, combine with dicalcium silicate ( $C_2S$ ) to form the compound  $KC_{23}S_{12}$  and with tricalcium aluminate ( $C_3A$ ) to form the compound  $NC_8A_3$ , and may adventitiously occur in solid solutions with clinker compounds or as a constituent of glass. The amount of sulphate ion derived from raw meal and fuel therefore affects the phase composition of the clinker. When the amount of sulphate ion is large and when the amounts of alkali ions are small, alkalies are present largely as sulphates. When the sulphate ion is deficient, the compounds  $KC_{23}S_{12}$  and  $NC_8A_3$  together with the potassium sulphate-sodium sulphate solid solution occur in variable amounts. With increasing amounts of alkali ions, the amounts of the compounds  $KC_{23}S_{12}$  and  $NC_8A_3$  increase and calcium oxide is displaced from dicalcium silicate and tricalcium aluminate. Since the amount of  $C_2S$  which is available to combine with the calcium oxide to form  $C_3S$  is rapidly depleted, free calcium oxide becomes an equilibrium phase in clinker. It is clear that changes in the chemical composition of raw meal, of raw materials and of fuels can have marked effects on the compound composition of clinker and consequently can influence cement behaviour. Moreover, since the clinkering reactions in kilns do not always reach their expected equilibria the amounts of the different compounds formed may differ markedly from those computed from the oxide analysis. The presence of other negative ions and variations in raw meal characteristics, in burning temperatures, in fuel combustion and in kiln operating conditions can also affect the alkali content and compound composition of clinker. Provided these variations are anticipated and suitable action is adopted to counter or minimize their effects, clinker and cement possessing satisfactory quality and properties can be produced.

Approximately 50% of the alkalies in raw meal and coal ash may be volatilized during burning, and much of this alkali is re-deposited in the chain section of the kiln, and in pre-heaters, dust precipitators and

filters. The practice of re-circulating re-claimed precipitated dust to the kiln generally changes the raw meal composition adversely and increases the alkali content of clinker. The burning of high sulphur fuel oil in place of coal tends to increase the sulphate content of clinker and, depending on burning conditions, may reduce the amount of alkalis that are volatilized and thus affect the compound composition of the clinker. On account of the specified limitation generally placed on the amount of sulphate in cement, the presence of large amounts of sulphate in clinker reduces the amount of gypsum that can be interground with it. Since a large proportion (e.g. 40-70%) of the sulphate in clinker is not readily soluble (Stikker, 1958<sup>10</sup>; Anderlini & Vivian<sup>1</sup>, unpublished data), cement made from it is deficient in readily soluble sulphate, its setting time is modified and its rate of strength development and shrinkage are adversely affected.

Potassium salts are generally more volatile than sodium salts. In some plants they have been extracted from precipitated kiln dust. This extraction process is not usually economic and can be improved only marginally by adding calcium chloride to raw meal, since the total amounts of alkalis in raw meal are low (approximately 1-2%) and increments in the amount of volatilized potash salt are limited. The demand for low alkali cement was first generated in some western areas of the United States where reactive siliceous components occurred in most aggregates. Subsequently the overall improvement noted in the quality of these cements has ensured a continuing demand for low alkali cement and has led to studies of the various procedures for reducing the alkali content of clinker.

Alkalies also affect clinker production in several different ways. In raw meal alkalies tend to reduce clinkering temperatures and generally increase the amount of liquid and the rate of clinkering. Simultaneously, however, alkali compounds penetrate a few centimetres into the kiln refractories and may react with the interstitial fosterite bond and with chromite to form alkali chromates. On account of differences between the coefficients of thermal expansion of basic brick and alkali compounds, large accumulations of alkali sulphates and chromates induce stresses which are additional to the high mechanical stresses resulting from kiln rotation, and accentuate the spalling tendency of brickwork.

### Alkalies in Cement

The immediate solubility of alkalies constitutes one of their most noticeable properties. When cement is mixed with water a portion of the total alkalies, which depends partly on the sulphate content of clinker, dissolves rapidly. This quantity increases as the alkali-containing compounds hydrate. Soluble alkali salts in contact with hydrating clinker will inevitably be converted to alkali metal hydroxides and negative ions such as sulphate and carbonate will form less readily soluble calcium sulphate and calcium carbonate. The solution therefore rapidly approaches a transient ionic equilibrium and has a relatively large hydroxyl ion concentration which continues to increase with time. The presence of soluble alkali metal hydroxides depresses the solubility of calcium ion and modifies the rates of hydration of clinker compounds and of the early reactions that occur on clinker compound surfaces. These modifications influence the developing physical associations between large and small clinker particles and the physical state of newly-formed products. These changes in turn affect such characteristics as sedimentation, bleeding and stiffening, all of which may be used to describe the behaviour of cement paste.

Cement pastes have very high solid/water ratios and contain particles of different sizes. Consequently their properties are markedly affected by small differences in water contents. The performance of different cements may be quite variable and any chemical variation or measured physical change or property may be affected by a wide variety of factors which includes the conditions of clinker manufacture, the fineness of the cement and degree of aeration of clinker before grinding and of cement after grinding. Alkalies may interact with other factors to modify the chemical and physical changes which occur in paste. Steinour (1945) has recorded experimental data showing that the bleeding rate and bleeding capacity of pastes decrease as their water-soluble alkali contents increase. In addition to clinker composition other factors including the rate of clinker cooling, grinding temperature, aeration, the addition of soluble salts and admixtures and test temperature are shown to affect the bleeding characteristics. Caution therefore should be exercised in drawing conclusions from data which represent rates of physical change in cement paste when the prior treatment and properties of the clinker and cement are not adequately described or controlled. While temperature typically modifies the rates of chemical reactions, the rate of physical

change after mixing has ceased depends not only on imposed environmental conditions and on the quantities of clinker or clinker compound undergoing reaction and of newly-formed products, but also on the intrinsic properties of these latter products and their distribution in the paste. Consequently physical changes in pastes can be significantly affected by the occurrence of occlusion-type reactions that greatly restrict the rates but do not inhibit reactions, by changes in the physical nature of reaction products and by the conditions of temperature and water content imposed on the paste.

When cement and water are mixed together readily soluble compounds enter solution, solid particles, which are readily wetted and affected by various forces of attraction and repulsion, associate in arbitrarily sized masses, hydration and other chemical reactions commence and the observable physical characteristics of the paste such as sedimentation, bleeding and changes in workability become apparent. The paste very rapidly acquires a physical framework that will persist unless changed by the application of external forces, and all the future autogenous changes occur within this framework. As hydration proceeds minor chemical reactions and effects produced by their products are progressively obscured and obliterated by the more widespread chemical reactions, which yield large quantities of hydration products. Tricalcium silicate is therefore the clinker compound which largely determines the final performance characteristics of cement. Gel layers form rapidly on clinker particle surfaces and crystals grow into the surrounding solution. Continued hydration of clinker compounds disrupts the gel layers which rapidly re-form and, although crystals growing radially from adjacent clinker particles tend to interact, they do not become intergrown.

The solution in cement paste rapidly becomes supersaturated with respect to calcium and hydroxyl ions and approaches saturation with respect to sulphate ions. Since the amounts of alkalies in cement are relatively small, the sodium and potassium ion concentrations do not reach saturation. Lawrence (1966)<sup>4</sup> has discussed the composition of solutions in a number of cement pastes, and Fig. 1 records in a general way the changes which may occur in the soluble ion concentrations over the early hydration period (approximately 16-24 h).

As the hydration time increases the alkali and hydroxyl ion concentrations increase while sulphate and calcium ion concentrations decrease. It should be noted that cements generally contain more sulphate

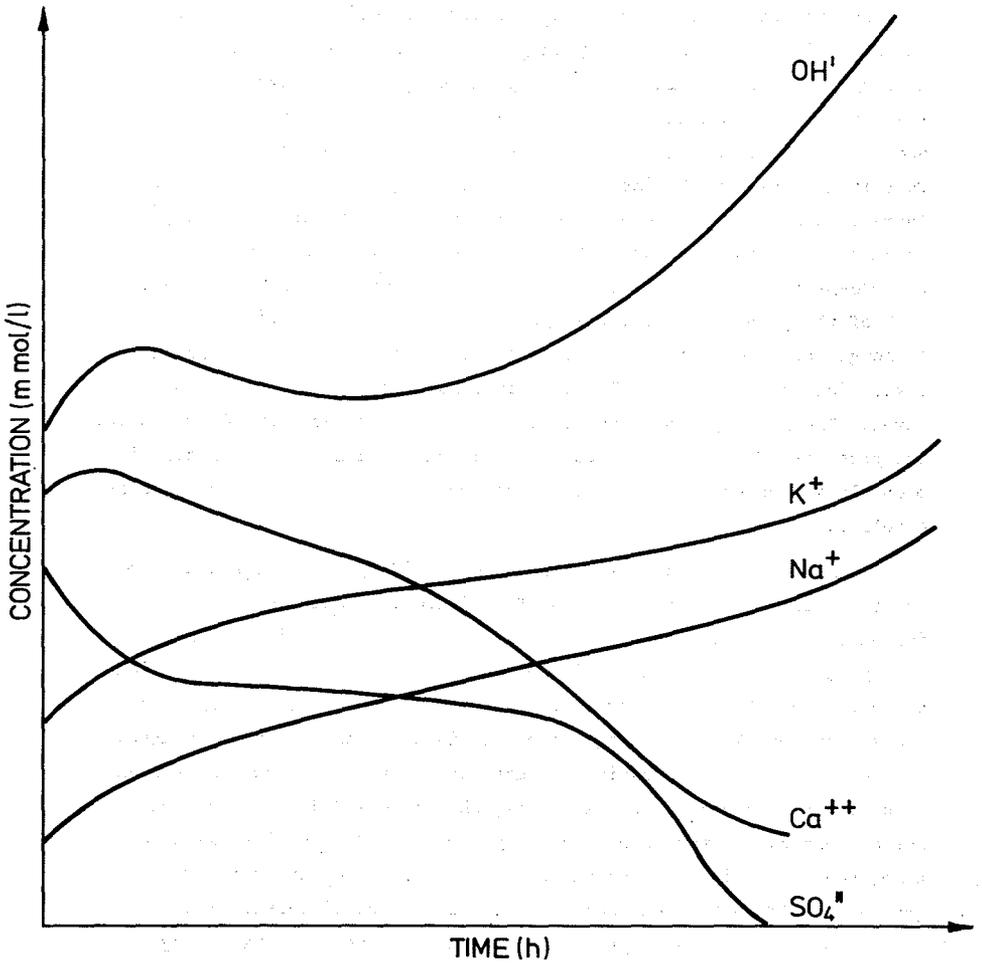


Fig. 1. Changes which occur in the composition of the solution phase in contact with hydrating cement.

ion than is needed to saturate the solution, especially at low water/cement ratios while excessively large amounts of both calcium and hydroxyl ions are continually being produced by the  $C_3S$  hydrolysis reactions. Although an increased water/cement ratio increases the amount of soluble sulphate, its concentration does not increase and in fact it decreases with time due to reaction with hydrated aluminate. There is also some evidence (Anderlini and Vivian, unpublished data), which suggests that occlusion-type surface reactions especially in low water/cement ratio pastes, between  $C_3A$  hydrate and gypsum may prevent much of the potentially soluble gypsum from dissolving rapidly. Although the calcium ion concentration decreases with time and as the alkali ion concentrations increase, it remains above the saturation level. The hydroxyl ion concentration also remains correspondingly high. The presence of very small amounts of silicate and aluminate in solution probably indicates the adventitious occurrence of colloidal particles or micelles.

An increasing hydroxyl ion concentration promotes  $C_3A$  hydration and tends to retard the hydration of silicates. Simultaneously an increase in sulphate ion concentration reduces the solution pH, retards  $C_3A$  hydration and promotes silicate hydration. The amount of hydration which produces the early physical changes in paste is relatively minor. The effects of alkalies, either alone or in the presence of admixtures, on the properties of hydration products and on resultant phenomena such as strength development, permeability, shrinkage and durability, are largely unknown. Studies published by Lerch (1947)<sup>5</sup> described setting time, heat evolution and shrinkage of a number of cements which were ground to different finenesses and which contained different amount of  $C_3A$ , alkalies and added gypsum. In general cements containing large amounts of alkalies required large additions of gypsum to achieve adequate set retardation. It should be noted however that many of the factors which affect the behaviour and properties of a cement were not known or controlled in these experiments.

Although variations in the properties of different cements are relatively large, available evidence suggests that variations caused by alkalies are minimal compared with those caused by modifications in the major clinker compounds, by the degree of aeration, involving moisture and carbon dioxide, of clinker and cement, by fineness of grinding and

by workability (water/cement ratio) differences. The fact that cement pastes and concretes made from both high and low alkali cements develop comparable characteristics suggests that alkalis do not cause major deleterious changes in the normal hydration and strength-gaining processes or in the nature of the hydration products.

#### Alkalies in Hardened Cement Paste and Concrete

Alkalies in hardened cement paste and concrete may influence reinforcement corrosion, the development of surface stains and efflorescence deposits, the incidence of surface scaling and "popouts", and the reaction with abnormal expansion of aggregates. The nature of the negative ion associated with positive alkali metal ion has a significant effect on the properties of the product and its action on the hardened mass. In addition the presence of potentially reactive materials and exposure to suitable environmental conditions or environmental cycling are necessary for some destructive actions to proceed.

Solutions of alkali metal hydroxides and calcium hydroxide, which have high pH's, passivate reinforcing steel surfaces and inhibit corrosion. Areas of the steel surface which are not completely coated with cement paste may undergo corrosion, especially if negative ions such as sulphate, chloride or carbonate are present to reduce the solution pH and to produce a conducting solution through which stray electric currents may discharge to earth. Moreover, too little cover over reinforcement or poorly compacted concrete allows the ingress of air, rapid carbonation of solutions, hydrated cement compounds and clinker particles surfaces and corrosion of reinforcement and disruption of concrete.

All types of concretes and concrete products as well as other porous solids can be affected by surface efflorescence deposits, staining and mould growth. Soluble alkali metal salts as well as calcium hydroxide and calcium salts may be deposited as white, crystalline, efflorescence deposits on concrete surfaces as the solution evaporates during periods of drying. These deposits, which vary from opaque coatings, which adhere tenaciously to the solid surface, to loose, fluffy masses, cause surface blotchiness, colour fading and general disfigurement of architectural surface finishes and features. On account of their insolubility in water, strongly adherent calcium carbonate coatings are difficult to remove. The loose coatings, which may sometimes be blown away, are usually readily soluble alkali salts which are re-dissolved by water, re-absorbed and

later re-deposited when drying conditions recur. In addition the presence in aggregate of oxidizable compounds such as pyrite and marcasite, and organic matter which becomes soluble in alkali solution, promote the irregular staining of concrete surfaces with brown deposits. Apart from an occasional surface "pop-out" pyrite and marcasite are not usually present in sufficiently large amounts to cause undue physical damage to concrete. The staining deposits are also aesthetically undesirable rather than physically damaging.

When concrete is exposed to a sequence of drying and wetting cycles, in soluble salts tend to concentrate near the concrete surfaces. If present in sufficiently large amounts these salts may cause surface scaling, a phenomenon produced by shallow micro-pop-outs. When concrete is exposed to dry-wet cycling conditions, salts such as sodium sulphate are not only concentrated near the surface but also undergo a change from an anhydrous to a hydrated state. This change in the state of hydration of the salt is highly significant since unhydrated salts or salts which, although hydrated, are not readily crystallized, do not cause scaling. Removal of the surface layers of cement paste or mortar exposes the coarse aggregate which eventually becomes loosened, and produces a general roughening of the surface of the concrete. It should be noted that this scaling process is not confined to concrete; it occurs generally in permeable materials such as natural stone, sand-lime bricks and blocks and in certain earthenware ceramic products. Scaling causes more damage than efflorescence because it adversely affects the operating surfaces of structures and slowly reduces the cross section of structural units.

Alkalies in hardened concrete were shown to react slowly with siliceous aggregates which contain opal (Stanton 1940)<sup>8</sup> or which contain acid and intermediate volcanic glasses (Blanks and Meissner 1941)<sup>2</sup>. This reaction, which was discussed recently (Vivian, 1975)<sup>12</sup>, produces quantities of an alkali hydroxide-silica complex which can absorb water and swell. The swelling complex exerts a disruptive force on the mortar surrounding the reacting aggregate particles. As cracks are formed and propagated through the concrete a significant overall expansion occurs. Since the concrete becomes extensively cracked its mechanical strength is markedly reduced and the space created by the cracks permits the ready entry of water or other salt solutions which may accelerate the disintegration of concrete exposed to adverse environmental conditions. It is impossi-

ble to control this reaction in large concrete masses which can undergo sufficient deterioration to cause the abandonment of the structure before it has completed its expected economic life. The testing of constructional materials before use and the prediction of the occurrence of this problem in concrete has now become widely accepted and practiced.

A somewhat similar but less widespread problem concerning the expansion of certain dolomitic aggregates in Canada and the United States has been reported by Swenson (1957)<sup>11</sup>, Hadley (1961)<sup>3</sup> and others. Some dolomites have been shown to be capable of reacting with alkalis and causing concrete expansion. This reacting system possesses some unusual features which have not yet been fully explained and the precise source of the disruptive forces has not been clearly demonstrated. Nevertheless this reaction suggests that the presence of relatively large amounts of alkalis in cement and their reaction with a susceptible dolomitic aggregate can cause large concrete expansions. To obviate damage from this source tests have been devised to permit the prediction of aggregate behaviour in concrete.

#### Economic Effects of Alkalis in Cement and Concrete

For much of the concrete that is produced the alkali contents (generally <1%w/w of cement and consequently <0.2% w/w of concrete) are so small that they have no significant adverse effects on desired properties. Moreover, unless other significant factors are present, in general constructional concrete, alkalis do not cause any adverse material modifications. Alkalis do not produce any significant changes in concrete that is kept completely and continuously wet is also relatively unaffected by alkalis. Exposed concrete, which is subjected to intermittent wetting and drying or subjected to water pressures on one face, may develop the typical wet-dry cycling effects which, if other essential factors are present, can include general deterioration, surface staining, efflorescence and scaling. The fact stands out quite clearly that, in evaluating the economic impact of any potential problem in concrete, environmental exposure conditions must be considered along with various material and structural factors.

Consideration of the economic effects of alkalis involves the cost of prior investigations of sites and materials. It also involves the maintenance of operation of the structure and the cost of repairing damage such as staining caused by efflorescence and mould growth on

architectural concrete finishes and surface scaling. Greater costs can be caused by the need to reconstruct a defective structure before its estimated economic life has elapsed. Since cement is manufactured and is usually the major source of alkalis in concrete, economic considerations tend to become involved with procedures for removing alkalis from clinker. Alkalis derived from ground-water or general working operations may sometimes cause problems which can only be prevented by good construction practices and surface protection.

In certain localities where all available aggregates are considered to be potentially reactive, a maximum alkali content has been specified for cement. Stanton (1949)<sup>8</sup> initially proposed as a maximum limit 0.5% total alkalis expressed as  $\%Na_2O + 0.658\%K_2O$ , and subsequently increased this maximum to 0.6%. This latter figure has been generally adopted as the limiting quantity which separates high from low alkali cements. It is quite possible that this arbitrary limit may still be too high because over long periods of time alkalis may concentrate in a relatively few areas and cause such damaging effects as surface efflorescence, scaling and aggregate expansion.

Since the cost of removing alkalis from clinker is high, it is essential where possible to choose raw materials that have low alkali contents. If such materials are not available, removal of a portion of the alkalis during clinker manufacture is more economic than their complete removal. The alkali contents of many low alkali cements are therefore just below the maximum limit. It will be seen that changes which are intended to reduce alkali contents may induce additional problems which reduce production rates and increase maintenance costs. Although volatilization of an increased amount of alkalis from raw meal by high burning temperatures may assist in producing a high quality clinker, it also increases fuel and kiln lining costs and may reduce output. Additions of compounds such as calcium chloride to raw meals or to fuel to increase the amount of volatilized alkalis are generally ineffective, increase costs and may induce additional corrosion and clogging problems in exhaust systems. Although dumping precipitated kiln dust in contrast the returning dust to the kiln, assists in reducing the alkali content of clinker, this practice wastes valuable material, reduces kiln output and therefore directly increases production costs. This practice also increases handling problems and accentuates the need for either storage or dumping space so that a pollution problem is not created.

Abrasion and corrosion of metal in plant units may be severe. The presence of calcium chloride dusts and moisture in flues, stacks and hoppers where temperatures fall sufficiently low for moisture to condense may accelerate metal corrosion. On the other hand the rate of steel losses from grinding media and liner plates in ball mills is up to 10 times greater in wet than in dry grinding mills. This difference is due to corrosion which can be significantly reduced by increasing the pH of the slurry (Anderlini and Vivian, 1961)<sup>1</sup>. Although such an increase in pH would increase the alkali content of clinker slightly and modify the flow characteristics of the slurry, it could be an economically viable addition in some plants.

The production of blended fly ash-portland cement mixtures can also affect alkali contents. If the alkali content of the fly ash is low, the overall alkali content of the blended cement can be effectively reduced. This reduction in alkali content has been regarded as one of the advantages of blending a pozzolan with portland cement to reduce the extent of alkali-aggregate reaction. However some fly ashes from coal-fired boilers contain large amounts (>5%) of alkalis and consequently in blended cements could significantly increase the alkali content of concrete.

The permeability of concrete and concrete products affects the incidence of efflorescence and scaling. Reduced permeability improves the general quality and performance of concrete significantly. It has long been recognised that the processes of glazing ceramic ware and of polishing natural stone seal the product surfaces and either eliminate or significantly reduce the movement of solutions under cycling environmental conditions. A reduced permeability in low priced concrete and concrete products which can be achieved without the use of costly material or production treatments would reduce the movement of solutions. Consequently any procedure that enables high density cement pastes to be produced without the need for large compacting pressures could be a suitable alternative to reducing the alkali content of cement. A reduction in paste permeability may be achieved by grinding cement more effectively and modifying its mean particle shape so that adequate workability is developed at a reduced water content.

#### Concluding remarks

1. Alkalies are present in varying amounts in all cements and concretes. They do not affect the performance of cement adversely

- and compared with other major components, their effects on many of the properties of concrete are small.
- 2 Alkalies may cause some surface blemishes in concrete such as:-
    - (a) staining,
    - (b) efflorescence, and
    - (c) scaling.
  - 3 Alkalies may cause more complex and damaging effects in concrete such as:
    - (a) reaction with siliceous aggregates, and
    - (b) reaction with dolomitic aggregates.
  - 4 Alkalies produce strongly alkaline solutions which have the beneficial effect of inhibiting reinforcement corrosion and minimizing steel media and liner plate corrosion in wet grinding mills.
  - 5 Wet-dry cycling exposure conditions are necessary to produce severe efflorescence and scaling problems. Exposure to continuously wet or dry conditions does not cause marked efflorescence or scaling.
  - 6 The presence of some alkali in cement and concrete must be accepted since it is neither technically nor economically feasible to remove alkalies completely. Some reduction in the amount of alkalies in cement can be achieved by:
    - (a) Choice of low-alkali raw materials.
    - (b) Increased volatilization of alkalies by high burning temperatures. This procedure also increases fuel costs and may reduce kiln lining life and kiln output.
    - (c) Additions such as calcium chloride to raw meal to increase the volatilization of alkalies. This may also increase corrosion and dust collection problems.
    - (d) Non-recirculation of precipitated kiln dust which may be dumped or used as a lime top-dressing for pastures.
  - 7 Improvement in the performance of concrete may be achieved by:
    - (a) The use of low alkali (<0.6%) cements.
    - (b) The use of blends containing suitable amounts of pozzolans such as burnt clays, volcanic ashes or fly ashes.
    - (c) The substitution of non-reactive aggregates for known reactive aggregates

(d) The use of surface treatments or barriers to prevent alkali-containing ground water from being absorbed by concrete.

8 Aggregates should be tested prior to use and those containing deleterious components discarded. Standard tests are available for this purpose. It should be noted however that these tests alone are not suitable for assessing the probable behaviour of the material under operating exposure conditions.

9 An improvement in concrete performance could be accomplished by reducing the permeability of cement paste. By modifying the shape of cement particles and reducing the water/cement ratio, the rate of movement of solutions in concrete could be restricted sufficiently to minimise the staining, efflorescence and scaling problems and other desirable physical properties of cement could be improved. Good constructional practices would still be essential to ensure complete compaction and tight joints and to eliminate undue cracking.

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## CONTRIBUTIONS TO DISCUSSION

### Mr. B. Mather

Firstly, I join Miss Moore in expressing regret that Mr. Vivian is not present. Second, I applaud the emphasis given in paragraph 1 of part 5 of the paper on environmental effects especially the statement "Alkalies do not produce any significant changes in concrete that is dried out and is then kept continuously dry". Third: I inquire whether there is documentation that alkalies in cement cause or encourage "mould growth" as noted in the second paragraph of part 5. Finally with regard to the point about high-alkali fly ashes as noted in the next to the last paragraph, at our laboratory we evaluated fly ashes of various alkali contents for effectiveness in reducing expansion of pyrex glass - high alkali cement mortar bars. High-alkali fly ashes were less effective than low-alkali but when used in appropriate (larger) amounts were equally effective; these higher amounts are reasonable and economical especially in mass concrete.

### Mrs. K. Mather

I would question Vivian's point: "Alkalies do not produce any significant changes in concrete that is dried out and kept dry"; How does this compare with the Hadley explanation of reaction with low alkali cement in the semi-arid climate of Kansas and Nebraska where drying the concrete concentrates the alkali from low alkali cement and permits reaction to occur. Answer to question by B. Mather is that the concrete in Kansas was occasionally subject to being rained on; thus a different situation than Vivian envisioned.

### Ms. A.E. Moore

In Section 2, paragraph 3, H.E. Vivian suggests that high sulphur fuels promote retention of alkalies and then that this may result in a large proportion of clinker sulphate which is not readily soluble. Surely alkali sulphate is highly soluble, and indeed the first line of Section 3 says this? Pollit and Brown (Tokyo Symposium) show that it is very unusual to have less than 70% of clinker sulphate readily soluble.

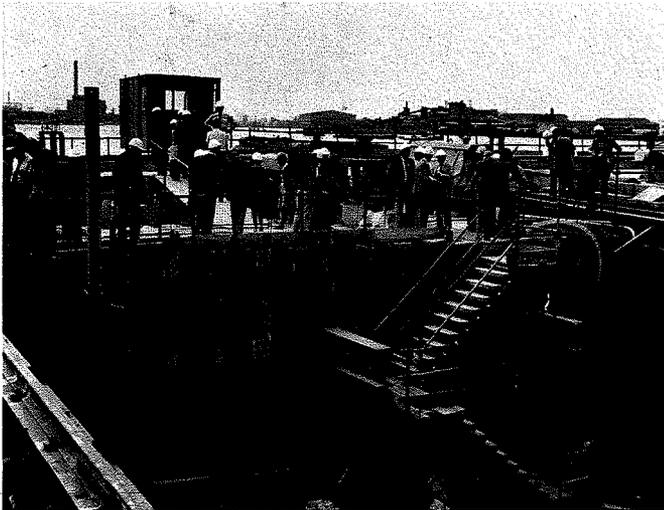
Mr. P.J. Jackson

1) On Page 11 the claim is made that recirculation of reclaimed precipitation dust generally changes the raw meal composition adversely. This contribution has been involved with this reaction for a decade now, and provided it is correctly carried out has found no such adverse effects.

2) On Page 12 it is noted that quality is said to improve with low alkali cements. This contribution is not clear what is meant by this. Certainly as far as strength and many other properties are concerned high alkali cements can be as good as or better than some low alkali cements. This matter is dependent on so many other considerations that a generalisation such as this is not warranted.

Mr. J. Figg

A possible explanation concerning Mr. Mather's query is that mould growth will be inhibited in high alkali environments and this may be the effect referred to in H.E. Vivian's paper.



The Thames Barrage Site