ALKALI - AGGREGATE REACTION

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THE IMPLICATIONS OF PRODUCING A LOW ALKALI ORDINARY PORTLAND CEMENT IN THE SOUTH WESTERN CAPE

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SYNOPSIS

The manufacture of low alkali cement imposes numerous additional burdens on the plant, which in turn makes the process more costly. To this must be added the fact that there will be an increase in the use of energy and less efficient use of raw materials. If the demand for low alkali cement remains high, new sources of low alkali feedstock will have to be found.

SAMEVATTING

Met die vervaardiging van lae-alkalisement word talle bykomende laste op die aanleg gelaai wat dan die proses duurder maak. Voeg hierby die feit dat daar toenemende energieverbruik en minder doeltreffende aanwending van rou materiaal sal wees. Indien die vraag na lae-alkalisement hoog bly sal nuwe bronne vir lae-alkaligrondstowwe gevind moet word.

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1. INTRODUCTION

Identification of an alkali-aggregate problem in various concrete structures in the South Western Cape during the mid 1970's made it desirable for the role and source of alkali in the cement manufacturing process to be investigated in order to determine whether a significant reduction in the alkali content of the ordinary Portland cements being manufactured, preferably to a level low enough to comply with any possible future national low alkali specification, would be feasible and if so, what the implications would be with regard to the manufacturing process and production costs.

2. SOURCES OF ALKALI

Before the implications of producing a low alkali Portland cement in the South Western Cape can be discussed it is essential that the alkali content of the various materials used, as well as their source, availability, and usage rates be known.

In the case of our company, which since the end of 1980 has become the only producer of cement in the South Western Cape, the typical alkali content of the main raw materials used at the two works is as follows:

	Na_2O (%)	K_2O (%)
Limestone	0,13 - 0,22	0,18 - 0,92
Shale	0,20 - 0,32	1,7 - 3,6
Sandstone	0,10 - 0,20	0,34 - 0,44
Iron Ore	0,12 - 0,22	0,34 - 0,38
Sand	0,04 - 0,10	0,08 - 0,16

The two cement plants are located on deposits of limestone, shale and, at Riebeeck, also sandstone. The other raw materials are obtained from outside sources. Other materials used in the production process in sufficient quantities to affect the alkali content of the cement produced are water, gypsum and coal ash (from the pulverised coal fired in the rotary kiln).

The main raw material used for producing kiln feed for cement clinker manufacture is limestone which in the case of the factories concerned is a sedimentary limestone, subsequently metamorphosed and with the development of phyllite partings between the bedding planes. Since limestone normally comprises about 90 per cent of the kiln feed it is obvious that the alkali content of the limestone used is highly significant in the design of a low alkali cement kiln feed. In addition it should be borne in mind that kiln feed has a loss on ignition of about 35 per cent - mainly carbon dioxide, which is lost in the clinkering process. This 'process loss' naturally concentrates the alkali content of the clinker being produced. Clinker is of course the major intermediate product in the cement manufacturing process.

3. METHODS OF ALKALI REDUCTION

Two possible methods of reducing the alkali content of the cement produced are by reducing the alkali content of the kiln feed and or by removing alkalis in the clinkering process.

Reduction of kiln feed alkali content. In the case of the kiln feed, steps that could be taken to reduce the alkali content are:

(i) Selective quarrying of the limestone.
(ii) Beneficiation of the limestone.
(iii) A reduction in the shale usage rate.
(iv) Increased use of components having lower alkali levels.
(v) The use of preblending plants in conjunction with (i) and (ii) to improve control procedures.

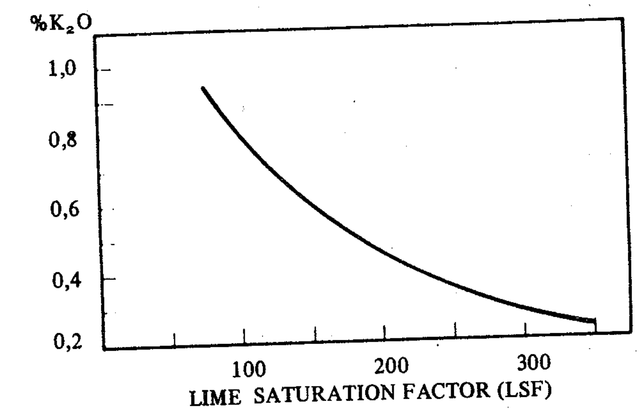
The implications of reducing the alkali content of the kiln feed, assuming the steps listed above are feasible from both the chemical and physical points of view, are:

(a) An increase in the amount of limestone and waste that has to be handled to produce the same amount of cement. This also means a reduction in the life of the limestone reserves. The following table shows the percentage of rejects or screenings compared with the quality of the limestone expressed as the lime saturation factor (LSF) at one of the works and will give an indication of the implications of beneficiation. It should be noted that these figures represent losses after the stone crushing processes and do not include direct waste due to selective quarrying methods.

Screenings (as a % of material crushed)	Lime saturation factor (LSF)
18,7	140
19,7	155
26,9	170
28,9	207
40,1	242

While some degree of beneficiation of limestone specifically with regard to its lime saturation factor (LSF) was always necessary in the past for ordinary Portland cement manufacture the main purpose of the beneficiation operation in the manufacture of low alkali Portland cement would of course be to reduce the alkali content of the limestone. Since, as shown by the following curve, the potassium oxide (K_2O) content, which is the major alkali component in the limestone, is inversely proportional to the LSF of the limestone, it is possible using this curve to estimate the degree of beneficiation needed to obtain a limestone that can be used for the manufacture of a low alkali cement assuming the other necessary raw materials are available.

(b) A matter of much concern is that the manufacture of low alkali cements will lead to the creation of an imbalance in the available raw material reserves, eg an increase in the sandstone usage with a reduction in the use of shale



Percentage K_20 vs Limestone LSF values

could mean insufficient sandstone reserves for the life of the quarry. A question mark must also exist as to the extent of suitable sand reserves. The sand used in the kiln feed mixes is Berg River sand and natural phenomena such as flooding might contaminate it with alkaline materials, such as clay or silt or might even conceivably wash away the deposit being worked.

(c) Another effect of the manufacture of low alkali cements would be a loss of flexibility in kiln feed design because of the alkali constraints - this in turn could lead to a loss of process efficiency and or output.

(d) There will obviously be a need for additional, more sophisticated, quality control facilities together with the means to take corrective action.

(e) It is also possible that in some cases the use of lower alkali kiln feeds could adversely affect kiln electrofilter performance.

(f) Changes in the raw mix could also effect changes in the properties of the cement produced especially in respect to its strength development profiles.

Steps taken at our factories to try and reduce the alkali content of our cements have in fact confirmed all the above-mentioned observations except possibly for the one on electrofilter performance for which unfortunately no figures are available.

As a result of the steps taken at the works there has in fact been a significant reduction in the alkali content of the cements being produced, but at the expense of significant increases in energy consumption (electricity, diesel and coal) and a significant increase in the amount of quarried material to be handled. As a matter of interest additional ground has already had to be purchased at one of the factories to accommodate the increase in waste material resulting from the beneficiation process. It is also noticeable in some instances that the maximum possible output of certain major items of plant has been reduced when they are being used for the manufacture of low alkali cement. Because of inherent fluctuations in the chemical composition of some raw materials, additional quality control measures have had to be taken.

Reduction of alkalis in the clinkering process. Steps that could in certain cases be taken to reduce the alkali content of the cement being produced, by removing some of the alkalis at some stage of the clinkering process include:

(i) The use of a kiln gas by-pass - this is a method by means of which hot dust-laden, alkali-rich gases are withdrawn from the back-end of the kiln before they enter the preheater. These gases are then stripped of their alkali and dust burden before being vented to the atmosphere. The kiln gas by-pass can only be used in conjunction with certain types of plant and if the nature of the alkalis present, with special reference to their volatility under the operating conditions concerned, is such that they lend themselves to this type of process.

(ii) The dumping of kiln electrofilter dust - this is also a possibility with certain types of plant. In our case this would not have a significant effect on the alkali content of the clinker produced.

The installation of kiln gas by-pass equipment where it is a feasible proposition would call for:

(a) The installation of expensive plant including additional fans, mixing chambers, conditioning towers and electrofilters for handling the by-pass gases.

(b) An increase in the energy cost of clinker production (12-15 per cent in the case of one of our kilns on which a feasibility study was carried out).

(c) Steps to be taken to dispose of the high alkali dust produced in the gas by-pass system, and which could create a dumping problem.

It should be noted that the decrease that can be obtained in the alkali content of the clinker is related to the percentage of the kiln gas routed through the by-pass system and the volatility of the alkali compounds present in the kiln system. The use of by-passes normally results in larger reductions of K_2O than Na_2O content. In order to produce a clinker that will have an alkali content low enough for the cement manufactured from it to comply with low alkali specifications, it may be necessary to use a lower alkali kiln feed in conjunction with a kiln gas by-pass system.

Even if the use of a by-pass were found to be a feasible method of reducing the alkali content of clinker, not all the kilns in use at the works are suitable for the installation of such by-passes. An added complication is that the use of common clinker transport and storage systems would reduce the effect of by-passes installed in kilns suited to their use.

Obviously in the interests of maximising the use of available raw material reserves, energy conservation and keeping down costs, the alkali content of any low alkali cement manufactured in the South Western Cape should be reduced, if at all possible, only to a level that will make the risk of alkali aggregate reactions extremely unlikely. The alkali content of low alkali cements manufactured would

thus probably be very close to the maximum laid down in any SABS specification. This in turn would mean that reliable and accurate methods of determining alkali content would have to be used for quality control purposes if disputes were to be avoided. In this regard it should be borne in mind that the methods of analysis laid down in standards are referee methods which are not always suited to control purposes. Another factor to consider is that should any future alkali specification be set at too low a level, say 0,50 per cent maximum as Na_2O, it will probably not be possible to produce a guaranteed low alkali ordinary Portland cement in the South Western Cape with the raw materials currently available. Future raw material investigations, especially in regard to limestone, will obviously have to take the alkali factor into account.

4. SOME POSSIBLE COURSES OF ACTION

From the cement manufacturers' point of view there would seem to be four possible courses of action to be considered:

(i) To supply a sulphate-resisting Portland cement currently being manufactured in the South Western Cape with a guaranteed low alkali content when a low alkali cement is required and to utilise the available local raw materials to maximum advantage for the manufacture of ordinary Portland cement which in effect means that for most of the time the alkali content of the cement produced will exceed the low alkali cement specification of 0,6 per cent as Na_2O. It can reasonably be expected that the alkali content of these cements will not reach the levels of some of the higher figures reached in the past, because of changes introduced in the kiln feed composition.

(ii) In addition to (i) to manufacture a special guaranteed low alkali ordinary Portland cement which would probably sell at a cost related premium, for use where alkali-aggregate reaction is an important consideration.

(iii) That apart from sulphate-resisting Portland cement (Sulfacem) ordinary Portland cement with no low alkali guarantee be available as at present and that the concrete manufacturer must then use a non-reactive aggregate where necessary.

(iv) The introduction of suitable additives such as granulated blast-furnace slag, PFA (where suitable), natural or artificial pozzolanas or the use of a guaranteed low alkali ordinary Portland cement from another source in the Republic.

The only objection to the use of a sulphate-resisting Portland cement as a low alkali cement in the Cape would seem to be the premium that has to be paid for this cement but in its favour is the fact that it is a guaranteed low alkali cement and that it is produced locally and is available as required. The manufacture of a special low alkali ordinary Portland cement would call for a large additional investment in plant, storage and packing facilities and this obviously may not be a proposition, even if feasible, unless the product can be sold at a premium. In this regard it is worth noting that it has been estimated that only about 15 per cent of the concrete used in the South Western Cape actually justifies the use of a low alkali cement. One in fact wonders if low alkali cements are not being written into many tenders when there may in fact be no real justification for their use.

When considering the making and guaranteeing of ordinary Portland cement to meet low alkali specifications, it must be borne in mind that this will lead to the wasteful use of available raw material and energy, losses in production and an increase in manufacturing costs.

Finally it is worth noting that the alkali content of the ordinary Portland cements being manufactured in the South Western Cape have in fact been significantly reduced over the past few years, at increased cost to the manufacturer, and are currently around the 0,6 per cent level expressed as Na_2O. The low demand for cement during recent years has made experimentation possible and because of the lack of demand, output was not a major factor when trials were being conducted. A rapid and sustained increase in demand for cement could put a different complexion on things. If the status quo with regard to the alkali content of cement is to be maintained for any great length of time additional reserves of low alkali materials for the cement kiln feed will have to be found.

DISCUSSION

Mr D A St John (DSIR, New Zealand) requested Mr Damp to comment on the economics of producing a low alkali cement versus shipping slagment or pulverised fuel ash from the Transvaal to Cape Town. He further asked if the economics of, for example, producing a blended cement with 30 to 40 per cent slagment (taking into account the transport charges) had been studied, or whether it was cheaper to produce a low alkali cement?

Mr Damp replied that the key factor involved was distance. Slag and pfa would have to be brought from the Transvaal (1 500 kilometres away) which meant that the railage factor became significant. On the energy side, all the coal used in the Cape also came from the Transvaal, and the price of the coal used versus the railage costs was a factor of between 2 and 2½ to 1 in favour of the railage. So it was an expensive proposition. Every increase in fuel consumption had a multiple effect. Slagment and pfa had been brought down to Cape Town on special occasions. However, as cement producers, they had not looked into the economics of producing a blended cement with, for example, slagment imported from the Transvaal.

Mr E H J van Rensburg (Murray & Roberts, Cape Town) asked why producers, particularly in the South Western Cape, did not inform consumers of the alkali content of their normal OPC. If it were possible to purchase an OPC with a guaranteed alkali content of, for example, 0,7 per cent Na_2O equivalent, then one could attempt to control the alkali content of the concrete by adjusting the cement content of the concrete.

Mr Damp said that in his experience people normally asked for guarantees, and that his company had informed people who had enquired that the alkali content was approximately 0,6 per cent but as there were heterogeneous raw materials they could not guarantee that it was below 0,6 per cent, except in the case of the sulphate resisting cement where they went to great lengths to insure that the alkali content was below 0,6 per cent. Thus anyone wishing to use a low alkali cement in the South Western Cape, knew that it was available as a sulphate resisting cement: the nuclear power station, for example, was built with sulphate resisting cement. To control the alkali content of the concrete by adjusting the cement content would be the ideal situation but the company would probably need a printing press to turn out alkali analyses and equipment to do it, as there were continual variations, so they could only say that it was above 0,6 per cent, and probably in the range of 0,6 to 0,7. Because of problems encountered with beneficiation and because cement production was a continuous process, one did not necessarily get cut-off points in the alkali content of the stocks of cement.

Prof J Gillott (University of Calgary, Canada) asked what was done with the dust produced when the alkalis were precipitated out and whether there were any potential uses for it.

Mr Damp replied that at present it was a hypothetical question. Under normal conditions he presumed one would attempt to put it back in the quarry. In some places the dust was used as a fertiliser. In the Cape, however, the alkali content of the dust was extraordinarily low, and was not being dumped. If it did have to be dumped, there had been suggestions from the agricultural sector to use it as a fertilizer, but if it had a high chloride content it might not be suitable. He mentioned that although it was not a wet process, the water used (for example, for conditioning the tiles), could have a rather high chloride content in the South Western Cape, and this could affect the operation of kilns. Chloride build-up would occur and associated with it, some sodium would come into the system. He mentioned that their attempts to reduce alkalis had been reasonably successful regarding the potassium but they had not been able to remove sodium. The only way to reduce sodium to any degree was to quarry selectively and choose the best stone they had in the quarry.

Dr W Schrämli (Holderbank, Switzerland) mentioned that after a careful investigation had been made it had been concluded that there was virtually no economical use of kiln-dust.

Dr E Otte (Van Wyk & Louw, Pretoria) referred to page 3 of the paper where it was stated that only about 15 per cent of the concrete used in the South Western Cape actually justified the use of low alkali cement. He asked how this figure had been arrived at.

Mr Damp replied that he had not calculated it himself, but had used somebody else's figures. This had been the highest estimate he had come across, and there were other estimates of about 5 per cent. He presumed that the calculations were based on the percentage of concrete structures exposed to conditions that favoured the alkali-aggregate reaction (for example continuous cycles of wetting and drying).