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(54) IMPROVEMENTS IN HYDRAULIC CEMENTS

(71) We, THE ASSOCIATED PORTLAND CEMENT MANUFACTURERS LIMITED, a Company organised under the laws of Great Britain, of Portland House, Stag Place, London, SW1E 5BJ, England, do hereby declare this invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to hydraulic

cements, that is cements which, upon mixing with water and placing, set and harden to give substantial strength, and more particularly to cements with high and rapid strength development of the Portland type.

Throughout this specification the following notations are used:—

S=SiO A=Al₂O₃ F=Fe₂O₃ C=CaO

The chemical parameters LSF, S/R and A/F referred to are defined as:—

$$\text{Lime Saturation Factor (LSF)} = \frac{\text{CaO}}{2.8 \text{ SiO}_2 + 1.2 \text{ Al}_2\text{O}_3 + 0.65 \text{ Fe}_2\text{O}_3}$$

$$\text{Silica Ratio (S/R)} = \frac{\text{SiO}_2}{\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3}$$

$$\text{Alumina Ratio (A/F)} = \frac{\text{Al}_2\text{O}_3}{\text{Fe}_2\text{O}_3}$$

In the foregoing ratios the chemical symbols represent percentage by weight of the identified substance present in the composition under consideration.

In the following description and claims the percentages referred to are by weight.

It is known that the hydraulic activity of conventional Portland cement can be modified to a limited extent by adjusting the proportion of the hydraulic phases in the clinker, or by altering the cement fineness or its particle size distribution. It is also known that very rapid setting and hardening can be produced by making additions of accelerators or of so-called High-Alumina cement to Portland cement. By High-Alumina cement is meant cement, referred to in the U.S.A. as Calcium Aluminate cement, in which the principal hydraulic constituent is monocalcium aluminate (CA). In practice such adjustments to Portland cement are limited in extent by other factors than setting and hardening and generally produce an improved early strength at the expense of the strength at later stages or conversely an improved

late strength at the expense of early strength. In the case where the strength is improved by altering the particle size distribution or overall fineness, this is often achieved at the expense of the workability of the resultant concrete. There is also the disadvantage, in some of the above methods of obtaining rapid setting and hardening, of it being difficult to obtain consistent and reproducible results, particularly when making a concrete with an aggregate contaminated with or containing substances capable of acting as accelerators or retarders since very small quantities of such substances can have a considerable effect on the setting time achieved. A further disadvantage of rapid hardening Portland cements in which accelerators have been incorporated is that a number of the applications in which rapid hardening cements are most useful are those which may involve the pumping of a slurry of the cement or a concrete containing it, and such Portland cements do not give good results with higher than normal water to cement ratios. High-Alumina cement on the other hand is expen-

sive and, although achieving rapid early strength development the ultimate strength obtained by the use of this cement alone is detrimentally affected by the conversion of its hydrated phases.

We have previously described three forms of early strength cement which did not present the rheological problems and poor reproducibility of results associated with accelerated Portland cements and which were cheaper than High-Alumina cement and did not produce potentially unstable hydrates.

These free forms of early strength cement are as follows:

- (1) An early strength hydraulic cement comprising 7 to 90 percent by weight of $C_{12}A_7$, most of the balance being calcium silicates and the cement being poor in CA or C_3A . In a preferred composition the clinker rich in $C_{12}A_7$ and poor in CA or C_3A is interground with Portland cement clinker, the resultant early strength cement including at least 10 per cent by weight of $C_{12}A_7$ with a majority of the balance being calcium silicates and including at least 10 per cent by weight of C_3S . (U.K. Patent No. 1,387,075).
- (2) An early strength hydraulic cement comprising from 15 to 90 per cent

by weight, based on the cement, of an alkali metal calcium aluminate phase formed in the calcium oxide-alumina-alkali metal oxide systems by the presence of at least one alkali metal oxide in a total amount of alkali metal oxide in excess of the solid solution limit thereof in cubic tricalcium aluminate, at least part of the alkali metal oxide being sodium oxide and the balance of the cement being predominantly calcium silicates. The above-mentioned alkali metal calcium aluminate phase is believed to correspond with the formula $(C_{1-x}N_x)_3A$ where x lies between 0.06 and 0.07, and N typically represents Na_2O which may be partly replaced by another alkali metal oxide; this phase approximates to $NC_{14}A_8$. (British Patent No. 1,449,905; U.S. Patent No. 3,942,994).

- (3) An early strength hydraulic cement comprising 7.0 to 90 percent by weight of $C_{12}A_7$, the majority of the balance being hydraulic calcium silicates, wherein the $C_{12}A_7$ phase is formed in an underlimed clinker burned to a low free lime (an underlimed clinker being defined as a clinker in which the lime limitation factor (LLF) is less than unity where

$$LLF = \frac{CaO}{1.87 SiO_2 + 0.94 Al_2O_3 + 0.65 Fe_2O_3}$$

the chemical symbols representing the amounts of the represented substances present), the underlimed condition being at least counterbalanced in the cement by the presence of a substance effective to increase the basicity of the composition. This cement can satisfy the preferred composition noted in foregoing paragraph (1). The substance effective to increase the basicity of the composition may be for instance a metal oxide present in the $C_{12}A_7$ -rich clinker in solid solution in substitution for CaO in the lattices of major phases, or a source of calcium ions added to the cement. (U.K. Patent Application No. 53104/74 (Serial No. 1,497,670).

The early strength cements of the three foregoing paragraphs are referred to herein as "early strength cements of the foregoing type". With such cements the rapid setting and early strength was achieved at the expense of the later strengths which were lower than those of normal Portland cements.

One object of this invention is the provision of cements having improved early and late strengths for a given specific surface area, that is to say, either having similar

setting and workability properties to those of normal Portland cement but with both a higher early and a higher late strength; or having similar strength development characteristics to those of normal Portland cements but with lower corresponding specific surface areas.

A further object of this invention is the provision of cements with at least similar setting, workability, and strength development properties to those of normal Portland cements but containing little or no sulphate.

A further object of this invention is the provision of cements with similar rapid but controlled setting and early strength properties to those of early strength cements of the foregoing type but which also possess very similar ultimate strength to that obtained with normal Portland cement.

A further object of this invention is to produce high early cements with similar properties of those of some early strength cements of the foregoing type but which require less retarder such as citric acid to achieve the desired pumpability time and delay in setting time.

Another object of this invention is to produce a cement with similar properties to those of some early cements of the foregoing

type but containing less of the hydraulic $C_{12}A_7$ phase which contributes to the very early setting and rapid hardening, thereby permitting the production of a clinker less rich in $C_{12}A_7$, which could be prepared from only cancerous and argillaceous raw materials and obviates the necessity for the more expensive aluminous component such as bauxite.

We have found that the foregoing objects can surprisingly be achieved by means of a particular combination of mineralisers.

It is known that small amounts of calcium sulphate, alkali metal sulphate, calcium fluoride or other compounds which are often present as trace impurities in Portland cement raw materials can aid in the combination of those materials during burning, i.e., as mineralisers. It is also known that by entering into solid solutions in certain of the clinker phases during burning these said impurities can affect the hydraulic properties of the resultant cement. Thus the mineralising effect of calcium fluoride on Portland cement mixes by enhancing the formation of the clinker phases, particularly the silicate phases, during burning, and the concomitant retardation of the set and the depression of the early strength of the resultant concrete by such an addition, is well documented in the literature.

The use of calcium sulphate or alkali metal sulphate additions as mineralisers for Portland cement compositions, permitting a reduction in the burning temperature and a saving in fuel consumption has also been reported by several workers, (P. P. Budnikov and I. P. Kuznetsova, *J. Appl. Chem. (U.S.S.R.)* 35,913, 1962; P. P. Budnikov, I. P. Kuznetsova and W. G. Savel'ev, *Silikattekhnika* 16, 414-417, 1965; R. D. Azelitskaya, I. F. Ponomarev et al., *Tsement* 2, 6, 1969; T. A. Ragozina and M. A. Akhmedov *Uzbek khim zh* 6,5-11 1962). In some instances, however, these additions rather than enhancing the combination of the raw materials may lead to sulphate ions entering into solid solution in the belite (essentially dicalcium silicate, C_2S) phase thereby stabilising this phase to the extent that the formation of alite (essentially tricalcium silicate, C_3S) phase is inhibited and the lime which would otherwise have combined to form this alite phase remains as uncombined lime in the clinker. Recent work has suggested that this phenomenon can occur when there is little or no MgO in the clinker (W. Gutt and M. A. Smith, *Trans. Brit. Cer. Soc.* 487-510, 1968, and *Cement Technology* Sept/Oct., 1971). We have determined that the level of MgO required to prevent this stabilisation of the belite is of the order of 2 per cent, although the presence of MgO contents of this order in the clinker could

under certain circumstances lead to potential unsoundness problems in the final cement.

However, we have also found, that if an addition of calcium fluoride or other suitable mineraliser containing fluorine is made with the addition of calcium sulphate or a mixture of calcium sulphate and alkali metal sulphate then this dependence of the mineralising action on the presence of a limiting level of MgO is eradicated.

In addition we have found that the addition of the above combination of mineraliser containing fluorine, and calcium sulphate or mixture of calcium sulphate and alkali metal sulphate, when made to a normal Portland cement raw mix such that part or all of the fluorine and sulphate components are retained within the clinker, surprisingly produces a cement with both enhanced early and late strengths. This may be because the combined mineralising action of both the fluoride and the sulphate additions, together with the initial stabilisation of the belite phase before this is countered by the fluorine, leads to the formation of alite crystals of increased hydraulic activity. We have found that the said combination of mineralisers is also particularly effective when incorporated in raw feeds to produce clinker compositions of high lime saturation factor (LSF), typically in the range 0.98-1.08, and of high silica ratio (S/R), typically in excess of 4, and preferably less than 20, since their mineralising action not only achieves the combination of these compositions at normal firing temperatures, which would otherwise be difficult if not impossible to achieve, but results in the formation of clinkers rich in silicates, particularly alite of the aforementioned active form, typically at least 65 per cent and advantageously at least 70 per cent, and sparse in both C_3A and C_4AF content. As a consequence these clinkers, when ground to specific surface areas similar to those of normal Portland cements, yield cements which have at least higher late strength even when little or none of the mineralisers or their derivatives are retained within them and may, if sufficient alkali metal sulphate is retained within them, have both enhanced early and late strengths.

The clinkers referred to in the foregoing paragraph which yield cements of enhanced strength as a result of an addition of the abovementioned combination of mineralisers of calcium fluoride and a calcium sulphate or a mixture of calcium sulphate and an alkali metal sulphate to their raw mixes, regardless of whether this enhanced strength arises from the retention of all or part of these mineralisers or their derivatives in the clinker or by the abovementioned mineralisers leading to the formation of clinkers of increased alite content, are for

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the purposes of this specification collectively called "active alite clinkers".

Cements produced from some of these active alite clinkers are particularly useful for incorporating with a pulverised fuel ash (PFA) to produce a pozzolanic cement of a blast furnace slag (BFS) to produce a blast furnace slag cement, since their higher strengths in comparison with normal Portland cement permit a larger addition of PFA or BFS to be made in order to achieve the same strength properties of the mixture. Some of the active alite clinkers defined above also have distinct advantages over normal Portland cement clinkers in the production of high early strength cements containing $C_{12}A_7$. Firstly, we have found that their contribution to the early strength is sufficient to permit reducing the $C_{12}A_7$ content in the $C_{12}A_7$ -rich component, thereby obviating the use of an expensive aluminous ingredient such as bauxite when preparing the raw mix for this clinker. Secondly, we have found that, because of their lower C_3A content and possibly other factors, a significant reduction in the quantity of retarder such as citric acid is required to control the pumpability and setting characteristics of these cements. Thirdly, we have found that, although the incorporation of the $C_{12}A_7$ phase in the final cement reduces the potential late strength of cements prepared from these active alite clinkers it is possible to adjust the proportions such that not only early strengths within 2 hours after gauging, but also ultimate strengths, similar to those of conventional Portland cement are obtained.

According to the present invention, therefore, we provide a method of making a cement of the Portland type, with high and rapid strength development, containing alite of improved hydraulic activity, wherein argillaceous and calcareous materials are combined to form clinker by heating in a kiln and the resulting clinker is ground to form a cement, comprising the step of introducing into the kiln a combination of mineralisers which contains fluorine and sulphur, provided that an alkali metal compound which can be a component of the aforesaid combination of mineralisers is included in the materials fed to the kiln at least when the condition that the lime saturation factor be at least 0.98 and the silica ratio be at least 4 is not met.

The combination of mineralisers including, where required, the alkali metal compound, may be introduced into the kiln either separately or together by incorporation in the raw feed or by some other method such as by insufflation, or with the fuel.

The source of fluorine other than that in the main raw materials is preferably calcium fluoride. The source of sulphur other than that derived from the main raw materials

and the fuel is preferably one or a mixture of calcium sulphate or its hydrates, an alkali metal sulphate or a double alkali metal calcium sulphate, most preferably gypsum or potassium sulphate. The preferred sources of alkali metal compound, where required, are the main raw materials or the fuel or the additions of alkali metal sulphate specified above. The mineralisers may be supplied as such or in a form which will yield them under kiln conditions or by reaction with the feed, such as by the addition of sulphuric or hydrofluoric acids. Other mineralisers may be present in the form of impurities.

Components of the mineralisers, containing part or all of the fluorine, sulphate and alkali metal therefrom, may be retained in the clinker and will be so retained in the case where the LSF is less than 0.98 and the silica ratio is less than 4. The sulphate may be present in the clinker as a calcium sulphate, an alkali metal sulphate, a double alkali metal calcium sulphate salt or a mixture thereof.

In the case where the lime saturation factor is less than 0.98 and the silica ratio is less than 4, the clinker preferably contains 0.01 to 1 per cent fluoride, more preferably 0.01 to 0.5 per cent fluoride, and 1.5 to 5.0 per cent SO_3 , of which at least 0.5 per cent is present in combination with an alkali metal, by weight based on the clinker. In the case where the lime saturation factor is at least 0.98 the clinker preferably contains 0.01 to 1 per cent fluoride, more preferably 0.01 to 0.5 per cent fluoride and 0.1 to 5.0 per cent SO_3 by weight based on the clinker; although where an enhanced early strength is required at least 0.5 per cent SO_3 should be present in combination with an alkali metal by weight based on the clinker.

In a preferred embodiment the invention permits the production of a clinker with a lime saturation factor from 0.98 to 1.08 and a silica ratio from 4 to 20, which is rich in alite, that is it contains at least 65 per cent, preferably 70 per cent, alite by weight.

Cements according to this invention are typically ground to specific surface areas as specified by the air permeability method according to British Standard Specification (BS) 12 (1971), in the range 200-800 m^2/kg and normally to specific surface areas in the range 250-500 m^2/kg . In general grinding to the higher specific surface areas improves both the early and late strengths of the cement.

The cement properties may be controlled by the quantity and nature of the mineralisers or their derivatives retained within the clinker. The desired level of retention may be obtained by varying the quantities and form of mineralisers added or their method

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of introduction or the clinker burning regime.

In some instances by retaining the desired quantity of sulphate or fluorine in the active alite clinkers it is possible to produce a cement with the requisite handling and setting characteristics without the necessity to make the otherwise usual extra additions of calcium sulphate or other retarders or setting time regulators at the final grinding stage.

In applications where high strength both at early and late ages is required, retention in the clinker of all or part of any alkali metal sulphate either added as a mineraliser or derived therefrom is advantageous.

In other particular applications such as in the binding of iron ore fines requiring very low sulphur contents in the final cement, we have found that adequate set control and strength development can be achieved without further addition of gypsum or other retarders even when little sulphate is retained in the clinker.

Alternatively and particularly where the clinker herein defined is only a part of the clinker components of a cement, calcium sulphate in the form of natural or synthetic gypsums, hemi-hydrate, soluble anhydrite or a mixture thereof is preferably added to the cement typically to give a total cement sulphate content of up to 8 per cent, preferably 2 to 5 per cent, to achieve the optimum strength development and the desired setting characteristics. Small additions of retarders or accelerators also effective in producing the desired setting characteristics and strength development may also be made to such cements. Typical retarders employed for this purpose are the established retarders for Portland cement, citric acid or other organic hydroxy acids, sucrose and glucose. Typical accelerators are established accelerators for Portland cement such as calcium chloride or grinding aids such as a mixture of triethanolamine and acetic acid.

Where the active alite clinker of the invention is only part of the clinker components of a cement it may be incorporated in such cements either by grinding together all of the several components or by grinding them separately and thoroughly blending them in a finely divided form. In the instance where very early strengths are produced by the incorporation of $C_{12}A_7$ in the cement it is particularly preferable to make small additions of the retarders or accelerators defined above effective to provide the desired setting time sufficient for the purpose for which the cement is intended. These additions may be ground with the clinker or in some instances either blended in the final cement before supply to a user, or supplied separately so that the user may add it during mixing in order to adjust the

setting time and hardening rate to his own requirements.

The mineralisers herein defined which are introduced into the kiln in the various ways hereinbefore mentioned may be in a variety of forms. They may be as pure compounds added in the same or different ways to either the raw feed or the fuel to supplement any desired mineraliser which may already be in these materials as minor components or impurities, or they may be a material which contains sufficient mineralisers together with one or more of the main chemical components of this cement, or they may be in any other form. As a particular example the requisite mineralisers could be introduced into the kiln by the insufflation of a suitable precipitator dust obtained from normal Portland cement manufacture.

It is also possible to utilise the combination of mineralisers herein defined in a number of different processes and this is illustrated in the several ways that the active alite clinker of the invention can be prepared.

In one method the raw feed is sintered in a conventional wet, semi-wet, semi-dry or dry process used for normal Portland cement manufacture or a cement/sulphuric acid process such as the Mueller-Kuhne process at a burning temperature typically in the range 1200—1550°C to provide a clinker with a satisfactory degree of combination as judged by the uncombined lime being below 5 per cent and preferably below 2 per cent. In a particular application of this method additions of compounds containing fluorine and sulphur as defined above, are made to a blend of raw materials consisting of argillaceous and calcareous materials in such proportions as to favour the formation of a large proportion of alite in a clinker with an LSF typically in the range 0.98 to 1.08, and a S/R typically greater than 4.

The amounts added of compounds containing fluorine lie typically in the range 0.1—2 per cent, and preferably 0.2—0.5 per cent, equivalent fluorine and the amount of sulphur bearing compounds herein defined, lies typically in the range 1 to 10 per cent, and preferably 2—5 per cent, equivalent SO_3 as a percentage of the clinker. These additions to the raw feed are made with the object of achieving during firing both a satisfactory degree of combination and the requisite retention of the volatiles in the clinker.

In another method a raw feed is sintered in a fluidised bed process in the presence of the mineralisers previously defined. An advantage of this technique over those described above is that in the fluidised bed process the volatilisation of mineralisers during sintering can be both enhanced and more accurately controlled. As a result it is possible to incorporate more of the said

mineralisers in the raw feed, thereby achieving a satisfactory degree of combination at burning temperatures typically in the region of 1100—1200°C, whilst retaining in the clinker only the desired levels of mineralisers or their derivatives.

The levels of mineralisers required can also be maintained in the above processes by achieving reincorporation of the volatile components, either by ensuring an efficient recirculating load or by returning the collected dust, thereby minimising the additions of mineralisers that need to be made to the system.

In another method the raw feed consisting of argillaceous and calcareous materials proportioned as in the foregoing method is at least partially melted in the presence of compounds containing fluorine, sulphur, and alkali if required, as previously defined, in a furnace such as a reverberatory furnace. The additions of compounds containing fluorine and sulphur and other mineralisers may be increased to achieve combination in the partial melt typically in the range of 900—1450°C. The advantage of such a process is that, unlike the sintering techniques described above, volatilisation and subsequent collection and recirculation of the alkalis and sulphate, which can present difficulties, are avoided. During the melting process crystals or alite and other phases which constitute the clinker herein defined form, and these can be physically separated from the liquid rich in the mineralisers. This process of separation either by centrifugal or other techniques is normally sufficiently beneficial to

product the desired clinker composition and to permit the re-use of the liquid rich in mineralisers. If required, further reduction in the volatiles retained within the high alite clinker fraction can be achieved by volatilisation in a further process step.

Cements composed wholly or in part of the active alite clinker of this invention may be used in a number of ways. They may be employed with high quality aggregates in applications where the higher early and late strengths than those achieved with normal Portland cements are distinctly advantageous. They may also be employed in patching roads or airport runways or in applications requiring a rapid turnover of shuttering or moulds, where the resultant product must not only have an adequate early strength but must eventually yield a strength at least as great as that of normal Portland cement. They may be used as a binder of fibre reinforced composites, light weight aggregates and foundry sands and can be used as a bonding agent in the binding of ore fines for metallurgical processes. In the particular instance where the cement is prepared from a clinker containing $C_{12}A_7$, and the active alite clinker of this invention, it finds special utility in binding materials from coal measures even when contaminated with or consisting of coal, the organic constituents of which can have an unpredictable effect upon the behaviour of some other known rapid hardening cements.

The invention is illustrated by the following Examples in which all percentages, parts and ratios are by weight.

EXAMPLE 1

A clinker comprising mainly alite was prepared as follows.

The following raw materials with principal oxide analyses of:—

	Chalk	Sand	Clay	Gypsum	Iron Oxide
SiO ₂	1.2	99.3	41.9	0.2	1.1
Al ₂ O ₃	0.4	0.3	11.5	0.3	0.6
Fe ₂ O ₃	0.2	0.1	3.8	0.01	96.9
CaO	54.8	0.1	19.5	32.0	0.5
SO ₃	0.1	0.01	0.1	46.5	0.02

were utilised to form a mix by blending in the approximate proportions (dry basis) 74.7 per cent chalk, 12 per cent sand, 5.8 per cent clay, 6.9 per cent gypsum, 0.1 per cent iron oxide together with 0.5 per cent calcium

fluoride and grinding in a ball mill to a residue of 5 per cent on a BS 90 μ m sieve. The raw feed so obtained was mixed with water and pressed into cakes and these after thoroughly drying were sintered in an oil-

fired furnace at about 1525°C to produce a clinker with the following analysis:—

	per cent
SiO ₂	24.5
Al ₂ O ₃	1.6
Fe ₂ O ₃	0.8
Mn ₂ O ₃	0.03
P ₂ O ₅	0.06
TiO ₂	0.05
CaO	70.5
MgO	1.1
SO ₃	0.12
F ₂ (as fluoride)	0.28
L.O.I.	0.6
K ₂ O	0.05
Na ₂ O	0.06

total cement sulphate content of 2.3 per cent. When made up as a concrete and tested as above the compressive strengths of 100 mm concrete cubes were as follows:—

After		
3 days	33 MN/m ²	65
7 days	44 MN/m ²	
28 days	61 MN/m ²	

EXAMPLE 2

A clinker was prepared as in Example 1 employing the raw materials described therein by blending in the approximate proportions (dry basis) 70.8 per cent chalk, 7.6 per cent sand, 6.8 per cent gypsum, 14.3 per cent clay, together with 0.5 per cent calcium fluoride, and sintering in an oil-fired furnace at around 1525°C to produce a clinker with the following analysis:—

The LSF was 0.99, the S/R 10.21, the A/F 2.00 and the free lime content as determined by the hot ethylene glycol extraction method 1.7 per cent. The potential compound composition of this clinker as calculated from its oxide analysis, allowing for the free lime and assuming that all the sulphate over that which could form alkali sulphate is present in the clinker as calcium sulphate is:

	per cent
C ₃ S	81.9
C ₂ S	8.5
C ₃ A	2.9
C ₄ AF	2.4
CaSO ₄	NIL
Alkali Sulphates	0.2
Free Lime	1.7

	per cent	
SiO ₂	23.1	
Al ₂ O ₃	3.2	80
Fe ₂ O ₃	1.1	
Mn ₂ O ₃	0.03	
P ₂ O ₅	0.06	
TiO ₂	0.06	
CaO	69.9	85
MgO	1.0	
SO ₃	0.5	
F ₂ (as fluoride)	0.15	
L.O.I.	0.7	
K ₂ O	0.06	90
Na ₂ O	0.05	

together with other minor phases.

The LSF was 1.01, the S/R 5.37, the A/F 2.91 and the free lime content as determined by the method previously described 2.9 per cent. The potential compound composition of this clinker as calculated by the method employed in Example 1 is:—

A cement was prepared by grinding this clinker with gypsum to a specific surface area of 330 m²/kg as measured by the air permeability method according to B.S. 12 (1971). The quantity of gypsum added was such as to give a total sulphate content in the cement attributable both to the added gypsum and to that present in the clinker of 1.5 per cent as determined by analysis. A concrete for compressive strength tests was made up from 1 part cement, 3.5 parts Mountsorrel granite, 2.5 parts Curtis sand and 0.55 parts water. The test results for the compressive strengths of 100 mm concrete cubes determined according to B.S. 12 (1971) were as follows:—

	per cent	
C ₃ S	72.9	
C ₂ S	11.3	100
C ₃ A	6.6	
C ₄ AF	3.3	
CaSO ₄	0.7	
Alkali Sulphates	0.2	
Free lime	2.9	105

together with other minor phases.

A cement was prepared by grinding this clinker to a specific surface area of 450 m²/kg as measured by the method in Example 1.

The paste setting times according to B.S. 12 (1971) were:—

A second cement was prepared by grinding this clinker with gypsum to a specific surface area of 450 m²/kg as measured by the method previously described. The quantity of gypsum added was such as to give a

At percent consistency	24.8	
water		
Initial Set	45 minutes	115
Final Set	100 minutes	

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When made up as a concrete and tested as in Example 1, the compressive strengths of 100 mm concrete cubes were as follows:—

5	After	
	3 days	41 MN/m ²
	7 days	57 MN/m ²
	28 days	69 MN/m ²

10 A second cement was prepared by grinding this clinker with gypsum to a specific surface area of 460 m²/kg as measured by the method in Example 1. The quantity of gypsum added was sufficient to give a total sulphate content in the cement attributable both to the added gypsum and to that present in the clinker of 2.4 per cent as determined by analysis.

15 The paste setting times according to B.S. 12 (1971) were:—

20	At percent consistency	
	water	25.5
	Initial Set	135 minutes
	Final Set	175 minutes

25 When made up as a concrete and tested as in Example 1 the compressive strengths of 100 mm concrete cubes were as follows:

30	After	
	3 days	40 NM/m ²
	7 days	53 NM/m ²
	28 days	63 MN/m ²

EXAMPLE 3

30 A clinker was prepared as in Example 1, employing the raw materials therein described, by blending in the approximate proportions (dry basis) 70.3 per cent chalk, 7.5 per cent sand, 13.2 per cent clay, 6.5 per cent gypsum, together with 2.0 per cent potassium sulphate and 0.5 per cent calcium fluoride, and sintering in an oil-fired furnace at around 1400°C to give a clinker with the following analysis:—

45		per cent
	SiO ₂	21.7
	Al ₂ O ₃	2.6
	Fe ₂ O ₃	1.2
	Mn ₂ O ₃	0.02
	P ₂ O ₅	0.08
	TiO ₂	0.13
	CaO	67.2
	MgO	1.0
50	SO ₃	3.0
	F ₂ (as fluoride)	0.23
	L.O.I.	1.3
	K ₂ O	1.4
	Na ₂ O	0.06

55 The LSF was 1.04, the S/R 5.71, the A/F

2.16 and the free lime as determined by the method previously described 1.9 per cent. The potential compound composition of this clinker as calculated by the method employed in Example 1 is:—

	per cent
C ₃ S	76.3
C ₂ S	4.7
C ₃ A	4.9
C ₄ AF	3.6
CaSO ₄	2.9
Alkali Sulphates	2.7
Free Lime	1.9

together with other minor phases.

A cement was prepared by grinding this clinker to a specific surface area of 250 m²/kg as measured by the method in Example 1.

The paste setting times according to B.S. 12 (1971) were:—

75	At percent consistency	
	water	28.5
	Initial Set	305 minutes
	Final Set	370 minutes

80 When made up as a concrete and tested as in Example 1 the compressive strengths of 100 mm concrete cubes were as follows:—

85	After	
	8 hours	1 MN/m ²
	16 hours	10 MN/m ²
	24 hours	18 MN/m ²
	3 days	37 MN/m ²
	7 days	44 MN/m ²
	28 days	52 MN/m ²

90 A second cement was prepared by grinding this clinker to a specific surface area of 330 m²/kg as measured by the method in Example 1.

The paste setting times according to B.S. 12 (1971) were:—

95	At percent consistency	
	water	28.0
	Initial Set	275 minutes
	Final Set	345 minutes

100 When made up as a concrete and tested as in Example 1 the compressive strengths of 100 mm concrete cubes were as follows:—

105	After	
	8 hours	1 MN/m ²
	16 hours	13 MN/m ²
	24 hours	24 MN/m ²
	3 days	42 MN/m ²
	7 days	50 MN/m ²
	28 days	57 MN/m ²

A third cement was prepared by grinding this clinker to a specific surface area of 450

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m²/kg as measured by the method in Example 1. The paste setting times according to B.S. 12 (1971) were:—

At percent consistency	
water	29.0
Initial Set	265 minutes
Final Set	295 minutes

When made up as a concrete and tested as in Example 1 the compressive strengths of 100 mm concrete cubes were as follows:—

After	
8 hours	2 MN/m ²
16 hours	20 MN/m ²
24 hours	32 MN/m ²
3 days	48 MN/m ²
7 days	56 MN/m ²
28 days	63 MN/m ²

EXAMPLE 4

A cement was prepared by intergrinding 98 per cent of the clinker prepared as in Example 3 with 2 per cent of calcium chloride to a specific surface area of 450 m²/kg.

The paste setting times according to B.S. 12 (1971) were:—

At percent consistency	
water	30.0
Initial Set	100 minutes
Final Set	125 minutes

When made up as a concrete and tested as in Example 1 the compressive strengths of 100 mm concrete cubes were as follows:—

After	
4 hours	2 MN/m ²
8 hours	13 MN/m ²
16 hours	30 MN/m ²
24 hours	37 MN/m ²
3 days	58 MN/m ²
7 days	66 MN/m ²
28 days	74 MN/m ²

EXAMPLE 5

A cement was prepared by grinding the clinker prepared as in Example 3 to a specific surface area of 450 m²/kg as measured by the method in Example 1.

An interblend was made of 10 parts of this cement with 90 parts of a first sample, A, of iron ore with a specific surface area of 518 m²/kg and a gangue content of 10 per cent. This blend was pelletised into 15 mm diameter nodules which were then cured for 24 hours in an atmosphere of 100 per cent relative humidity at 20°C followed by a period of immersion in water at 20°C until the age of testing. Values of loads re-

quired to fracture nodules, on compression between parallel platens are shown for determinations after 1, 3, 7 and 28 days curing and, in addition, after drying similar 28 day cured specimens at 95°C for 3 hours:—

After	kg breaking load
1 day	43
3 days	67
7 days	79
28 days	111
28 days+3 hours at 95°C	373

For comparison, results for an ordinary Portland cement clinker ground to a specific surface area of 450 m²/kg and incorporated with this same ground ore, A, in nodules in the same proportion are:—

After	kg breaking load
1 day	10
3 days	34
7 days	51
28 days	70
28 days+3 hours at 95°C	220

Results for a second sample, B, of iron ore of gangue content 4 per cent ground to a specific surface area of 391 m²/kg and incorporated in the same proportion with the cement derived from the clinker described in Example 3 by grinding to 450 m²/kg, in 15 mm diameter nodules cured under identical conditions are:—

After	kg breaking load
1 day	61
3 days	71
7 days	77
28 days	106
28 days+3 hours at 95°C	263

For comparison, results for an ordinary Portland cement clinker ground to a specific surface area of 450 m²/kg and incorporated with this second ground ore, B, in nodules in the same proportion are:—

After	kg breaking load
1 day	13
3 days	28
7 days	35
28 days	62
28 days+3 hours at 95°C	172

16

10

1,498,057

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EXAMPLE 6

The following raw materials with principal oxide analyses of:—

		Limestone	Lias	Sand	Gypsum
5	SiO ₂	2.7	24.1	97.8	0.5
	Al ₂ O ₃	0.2	8.2	1.3	0.04
	Fe ₂ O ₃	0.15	3.7	0.1	0.05
	CaO	53.9	29.2	0.03	33.2
	SO ₂	0.23	0.15	0.04	47.0

10 were utilised to form a mix by blending in the approximate proportions (dry basis) 70.7 per cent limestone, 12.3 per cent lias, 9.1 per cent sand, 5.6 per cent gypsum together with 1.4 per cent potassium sulphate and 0.9 per cent impure calcium fluoride and grinding in a water swept ball mill to a residue of 4 per cent on a B.S. 90 μ m sieve. The raw feed slurry so obtained was introduced into a coal-fired rotary kiln where sintering at around 1400°C produced a clinker with the following analysis:—

	per cent
25	SiO ₂ 21.7
	Al ₂ O ₃ 2.7
	Fe ₂ O ₃ 1.3
	Mn ₂ O ₃ 0.02
	P ₂ O ₅ 0.05
	TiO ₂ 0.04
	CaO 67.5
30	MgO 1.0
	SO ₂ 3.4
	F ₂ (as fluoride) 0.4
	L.O.I. 0.4
	K ₂ O 1.1
	Na ₂ O 0.2

35 The LSF was 1.04, the S/R 5.43, the A/F 2.08 and the free lime content as determined by the method previously described 0.6 per cent. The potential compound composition of this clinker as calculated by the method employed in Example 1 is:—

	per cent
45	C ₃ S 81.1
	C ₂ S 1.1
	C ₃ A 5.0
	C ₄ AF 4.0
	CaSO ₄ 3.7
	Alkali sulphates 2.5
	Free lime 0.6

together with other minor phases.

50 A cement was prepared by grinding this clinker to a specific surface area of 465 m²/kg as measured by the method in Example 1.

55 The paste setting times according to B.S. 12 (1971) were:—

At percent consistency	
water	25.0
Initial Set	205 minutes
Final Set	300 minutes

When made up as a concrete and tested as in Example 1, the compressive strengths of 100 mm concrete cubes were as follows:—

After	
8 hours	1 MN/m ²
16 hours	16 MN/m ²
24 hours	28 MN/m ²
3 days	45 MN/m ²
7 days	58 MN/m ²
28 days	63 MN/m ²

EXAMPLE 7

A clinker was prepared as in Example 1, employing the raw materials therein described, by blending in the approximate proportions (dry basis) 76.5 per cent chalk, 9.5 per cent sand, 9.2 per cent clay, together with 2.3 per cent iron pyrites, 2.0 per cent potassium sulphate and 0.5 per cent calcium fluoride, and sintering in an oil-fired furnace at around 1400°C to give a clinker with the following analysis:—

	per cent
85	SiO ₂ 21.7
	Al ₂ O ₃ 2.2
	Fe ₂ O ₃ 3.1
	Mn ₂ O ₃ 0.03
	P ₂ O ₅ 0.06
	TiO ₂ 0.08
	CaO 66.5
	MgO 0.8
90	SO ₂ 3.8
	F ₂ (as fluoride) 0.17
	L.O.I. 0.3
	K ₂ O 1.2
	Na ₂ O 0.04

The LSF was 1.02, the S/R 4.09, the A/F 0.71 and the free lime as determined by the method previously described 1.8 per cent.

The potential compound composition of this clinker as calculated by the method employed in Example 1 is:—

	per cent
105	C ₃ S 71.4
	C ₂ S 8.4
	C ₃ A 0.6
	C ₄ AF 9.4
	CaSO ₄ 4.6
	Alkali sulphates 2.3
	Free lime 1.8

together with other minor phases.

A cement was prepared by grinding this clinker to a specific surface area of 450 m²/kg as measured by the method in Example 1.

The paste setting times according to B.S. 12 (1971) were:—

At percent consistency

water	29.0
Initial Set	215 minutes
Final Set	250 minutes

When made up as a concrete and tested as in Example 1 the compressive strengths of 100 mm concrete cubes were as follows:—

After	
8 hours	2 MN/m ²
16 hours	19 MN/m ²
24 hours	32 MN/m ²
3 days	50 MN/m ²
7 days	55 MN/m ²
28 days	63 MN/m ²

EXAMPLE 8

A cement was prepared by intergrinding 80 per cent of an active alite clinker prepared in a similar way to that described in Example 3 but with the following analysis:

	per cent
SiO ₂	22.3
Al ₂ O ₃	2.6
Fe ₂ O ₃	1.2
Mn ₂ O ₃	0.05
P ₂ O ₅	0.11
TiO ₂	0.08
CaO	68.2
MgO	1.0
SO ₃	2.6
F ₂ (as fluoride)	0.23
L.O.I.	0.3
K ₂ O	1.2
Na ₂ O	0.10

with 20 per cent of a C₁₂A₇-rich clinker specified below to a specific surface area of 450 m²/kg as measured by the method previously described. The C₁₂A₇-rich clinker used in this example had an analysis as follows:—

	per cent
SiO ₂	19.3
Al ₂ O ₃	19.0
Fe ₂ O ₃	2.0
Mn ₂ O ₃	0.05
P ₂ O ₅	0.17
TiO ₂	0.29
CaO	56.5
MgO	0.9
SO ₃	0.27
K ₂ O	0.72
Na ₂ O	0.13

The lime saturation factor was 0.72, the

silica ratio 0.92, the alumina ratio 9.5, and the free lime determined by the method previously described 1.5 per cent. The potential compound composition of this clinker, allowing for the free lime, and calculated from its principal oxide analysis is as follows:—

	per cent
C ₃ S	55.3
C ₁₂ A ₇	32.1
CA	1.9
C ₄ AF	6.1

together with other minor phases.

No other addition was made to the cement and the total sulphate content as calculated from the clinker analyses was therefore 2.1 per cent. The setting times according to B.S. 12 (1971) were:—

At percent consistency

water	29.0
Initial Set	11 minutes
Final Set	12 minutes

When made up as a concrete and tested as in Example 1 the compressive strengths of 100 mm concrete cubes were as follows:—

After	
2 hours	1.8 MN/m ²
8 hours	2.3 MN/m ²
24 hours	15 MN/m ²
3 days	26 MN/m ²
7 days	34 MN/m ²
28 days	40 MN/m ²

As a comparison a cement was prepared by intergrinding 80 per cent of an ordinary Portland cement clinker with 20 per cent of the C₁₂A₇-rich clinker specified above together with gypsum to a specific surface area of 450 m²/kg as measured by the method previously described. The ordinary Portland cement used in this comparative example had an analysis as follows:—

	per cent
SiO ₂	20.2
Al ₂ O ₃	5.1
Fe ₂ O ₃	4.6
Mn ₂ O ₃	0.11
P ₂ O ₅	0.16
TiO ₂	0.11
CaO	65.0
MgO	0.9
SO ₃	1.0
K ₂ O	0.93
Na ₂ O	0.37

The lime saturation factor was 0.99, the silica ratio 2.08, the alumina ratio 1.11, and the free lime as determined by the method previously described 1.8 per cent. The poten-

tial compound composition of this clinker allowing for the free lime and calculated from its principal oxide analysis is as follows:—

	per cent
5 C_3S	62.9
C_2S	10.5
C_3A	5.7
C_4AF	14.0

together with other minor phases.

10 No other additions were made to the cement and the gypsum content was such as to give an SO_3 content in the final cement of 2.5 per cent by weight.

15 The setting times according to B.S. 12 (1971) were:—

At percent consistency	32.5
water	
Initial Set	10 minutes
Final Set	15 minutes

20 When made up as a concrete and tested as in Example 1, the compressive strengths were as follows:—

After	
2 hours	2.1 MN/m ²
8 hours	2.3 MN/m ²
24 hours	2.9 MN/m ²
3 days	6 MN/m ²
7 days	12 MN/m ²
28 days	20 MN/m ²

EXAMPLE 9

30 A cement was prepared by intergrinding 50 per cent of the active alite clinker prepared as in Example 6 with 50 per cent of the $C_{12}A$ -rich clinker described in Example 8 together with gypsum and citric acid to a specific surface area of 450 m²/kg as measured by the method previously described. The quantity of gypsum added was such as to give a total cement sulphate of 2.0 per cent as determined by analysis, whilst the amount of citric acid added was 0.3 per cent.

45 A cement water grout mix using this cement and having a water-cement ratio of 0.5 was prepared and its pumpability time as assessed from a simple penetration test was estimated at 30 minutes.

50 When used as a binder for coal shale, the overall composition of the mix being 1 part cement, 6 parts dry shale and 2 parts water, the setting time of the mix as judged by the time the mix was self-supporting was approximately 30 minutes and the compressive strengths were:—

55 After	
2 hours	90 p.s.i.
4 hours	110 p.s.i.
24 hours	120 p.s.i.

As a comparison a cement was prepared by intergrinding 50 per cent of the ordinary Portland cement clinker and 50 per cent of the $C_{12}A$ -rich clinker both described in Example 8 together with gypsum and citric acid to a specific surface area of 450 m²/kg as measured by the method previously described. The quantity of gypsum added was such as to give a total cement sulphate of 2.0 per cent as determined by analysis, whilst the amount of citric acid added was 0.5 per cent.

A cement water grout mix using this cement with a water-cement ratio of 0.5 had a pumpability time as estimated above of 29 minutes.

When used as a binder for coal shale and tested as above the setting time was approximately 25 minutes and the compressive strengths were:—

After	
2 hours	85 p.s.i.
4 hours	95 p.s.i.
24 hours	105 p.s.i.

EXAMPLE 10

A clinker comprising $C_{12}A$, was prepared as follows:—

The following raw materials with principal oxide analyses of:—

	Chalk	China-Clay
SiO_2	2.1	48.9
Al_2O_3	0.2	34.8
Fe_2O_3	0.1	0.3
CaO	54.6	0.2

were utilised to form a mix by blending in the approximate proportions (dry basis) 72 per cent chalk with 28 per cent china clay and grinding in a ball mill to a residue of 5 per cent on a B.S. 90 μ m sieve. The raw feed so obtained was mixed with water and pressed into cakes and these were sintered in an oil-fired furnace at about 1300°C to produce a clinker with the following analysis:—

	per cent
SiO_2	23.7
Al_2O_3	14.6
Fe_2O_3	0.4
Mn_2O_3	0.05
P_2O_5	0.15
CaO	59.0
MgO	0.4
SO_3	0.20
K_2O	0.70
Na_2O	0.14

The lime saturation factor was 0.70, the silica ratio 1.58, the alumina ratio 36.5 and the free lime as determined by the method previously described 1.0 per cent. The potential compound composition of this clinker,

allowing for free lime, and calculated from its principal oxide analysis is as follows:—

	per cent
C ₃ S	67.9
C ₂ A	26.6
CA	1.0
C ₄ AF	1.2

together with other minor phases.

10 A cement was prepared by intergrinding 50 per cent of this clinker comprising C₃A, with 50 percent of the active alite clinker described in Example 6 together with gypsum and citric acid to a specific surface area of 460 m²/kg as measured by the method previously described. The quantity of gypsum added was such as to give a total cement sulphate of 2.0 per cent as determined by analysis, while the amount of citric acid added was 0.3 per cent.

20 A cement water grout mix using this cement with a water-cement ratio of 0.5 had a pumpability time as estimated in Example 9 of 28 minutes.

25 When used as a binder for coal shale and tested as in Example 9, the setting time was 30 minutes and the compressive strengths were:—

	After	
	2 hours	70 p.s.i.
30	4 hours	80 p.s.i.
	24 hours	90 p.s.i.

35 As a comparison, a cement was prepared by intergrinding 50 per cent of this clinker comprising C₃A, with 50 per cent of the ordinary Portland cement clinker described in Example 8 together with gypsum and citric acid to a specific surface area of 455 m²/kg as measured by the method previously described. The quantity of gypsum added was such as to give a total cement sulphate of 2.1 per cent as determined by analysis, whilst the amount of citric acid added was 0.4 per cent.

45 A cement water grout mix using this cement with a water-cement ratio of 0.5 had a pumpability time, as estimated above, of 30 minutes.

50 When used as a binder for coal shale and tested as above, the setting time was 45 minutes and the compressive strengths were:—

	After	
	2 hours	45 p.s.i.
55	4 hours	55 p.s.i.
	24 hours	70 p.s.i.

EXAMPLE 11

A clinker was prepared as in Example 1, employing the raw materials therein described by blending in the approximate proportions (dry basis), 70.5 per cent chalk, 7.5 per cent sand, 13.2 per cent clay, 6.5 per cent gypsum, 0.2 per cent iron oxide together with 2.0 per cent potassium sulphate and 0.1 per cent calcium fluoride, and sintering in an oil-fired furnace at around 1400°C to give a clinker with the following analysis.

	per cent
SiO ₂	21.7
Al ₂ O ₃	2.9
Fe ₂ O ₃	1.3
Mn ₂ O ₃	0.03
P ₂ O ₅	0.09
TiO ₂	0.13
CaO	68.0
MgO	1.0
SO ₃	2.0
F ₂ (as fluoride)	0.07
L.O.I.	1.5
K ₂ O	1.0
Na ₂ O	0.1

The LSF was 1.04, the S/R 5.17, the A/F 2.23 and the free lime, as determined by the method previously described, 3.3 per cent. The potential compound composition of this clinker as calculated by the method employed in Example 1 is:—

	per cent
C ₃ S	74.2
C ₂ S	6.4
C ₃ A	5.5
C ₄ AF	4.0
CaSO ₄	1.7
Alkali Sulphates	2.1
Free Lime	3.3

together with other minor phases.

A cement was prepared by grinding this clinker to a specific surface area of 460 m²/kg as measured by the method in Example 1.

The paste setting times according to B.S. 12 (1971) were:—

At percent consistency	
water	25.3
Initial Set	90 minutes
Final Set	110 minutes

When made up as a concrete and tested as in Example 1 the compressive strengths of 100 mm concrete cubes were as follows:—

After		
8 hours	7 MN/m ²	110
16 hours	18 MN/m ²	
24 hours	23 MN/m ²	
3 days	34 MN/m ²	
7 days	42 MN/m ²	115
28 days	52 MN/m ²	

EXAMPLE 12

A clinker was prepared as in Example 3 employing the raw materials described therein but replacing the 2.0 per cent potassium sulphate used in that mix with 1.6 per cent potassium carbonate to give a clinker with the following analysis:—

	per cent
SiO ₂	21.8
Al ₂ O ₃	2.6
Fe ₂ O ₃	1.2
Mn ₂ O ₃	0.02
P ₂ O ₅	0.08
TiO ₂	0.13
CaO	67.0
MgO	1.0
SO ₃	2.9
F ₂ (as fluoride)	0.24
L.O.I.	1.4
K ₂ O	1.5
Na ₂ O	0.06

The LSF was 1.03, the S/R 5.74, the A/F 2.17 and the free lime as determined by the method previously described 2.4 per cent. The potential compound composition of this clinker as calculated by the method employed in Example 1 was:—

	per cent
C ₃ S	73.6
C ₂ S	7.1
C ₃ A	4.8
C ₄ AF	3.6
CaSO ₄	2.7
Alkali sulphates	2.9
Free lime	2.4

together with other minor phases.

A cement was prepared by grinding this clinker to a specific surface area of 460 m²/kg as measured by the method of Example 1.

The paste setting times according to B.S. 12 (1971) were:—

At percent consistency	
water	30.5
Initial Set	190 minutes
Final Set	240 minutes

When made up as a concrete and tested as in Example 1 the compressive strengths of 100 mm concrete cubes were as follows:—

After	
8 hours	4 MN/m ²
16 hours	24 MN/m ²
24 hours	35 MN/m ²
3 days	49 MN/m ²
7 days	57 MN/m ²
28 days	63 MN/m ²

EXAMPLE 13

A clinker was prepared as in Example 3 employing the raw materials described therein, but replacing the 0.5 per cent calcium fluoride used in that mix with 0.5 per cent of magnesium silicofluoride (MgSiF₆) to give a clinker with the following analysis:—

	per cent
SiO ₂	22.2
Al ₂ O ₃	2.8
Fe ₂ O ₃	1.4
Mn ₂ O ₃	0.0
P ₂ O ₅	0.08
TiO ₂	0.14
CaO	68.5
MgO	0.9
SO ₃	1.7
F ₂ (as fluoride)	0.12
L.O.I.	1.0
K ₂ O	1.0
Na ₂ O	0.07

The LSF was 1.03, the S/R 5.29, the A/F 2.00 and the free lime, as determined by the method previously described 2.1 per cent. The potential compound composition of this clinker as calculated by the method employed in Example 1 is:—

	per cent
C ₃ S	78.5
C ₂ S	4.5
C ₃ A	5.1
C ₄ AF	4.3
CaSO ₄	1.3
Alkali sulphates	2.0
Free Lime	2.1

together with other minor phases.

A cement was prepared by grinding this clinker to a specific surface area of 450 m²/kg as measured by the method in Example 1.

The paste setting times according to B.S. 12 (1971) were:—

At percent consistency	
water	28.8
Initial Set	155 minutes
Final Set	190 minutes

When made up as a concrete and tested as in Example 1 the compressive strengths of 100 mm concrete cubes were as follows:—

After	
8 hours	4 MN/m ²
16 hours	13 MN/m ²
24 hours	23 MN/m ²
3 days	40 MN/m ²
7 days	51 MN/m ²
28 days	65 MN/m ²

EXAMPLE 14

A clinker was prepared as in Example 3 employing the raw materials described therein, but replacing the gypsum used with aluminium sulphate. The approximate proportions of the raw materials (dry basis) were 73.1 per cent chalk, 6.4 per cent clay, 7.9 per cent hydrated aluminium sulphate, 10.1 per cent sand together with 0.5 per cent calcium fluoride and 2.0 per cent potassium sulphate which after sintering in an oil-fired furnace gave a clinker with the following analysis

	per cent
SiO ₂	22.3
Al ₂ O ₃	3.7
Fe ₂ O ₃	0.7
Mn ₂ O ₃	0.03
P ₂ O ₅	0.07
TiO ₂	0.12
CaO	67.7
MgO	0.9
SO ₃	2.3
F ₂ (as fluoride)	0.24
L.O.I.	0.7
K ₂ O	1.0
Na ₂ O	0.2

The LSF was 1.01, the S/R 5.07, the A/F 5.29 and the free lime as determined by the method previously described 1.9 per cent. The potential compound composition of this clinker calculated as in Example 1 was:—

	per cent
C ₃ S	69.1
C ₂ S	11.9
C ₃ A	8.6
C ₄ AF	2.1
CaSO ₄	2.0
Alkali sulphate	2.3
Free lime	1.9

together with other minor phases.

A cement was prepared by grinding this clinker to a specific surface area of 450 m²/kg as measured by the method in Example 1.

The paste setting times according to B.S. 12 (1971) were:—

At percent consistency	
water	29.0
Initial Set	125 minutes
Final Set	165 minutes

When made up as a concrete and tested as in Example 1 the compressive strengths of 100 mm concrete cubes were as follows:—

After	
8 hours	7 MN/m ²
16 hours	18 MN/m ²
24 hours	25 MN/m ²
3 days	46 MN/m ²
7 days	60 MN/m ²
28 days	65 MN/m ²

60

EXAMPLE 15

A clinker was prepared as in Example 1 employing the raw materials described therein, by blending in the approximate proportions (dry basis) 62.5 per cent chalk, 0.6 per cent sand, 27.9 per cent clay, 6.5 per cent gypsum, together with 2.0 percent potassium sulphate and 0.5 per cent calcium fluoride and sintering in an oil-fired furnace at around 1400°C to give a clinker with the following analysis:—

	per cent	
SiO ₂	20.4	
Al ₂ O ₃	5.4	75
Fe ₂ O ₃	1.8	
Mn ₂ O ₃	0.02	
P ₂ O ₅	0.08	
TiO ₂	0.12	
CaO	65.5	80
MgO	1.0	
SO ₃	3.7	
F ₂ (as fluoride)	0.23	
L.O.I.	0.4	
K ₂ O	1.1	85
Na ₂ O	0.2	

The LSF was 1.01, the S/R 2.83, the A/F 3.00 and the free lime as determined by the method previously described 1.9 per cent. The potential compound composition of this clinker as calculated by the method employed in Example 1 is:—

	per cent	
C ₃ S	57.8	
C ₂ S	15.0	95
C ₃ A	11.3	
C ₄ AF	5.5	
CaSO ₄	4.3	
Alkali sulphates	2.5	
Free Lime	1.9	100

together with other minor phases.

A cement was prepared by grinding this clinker to a specific surface area of 450 m²/kg as measured by the method as used in Example 1.

The paste setting times according to B.S. 12 (1971) were:—

105

At percent consistency
water 31.8
Initial Set 270 minutes
Final Set 315 minutes

The potential compound composition of this clinker calculated as in Example 1 was:—

	per cent
C ₃ S	66.1
C ₂ S	10.7
C ₃ A	5.8
C ₄ AF	3.3
CaSO ₄	3.8
Alkali sulphates	3.8
Free Lime	2.0

When made up as a concrete and tested as in Example 1 the compressive strengths of 100 mm concrete cubes were as follows:—

After	
8 hours	2 MN/m ²
16 hours	20 MN/m ²
24 hours	32 MN/m ²
3 days	45 MN/m ²
7 days	51 MN/m ²
28 days	55 MN/m ²

together with other minor phases.

A cement was prepared by grinding this clinker to a specific surface area of 450 m²/kg as measured by the method in Example 1.

The paste setting times according to B.S. 12 (1971) were:—

At percent consistency	
water	30.0
Initial Set	220 minutes
Final Set	280 minutes

When made up as a concrete and tested as in Example 1 the compressive strengths of 100 mm concrete cubes were as follows:—

After	
8 hours	2 MN/m ²
16 hours	20 MN/m ²
24 hours	34 MN/m ²
3 days	47 MN/m ²
7 days	54 MN/m ²
28 days	59 MN/m ²

EXAMPLE 17

A cement 'A' was prepared from the clinker produced in Example 3 ground to a specific surface area of 330 m²/kg and admixed with varying proportions of pulverised fuel ash (P.F.A.) of 415 m²/kg specific surface area to produce pozzolanic cements.

When made up as a concrete and tested as in Example 1 the compressive strengths of 100 mm concrete cubes were as follows:—

Compressive strength (MN/m²)
after:

100 per cent cement 'A'
80 per cent cement 'A':
20 per cent P.F.A.
60 per cent cement 'A':
40 per cent P.F.A.

3 days	7 days	28 days
42	50	57
40	48	56
35	38	45

The LSF was 1.02, the S/R 5.28, the A/F 2.64 and the free lime as determined by the method previously described 2.0 per cent.

	per cent
SiO ₂	21.1
Al ₂ O ₃	2.9
Fe ₂ O ₃	1.1
Mn ₂ O ₃	0.03
P ₂ O ₅	0.07
TiO ₂	0.12
CaO	64.4
MgO	3.4
SO ₃	4.1
F ₂ (as fluoride)	0.25
L.O.I.	0.5
K ₂ O	1.7
Na ₂ O	0.3

For comparative purposes a normal Portland cement (B) of 350 m²/kg specific surface area was also admixed with varying proportions of the same P.F.A. as used above and when made up as a concrete and tested as in Example 1 the compressive strengths of 100 mm concrete cubes were as follows:—

Compressive strength (MN/m ²) after:	3 days	7 days	28 days
100 per cent cement 'B':	20	29	41
80 per cent cement 'B':			
20 per cent P.F.A.	19	28	40
60 per cent cement 'B':			
40 per cent P.F.A.	17	22	33

EXAMPLE 18

A cement 'C' was prepared from 70 per cent of the clinker produced in Example 3 ground with 30 per cent of a granulated blast furnace slag to a specific surface area of 330 m²/kg.

For comparative purposes a cement 'D' was prepared from 66.5 per cent of a normal Portland cement clinker and 3.5 per cent

gypsum ground together with 30 per cent of the granulated blast furnace slag used in cement 'C' to a specific surface area of 330 m²/kg.

When these cements were made up as concretes and tested as in Example 1 the compressive strengths of 100 mm concrete cubes were as follows:—

Compressive strength (MN/m ²) after:	3 days	7 days	28 days
Cement 'C'	28	38	54
Cement 'D'	13	21	40

EXAMPLE 19

A clinker was prepared as in Example 1, employing the raw materials therein described, by blending in the approximate proportions (dry basis) 67.8 per cent chalk, 9.0 per cent sand, 14.2 per cent clay, 6.5 per cent gypsum, together with 2.0 per cent potassium sulphate and 0.5 per cent calcium fluoride, and sintering in an oil-fired furnace at around 1400°C to give a clinker with the following analysis:—

this clinker as calculated by the method employed in Example 1 is:—

	per cent
C ₂ S	47.7
C ₃ S	33.2
C ₂ A	6.4
C ₄ AF	3.3
CaSO ₄	3.8
Alkali sulphates	2.3
Free lime	0.7

together with other minor phases.

A cement was prepared by grinding this clinker to a specific surface area of 450 m²/kg as measured by the method in Example 1.

The paste setting time according to B.S. 12 (1971) were:

At per cent consistency	
water	28.5
Initial set	300 minutes
Final set	355 minutes

When made up as a concrete and tested as in Example 1, the compressive strengths of 100 mm concrete cubes were as follows:—

After	
8 hours	1 MN/m ²
16 hours	13 MN/m ²
24 hours	21 MN/m ²
3 days	36 MN/m ²
7 days	44 MN/m ²
28 days	58 MN/m ²

The LSF was 0.90, the S/R 5.74, the A/F 2.82 and the free lime as determined by the method previously described 0.7 per cent.

The potential compound composition of

	per cent
SiO ₂	24.1
Al ₂ O ₃	3.1
Fe ₂ O ₃	1.1
Mn ₂ O ₃	0.03
P ₂ O ₅	0.07
TiO ₂	0.12
CaO	64.5
MgO	0.8
SO ₃	3.3
F ₂ (as fluoride)	0.19
L.O.I.	1.2
K ₂ O	1.2
Na ₂ O	0.04

EXAMPLE 20

A clinker was prepared as in Example 1, employing the raw materials therein described, by blending in the approximate proportions (dry basis) 61.9 per cent chalk, 1.5 per cent sand, 27.6 per cent clay, 6.5 per cent gypsum, together with 2.0 per cent potassium sulphate and 0.5 per cent calcium fluoride, and sintering in an oil-fired furnace at around 1400°C to give a clinker with the following analysis:—

	per cent
SiO ₂	21.5
Al ₂ O ₃	5.4
Fe ₂ O ₃	1.8
Mn ₂ O ₃	0.04
P ₂ O ₅	0.08
TiO ₂	0.15
CaO	64.0
MgO	0.9
SO ₃	3.7
F ₂ (as fluoride)	0.14
L.O.I.	0.9
K ₂ O	1.1
Na ₂ O	0.11

The LSF was 0.94, the S/R 2.99, the A/F 3.00 and the free lime as determined by the method previously described 1.1 per cent.

The potential compound composition of this clinker as calculated by the method employed in Example 1 is:—

	per cent
C ₃ S	46.3
C ₂ S	26.8
C ₃ A	11.3
C ₄ AF	5.5
CaSO ₄	4.5
Alkali sulphates	2.3
Free lime	1.1

together with other minor phases.

A cement was prepared by grinding this clinker to a specific surface area of 330 m²/kg as measured by the method in Example 1.

When made up as a concrete and tested as in Example 1, the compressive strengths of 100 mm concrete cubes were as follows:—

After	
16 hours	11 MN/m ²
24 hours	20 MN/m ²
3 days	35 MN/m ²
7 days	42 MN/m ²
28 days	52 MN/m ²

For comparative purposes a second cement, ground to 340 m²/kg, was prepared from an ordinary Portland cement clinker with similar values for the three major chemical parameters, namely LSF 0.94, S/R 3.1 and A/F 2.5.

When made up as a concrete and tested as in Example 1, the compressive strengths of 100 mm concrete cubes were as follows:—

After	
16 hours	5 MN/m ²
24 hours	9 MN/m ²
3 days	24 MN/m ²
7 days	34 MN/m ²
28 days	48 MN/m ²

WHAT WE CLAIM IS:—

1. A method of making cement of the Portland type, with high and rapid strength development, containing alite of improved hydraulic activity, wherein argillaceous and calcareous materials are combined to form clinker by heating in a kiln and the resulting clinker is ground to form a cement, comprising the step of introducing into a kiln a combination of mineralisers which contains fluorine and sulphur, provided that an alkali metal compound which can be a component of the aforesaid combination of mineralisers is included in the materials fed to the kiln at least when the condition that the lime saturation factor be at least 0.98 and the silica ratio be at least 4 is not met.

2. A method according to Claim 1, wherein the mineraliser containing fluorine is calcium fluoride.

3. A method according to Claim 1, wherein the mineraliser containing sulphur is calcium sulphate or a hydrate thereof, an alkali metal sulphate or a double alkali metal calcium sulphate, or a mixture thereof.

4. A method according to Claim 3, wherein the mineraliser containing sulphur is gypsum or potassium sulphate or a mixture thereof.

5. A method according to Claim 1, wherein the mineraliser containing alkali metal is an alkali metal sulphate.

6. A method according to Claim 5, wherein the alkali metal sulphate is potassium sulphate, a double alkali metal calcium sulphate or a mixture thereof.

7. A method according to Claim 1, wherein components, containing fluorine, sulphate and alkali metal, of the mineralisers introduced, are retained in the clinker.

8. A method according to Claim 7, wherein at least 0.5 per cent based on the clinker of the sulphate retained in the clinker is present as alkali metal sulphate.

9. A method according to Claim 7, wherein the clinker contains 0.01 to 1 per cent fluoride and 0.1 to 5.0 per cent SO₃ by weight of the clinker.

10. A method according to Claim 9, wherein the clinker contains 0.01 to 0.5 per cent fluoride by weight of the clinker.

11. A method according to Claim 1, wherein the lime saturation factor of the clinker is from 0.98 to 1.08.



EXAMPLE 20

A clinker was prepared as in Example 1, employing the raw materials therein described, by blending in the approximate proportions (dry basis) 61.9 per cent chalk, 1.5 per cent sand, 27.6 per cent clay, 6.5 per cent gypsum, together with 2.0 per cent potassium sulphate and 0.5 per cent calcium fluoride, and sintering in an oil-fired furnace at around 1400°C to give a clinker with the following analysis:—

	per cent
SiO ₂	21.5
Al ₂ O ₃	5.4
Fe ₂ O ₃	1.8
Mn ₂ O ₃	0.04
P ₂ O ₅	0.08
TiO ₂	0.15
CaO	64.0
MgO	0.9
SO ₃	3.7
F ₂ (as fluoride)	0.14
L.O.I.	0.9
K ₂ O	1.1
Na ₂ O	0.11

The LSF was 0.94, the S/R 2.99, the A/F 3.00 and the free lime as determined by the method previously described 1.1 per cent.

The potential compound composition of this clinker as calculated by the method employed in Example 1 is:—

	per cent
C ₃ S	46.3
C ₂ S	26.8
C ₃ A	11.3
C ₄ AF	5.5
CaSO ₄	4.5
Alkali sulphates	2.3
Free lime	1.1

together with other minor phases.

A cement was prepared by grinding this clinker to a specific surface area of 330 m²/kg as measured by the method in Example 1.

When made up as a concrete and tested as in Example 1, the compressive strengths of 100 mm concrete cubes were as follows:—

After	
16 hours	11 MN/m ²
24 hours	20 MN/m ²
3 days	35 MN/m ²
7 days	42 MN/m ²
28 days	52 MN/m ²

For comparative purposes a second cement, ground to 340 m²/kg, was prepared from an ordinary Portland cement clinker with similar values for the three major chemical parameters, namely LSF 0.94, S/R 3.1 and A/F 2.5.

When made up as a concrete and tested as in Example 1, the compressive strengths of 100 mm concrete cubes were as follows:—

After	
16 hours	5 MN/m ²
24 hours	9 MN/m ²
3 days	24 MN/m ²
7 days	34 MN/m ²
28 days	48 MN/m ²

WHAT WE CLAIM IS:—

1. A method of making cement of the Portland type, with high and rapid strength development, containing alite of improved hydraulic activity, wherein argillaceous and calcareous materials are combined to form clinker by heating in a kiln and the resulting clinker is ground to form a cement, comprising the step of introducing into a kiln a combination of mineralisers which contains fluorine and sulphur, provided that an alkali metal compound which can be a component of the aforesaid combination of mineralisers is included in the materials fed to the kiln at least when the condition that the lime saturation factor be at least 0.98 and the silica ratio be at least 4 is not met.

2. A method according to Claim 1, wherein the mineraliser containing fluorine is calcium fluoride.

3. A method according to Claim 1, wherein the mineraliser containing sulphur is calcium sulphate or a hydrate thereof, an alkali metal sulphate or a double alkali metal calcium sulphate, or a mixture thereof.

4. A method according to Claim 3, wherein the mineraliser containing sulphur is gypsum or potassium sulphate or a mixture thereof.

5. A method according to Claim 1, wherein the mineraliser containing alkali metal is an alkali metal sulphate.

6. A method according to Claim 5, wherein the alkali metal sulphate is potassium sulphate, a double alkali metal calcium sulphate or a mixture thereof.

7. A method according to Claim 1, wherein components, containing fluorine, sulphate and alkali metal, of the mineralisers introduced, are retained in the clinker.

8. A method according to Claim 7, wherein at least 0.5 per cent based on the clinker of the sulphate retained in the clinker is present as alkali metal sulphate.

9. A method according to Claim 7, wherein the clinker contains 0.01 to 1 per cent fluoride and 0.1 to 5.0 per cent SO₃, by weight of the clinker.

10. A method according to Claim 9, wherein the clinker contains 0.01 to 0.5 per cent fluoride by weight of the clinker.

11. A method according to Claim 1, wherein the lime saturation factor of the clinker is from 0.98 to 1.08.

12. A method according to Claim 11 wherein the silica ratio of the clinker is from 4 to 20.

13. A method according to Claim 11 or 12, wherein the alite content of the clinker is at least 65 per cent thereof by weight.

14. A method according to Claim 11 or 12, wherein the alite content of the clinker is at least 70 per cent thereof by weight.

15. A method according to Claim 8, wherein the lime saturation factor of the clinker is less than 0.98.

16. A method according to Claim 15, wherein the silica ratio of the clinker is less than 4.

17. A method according to Claim 11, 12, 15 or 16, wherein mineraliser components from the material forming the clinker are recycled for use in the combination of further clinker.

18. A method according to any preceding Claim, wherein the clinker is ground to a specific surface area of from 200 to 800 m²/kg.

19. A method according to Claim 18, wherein the clinker is ground to a specific surface area of from 250 to 500 m²/kg.

20. A method according to any preceding Claim, wherein the clinker formed is mixed with a clinker containing from 7 to 90 per cent by weight C₁₂A₇.

21. A method according to Claim 1, wherein the combination of mineralisers introduced to the kiln contains 0.1 to 2 per cent fluorine by weight and 1 to 10 per cent SO₂ by weight based on the clinker.

22. A method according to Claim 1, wherein the combination of mineralisers introduced to the kiln contains 0.2 to 0.5 per cent fluorine by weight and 2 to 5 per cent SO₂ by weight based on the clinker.

23. A method according to Claim 21 or

22, wherein at least part of the combination of mineralisers is introduced to the kiln in the raw feed.

24. A method according to Claim 21 or 22, wherein at least part of the combination of mineralisers is introduced to the kiln in the fuel.

25. A method according to Claim 1, wherein the kiln is a fluidised bed kiln.

26. A method according to any preceding Claim, wherein the clinker is ground with sufficient calcium sulphate in the form of a natural or synthetic gypsum hemihydrate, soluble anhydrite or a mixture thereof, to give a total SO₂ content of up to 8 per cent in the finished cement.

27. A method according to Claim 26 wherein sufficient calcium sulphate of whatever form is incorporated in the cement to give a total SO₂ content in the range 2 to 5 per cent.

28. A method according to any preceding Claim, wherein the clinker is ground with an accelerator.

29. A method according to Claim 28, wherein the accelerator is calcium chloride.

30. A method according to any preceding Claim, wherein the clinker is ground with a retarder.

31. A method according to Claim 30, wherein the retarder is citric acid.

32. A method of making Portland cement containing alite of improved hydraulic activity substantially as described in the foregoing Examples.

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