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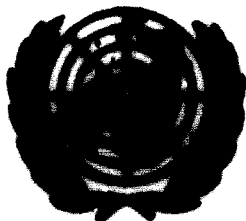
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PORTLAND CEMENT
MANUFACTURE, PROPERTIES AND USE 1/

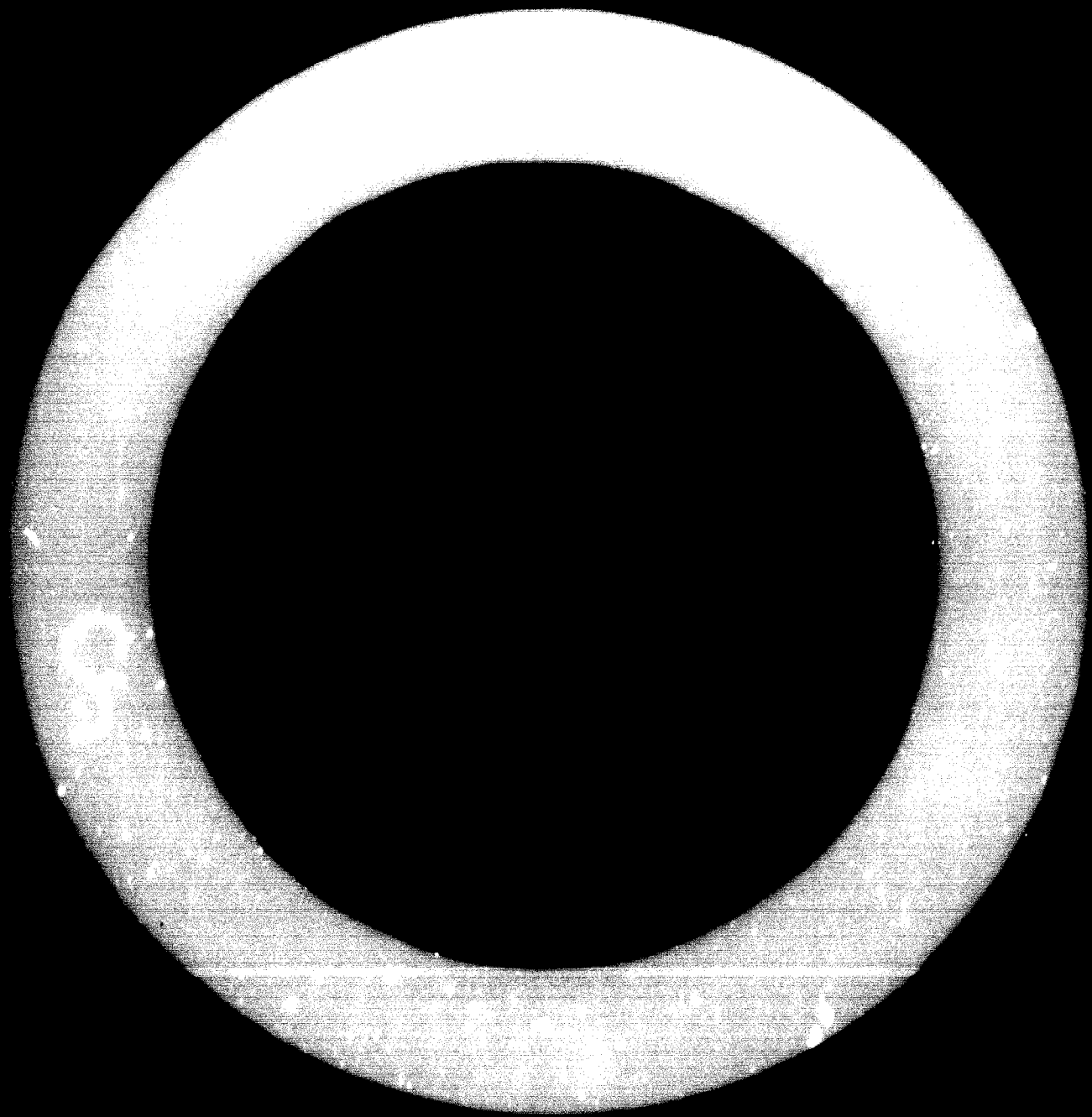
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In order to be able to put the numerous types of cement in their right perspective I should like to show briefly some statistics relating to the production of cement from 1913 to 1970. (Slide No 1).

This curve shows the development so far - and an extrapolation to the year 1980. During the last decade world cement consumption has shown a growth rate of 6.3% per annum.

Assuming that this trend continues, the consumption will increase according to the dotted part of the curve, which roughly corresponds to a doubling from 1969 to 1980.

The magnitude of these figures leaves no doubt about the overwhelming importance of the industry, which ranks as one of the most fundamental of the heavy industries.

The statistics concerning the total production of cement should now be followed by similar graphs for the individual types of cement. Such figures are hard to come by, however, and perhaps really not necessary, as 95% of the world production of cement is Standard Grey Portland Cement.

In the following I shall make the distinction between Portland Cements and "Other Cements" which normally means Portland Cement with additions, such as blast furnace slag, puzzolana, etc.

In the Western European countries, the group "other cements" constitutes as little as 7% of the total cement production, on a world wide basis considerably less.

On slide No. 2 are shown the various types of cement which are commercially available to-day:

The background for the demand of various types of cement will be found in the use of the cement, and in the availability of certain raw materials, which are very generally introduced in the manufacture of cement. This kind of purpose is in an ordinary Portland cement. However, in many special cases, such as in the manufacture of rapid concrete cements, the manufacturer will see a great advantage in using a cement with a more rapid strength development, for the simple reason that he will be able to save more time and space from the moulds in a much quicker pace, thus substantially increasing the output of a given plant facility.

For concreting in cold weather rapid hardening Portland cement also offers considerable advantages over ordinary Portland cement, simply because of the more rapid heat evolution, and for this reason rapid hardening Portland cement is almost standard for winter concreting jobs in Scandinavia.

Sulphate resisting cements have been introduced because of the need for such cements for underground construction work in countries with sulphate containing soils, such as England and France. In Denmark, where sulphate containing soils are not found, a sulphate resisting cement is nevertheless manufactured and used for seawater construction work.

Low heat cement was introduced in the United States because of the need for being able to control the heat development inside large structures of mass concrete, such as power station dams. This is another example of a case where the composition of the cement has been determined by the use for which the cement was intended.

White cement is another example of a special Portland cement which is made entirely for decorative purposes. Apart from its white colour it has no special advantages compared to ordinary Portland cement.

Other cements

A rather special type of cement is high alumina cement, which was introduced in 1918 by the French Lafarge Co. The invention of high alumina cement was a result of a desire for manufacturing a cement with resistance to sulphate attack.

The French railways had experienced very serious attacks on ordinary concrete structures on railway works in Southern France in certain regions where the subsoil strata consisted of anhydrite or gypsum. In the years from 1916 to 1923 the French railways used more than 7000 tons of high alumina cement for construction work in sulphate bearing soils with very satisfactory results.

High alumina cement is usually made from limestone and red bauxite by complete fusion. The most common method of manufacture today is by fusion in a reverberatory open-hearth furnace. The furnaces are rather small and produce about 70 tons of cement per day.

The fuel consumption is about 25% by weight of the cement produced, and the fusion temperature is about 1550-1600°C.

The most important chemical components in high alumina cement, or Ciment's Fondu, as it is also called because of the most common way of manufacture, are CA_2 , CA , and CA_2 . One of the most characteristic properties of high alumina cement is the very high early strength obtained. High alumina cement will in 24 hours develop a strength which is approximately 5 times the strength of rapid hardening Portland cement, and in 7 days about twice the strength of rapid hardening Portland cement.

A very serious drawback of the high alumina cement is, however, that the strength development is extremely sensitive to water-cement ratio and, most of all, to curing temperature. High alumina concrete with a water-cement ratio of 0.8 will attain its maximum strength in about 24 hours and will retain that almost indefinitely at curing temperatures below about 20°C. If the curing temperature is increased to 35°, however, the strength will obtain its maximum in about 24 hours, but after 90 days the strength will be reduced to less than half of the 24 hours strength.

If the water-cement ratio can be kept lower than the order of 0.4 or less the problem is not quite so serious, but in any case it is not to-day considered sound practice to use high alumina cement in mass concrete constructions. While the high alumina cement is not at all suitable for use in the tropical climate it may have rather great advantages for constructions works under arctic conditions.

Perhaps the most important use of high alumina cement to-day is for refractory concrete to withstand medium or high temperatures. Refractory concretes set in the ordinary way and develop strength by a hydraulic bond. From a temperature of about 700°C and upwards, depending on the type of aggregate, a new form of ceramic bond starts developing by solid reactions between the cement and the fine aggregate and increases with temperature. High alumina cement is thus perhaps the most important cementing material used in refractory concretes that are at the moment being used in the cement industry for kiln outlet sections, cooler tops, and burner pipe insulation.

Portland blast furnace slag cement, which is made by grinding together Portland cement clinker, watercooled blast furnace slag, and gypsum or anhydrite, is an example of a cement that is not made so much to fulfill certain required properties as to permit the use of a waste product which can be obtained at a reasonable price, and which has certain cementitious properties. For this reason Portland blast furnace slag cement is normally only produced by cement works in the vicinity of steel works. The properties of the cements are perhaps not quite as good as those of Portland cement, but nevertheless the product has been accepted as equal with Portland cement for most applications in countries where it has been made.

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Puzzolanic cement, which is manufactured by grinding together Portland cement clinker, a puzzolanic material and gypsum, is an example of a cement which is being made partly because of its special properties, and partly because of the economic advantages in using the puzzolanic material. Puzzolanic materials contain silica in a special reactive form which is able to combine with lime. They were originally used in Portland cement mortars and concrete on account of this ability of combining with lime and so removing the calcium hydroxide which was liberated during the setting of the Portland cement. The calcium hydroxide which is rather susceptible to chemical attack is thus removed, and a lime puzzolana compound is formed instead of it. The substitution of puzzolana for Portland cement clinker in a cement does reduce the strength somewhat at early ages, but at later ages the strength can actually be somewhat higher than that of the corresponding Portland cement.

A rather interesting type of puzzolanic cement is the so-called fly ash cement in which the puzzolanic material is pulverised fuel ash from coal burning power generating stations. The fly ash is normally precipitated in the electrostatic precipitators as a very fine powder with a specific surface similar to that of Portland cement or higher. The fly ash can thus be mixed directly into the finished cement, or it can be introduced into the mills together with the clinker at the grinding of the cement.

The use of fly ash in cement is claimed to give a number of advantages. It should improve the workability of the concrete because of the rounded shape of the fly ash particles, thus reducing the amount of water required for a certain workability of the concrete. The addition of fly ash with more than 52% of silica to magnesia-rich cement with a high autoclave expansion is claimed to be the most efficient way of reducing the autoclave expansion to permissible levels.

The strength properties of a Portland cement is changed somewhat by addition of fly ash. With a substitution of 20% of Portland cement by fly ash the strength of the concrete cured at 18-20° is reduced by 10-30% at 7 days, 0-25% at 28 days, and practically unchanged after one year.

Fly ash was first used in cement or concrete for Large Dam constructions in the United States, partly for economic reasons, and partly because of its influence on workability and heat evolution. To-day it is used rather extensively in Germany as the fine sand fraction of concrete aggregates in amounts of some 100,000 ts.

In the United States of America, the Soviet Union, France, and Austria it is also used ground into the cement in quantities up to 30%. In France, for instance, it is permitted in one class of Portland cement in an amount of up to 20%.

The original reason for using puzzolanic cements was improved durability obtained in concrete in marine, hydraulic, and underground structures, in combination with some economy. The reduction in heat evolution later provided another reason to use puzzolanic cements in mass concrete for Large Dam constructions, for instance. After the discovery of the alkali aggregate reaction it was found that addition of puzzolanas could check the destructive expansion arising from this cause.

Supersulphated Cement

Supersulphated cement is made from blast furnace slag activated by means of calcium sulphate and a small amount of Portland cement.

It is usually made by grinding a mixture of 80-85% of granulated slag, 10-15% of anhydrite and about 5% of Portland cement. It is usually ground to a high specific surface, according to BS not less than 4000 cm^2/g .

It has a high resistance to sulphate attack, a low heat of hydration and has particularly been used for structures below ground.

The manufacture has practically ceased to-day because of its various drawbacks and the lack of a suitable slag with high Al_2O_3 content (min. 13% Al_2O_3).

Expanding Cement

Expanding and shrinkage compensated cements have been made in the USSR since 1942. They have been manufactured in France by the firm of Poliet & Chausson in the nineteen fifties, but the manufacture in France has now been abandoned.

They are now being manufactured in the USA and the USSR; two main types of material have been produced, a "shrinkage - compensating cement" and a "self - stressing cement".

The addition of excess calcium sulphate to Portland cement leads to unsoundness because of the continued gradual reaction of the gypsum with the tricalcium aluminate in the cement after it has hardened. In expanding cements the formation of calcium sulphoaluminate should therefore occur at a time when the concrete has developed some strength but is still sufficiently plastic to accommodate some limited expansion without significant cracking. The formation of calcium sulpho-aluminate requires the presence of calcium, aluminium, and sulphate ions in the alkaline solution and this can be achieved in several ways.

The expanding cement developed in the USA is based on a mixture of Portland cement with an expansive agent prepared by clinkering a mixture of chalk, bauxite, and gypsum of 1300-1400°C. The expansion increases with the proportion of the expansive component and with the fineness of the cement. The shrinkage-compensating cement contains about 10-15% of the expansive component and the self-stressing cement about 25-40%.

In the first case a relatively low unrestrained expansion potential of about 0.2% is aimed at, in the second case a much higher one of 3-6% is desired.

The shrinkage-compensated cement is available commercially in the USA, and the annual production amounts to some hundred thousands tons. The use of self-stressing cement for prestressed concrete is still in the development stage, but it is indeed a development to watch.

The expansive cements developed in the Soviet Union are of two types. The shrinkage-compensating variety consists of a mixture of high alumina cement, gypsum, and hydrated calcium aluminate. The self-stressing cement is made from a mixture of Portland cement, high alumina cement, and gypsum. A further type of low expansion cement is made in the USSR from high alumina cement ground with anhydrite.

Shrinkage

When drying out for the first time, a set cement undergoes a diminution in volume which is partly irreversible.

If ordinary concrete is treated carefully and is kept moist for 7 days and protected against sun, wind, and draught there will be no danger of shrinkage cracks. The dimensional changes of concrete due to shrinkage correspond to a temperature drop of 15-20°C only, and a statistical survey of cracks in concrete has shown that only about 10% of cracks found in concrete could be attributed to the shrinkage phenomenon.

The irreversible shrinkage of concrete is due to the fact that the water added to the cement takes up less space in the crystal lattice of the reaction products than in the liquid form.

On a length-change basis the shrinkage amounts to about 0.2% only; it is this dimensional change which it is attempted to eliminate in the shrinkage compensating cement.

Up to 1958 there was a shrinkage test in the German norm DIN 1164. Cements to be used in highway construction should not show a shrinkage of more than 0.6 mm per m when they were dried out over pot ash after 7 days' wet storage.

Addition of natural Pozzolanas tends to increase the shrinkage while the addition of flyash to the cement in some cases is reported to reduce shrinkage.

Creep

Shrinkage should not be mixed up with another property of set cement which is known as creep, which is a slow continued deformation under load.

It was first discovered in 1930, and has usually for engineering purposes been regarded as independent of shrinkage, but it is clear that actually the two are interdependent. Both are caused by reversible and irreversible changes in the set cement paste.

On unloading of a pressure put on a specimen there is an immediate elastic recovery followed by a delayed recovery leaving a part of creep not recoverable. Creep in concrete differs from that in metals in that it occurs down to the smallest loads at which measurements can be made.

There are numerous theories of creep and variants of them, but a full explanation is still lacking. The truth probably is that there is more than a single cause.

In any case, the phenomenon is so important that it is necessary to take it into account when manufacturing prestressed concrete.

Oil Well Cement

Very special cements are used in the petroleum industry for cementing the steel casing to the surrounding rock formation, and to seal off porous water- and gas-bearing formations through which the drilling passes.

The cement is pumped in position in the form of a slurry and it will be subjected to high temperatures and pressures as well as the corrosive action of salts and sulphur gases.

The properties of oil well cements are standardized by the American Petroleum Institute by the specifications API STD 10A and 10B. The types of cement used include a glow setting cement with an Al_2O_3 to SiO_2 ratio rather below 0.64, pozzolanic cements and coarsely grained ordinary Portland cements. Special retarders are being used, such as starch, sugar methyl-cellulose, tannin, and quebracho. The cements must remain pumpable for about 3 hours and then reach a strength of at least 35 kg/cm^2 in the shortest possible time.

Testing of Oil Well Cement requires a very specialized and costly laboratory equipment; the cement is made only by relatively few manufacturers authorized by the API.

Masonry Cements

Masonry cements are used as a substitute for lime in the manufacture of mortar. A mortar composed of pure Portland Cement, sand and water is harsh and unworkable, and in order to improve the workability cement-lime-sand mortars were often prepared at the building site.

This leads to the development of special masonry cements, which were first introduced in the USA. The use has spread to many countries and masonry cements are now widely used.

Generally, masonry cements are made by intergrinding Portland cement, clinker, gypsum, limestone, and an air entraining agent. Further are often added special plasticizers in order to improve plasticity and water retentivity which are two of the fundamental properties of masonry cements.

Portland Cement

Quality Trends and Manufacture

Since the turn of the century there has been a gradual change in the composition of Portland cement, the content of lime rising steadily and that of silica falling somewhat. This has been made possible by improved methods of manufacture which has enabled the manufacturer to produce cements of higher lime content without resulting unsoundness. In the period 1900-1910 the average mineral composition of 16 different cements produced were as follows:

C_3S :	20%
C_2S :	45%
C_3A :	17%
C_4AF :	18%

assuming a free lime content of 1.1/2%.

The corresponding average values for modern ordinary Portland cements are about 45% of C_3S , 25% C_2S , 11% C_3A , and 8% C_4AF . The free lime of modern cements usually run about 1%. As a result of the increased content of tricalcium silicate, the strength properties of the Portland cement have - of course - improved correspondingly. However, due to changes in testing methods it is rather difficult to give comparable strength figures for the cements produced in the period 1900-1910. The trend continues,

however, and also in these years three issues come in the foreground:

1.

Increased demands on the cement quality - strength properties, uniformity, and some special properties. As a specific example should be mentioned the tendency of the cement imp. formation during storage and transportation.

2.

New and larger types of machines, especially rotary kilns, have caused production problems, partly through a changed clinker size distribution and alkali content which is often increased, but usually a low content of free lime.

3.

The development of extensive automation equipment which is now available for cement plants, especially large cement plants, where the economy of installations of this kind must be considered favourable, opens the possibility to operate the machines with much greater precision than earlier, and thereby opens the possibility of optimizing the processes to a much higher extent than has been possible earlier.

When the demands on the quality of the cement has been increasing through the years this is probably to be understood as a consequence of the increasing rationalization regarding the use of the cement, especially in the concrete production. A rational concrete producer very soon discovers that increasing strength properties of the cement makes the concrete cheaper, especially in the way that a certain quality of concrete can be obtained with a lower content of cement per m^3 . The rationalization of concrete manufacture has been inspired to a high extent by the use of ready-mix concrete. Especially factories for ready-mix concrete feel in a very direct way the economic problems in connection with the actual concrete manufacture.

If we consider the increasing demands on the strength properties of the cement as a natural consequence of the rationalization of the concrete industry it is quite natural that you will meet widely different demands to cement quality in different countries, depending to a high extent on how rational the concrete manufacture is. It is quite natural that the increasing quality demands also lead to the demands of greater uniformity of the cements, as variations especially downwards, with respect to strength properties immediately are felt and will be of economic consequences.

It is, therefore, important that cement manufacturers everywhere acknowledge the development which is going on everywhere. It does go on in all markets, but perhaps to a different extent and with different speed, but the tendency seems to be the same all over.

It would be quite relevant to ask which factors especially influence the good strength properties. We all know that good strength properties are primarily obtained through a high lime saturation, or more specifically, through a high content of tricalcium silicate. To be able to obtain a high tricalcium silicate content without the risk of excess of lime, which will result in free lime in the clinker, the clinker homogeneity is of paramount importance. It is quite clear that a high content of tricalcium silicate is only obtainable if in all parts of the individual clinker there is a uniform proportion between tricalcium silicate and the other clinker minerals, notably dicalcium silicate. Inhomogeneity can be caused by a high ash content in coal used for firing the rotary kiln, as a rule it is rather difficult to ensure a homogeneous absorption of the coal ash in the clinker. While it was earlier considered that clinker of good quality could be obtained by perhaps 6-7% of ash absorbed in the clinker the high strength requirement to-day will hardly permit the absorption of more than 3-4%, and the best results as regards clinker homogeneity and strength properties are, no doubt, achieved by using ash free fuels, such as fuel oil or gas.

Another important factor for clinker homogeneity is the fineness of the raw mix. When the fineness means so much for clinker homogeneity it is due to the fact that the individual mineral grains of the raw mix only have a very limited radius of reaction as regards chemical activity, only about 0.5 mm. This means that a large grain of sand or large grain of lime is able to react only with the immediately surrounding mineral grains, and for that reason it will not be able to react completely. Therefore such large grains cause inhomogeneity in the clinker.

For this reason it is very obvious that raw materials which in composition approaches a natural cement, and also have a fine grained mineral structure, open the possibility to produce clinker with a high homogeneity even when they are relatively coarsely ground. The same also applies to naturally fine grained raw materials, such as chalk and clay. In contrast to this it is often experienced that relatively pure and coarsely crystalline raw materials require a fine grinding in order to give clinker of a satisfactory quality.

The next point of general interest I should mention is the problems which the introduction of new and larger types of machinery, especially kilns, have caused. The new types of kilns are characteristic by the use of cyclone preheaters of different kinds. These preheaters cause an increased circulation of alkali and chlorides in the kiln system. It should also be mentioned that it is characteristic for the majority of the large kilns that have been installed in the later years that the clinker are more fine grained and often dusty, which means that a major proportion of the clinker will be smaller than about 1/2 mm. I shall go into more details with these problems later. I shall just mention that clinker for kilns with cyclone preheaters installed in old plants often turn out to have a higher alkali content than clinker from kilns of older types.

It is characteristic for the dusty clinker from large kilns that they are hard burnt which manifests itself in this way that they, in spite of their fine structure often are quite difficult to grind in the cement mills, especially as regards the fine grinding.

The higher alkali content of clinker from these types of kilns usually changes in the strength properties in this way that the early strengths, the one and three day strength, are relatively higher, whereas the 28-day strengths are somewhat lower. The 7-day strengths seem to be mainly unaffected by the alkali content of clinker.

The trend towards automation within the cement industry which has been very pronounced during the later years has had influence not only upon the actual operation and quality control in the cement plant, but has also given importance as regards the quality and uniformity of clinker and cement. Automation is an originally only automatic control of the individual unit operations. The further development has led to a more or less complete automation of the whole manufacturing process. In general we could say that this process has been very successful for some cement plants or cement manufacturers, whereas other unfortunately only to a lesser extent have obtained real production of quality advantages of the automation.

The primary objective of automation has in many cases been to save labour and better control of the raw mix composition and the burning process which means that clinker of more uniform composition and higher lime saturation can be obtained, which again means cement of a high uniform quality.

By automation of the chemical control in a cement plant two principles can be used: you either try to correct for the irregularities which happen to present themselves, or you can, to the widest possible extent, try to eliminate irregularities, which simply means try to dry out the source from which they originate. With a uniform raw mix, well-controlled kiln feed as well as firing rate and air excess there will be very little need for further automation of a kiln, you could say that it all goes by itself without any need for intervention. This may sound too simple, but nevertheless there are many examples that support that this philosophy of automation is one that has so far given the best result.

The actual manufacturing process may be divided into three:

- a) The raw mix proportioning and homogenizing
- b) The burning, and
- c) Cement grinding and storage

In the factory these three processes are usually carried out in separate departments, which from a process technical point of view are intimately related, and it should be emphasized that a well-controlled raw mix composition and a good homogenizing actually is the key to get a smooth run of the rest of the plant.

Now, how is this done?

It all starts in the quarry, and the first thing that must be done in order to get a good raw mix control is:

1. Detailed study of the raw material deposit and a careful planning of the quarry operation. Perhaps it will be necessary to subdivide a raw material deposit in sections, so that material of rather uniform character and composition may be quarried separately.
2. Use of prehomogenization of the individual raw materials or mixtures of them.

3. Proportioning of the different components to the raw mill by means of accurate weighing feeders.
4. Control of the raw mix composition by means of a fast complete analysis, usually by employing the X-ray fluorescence principle.
5. Calculation of the analytical results by means of a small computer in order to be able to carry out the correct setting of the weighing feeders of the raw mill.
6. After-homogenization of the finished raw mix in mixing and storage silos.

In general terms it is quite true to say that homogenization starts in the quarry. Without an intimate knowledge of the different raw material deposits upon which a production is based, it will not be possible to determine which type of process equipment is needed in order to produce most economically a kiln feed with the desired degree of homogeneity, as far as the chemical composition is concerned.

Sometimes it will be possible by careful planning of, for instance, a limestone deposit to avoid variations in chemical composition of the quarried stone, which would otherwise require a costly pre-homogenization plant. However, a limestone deposit might be so irregular that it will not be possible just by suitable quarrying to deliver a product to the plant with a sufficiently constant composition, and in that case pre-homogenization will be necessary.

Mixing of pre-crushed material can take place in any kind of buffer storage between the continuously working raw mill and the periodically working quarry and pre-crushing plant. The general philosophy should be that any buffer storage might as well be laid out in order to get the best possible mixing effect.

To be a true pre-homogenization plant, however, the following conditions must be fulfilled:

1. The stacking and the reclaiming must follow a pre-laid program.
2. The storage capacity must correspond to at least one week's consumption.
3. The frequency of change of the reclaimed material must be much higher than the deadline of the grinding plant system, including the time for analysis.

The best pre-homogenization is obtained by depositing the material horizontally in a large number of thin layers, whereafter the heap is reclaimed end on in the thinnest possible slices by means of some kind of excavating device.

The installation costs are rather heavy because two storage heaps are required; one which is being formed, and one which is under reclamation each corresponding to about one week's consumption.

The plant is only suitable for large factories, and the reduction of the standard deviation in chemical composition that can be obtained by such a system, is of the order of 10 : 1.

The final proportioning of the raw materials can take place either at the entrance to the pre-homogenization plant, or at the entrance to the mill.

The first system requires the installation of rather complex and extensive sampling systems for lump sized materials, whereas if the raw materials are mixed in the mill, the control can take place on the basis of samples of raw meal taken after the mill. Such samples can be taken with much simpler and less expensive equipment, and with a good deal more accuracy.

When the proportioning is based on samples taken after the mill two procedures can be followed. One is the (so-called) tendency control, where you just try all the time to keep the raw meal composition right on the aim. This means that no attempt is being made to compensate for raw meal produced of incorrect composition, the only action taken is to try to bring the composition right back on the desired value. With the (so-called) integration control it is attempted to compensate for errors in produced raw meal by afterwards producing a corresponding quantity of raw meal with an error of opposite sign, so that the errors compensate each other. In other words, in this way you are not trying to keep the composition right on the aim at any one moment, but only as average values of larger quantities over longer periods. With integration control it is, therefore, strictly necessary to have a homogenization plant after the mill of a dimension and type which is adapted to the present homogenization job. You might also look upon the matter this way that the minimum storage capacity which in any case is needed between raw mill and kiln always ought to be planned so that it has as much homogenization effect as possible, in the same way as the intermediate raw material storage.

The most efficient raw meal control is obtained by using X-ray fluorescence analysis, preferably in combination with a process computer for calculation of analytical results and automatic correction of weighing feeder settings.

The reproducibility of a complete analysis is so good that you can expect standard deviations of about .5 for lime saturation and about 0.03 for silica modulus. The greatest advantage of the X-ray fluorescence analysis is the speed, as you can carry out a complete analysis, including sample preparation, in about 10-15 minutes, which corresponds more or less to the usual titration or carbonate determination.

If you have three raw material components available, it is possible by means of X-ray fluorescence analysis and a small mini-computer to run separate controls for, for instance, lime saturation and silica modulus and to keep the two variables within very close tolerances.

Such a well-controlled raw mix composition is the key to obtaining a regular kiln performance. There are many examples that a kiln, especially perhaps a short dry process kiln, which is fed with raw meal of constant composition, can be kept in balance for long periods without any intervention at all. The small variations that can occur for various reasons, say, varying radiation loss because of varying coating thickness can easily be compensated for by small adjustments of the kiln speed. The impulse to this adjustment can come from a two colour pyrometer, if the kiln is clear enough to obtain useful readings with such an instrument, or perhaps just from a measurement of the torque of the kiln motors or the motor current.

Regulations can be made by a mini-computer with a fixed programming, or perhaps even by a simple analogue controller.

Of other means being worked with to-day for automatic kiln control should be mentioned automatic free lime determination which can be made either by an automated wet chemical method or by X-ray diffraction.

The principle drawback of the method, although the actual analysis is very quick, is the very long time delay arising from the fact that a corrective or controlling measure can first be given when the materials have left the kiln or perhaps even the cooler.

The most popular kiln to-day, the four-stage pre-heater kiln, has the drawback that the cyclone pre-heater permits practically no escape of volatile components, such as sulphur, alkalis, and chloride. Due to the high burning zone temperature, a considerable volatilization of the volatile components takes place, and this results in very substantial internal circulations of alkalis, sulphur, and chlorides in the system, before the components finally leave with the clinker. This circulation may cause coatings in kiln and pre-heater, and it is therefore essential to limit the content of these components in the raw material to safe levels when considering the use of such a kiln system. To-day it is considered sound practice to limit the chloride content to 0.015, the total alkali content to 1%, and to keep the ratio $SO_3 : (K_2O + 0.5 Na_2O)$ at below 1.

Cement Grinding

Assuming a uniform clinker quality, the first condition to obtain a uniform cement quality is a reliable and well-controlled feed of clinker and gypsum. To-day, accurate weighing feeders must therefore be considered "a must". Intensive work is going on these years in order to develop automatic devices for on-line fineness determination of cement according to the permeability principle as well as according to the air separation principle, and it is to be expected that fully automatic cement mill control, where devices of the type mentioned via suitable regulators control the mill feed, or separator adjustment, will be common in a few years' time.

In addition, it is very important to keep a strict control of the temperature during the grinding process in order to check the dehydration of the gypsum. A too high grinding temperature will cause dewatering of the gypsum and induce tendency to false set in the cement, which in modern concrete technology is considered rather undesirable.

It is important to realize that it does not give enough security for avoiding false set that efficient cooling is arranged in the last compartment of the mill. A too high material temperature at any place in the mill can cause dewatering of the gypsum. Especially in large grinding mills, and in cases where hot clinker directly from the kiln is brought to the mill, it must be considered a necessity to arrange cooling in the first compartment of the mill, to ensure a satisfactory quality of the cement.

It is also worth remembering that a continued dewatering of the gypsum may take place during the storage of the cement, and, thus result in false set, lump formation, and also a reduction of the early strength of the cement.

The reason for the strength reduction is that the water liberated by the gypsum will be absorbed on the surface of the cement particles, where it reacts with the clinker minerals. In this way the cement grains are covered by a layer of reaction products, which reduce their reactivity, and, consequently, the early strength.

Certain other conditions may have as a result that this effect of migration of water can be different from cement to cement. For example, a certain high content of free lime will prevent lump formation and loss of strength, because the water liberated from the gypsum is being absorbed by the free lime. Free lime is, however, an undesirable part of cement, and an improvement of the storage properties of the cement should, therefore, rather be obtained by a more extensive dewatering in the mill, if this is possible without getting false set, or, which is the best solution, by cooling of the cement in a cement cooler after the mill.

It should be mentioned that also the content of potassium is important for the resistance of the cement to storage at high temperatures.

Part of the water liberated by the gypsum will enter into the compound syngenite, which is a calcium potassium sulphate. This double salt forms needle shaped crystals, which bind the cement grains together in lumps.

World Cement Standards

U.S.A.

The United States was the first country to introduce a classification according to strength as well as chemistry for Portland cements.

The next slide shows the well known five types of cement, according to ASTM C-150-71.

- Type I: Ordinary Portland Cement
- Type II: Moderate Low Heat & Moderate Sulphate Resisting
- Type III: High Early Strength
- Type IV: Low Heat
- Type V: Sulphate Resisting

Of special interest in this specification is the general 5% MgO limit, and the 6% C₃A limit for type V. The limits for SO₃-content which previously were unrealistically low have from 1970 been increased by 0.5%.

I should also call attention to the general 0.8% limit on autoclave expansion and the fact that tensile strength has been eliminated from the specification.

The cement is to be manufactured from ground Portland clinker exclusively the only additions permitted are water, calcium sulphate and very small proportions of grinding aids.

United Kingdom

The British Standards for Portland cement comprise:

- BS 12 for ordinary Portland and rapid hardening Portland cement
- BS 1370 for low heat cement
- BS 4027 for sulphate resisting cement

They follow the pattern of most of the ASTM specifications, but are especially interesting by limiting the lime content in all Portland cements, not only in the low heat types.

They are also interesting by giving the choice between two methods for determination of compressive strength. One is based on 1:3 cement:sand mortar cubes, the other on 1:2:4 concrete cubes. The latter method seems to be preferred by the concrete producers as the method is not only very reproducible but also shows good correlation with the strength obtained in practice.

The testing ages for the mortar as well as the concrete cubes are 3 and 7 days for ordinary, rapid hardening, and sulphate resisting cement; only the low heat cement is tested at 28 days.

Slides No. 6 and 7 show the main requirements of the British Standards for Portland cement.

USSR

In the Soviet Union, Portland cements are classified in four grades of ordinary Portland cement, according to strength, a rapid hardening, and a sulphate resisting/moderate heat cement.

The different requirements are shown on slide

West Germany

The latest German cement norm DIN 1164, 1970, represents an interesting trend

The Portland cements are divided into 4 strength classes, as shown on the next slide.

This new set of norms is remarkable in two ways by fixing a lower as well as an upper limit for the 28 day strength, and by fixing two different values of earlier strength, thus subdividing the PZ 850 and PZ 450 into two classes, a slow (I.) and a fast (F). I am inclined to believe that this represents the modern trend, enabling the consumers to select precisely the cement which is most suitable and economical for a given application.

From the producers' point of view this kind of norms has the advantage that it rules out the fierce competition on quality between cement makers, which has had the result that the type I cement sold in large parts of the U.S. market easily complies with the requirements for type III.

On the other hand, it does not rule out such competition that can be realised within the 200 kg limit between the lower and upper limits of a certain classification, and quite a few cement manufacturers see their advantage by keeping as close to the upper limit as possible.

The larger number of cement classes created by specifications as the new DIN 1164 does bring the producers into some what of a dilemma, as it is rather more difficult in a modern cement plant with perhaps only one production line to manufacture a large number of different cements. Not only the manufacture, but also the storage and distribution of the many types of cement can be rather costly and the trend seems to be to specialize in one or a few types only at each cement plant.

France

The French specification NF p 15-302 makes a distinction between "Portland cements without secondary constituents" and "Portland cements with secondary constituents". In the second category is permitted the addition of up to 20% of granulated blast furnace slag, fly ash, natural pozzolan, or up to 20% of a slag/fly ash or slag/pozzolan mixture. These cements with up to 20% additions are still considered Portland cements.

No French specifications exist for low heat or sulphate resisting cement, although cements corresponding to ASTM types IV (or II) and V actually are being manufactured in France.

It will no doubt, however, be possible almost everywhere in France to find a cement with additions of one kind or the other, above or below the 20% mark, which is suitable as either low heat or sulphate resisting cement, or both.

The French Portland cements are classified according to their 28 day strength as shown on slide 18.

ISO Standards

In 1968 the RILEM-Conbureau method of testing strengths of cement was accepted by The International Organization for Standardization (ISO) as ISO Recommendation R 679, together with definitions and terminology and chemical analysis.

Shortly the test specimens for the strength test are 40 x 40 x 160 mm prisms, made from cement and a graded standard sand in the proportion 1 : 3. The water : cement ratio has a fixed value of 0.5.

As far as I have been able to count 10 different countries are using the ISO R 679 method of strength testing in their national standards, and more are to follow. A similar number of countries are already using the 40 x 40 x 160 mm prismatic test specimens, but made from mortar with another composition, usually another water : cement ratio.

The tendency to adopt internationally standardized test methods has steadily grown in spite of the great difficulties which often have to be overcome. This is a useful development as it makes possible a more accurate comparison of cement standards than in the past. Despite such progress, however, it is necessary to treat such comparisons with caution, and it would certainly be incorrect to draw any inferences about the quality of cement produced in different countries without actual testing.

A question that comes naturally is of course this: How good is the ISO mortar test really? How well does it reflect the properties of the cement in its actual use, which is as a binder in concrete?

The VDZ in Germany has made a comparison between 3 testing procedures, using 28 different cements. The aim of the test was to establish how well the mortar strength test results satisfied the equation:

Concrete Strength = a + b x Mortar Strength.

The concrete had a water : cement ratio of 0.6 and contained 310 kg of cement per m³, and the following results were obtained:

Old German norms DIN 1164 - 1958	ISO	ASTM - C 109
B 0.85	0.81	0.50

Of these testing procedures the ISO is clearly the best. But would it not make more sense to standardize a test on concrete specimens, rather than mortar ones, as done in the British Specifications BS 12?

A comparison between the ISO test and the BS 12 concrete cube test has actually been performed by the ISO Technical Committee ISO TC/74 in 1966.

In the BS 12 test was used hand as well as machine mixing, and crushed aggregate as well as natural.

Within the same laboratory the reproducibility was on an average 3.5%. Best results reported were 2.5% obtained with crushed aggregate and machine mixing.

The corresponding reproducibility of the ISO test was 3.3%.

Between different laboratories the reproducibility was on an average 7.5%. Best results were obtained with natural aggregate and machine mixing (5.3%) worst with crushed aggregate and machine mixing (9.1).

The reproducibility of the ISO mortar test between laboratories was 9.4%.

The conclusion of this test is rather clear: Not only is the concrete test the more reproducible, but it also offers the advantage of eliminating the inevitable errors in transforming the mortar test strength to what matters in practice: The strength of the final concrete structure!

The future trend in cement strength testing will therefore hopefully be a test on concrete rather than mortar. Either a simple cube crushing test, or something more refined.

Although it has been possible to make a number of countries agree on standards for methods of tests the matter is rather different when it comes to standards for specifications, such as strength requirements etc. Attempts have been made indeed.

In 1965 a working group within the ISO/TC 74 prepared a proposal for international specifications for cement. Rather like the ASTM norms they were operating with "low heat cement", "moderate low heat", "sulphate resisting" and "moderate sulphate resisting" as the chemical classification, and the following two proposals for classification according to strength:

What has happened since to this proposal is not clear to me. Such a proposal for international standard specifications is bound to meet a lot of resistance, and perhaps for good reasons.

The desire of international standards for cement specifications seems mainly to originate from political circles because of the notion that uniform international regulations and standards for construction materials on line with the removal of tariffs and other economical barriers is a prerequisite for a free trade in this field. It should be pointed out that existing national standards for specifications have not so far created any difficulties for the international trade with cement. Two points should be borne in mind. Cement is an auxiliary material, which forms part of concrete, mortar etc. which are the essential products covered by standards and regulations for building materials. Through proper proportioning of the concrete it is possible to produce a concrete satisfying the minimum strength requirements from different cement qualities. International trading with cement is usually a trading with clinker, and it is the responsibility of the importing cement manufacturer to produce a cement from the imported clinker that will comply with the national norms of his country.

Although Portland cement as the product of a heavy industry is commonly considered a well defined article, there are nevertheless clear distinctions between the product from different factories. This is due to the remarkable fact that Portland cement - contrary to the products from most other heavy industries - retains certain peculiarities originating from the raw materials used. Also the process type and process equipment chosen give the product certain individual features.

These works - specific modifications of the properties of the cement are notably the time-strength relationship, but also such properties as colour and water requirement. It is thus very often the case that two plants with different raw materials may produce clinker which after suitable grinding produces identical 28-day strengths but show remarkable differences in early strength. Such differences are known to practically all countries and consumers as well as producers have learnt to accept them, in so much as they have only practical and economical consequences for the local consumer.

The functional properties of the final product for which cement is normally used, concrete, does not depend only upon the quality of the cement, but also upon other factors such as the aggregate, the mix ratio, the mixing plant, the pouring and compacting etc. For this reason it seems rather irrelevant to standardise the cement quality only among so many variables.

It should also be remembered that the functional requirements of concrete may vary considerably, due to different climates, soils, etc. An international standardisation of concrete quality may thus well lead to the use of too good and too expensive construction materials in areas where conditions are less demanding.

Returning to the cement, it must be admitted that by the addition of imported correction materials it may indeed be feasible to adjust the cement to international norms. But one of the fundamental reasons for the popularity of Portland cement is the very fact that it can be produced practically in any country from local raw materials, for which reason the import of correction materials to meet certain international standards would only mean an unnecessary increase of the cost of production, which will hardly be recovered in savings in the concrete production.

A proposal for international standards must, therefore, in order to have some chance of being accepted by the industry, be broad and accommodating enough to permit the producers in the different countries to continue their already established quality levels. Normally, international cement trading will be easier, but in reality nothing will be changed.

A practical consequence will be, however, that the value of the norm as a quality standard will suffer. In this connection it should be mentioned, though, that to-day's very knowledgeable cement consumers, notably the ready-mix people and the concrete element producers, are not at all happy if only a cement passes the minimum requirements of a certain norm. They want better cements and accurate information about the strength level of the cement actually supplied.

The other alternative, narrow and strict international norms, will probably only be of advantage to the producer lucky enough to have raw materials and process equipment resulting in cement properties which just happen to suit such norms.

In the long run it is to be feared that narrow international norms will only restrict a continued healthy development of cement qualities suiting the requirements of the users.

The tendency to-day in the ISO work is that while earlier ISO recommendations were taken from or strongly inspired by national norms, the organization is now aiming at directly preparing an international norm which should then afterwards be accepted as a national norm with as few modifications as possible.

The 6 countries in the Common Market have started negotiations concerning common cement standards. So far the negotiations have been proceeding very slowly and a general lack of motivation seems evident.

However desirable a liberalization of world trade is, one fact must not be forgotten: raw materials for cement production and aggregates for concrete production are natural geological deposits, and geological deposits are facts that you cannot change, facts you have to live with. I wish you all success in doing so!



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