Portland cements in building construction

Swenson, E. G.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40000791
Canadian Building Digest, 1972-01

Canadian Building Digest

Division of Building Research, National Research Council Canada

CBD 145

Portland Cements in Building Construction

Originally published January 1972

E.G. Swenson

Please note

This publication is a part of a discontinued series and is archived here as an historical reference. Readers should consult design and regulatory experts for guidance on the applicability of the information to current construction practice.

The firing of stone or clay to produce cementing materials for construction is as old as recorded history. The ancient binders - lime, hydraulic lime, gypsum and certain volcanic rocks (pozzolana) - are still in use, but today they are far overshadowed by portland cement, a highly sophisticated relative of hydraulic lime.

Portland cement concrete is by far the most widely used of construction materials (**CBD 15**) and its general versatility has been greatly extended through the development of a number of modified forms. The concrete used in Canada is largely in the form of the ready-mix product and still requires the last four important steps in manufacture: placing, compacting, finishing, and curing. The proper execution of these operations to achieve desired final properties requires specific technical knowledge of the performance properties of the ingredients - cement, aggregate, water, and admixtures. The nature and use of the several types of portland cement as related to Canadian conditions and practices are the subject of this digest.

Manufacture of Portland Cement

Raw materials required to give the correct composition of high quality portland cement are to be found almost everywhere. This is important in Canada where population and industry centres are separated by great distances. Because concrete aggregates also are to be found in most areas, cement and concrete are essentially "regional" materials available at relatively low cost.

Sources of raw materials for the manufacture of portland cement must provide for the two main components, lime (CaO) and silica (SiO_2), and for two secondary components, alumina (Al_2O_3) and iron oxide (Fe_2O_3). Lime is usually derived from limestones but may also be obtained from coral, chalk and marl. Silica is obtained from sands or shales, alumina from sands, shales and bauxites, and iron oxide from any of these materials, depending on composition, and from by-products of other industries. Because of the economics of using available materials, there are, inevitable, unwanted or undesirable compounds sometimes present. These are known better as minor components: magnesia (MgO), alkalis (Na_2O and K_2O), and trace elements such as phosphorus, titanium and manganese.

Suitable raw materials are separately analysed and proportioned to give the desired composition of the cement clinker when burned in the kiln. This composition, the same the world over, is determined by considerations of optimum burning properties, optimum cementing properties, and optimum soundness. The proportioned raw materials are ground in ball mills, and the resulting raw mix is analysed and then thoroughly blended by either a wet or dry process before being burned in the kiln. Firing is of great important because the chemical recombinations taking place in the semi-molten state must be complete or the cement will be unsound. In this firing process the alumina and iron oxide act as fluxing materials for improved chemical combination.

The clinker product is interground with gypsum (the latter added to regulate setting properties) to produce portland cement. Like the burning process, grinding is one of the important cost items in manufacture. Grinding aids are therefore used extensively to cut costs and improve degree of fineness.

The final portland cement product is anhydrous and must be protected from moisture and carbon dioxide if it is to retain its cementing action. Packaged cement, for example, requires tightly sealed moisture-proof bags.

Nature and Hydration of Portland Cement

The main cementing and strength-producing compounds formed in portland cement clinker are the calcium silicates $3CaO.Si)_2$ and $2CaO.SiO_2$.When mixed with water these anhydrous compounds hydrate, set, and slowly harden in the familiar behaviour of portland cement. Tricalcium aluminate, $3CaO.Al_2O_3$, in the clinker also forms a hydrate with water, but although it contributes to setting and early hardening properties it has undesirable attributes that will be discussed later.

Sand incorporated in a cement-water slurry produces mortar; when both sand and stone are present the product is concrete. These aggregates naturally reduce the cost of the final building material, but they are also necessary in reducing the proportion of pure cement paste, which has a high shrinkage characteristic.

Because water is an essential reactant in producing cementing hydrates and for the proper maturing (strength gain) of concrete, it is critically important to provide a thoroughly wet environment for as long as is practical - at least 6 days. If drying periods intervene early in the hydration process, the reaction is retarded seriously and later wetting does not compensate in full for early loss in strength. Curing is therefore very important to good quality concrete. The lowest possible water-cement ratio consistent with workability is required for maximum strength and durability. Excess water produces voids that reduce density and hence the strength of the cement paste.

Rate of hydration and therefore strength gain increase with increasing temperature, as for most chemical reactions. A set-retarding admixture is often used to modify setting time, especially in hot weather. An accelerator admixture, besides affecting setting time of concrete, is used primarily to increase rate of strength gain through increased rate of hydration.

Certain problems experienced with portland cement may or may not be readily prevented. False set is an abnormally early stiffening that can be worked out by subsequent mixing. It is, therefore, not a difficult problem in ready-mix operations where prolonged agitation in transit ensures a workable mix at the job site. It can be serious where the concrete is mixed on the job site. False set can usually be prevented by implant formulations and procedures. The phenomenon of pack-set, where the dry cement powder densifies in silos and bins and becomes hard and difficult to discharge, can be prevented by the use of certain additives during the grinding of clinker.

Types of Portland Cement

The rapid increase in sophistication of design and construction techniques and the greater attention to variations in regional and job conditions have created demand for modifications of certain properties of concrete. This has resulted in the development of several "types" of portland cement and a greater use of concrete admixtures (the latter described in **CBD 103**). These adaptations have had extensive use in the precast and ready-mix concrete industries.

The production of a different type of portland cement involves certain adjustments in the manufacturing process, mainly the selection of raw materials, chemical proportions, special additives, and degree of grinding. The inevitable increase in cost of these modified portland cements over the normal product is due partly to the above adjustments in manufacture and partly to additional handling and storage requirements in the plant.

Normal Portland

This is the standard product that adequately serves most concreting requirements, is the cheapest, and therefore by far the most widely used. Its composition and properties are determined by minimum quality standards such as CSA A5. Above these minima normal portland cements may vary considerably from plant to plant and still meet such specification requirements. Within a given plant changes in properties may occur, sometimes due to seasonal changes, sometimes to changes in quarried raw materials, and sometimes to small changes in burning.

High Early Strength and Precast Product Cements

As the name implies, high early strength portland cement achieves much higher strength than normal portland at early ages of one, three and seven days. At 28 days or later there is usually little difference, depending on the modification used in cement manufacture. High early strength cement is frequently used for such special situations as early removal of formwork, early application of load, special precasting procedures, and rapid maturing to aid in frost resistance of concrete (for the latter see **CBD 116**).

High early strength cement is achieved today mainly by extra fine grinding of the clinker-gypsum mixture. Frequently, the same clinker is used as for normal portland. In some cases, however, finer grinding must be supplemented by a change in chemical composition in favour of the faster hydrating compounds of tricalcium silicate and tricalcium aluminate. Both represent an increase in cost over normal portland.

When the clinker is ground to a fineness intermediate between that of normal portland and high early strength cement, a product of intermediate cost and intermediate early strength is obtained. On the market cements of this type are known by various names such as "concrete products cement" and "block-type cement." The main alternative to high early type cements is the use of an accelerator, calcium chloride, with normal portland.

Sulphate-Resistant and Low Heat Cements

These portland cement types are considered together because the change in their composition from that of normal portland cement is basically the same, although they were developed for quite different purposes: reduction of the component tricalcium aluminate. The composition of sulphate resistant cement is briefly discussed in **CBD 136**.

More portland cements, including those made in Canada, have a tricalcium aluminate content of about 9 to 15 per cent. It has already been noted that this compound contributes to early strength and in this context may be considered desirable. In both sulphate resistant cement and low heat cement, however, its presence is highly undesirable.

Tricalcium aluminate combines rapidly with sulphates in the early stages of portland cement hydration, forming products that result in a net expansion of the hardened cement paste. When sulphate concentrations are low, including the sulphate derived from the gypsum present in portland cement, there is no significant expansion. When sulphate concentrations are high, as in many soils and groundwaters of Western Canada, expansions become great enough to produce a breakdown of concrete when normal portland is used. Sulphate-resistant cements are specially manufactured with much lower tricalcium aluminate content and have been used successfully for some 40 years to combat sulphate attack. Specifications such as CSA A5 provide pertinent limits for this type of portland cement. Alternative or supplementary preventive methods include protective covering, drainage, and dense impermeable concretes.

The hydration of the tricalcium aluminate component of portland cements produces considerable heat (exothermic reaction). In most concrete elements the resulting temperature rise is small because the heat is dissipated rapidly from exposed surfaces. If moderate, it can be beneficial in speeding up hydration and maintaining reasonable temperatures for hydration in cold weather concreting. In mass concrete, on the other hand, the lower surface to volume ratio retards dissipation of heat and excessive internal temperatures may occur. Sharp temperature gradients may then result that produce cracking of the concrete. Generally, temperatures within the mass must be kept below about 130°F if trouble is to be avoided. Low heat cements are manufactured to yield lower tricalcium aluminate contents than does normal portland and are therefore similar in this respect to sulphate-resistant cements. Other compositional or physical factors may, however, require adjustment to avoid loss in early strength normally contributed by the tricalcium aluminate. No Canadian standard has been developed for low heat portland cement: specifications have been developed individually for jobs requiring this material.

Alternatives to the use of low heat cements for mass concrete or hot weather construction include pre-cooled concrete (usually by means of ice as a part of the mix water) or cold water circulated through pipes incorporated in the mass concrete. When available, pozzolanic materials or fly ash are used to replace a part of the normal portland cement in mass concretes.

As for high early strength cements, there are intermediate grades of sulphate-resistant and low heat cements, that is, cements in which the tricalcium aluminate component is reduced in manufacture to values between those for normal portland and sulphate-resistant cement. These are cheaper and are often specified as adequate for moderate sulphate conditions or for moderately massive concrete elements.

Low Alkali Portland Cement

When used as concrete aggregates some rock types are susceptible to what is known as alkali-aggregate reaction. This is a reaction between the alkali component of portland cement (sodium and potassium oxides) and certain minerals or rock types present in the aggregate. Although this reaction is always present because of the highly caustic solution in concrete, it becomes a problem if the degree of reactivity is so high that excessive expansion and cracking occur.

The most common preventive measure found to be effective is the use of a low alkali cement. Cements of this type are manufactured in Canada for areas where potential alkaki-aggregate problems are known to exist. Several alternative or supplementary preventive methods are also recognized, the main one being to design concrete structures subjected to this reaction in such a way as to minimize wetting (since a moist environment is necessary for the alkali-aggregate reaction to proceed).

Unfortunately, all Canadian portland cements (with one exception) are of the high alkali type, but one or more adjustments in manufacture, without changing raw materials, can be made to reduce the alkali contents to safe levels. Some moderate cost increase must be accepted. Standards such as the CSA Standard A5 have not yet included specifications to cover low alkali cements.

Cements Related to Portland Cement

In Canada and the United States masonry cement mortar has largely replaced lime and lime-portland cement mortars for masonry work. Most masonry cements are made by intergrinding approximately equal parts of normal portland cement clinker and limestone with the usual small proportion of gypsum for set regulation. During grinding, organic additives are used that provide for the workability and trowelling properties required of masonry mortars. As a consequence, mortars made with such masonry cements contain a high proportion of entrained air, which contributes to durability against frost action.

White portland cement is manufactured from specially selected raw materials and has properties similar to those of normal portland. Both it and white masonry cement are used for architectural purposes.

One recently developed cement is a "shrinkage-compensating" cement formulated in manufacture with expanding components that counteract the normal drying shrinkage property of portland cement. A portland slag cement is also being manufactured in Canada. Such products not only utilize a less costly component to replace part of the cement but also gain benefits such as greater resistance to sulphate attack and reduction in heat evolution.

Plant Quality Control, Tests and Specifications

In Canada the Canadian Standards Association Standard A5 for Portland is used. It imposes compositional limits to assure a properly burned clinker within the range of composition yielding a sound product. Depending on the type of cement, limits are placed on such components as tricalcium aluminate (C_3A), sulphur trioxide (mainly SO_3 from added gypsum) and magnesium oxide (MgO). Performance limits are imposed on physical properties such as setting time, specific surface, and compressive strength at several ages.

Such general specifications provide for test methods for cement. For plant quality control, testing must also be made at various steps in manufacture: for example, to determine raw mix composition and clinker composition. Limits for certain properties of frequent interest to the user of portland cement are not usually provided for in the general specification even though test methods and limits have been developed. False set and pack set belong to this category. Their occurrence is generally infrequent, but purchases of cement may require test data for such characteristics.

One important limitation of the general specification is that it does not provide for uniformity of properties. Either upper or lower limits are provided, but not both. Thus, two normal portland cements may each meet CSA A5 requirements but vary considerably in some properties. This is of particular concern to continuing operations such as ready-mix or precast plants. Uniformity of strength, for example, in ready-mix concrete mixes is difficult to achieve when fluctuations occur. The user of portland cement can, however, specify both upper and lower limits on those properties of special concern to him.

The type of portland cement and its various properties determine, in large measure, the performance of concrete in the plastic as well as the hardened state. Because in situ concrete is wholly or partly made on the job, it is essential that the authorities responsible for design and construction of a building have a good working knowledge of portland cement and its several modifications.