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Publisher’s version / Version de l'éditeur:
https://doi.org/10.4224/40000766
Canadian Building Digest, 1961-03

Canadian Building Digest

Division of Building Research, National Research Council Canada

CBD 15

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Originally published March 1961

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Please note

The extensive use made of concrete is proof of its outstanding characteristics as a construction material. It is such a familiar material that we take for granted the quite remarkable process by which cement and water mixed with a wide range of aggregate materials into a plastic mass are converted into a strong, durable material, in almost any desired shape on the job. The development of modern portland cements having a property of setting up quickly, even under water, began a little over a hundred years ago when the necessary basic raw materials for their manufacture, together with the required burning process, began to be recognized. Today many hundreds of highly qualified scientists and engineers throughout the world are continuously engaged in studies of these materials in attempts to understand them better and to improve them still further.

Many of the chemical and physical reactions which take place during the setting of concrete and subsequently are so complicated that they are still not fully understood. This is due in part to the wide range of chemical substances that can exist partly by design and partly by chance in any given concrete mix. Additional variations may be introduced in the methods of manufacturing, handling, and curing on the site. All of the changes that take place relatively rapidly in new concrete do not cease at the end of the formal curing period. Some may continue slowly over a long time and others may be initiated by elements in the environment to which the concrete is subsequently exposed. Despite all these complications, concrete of predictable properties and performance is regularly produced and used. This does not occur by chance.

Fortunately it is not necessary for the designer, specification writer, job engineer and materials supplier to keep in touch with the whole field of concrete technology. There are various guides to practice by way of manuals, codes, standards and specifications from such sources as the American Society for Testing Materials, the American Concrete Institute, and in Canada, the Canadian Standards Association and the National Building Code. But it is highly desirable if not essential to have some idea of the general nature of the material and its more important properties. This Digest attempts to provide such a picture.

The Concrete Mix

Concrete results from the combination of cement paste formed from cement and mixing water, with aggregate. Since cement is up to 10 times more costly than the aggregate it is desirable to use the minimum amount of cement for this reason alone. In standard, dense concrete it is necessary to have enough cement paste to fill the voids in the aggregate. Economy in use of cement is thus to be achieved by arranging the grading of the aggregate to produce a practical minimum of voids. But there is usually another reason for avoiding too much cement. All cement products undergo small changes in volume with changes in moisture content. Though small, these changes are very important since they may be considerably greater than the strains produced by normal loading. The dimensional changes in cement paste, however, may be as much as ten times those occurring in normal good concrete or in the aggregate itself. In a concrete made from a "rich mix" containing more cement paste than is necessary to fill the voids in the aggregate, the concrete takes on more of the shrinkage characteristics of the cement paste. Excessive cracking due to shrinkage often occurs in concrete floor toppings because excess cement has been added in a misguided effort to make them better.

The volume of voids in a sample of any aggregate of fairly uniform size is likely to be roughly 1/3 of the gross volume. The percentage of voids is roughly the same regardless of size. A commonly used proportion of cementing material to sand used in making mortars is 1 to 3. That is, one volume of cementing material is required to fill the voids in 3 volumes of sand. The same ratio would hold, roughly, for a coarse aggregate. If, however, the voids in a coarse aggregate are first filled with a fine aggregate the remaining voids in the combination will be reduced to 1/3 of 1/3, or 1/9 and the resulting mix will be 1:3:9 by volume. This is an over simplification of the basis for proportioning concrete mixes but it serves to illustrate the importance of grading of aggregate in the making of good concrete. Aggregate shape, gradation in aggregate size, total surface area of aggregate and considerations such as workability of the fresh concrete may call for adjustments in the amount of cement paste required and thus lead to necessary deviations from the rough 1 to 3 proportion indicated above for a two-component mix.

The proportion of water to cement, these two ingredients together constituting the cement paste, is of prime importance. The amount of water required in a normal mix is always much in excess of that required for the "hydration" of the cement in the attainment of its final form in the concrete. Much of the extra water which is necessary in practical mixes to make them workable will be lost as the concrete attains its final form. But the volume that the hydrating cement must eventually try to fill is predetermined by the volume of the paste. Thus it may be concluded that the final density of the hardened cement paste, and therefore several other important properties such as strength and porosity, will be determined by the ratio of water to cement used in the original mix. This has been found to be substantially the case and has led in turn to the use of water-cement ratio as an index of strength in the design of concrete mixes. The lower the water-cement ratio the higher will be the strength of the hardened paste and thus of the concrete. This explains the engineer's dislike of excess water in the making of good structural concrete and justifies his contention that good concrete is placed, and never poured; if it can be poured it will not be good concrete.

Setting and Hardening of Cement Paste

Portland cement is prepared from raw materials consisting in large part of calcium carbonate frequently in the form of limestone, and of aluminium silicates often suitably obtained in the form of clay. Marls containing both of these substances may often be used. An intimate mixture of the raw materials is burned at a clinkering temperature. The resulting clinker is then ground to a fine powder. The major constituents are lime, alumina and silica.

Distinct differences in properties of portland cement may be produced by suitable adjustments in chemical composition. There are available many types of portland cement having specified properties. These may be designated by descriptive names such as Ordinary, Rapid Hardening, Quick Setting, White, Low Heat and Sulphate Resisting or, as in the United States, by special designations such as the Types I to V used by A.S.T.M.

All the compounds present in portland cement are attacked or decomposed when brought into contact with water. A variety of products is formed, some of them only temporarily, to be converted later to others in the process of hydration. These products form, first at the boundaries of the grains of cement and as their development continues, the cement paste "sets" and later "hardens". Heat is released during this hydration process.

The setting of cement may begin in as little as 30 minutes and continue for several hours until a stage known as final set is reached. Special quick setting cements may achieve final set in as little as 30 minutes. The compressive strength of concrete made from ordinary cement takes longer to develop. It increases rapidly over a period of several days then more slowly over several weeks and may continue to increase slowly for many months. No simple guide to the rate of attainment of strength can be given since this can be varied over a very wide range by varying the water-cement ratio, and is influenced as well by cement type, and by curing conditions. It is a necessary part of the design of a concrete mix to arrange that the strength attained at various times will be appropriate to the requirements of the particular application. The stripping of forms and the application of load as construction proceeds must obviously be related to the attainment of sufficient strength by the time these various events occur.

Since the progress of hydration leading first to setting and later to hardening is dependent upon the presence of water it is necessary to keep concrete from drying out during the curing period. Suitable curing conditions may be ensured by keeping concrete damp by flooding, by spraying or by the application of wetted coverings for periods up to 7 days or in special cases to 14 days or more. Alternatively in some cases where it is suitable a curing compound may be applied to the surface. It forms an impermeable film which prevents drying out.

The process of hydration is very considerably retarded at low temperatures. In winter construction, special precautions by way of heating of materials before mixing, or the use of insulation or enclosures may be necessary to ensure the development of sufficient hardening by maintaining an adequate temperature for some time before exposure to freezing conditions. Advantage may be taken of the heat generated during the hydration process in the case of mass concrete which will keep the interior of a large mass warm for many days.

In summer, the heat of hydration may cause difficulties through the development of excessively high temperatures in mass concrete. Low heat cements may have to be used. In more extreme cases with massive structures such as dams, artificial cooling through pipes embedded in the concrete may have to be employed.

Properties of Cured Concrete

Fully hardened standard or dense concrete becomes stonelike in nature. In common with most stonelike materials its strength, in compression greatly exceeds its strength in tension, these often being in the ratio of 10 to 1. It is not therefore an efficient material by itself in resisting bending and tensile stresses,but can for such applications be combined with steel reinforcement. The reinforcement carries the tensile stresses while the concrete carries compression and serves to bind the whole assembly together. Fortuitously, the thermal expansions of ordinary concrete and steel are approximately the same and both of them exhibit approximately the same strains when loaded to their normal working stresses, so that they work well together. Special problems may arise in a few applications when these conditions are not obtained.

Concrete bas a tendency to shrink as it attains strength. These shrinkage strains are not insignificant and must often be reckoned with in design. There is a further tendency to shrinkage as concrete dries out. Cracks from this cause may develop months or even years after manufacture in the case of heavy sections which lose their excess water very slowly. This dimensional change due to drying can be reversed when the water content is restored. A further kind of shrinkage due to chemical reaction between carbon dioxide in the air and the cement, leading to carbonation adjacent to exposed surfaces, takes place still more slowly, requiring many years to penetrate as much as one inch into normal concrete. Under certain special conditions, this effect can aggravate shrinkage and cracking problems.

There is a variety of other circumstances involving unusual aggregate properties and sometimes involving unusual chemical reactions between the cement and the aggregate which can lead to abnormal dimensional changes. Many of these potential difficulties can be avoided by the application of various special tests which have been devised. New difficulties not previously identified can arise, but this occurs infrequently.

Excessive shrinkage of concrete masonry units can occur if they are used before the major portion of the curing and drying shrinkage has taken place. Many of these products are now autoclaved or steam, cured at the plant to accelerate the curing and shrinkage. Some masonry units are now being exposed to flue gases in a chamber at the plant in an attempt to reduce still further the amount of shrinkage that can occur on the job. The tendency to some degree of dimensional change is an inherent property of concrete, as well as of many other materials. Difficulties from this, however, can be avoided by realistic designs taking into account the nature of the materials, by care in the selection of adequately cured units and by attention to the moisture content at the time of laying. Units that are laid up wet will inevitably shrink when they dry to a more normal average moisture content characteristic of the exposure. By the same reasoning units delivered very dry could expand upon regain of moisture to a more normal working level but this is seldom a problem.

Lightweight Concretes

Standard or dense concrete is made from aggregates obtained from natural deposits of sand and gravel or from the crushing of stone materials, but a wide range of aggregates may be used in the manufacture of other types of concretes. The object in the use of these other aggregate materials is in most cases to produce concretes which are lighter in weight but still of sufficient strength for the intended purpose. Cinders, slag, foamed slag, expanded clays or shales, perlite, vermiculite, and even sawdust and other forms of wood waste, are being used. The extreme in light weight is represented by the foamed concretes in which bubbles of gas take the place of the aggregate. Strength and certain other properties may vary substantially from those of standard dense concrete, depending on the properties of the aggregate.

Durability of Concrete

It is the quality of the hardened cement rather than the aggregate which will in the first instance determine the durability of concrete under severe or aggressive environmental conditions. If the paste is dense and occupies all possible voids around the aggregate, water will be able to enter only very slowly, if at all. This is a big step in achieving durability since both cement and aggregate will thus be protected from contact with chemical agents in the environment.

The more common of the chemical agents which give rise to degradation of concrete in Canada are the sulphates. These may be present in some open waters in concentrations likely to be significant, but are more often to be found in serious proportions in the soil or in the soil water. Good, sound, dense concrete is usually able to provide good service under moderate sulphate conditions, and the time for a given degree of degradation. may be greatly extended in the case of more severe conditions by the use of sulphate-resistant cements.

Durability under freezing and thawing conditions is not guaranteed by density and impermeability in the concrete. These proper ties are desirable since they are usually accompanied by superior strength, and they serve to limit the entry of the water which is a necessary companion to freezing in the case of freeze-thaw breakdown. It has been found that dense paste can be vulnerable to repeated freezing when wet, but that its resistance can be increased many times when air is introduced or entrained during mixing to create a pattern of tiny, loosely spaced bubbles throughout the mix. Air-entraining agents can be added in small quantities at the time of mixing or can be incorporated in the cement during manufacture. It is the close spacing of these air bubbles rather than their size which determines the degree of protection, so that the percentage of air in the mix is not alone a good index of the suitability. The air content required for good protection has relatively little effect on other desirable properties and since the tiny air bubbles are totally enclosed in the cement paste they do not add to the permeability in any significant way, and are not in conflict with practices designed to produce impermeable concrete. The presence of the proper amount of entrained air, properly distributed in the paste, will do more to improve the durability of a concrete of normal quality under freeze-thaw conditions than will moderate changes in any of the other pertinent factors that determine its general suitability.

Some of the characteristics of concrete which have been discussed can create problems. The same can be said for all other materials. Many problems can be avoided, usually without much difficulty, at the design stage provided that the designer knows his material. The same may be said for the manufacturing and construction stages. There is an extensive literature on almost every aspect of concrete through which the story which has been given can be expanded and extended.