COMO OBTENER CONCRETO DURABLE*

por

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RESUMEN

El concreto se comportará tal como se desee en los edificios, puentes, compuerta diques, pavimentos para campos aéreas, carreteras, estructuras para estacionamiento embarcaderos, rompeolas, revestimientos, etc., siempre y cuando tenga los nivele apropiados de las propiedades relevantes. El concreto tendrá estos niveles si l especificaciones bajo las cuales es elaborado son las correctas y si se siguen al pie de letra. Esto podrá llevarse a cabo si el control de la calidad por parte del contratista y confirmación de la calidad por el propietario, funcionan como deben. Ellas serán l correctas si cubren los niveles necesarios de las propiedades de los materiales, l proporcionamientos requeridos para las mezclas y las prácticas de construcción empleada para llevar a cabo el trabajo. Los niveles de las propiedades de los materiales, l proporcionamientos de las mezclas y las prácticas de construcción serán correctament seleccionados y especificados si se posee el conocimiento adecuado y se usa pa relacionar el comportamiento del concreto con los factores relevantes del medio ambient de servicio, para la vida útil que se pretenda. Al seleccionar estas características se deb tomar en cuenta el cambio tolerable y el intolerable en el concreto en una estructu particular en un lugar de servicio dado. En resumen, si el concreto no se comporta com se desea, es porque las especificaciones no eran las correctas o porque no se siguiero adecuadamente: porque no se ordenó lo que se debía o porque lo que se ordenó no se llev a cabo.

Este trabajo es acerca del concreto, específicamente del concreto fabricado co cemento hidráulico. Si se empieza con el polvo seco, que es el cemento hidráulico; menudo, de la clase particular de cemento hidráulico conocido como Portland; y se añad agua, da por resultado, dependiendo de la cantidad de agua añadida, una pasta de cement o lechada; esta última puede ser usada como salsa. Si se añade agregado fino, resultado es un mortero o lechada arenosa. Si se añaden agregado fino y grueso resultado es concreto. Como escribió alguna vez la Suprema Corte de Pensilvania sob una decisión relacionada con las plantas manufactureras de cemento," el cemento es pa el concreto como la harina al pastel de frutas". Mi primer propósito es, obtener el concret apropiado y la terminología correcta. No hay nada mejor como la mezcla de cement Además, arena no es un sinónimo de agregado fino, ésta es una clase de agregado fi producido por la naturaleza y no por trituradores o molinos de roca.

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HOW TO OBTAIN DURABLE CONCRETE*

by

Bryant Mather

ABSTRACT

Concrete will perform as desired in buildings, bridges, locks, dams, airfield pavements, highways, parking structures, wharves, piers, revetments, and so on-if it has the appropriate levels of relevant properties. It will have such levels if the specifications under which it was produced are proper and if they are followed. They will be followed if the quality control by the contractor and the quality assurance by the owner function as they should. They will be proper if they cover the levels of the materials properties needed, the proportions required for the mixtures, and the construction practices used in carrying out the work. The levels of the materials properties, the mixture proportions, and the construction practices will all be properly selected-and specified-if adequate knowledge is available and is used to relate performance of concrete to the relevant factors in the environment of service for the intended service life. In making these selections, due account must be taken of what is tolerable and intolerable change in the concrete in a particular structure in a particular location of service. In short, if concrete fails to perform as desired, it is because the specifications either were wrong or were not followed: either what should have been ordered was not, or what was ordered was not delivered.

This paper is about concrete, specifically, hydraulic-cement concrete. If one starts with the dry powder that is hydraulic cement-usually the particular class of hydraulic cement known as portland cement-and adds water, what results, depending on the amount of water added, is cement paste or grout; grout can be poured like gravy. If fine aggregate is added, the result is mortar or sanded grout. If both fine aggregate and coarse aggregate are added, the result is concrete. As the Supreme Court of Pennsylvania once wrote in a decision dealing with cement-manufacturing plants, "cement is to concrete as flour is to fruitcake." My first point is, to get proper concrete, get the terminology right. There is no such thing as a cement mixer. And sand is not a synonym for fine aggregate; sand is a class of fine aggregate produced by nature rather than by rock crushers and grinding mills.

Having dealt briefly with terminology, I will now provide the procedure for obtaining concrete that has the desired performance. It is, simply, to include the relevant

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requirements in the contract documents and ensure through proper contractor qualit control and proper owner quality assurance that the requirements of the specifications ar followed. In fewer words, order the concrete that you need and make sure that you ge it.

DEVELOPMENT OF HARDENED CONCRETE PROPERTIES

Bob Philleo, in 1986, described the fundamental features of concrete. The followin is paraphrased from his papers (1, 2). For concrete to stiffen, harden, and develo strength, there must be a chemical reaction between the constituents of the cement an the mixing water. This reaction causes the anhydrous calcium silicates in the cement t be converted into calcium silicate hydrate (CSH), the cement gel or hydrated cement. Th critical feature of this reaction is that if the ratio of the volume of water to the volume c cement is 1.2, then all the water and all the cement can combine and all the original mixing water-filled space can be filled with hydration product. A water-cement ratio (w/ of 1.2 by volume is 0.4 by mass. If the w/c is higher than 0.4, even if all the ceme hydrates, there will always be some residual originally mixing water-filled space that ca hold freezable water. If the w/c is lower than 0.4, then some of the cement will alway remain unhydrated but, in theory, all the originally mixing water-filled space could be fille with hydration products. There is a misconception, often stated, that it only takes th amount of water in an 0.2 w/c paste to hydrate all of the cement. This is based on th fact that only 0.2 units of water by mass chemically combine with cement durin hydration. However, for a given volume of cement to hydrate there must be an amou of originally mixing water-filled space equal to 1.2 times the volume of the cement. Th is because the hydration product has about 30 percent pore space that must be prese and water must be available to fill it. If the amount of originally mixing water-filled spa is less than that provided at a w/c of 0.4, not all of the cement can hydrate, even thou only half of that water will go into chemical combination.

A lot of modern "high performance" concrete made at w/c's well below 0.4 by ma will not, in fact, have all of the originally mixing water-filled space filled with hydratio product. This is because the part of the mixing water that ends up in the gel por undergoes a 10 percent reduction in volume because the pores are so small and the wat is adsorbed. Philleo's 1991 discussion goes into the implications of the fact that addition water may enter while test specimens of very low w/c concrete are curing in th laboratory but such externally available water will not get very far into larger masses field concrete even if it is made available. It is worth noting that even though I am a we known as an advocate of membrane curing for field concrete, I put in the Americ Concrete Institute (ACI) standard for curing concrete (ACI 308-81) Section 3.2.2 that th use of liquid membrane-curing compounds should not be approved "when the concrete h a water-cement ratio of 0.4 or less."

In these comments there may have been the implication that something is desira about hydrating all the cement in a concrete mixture. If the w/c is higher than 0.4, th the more of the cement that hydrates, the larger the proportion of the originally water-fill

space that gets filled, the higher the strength, and the lower the permeability. Therefore, if the concrete needs all the strength and reduced permeability that it can get, then the longer it is kept moist, the closer it will come to having all its cement hydrated and the greater its strength and impermeability will be. There are, however, at least two possibly undesirable consequences of a concrete having all of its cement hydrated and becoming as strong as it can become. First, if there is no remaining unhydrated cement, then there can be no autogenous healing of microfractures as water enters and is available to react with unhydrated cement to accomplish the healing. Second, if the concrete is as strong as it can possibly become, it will have a higher modulus of elasticity, be more brittle, and crack at a lower strain level. Reduced strain capacity-both elastic strain and creep strain-is not a desirable property in a lot of concrete. As Philleo put it:

> "The desirable magnitude of creep is an issue on which practitioners have not agreed. Structural engineers find it a nuisance they could easily do without.... On the other hand, builders of unreinforced mass concrete structures find creep an indispensable property of concrete.... Creep redistributes stresses... permitting highly stressed regions to shed some of their stresses to low-stressed regions before cracking occurs... [Mass Concrete] structures could not survive if concrete behaved elastically." (1)

I was tempted to paraphrase more of this story but I refrain. I suggest that those further interested in concrete read Philleo (1, 2).

CLASSES OF DETERIORATION

Very little concrete fails to provide the desired level of performance because its mechanical strength is intrinsically insufficient. Indeed, as noted earlier, one of the undesirable things that can happen to concrete is that, by getting too strong, it can also get too brittle and have an undesirably low-strain capacity before fracturing. Consequently, the efforts to achieve the desired performance should be those that avoid the problems generally comprehended under the subject "durability."

I have spent a great deal of time over a good many years explaining to people that concrete has no property called durability. Any concrete, no matter how unsuitable for use in many environments, will be completely durable in some environment. I have argued that any concrete that is strong enough to resist the loads to which it will be subjected in service will also be durable in that service, regardless of all other considerations, if it is allowed to get dry and stay dry. Dry in this context means that the evaporable water is allowed to and does escape, and the internal relative humidity drops below 80 percent under which conditions there are no longer any chemical reactions that can take place and there is no water that can freeze. Earthquakes and possibly fire could damage such concrete, of course, but generally speaking, the resistance to earthquakes comes under the heading "if it is strong enough" and the damage due to fire is much lower in concrete that is dry than in concrete that is not.

We may thus explore durability as it relates to concrete with the assumption that the concrete that we are talking about is being used in an environment in which rarely, if ever, are the structures allowed to get dry and stay dry. However, we should remember that if we have any such structures, we are in a fortunate position with respect to the steps we need to take to achieve satisfactory performance.

I suggest classifying the causes of deterioration of concrete into two categories. The first category includes those causes of damage in which the cause acts on the concrete, causes the damage, and then ceases to act usually for a very long time or forever. These causes include earthquakes, tornadoes, hurricanes, fire, and lightening strikes. Once a gasoline truck has burned up on a pavement, the damage done to that concrete by that fire is the damage that can be discovered by simply examining the affected structure. Any concrete that has not been damaged by that influence is not going to be damaged by that event subsequently. Therefore, from the standpoint of maintenance and repair, if what has been damaged is repaired, that which is undamaged will never be damaged by whatever brought about the need for the repair.

The second, more difficult class of deteriorative influences includes all of the mechanisms that, when recognized as having caused damage to some concrete in service, are of such a nature that the prudent conclusion is that much more of the concrete may be expected to be damaged unless it can be protected from the processes that caused the initial damage. In this class are those concretes that are unable to resist freezing and thawing or chemical attack (especially sulfate attack); those concretes that have been produced of materials that contained the seeds of their own destruction such as aggregates of inadequate volume stability, unsound cement, and unfortunate combinations of alkali-reactive aggregate and high-alkali cement or high-alkali solutions from the environment; and those concretes whose structures contain unprotected reinforcing steel with inadequate cover over the steel and an excess of substances that promote corrosion in the environment. All such damage may be expected to be progressive unless there is a way to stop it. This line of reasoning yields the conclusion that a very important purpose of the investigation of damage, distress, deterioration, and failure is to have a clear appreciation of the causes. This is essential in establishing whether the causes were permitted to work because of a defective specification or the failure to follow a proper one, which is relevant to issues of liability. It is also essential to planning a proper repair or replacement strategy. And it is essential to one's overall strategy in preparing proper specifications for future work.

The way to obtain satisfactory concrete is to know what to avoid and to take proper steps to avoid it. The art of knowing what to avoid means matching up the intended environment of service with similar environments in which concrete has performed less well than desired and knowing what interrelationship of environmental stress and concrete deterioration produced that less-than-desired result. There is sufficient available knowledge, summarized perhaps best in the 1992 report of ACI Committee 201 (3), that we need not go back to square one. The ACI committee report takes up the problems of durability of concrete in chapters dealing with freezing and thawing; aggressive chemical exposure including sulfate attack, acid attack, and carbonation; abrasion; corrosion of embedded metals and other materials; and chemical reactions of aggregates. The report also includes two more chapters which address the repair of concrete and the use of protective barrier systems to enhance concrete durability, respectively.

I will talk no further about repair practices, but I would say in passing that although protective barrier systems can function beneficially-especially if by some means one can cause some concrete to become dry and the barrier can be applied in such a manner as to cause the concrete to stay dry-then if the concrete is afflicted with a defect that would make it nondurable in service and it can be caused to become dry and stay dry, it may very well survive for a long time in that environment. However, most concretes that are vulnerable to damage in service have difficulty getting dry, and if they do dry, it is difficult to keep them dry by sealing them because one cannot seal all six sides: top, bottom, front, back, left, and right. Some bridge decks appear to be the exception to this rule. In most other concrete structures at least the bottom in contact with moisture.

Let me now comment briefly on the several classes of phenomena potentially harmful to the durability of concrete as they are dealt with in the ACI 201 report.

<u>Freezing and Thawing</u>

I recently summarized what I thought I understood about the resistance of concrete to freezing and thawing in a paper entitled <u>How to Make Concrete that Will be Immune to the Effects of Freezing and Thawing</u> (4). The content of this paper is not in conflict, I think, with what ACI Committee 201 says; however, I approach it from a slightly different point of view. I point out, rather obviously, that concrete will be immune to the effects of freezing for several reasons: (a) if it is not in an environment in which freezing and thawing takes place so as to cause water in the concrete to freeze; (b) if, when freezing takes place, there are no pores in the concrete large enough to hold freezable water; (c) if any pores that can hold freezable water, they are less than 91 percent filled at the time of freezing; or (d) if pores that can hold freezable water are more than 91 percent full, the cement paste has a proper air-void system, sound aggregate, and moderate maturity. In the extensive work of Paul Klieger, moderate maturity was discovered to exist if the combination of w/c and cement hydration has proceeded so that the concrete has developed a compressive strength of about 30 MPa (4,000 psi) before it is allowed to freeze and thaw in a critically saturated state. Sound aggregate is the kind of aggregate that when used in concrete containing a proper air-void system in the paste, which is allowed to get moderately mature before freezing, gives frost-resistant concrete as can be measured in the laboratory using ASTM C 666 Procedure A. A satisfactory air-void system in the paste is one that is characterized by having an air bubble located not more than 0.2 mm (0.008 in.) from anywhere.

As far as I am aware, there is essentially no place in the world today where concrete is needed that is likely to be critically saturated when exposed to freezing and thawing for which sound aggregates cannot be obtained and the concrete cannot be protected against freezing and thawing while critically saturated until it is moderately mature, and for which