

circumstance precludes using an appropriate amount of proper air-entraining admixture so as to produce concrete with a satisfactory air-void system. Some of us feared that we might be in a situation in which we could not produce concrete with a satisfactory air-void system using roller-compacted concrete, which is of considerable interest especially for paving in military reservations. However, recent work (5) has made it clear that adequately frost-resistant concrete can be made even at the levels of harshness and dryness that characterize concrete suitable for roller compaction.

AGGRESSIVE CHEMICAL EXPOSURE

Sulfate Attack

The Corps of Engineers' requirements (6) for taking account of sulfate in the environment say that if the level of water-soluble sulfate in soil or dissolved in fresh water expressed as SO_4 is less than 0.1 percent or 150 ppm, respectively, no precautions are necessary. If the amount of sulfate is between 0.1 percent and 0.2 percent in soil, or 150 and 1,500 ppm in water, the attack is considered moderate and the appropriate precaution is to use Type II moderately sulfate-resisting cement in which the calculated C_3A , tricalcium aluminate, content is 8 percent or less. If Type II cement is not economically available, an equivalent degree of sulfate resistance can usually be obtained by using blended cement made with pozzolan or granulated blast-furnace slag or by adding a proper amount of ground slag or an effective pozzolan such as fly ash or silica fume. Finally, if the sulfate content is higher than the larger values just mentioned, the level of protection should be proportionately greater and will be achieved by using either Type V highly sulfate-resistant cement in which the C_3A content must be kept to 5 percent or less. If such cement is not economically available, a proper amount of an appropriate ground slag or pozzolan can be used.

It is interesting to note that much work has indicated that if the permeability of the concrete is reduced, either by adhering to a lower w/c or by adding ground slag, the amount of C_3A in the cement can be allowed to rise. The Corps of Engineers now permits up to 10 percent calculated C_3A if the w/c of the concrete is kept below 0.45 and the concrete is permanently submerged in sea water.

Another relevant recent development is a performance test that will properly evaluate the sulfate resistance of a cementitious material or blend of such materials. This is ASTM C 1012, which involves fabricating mortar bars and storing them in water until they develop a specific degree of maturity and thereafter immersing them in a standard sulfate solution. The sulfate resistance of the cementitious material is regarded as adequate if the expansion of the mortar bars remains below 0.1 percent. This limit has been adopted in the new performance-based ASTM specification for blended hydraulic cements (ASTM C 1157).

Acid Attack

Besides sulfate attack, other aggressive chemical exposures involve acid and CO_2 . Concrete in most structures is not likely to be exposed to acid very often or very severely. If I were making this talk 10 or 15 years ago, I would warn against the hazards to concrete bridge piers that might result from the establishment of an industry upstream that released strong acids into the water, but clean water laws make this much less likely today. There are cases in which acid from coal mine drainage can cause rivers and streams to have very low pH, in which case it would be better if there was no structure made out of concrete that came into contact with the acid. The Corps of Engineers was asked to build a dam where the so-called water in the reservoir was said to have a pH as low as 2.0 except after a heavy rain when it went up to 2.4. Nobody suggested making concrete that would be intrinsically resistant to this exposure; instead, we worked on developing an organic coating that would keep the acid from coming into contact with the concrete.

Carbonation

The effects of exposure to concrete of CO_2 in the atmosphere and the resulting carbonation of the concrete appear to be the current scare phenomenon in concrete technology. People have noticed for a century or more that, after some years of exposure in the first few millimetres below the surface, the cement paste in hardened concrete typically no longer contains calcium hydroxide but calcium carbonate. It has been assumed, correctly, that this represents the reaction of CO_2 from the air with calcium hydroxide in the cement paste to produce calcium carbonate. The carbonation of the cement paste in concrete lowers the amount of calcium hydroxide that is available to replenish the aqueous phase of that concrete with calcium hydroxide in solution to maintain saturation, and hence, a pH of about 12.6 which is, of course, the normal and desirable circumstance from the standpoint of preserving embedded steel from corrosion. Much nonsense has been perpetrated largely by people who oppose the use of ground slag and pozzolans in concrete; they have argued that such use consumes some of the calcium hydroxide that would otherwise be present and is needed to keep up the pH and prevent corrosion of steel. The other argument has been that one ought to use pozzolans for converting the otherwise useless and to some extent undesirable calcium hydroxide-or, as they would call it, free lime-to beneficial CSH with the concomitant reduction in the amount of soluble calcium hydroxide that could go into solution, be carried to the surface through cracks, exit the cracks, and produce ugly efflorescence. In my judgment, both of these arguments are without practical merit and have little theoretical justification. It would take a great deal of activity to produce an aqueous phase in concrete of even modest quality that was not a saturated solution of calcium hydroxide considering the great excess of calcium in portland cement beyond that needed to make CSH of all the silica in the cement plus all of the available pozzolanic silica at the normal ratios of cement to pozzolan in high-quality structural concrete. To avoid efflorescence, one should provide appropriate drains so that water does not pass through cracks in walls and bridges and deposit calcium hydroxide that later carbonates.

Abrasion

The third chapter of the ACI 201 report deals with abrasion. This subject is a very important one in transportation because probably more concrete in the world is subject to abrasion in transportation uses than in any other class of use. When concrete is less resistant to abrasion than desired, sometimes unsafe surface textures develop that create severe hazards because the pavement is nonresistant to skidding.

ASTM has developed several tests to evaluate the degree to which concrete is worn away by rubbing and friction; however, it is important to separate the things that are relevant to one class of structure from those relevant to another. The wearing away of the top surface layer of a very smooth industrial floor under vehicular or other traffic and the consequent production of dust that can harm manufacturing operations is quite different than the wearing away of the texture of a pavement surface. Similarly, the issue of the relative resistance to wear of the mortar portion of the concrete and the coarse aggregate portion becomes very important to skid resistance. It has been necessary and effective to use a special abrasion-resistant coarse aggregate so that if the surface mortar skin is removed by abrasion, the coarse aggregate will continue to protrude above the base level and provide a skid-resistant surface.

The ACI 201 recommendations suggest that almost all the good practices in concrete production benefit the improvement of abrasion resistance of the surface, especially practices that reduce segregation and the consequent development of a thicker-than-desired layer of mortar at the surface, avoiding bleeding that may cause the surface mortar to have a higher-than-intended w/c and avoiding finishing procedures that bring up more fines or take place at an undesirable time. Obviously, one cannot develop an abrasion-resistant concrete surface unless the concrete at that surface is allowed to develop its potential strength and, hence, abrasion resistance. Thus, a major factor in producing abrasion-resistant concrete is the quality of the curing.

Section 3.6 in the ACI 201 report deals specifically with wear on concrete resulting from tire chains and studded snow tires. It says that studded snow tires have caused widespread and serious damage even to high-quality concrete. It adds "fortunately the use of studded snow tires has been declining for a number of years," and it specifically calls attention to the NCHRP Synthesis 32 (7).

Corrosion of Metal

It is my guess that more concrete that has failed to provide satisfactory service for its intended service life because of premature deterioration from interacting with its environment, especially over the last couple of decades, has done so because the precautions taken to prevent corrosion of the reinforcing steel turned out to be inadequate. I have gone on record several times to the effect that all that is needed to prevent corrosion of the steel is a 50-mm-thick (2-in.) cover of high-quality concrete over the steel and appropriate measures to control concrete cracking. This approach usually works with

massive constructions such as bridge piers, dry docks, wharf structures, and off-shore structures. However, this has not been the case with highway bridge decks and superstructures and parking structures. People who design bridge decks, or at least who did in the past, often failed to provide decks thick enough that the required reinforcing steel could be put in place and still have 50 mm (2 in.) of good concrete over it. Thin, strong bridge decks are preferred because they have less deadweight and are more aesthetically pleasing. We need to take extra precautions to protect steel from corrosion if we must live with thin reinforced concrete structures in environments of high potential for materials corrosion; these include highway bridge decks that are deiced with chloride-based chemicals and parking garages in which slush caught under vehicle fenders melts and runs out onto the floor as water with a rather high chloride concentration. We should not, however, in the process give up the effort to make the concrete that we do have high-quality, low w/c, properly cured concrete. What we do is one or both of two things, and some recent experiences have suggested that where the need for protection is great, it is prudent to do both. These two measures are as follows: (a) use properly prepared, thermally bonded epoxy coatings on the reinforcing steel, and (b) use corrosion-reducing chemical admixtures such as calcium nitrite. I believe that in nearly all cases of serious risk of corrosion, either of these solutions by itself will be completely satisfactory if the potential benefits are realized. However, it has become apparent that structures do exist where their owners believed that they were using properly protected epoxy-coated steel when, in fact, the steel put into the structure corroded very quickly. I have not heard recently of an owner who believed that his or her reinforced concrete was protected by a chemical admixture and was not, but I am sure I will someday. Then one should consider the use of lightweight concrete with which, for the same deadweight, one can have greater cover over the steel. Alternatively is the option using up to 30 percent less concrete to achieve a 25 percent reduction in deadweight by using stronger concrete, 60-MPa (8,700 psi) concrete, rather than 35-MPa (5,000 psi) and concrete and external prestressing.

There has been much debate on the issue of how much chloride should be allowed to be present in the concrete at the time it is produced. We are now, of course, aware that in addition to the intentional use of calcium chloride as an accelerator to assist in producing early strength in concrete, there is chloride to some degree in other admixtures used for other purposes. Chloride is present in some cementitious materials, and chloride can be present in sea-dredged aggregates, as are used in several places, notably England and Japan, and in certain limestones that are used as concrete aggregate in the United States far from the seacoast. There is also chloride in some mixing water. If one is using epoxy-coated steel or calcium nitrite, it shouldn't matter how much chloride is in the concrete as made. If neither of these precautions is taken, it might matter a lot.

The question of whether it is ever prudent to assume that none of the measures that I have mentioned will be satisfactory and to install cathodic protection for the steel at the time the structure is built is, I think, still undecided. This may be wise in some cases, but I expect that they are few and far between.

Chemical Reactions of Aggregates

Tom Stanton, of the California Department of Transportation (although they didn't call it that then), discovered alkali-silica reaction in 1940 (8, p 54 ff). I went to work for the Concrete Laboratory at the Corps of Engineers in August 1941. Word of his discovery had already reached that laboratory, and one of the first bits of work I did was looking at "siliceous magnesian limestone," which was described as the offending ingredient of concrete that had deteriorated. At that point the Corps of Engineers was quite concerned because, to us, magnesian limestone meant dolomite, and dolomite was a very widely used as aggregate in Corps of Engineers structures. Our position had been that most limestones were satisfactory but substantially all dolomites were. It turned out that the siliceous magnesian limestone that caused the trouble in California is an almost unique rock that contains a lot of opaline chert. As far as I know, no other dolomite in the world contains enough opaline chert to cause trouble.

The Ninth International Conference on Alkali-Aggregate Reaction on Concrete took place in July 1992 in London in the Queen Elizabeth II Conference Center across the street from Westminster Abbey; several hundred people attended from essentially everywhere in the world. Aggregates that were not previously regarded as reactive are now shown to be reactive when used with cements of higher alkali content than they had been used with. Cements in many parts of the world are now of higher alkali content than they used to be, partly because more of them are made using raw materials containing relatively large amounts of alkali (such as all of the cement in Iceland for which all of the calcareous raw material is sea shells dredged from the ocean) and partly because of the capture of kiln dust and its insertion into the product. With regard to this last point, I am told that some farmers must buy substantial amounts of potash fertilizer because the cement plant upwind is catching the kiln dust that used to go out its stack and putting it back into the cement, to the detriment of both the cement and the farmer.

Alkali-silica reaction involves a series of events. A reactive aggregate is one that contains silica, SiO_2 , in a form that is capable of being dissolved by pH solutions substantially higher than the 12.6 pH that characterizes the saturated calcium hydroxide solution that is normal in concrete. Either the cement contains enough sodium or potassium so that the pH is raised when the cement hydrates and these ions go into solution, or the alkalies come in from the outside they raise the pH. In any event, the pore fluid in the concrete gets to be high enough in pH to dissolve the silica and produce an alkali-silica gel that has the property of taking up water, swelling, expanding, and disrupting the concrete.

If the circumstances are such that any problem that might be brought about by alkali from the environment can be ignored, then, in many cases, all that is necessary is to invoke the specification option for cement and require the use of low-alkali cement when reactive aggregate must be used. This requirement means that the cement will not be allowed to contain more than 0.60 percent alkalies calculated as the percent Na_2O plus 0.658 times the percent K_2O . If low-alkali cement is not available, then equivalent

protection can usually be provided by using an appropriate amount of an acceptable ground slag or pozzolan; the acceptability being based on tests by ASTM C 441.

There is also an alkali-carbonate-rock reaction which has been found in a number of structures, especially some in Illinois, Indiana, Iowa, Michigan, Missouri, New York, South Dakota, Tennessee, Virginia, and Wisconsin. Not all such reactions are deleterious. Sometimes the reaction simply takes place, and a small portion inward from the outer surface of an aggregate particle is altered so that when one slices through the concrete and acid etches the sawed surface, the aggregate particle develops two levels of etching. Sometimes the interior is more acid soluble than the rim, and sometimes it is less acid soluble than the rim; in either the case the fact that the rim is on crushed stone particle is evidence that a reaction that took place in the concrete.

The way to avoid harmful alkali-carbonate-rock reaction is to use nonreactive aggregate or to figure out a combination with low-alkali cement. The ACI committee report recommends a value less than 0.60 percent Na_2O equivalent.

CONCLUSIONS

To obtain durable concrete, it is necessary to:

1. Decide what sorts and levels of imperfections are tolerable and intolerable,
2. Understand what causes imperfections that are intolerable,
3. Evaluate the environment in which the concrete is to serve to recognize the presence of influences that must be resisted if the concrete is to perform as desired,
4. Prepare specifications that require appropriate levels of relevant properties of concrete so that the concrete can resist the deteriorative influences it will encounter in service, and
5. Ascertain that both the contractor's quality control and the owner's quality assurance systems work to ensure that the concrete produced is as specified.

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ODMALLA AGREGATE REACTION DIRECTA EN EL CONCRETO

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Synopsis: In this paper it is intended to show the Alkali-Aggregate Reaction State of the Art which is a very important aspect in concrete structures durability. How a dangerous subject is becoming more and more important due to the increase of durable structures affected by this reaction as well as more aggregates are being submitted as potentially reactive ones. In this paper, some additional facts are obtained in the laboratory and in the field. Mechanisms of reaction are explained in a general way, as well as factors which influence its development. For example, alkali content in concrete and potentially reactive aggregates etc. Main effects of this reaction in concrete are mentioned according to the strength which affects structures safety and durability. Some measures to avoid the reaction and its effects are also mentioned.