MCC CEMENTITIOUS DURABILITY STUDY

Literature Search Summary

"It is almost a rule in concrete making that whatever improves one quality is likely to hurt other qualities."

What is Concrete Durability?

Durability of hydraulic-cement concrete is defined as its ability to resist weathering action, chemical attack abrasion, or any other process of deterioration. Durable concrete will retain its original form, quality and serviceability, when exposed to its environment.

Concrete durability is largely dependent on the ease with which either or both liquids and gasses enter into move through the concrete. This is commonly referred to as the permeability of concrete.

Principles Responsible for Concrete Deterioration

The principal causes responsible for deterioration of concrete structures are the corrosion of reinforcing steel, exposure to cycles of freezing and thawing, alkali silica reaction and sulfate attack. In each of these four cases of concrete deterioration, water is implicated in the mechanisms of expansion and cracking. Also, water is the primary vehicle for the diffusion of aggressive ions (e.g., chloride and sulfate) into the interior of the concrete.

Once the watertightness of concrete is lost, the interior of concrete can become saturated. Consequently, water and ions which play an active role in process of deterioration can now be transported readily into interior.

If the hydroxyl ions in the cement paste are being leached away and replaced by chloride or sulfate ions, the calcium silicate hydrate will suffer a loss of adhesion and strength.

With an increasing proportion of cement paste, the concrete's extensibility (crack resistance) would decrease because of increase in both drying shrinkage and thermal shrinkage. At the same time, an increase in strength will tend to increase the elastic modulus and reduce the creep coefficient which would also have an adverse effect on the concrete extensibility. This is the reason why high early-strength concrete mixtures are generally more prone to cracking than moderate or low strength concrete mixtures.

It is not the strength but the soundness (freedom from cracking) of concrete under service conditions that plays an important role in assuring watertightness and durability.

We should require the use of blended portland cements containing large amounts of fine particles of relatively less reactive materials, such as slag and fly ash.

<u>Is Concrete Less Durable today</u>?

Cement has changed.

The change of greatest practical interest was the increase in 28-day strength at a fixed water-cement (w/c) ratio. The main reason for this was a large increase in the tri-calcium silicate; on average this was from about 47% in 1960 to about 54% in the 1970's. This change was made possible by improvements in the manufacture of cement.

This change resulted in a reduction in cement content for a given specified strength, earlier form removal and faster for construction.

In 1974, concrete with a characteristic strength of cubes of 4700 psi required a w/c of 0.50. In 1984, the same cube strength could be achieved using a w/c of 0.57. Designers continued to specify the same characteristic strength so that concrete producers could take advantage of this change in the 28-day strengths by changing the mix proportions. They had to maintain the same workability and therefore, the same water content in gallons per cubic yard, but they could lower the cement content of mix. This could be reduced by 100 to 170 lb/yd^3 of concrete. The concomitant increase in the w/c was between 0.09 and 0.13.

Even if it was not widely known then, we all know now that concrete with a higher w/c and lower cement content has a higher permeability. The 28-day strengths remain the same, but the concrete had lower durability.

The rapid early gain of strengths means the form work could be removed earlier so that effective curing caused at an early age.

Gary Brenno

Gary would batch concrete with me by placing all the aggregate in the mixer first and then we would mix a cementitious slurry separately at a prescribed w/cm. We would then add as much slurry as needed to the mixer to obtain a workable mix. Our goal was to determine our total cementitious materials needed to have a workable mix. Thus limiting our total paste yet have the paste used have the most cementitious material as possible. Thanks to this literature search I get it now, Gary.

Strength alone cannot be used as an indicate of durability.

It is also important to note that the cement content as such does not control durability. It does so only in so far as it influences the w/c at a given workability. Moreover, considering reliance on a minimum cement content, it should be remembered that this value applies to a unit volume concrete whereas durability depends largely on the properties of the hydrated cement paste. Thus, it is the cement content of the paste that is relevant.

Keeping both the water cementitious contents as low as possible and the aggregate content as high as possible provides one way to reduce both the drying and thermal shrinkage, and the related cracking.

Have You Met Mr. Ternary?

Twelve years ago I was at a meeting with several people and they were talking about a Ternary Mix. I assumed the fellow that designed the mix had a last name Ternary. I made the mistake of asking Gary Brenno who this Ternary guy was anyway. About a week later Kevin MacDonald called me up and asked me if I had met Joe Quadri.

The following graphs and charts demonstrate how Ternary mixtures are advantageous in increasing durability.

Ozyildirum's Work

Detwiler's Work

The use of supplementary cementing materials is clearly more effective than lowering the w/c from 0.50 to 0.40 in improving the resistance to chloride-ion ingress.

Concrete containing both ground granulated blast furnace slag and silica fume offer particular good resistance to chloride-ions. Silica fume reduces the permeability of the transition zone around the aggregate particles as well as the permeability of the bulk cement paste. In relative terms the influence of silica fume on permeability is much greater than on compressive strength.

The positive effect of silica fume on the chloride-ion penetrability of the concrete is mainly due to the fact that the incorporation of such material in the concrete results in finer pores in the hydrated cement paste.

When both fly ash and silica fume are used the synergetic effect of both materials on chloride-ion penetrability of the concrete, in which the silica fume decrease the chloride-ion penetrability at an early age and the fly ash decreased it at later age, results in a concrete with very low chloride-ion penetrability at both 28 and 120 days.

Increasing the resistance of concrete to penetration of chloride-ion is a "first line of defense" in increasing the service life of concrete structures.

Through its combination with calcium, potassium and sodium hydroxides to produce calcium silicate hydrates. Fly ash reduces permeability, thereby reducing access by aggressive chemicals, oxygen, and moisture.

Corrosion

Steel in concrete is usually protected against corrosion by high pH of the surrounding cement paste. Uncarbonated cement paste has a minimum pH of 12.5, and steel will not corrode at the pH.

If pH is lowered (e.g., pH 10 or less) corrosion may occur. Carbonation at the cement paste can lower pH to levels of 8 to 9 and corrosion may ensue. When moisture and a supply of oxygen are present, the presence of water-soluble chloride-ions, above threshold levels of 0.2% (0.4% calcium chloride) by mass of portland cement can accelerate corrosion.

Protective oxide film on the steel due to the alkaline environment. Chloride-ions can destroy this protective film.

Curing

Permeability is reduced by good curing because of increase hydration of the cement. If the concrete dries out the hydration products can be altered. Some gel pore water is lost and this tends to increase the average size and continuity of the capillary pores.

ACI recommends at least 7 days of uninterrupted moist curing or membrane-curing should be specified. Prevention of the development of excessive early thermal stress is also important.

Curing should be detached from the general item of concrete placing, and paid for by the consumption of water, or by man hours or some other way.

The intent of this summary was to extract the concepts from the literature that will help MCC 's Cemetitious Durability Study. A complete catalog of all the original work is available upon request from MCC.