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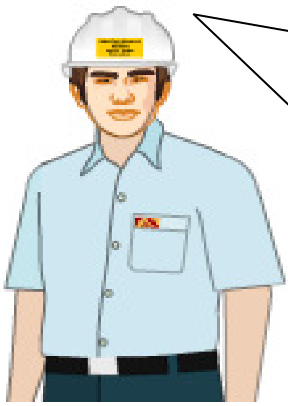


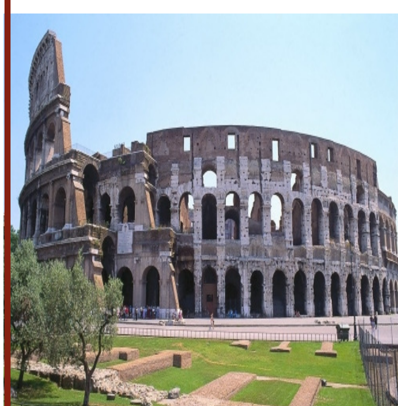
Dear Reader,

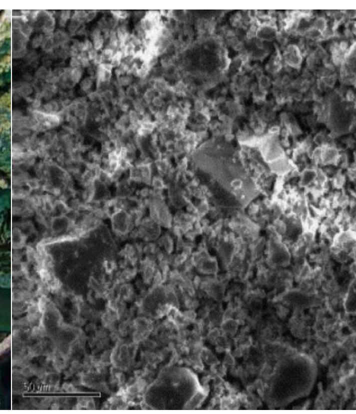
Welcome to the Technical Mailer from UltraTech Cement Ltd. Every issue carries an article related to Concrete & Construction that we feel would be of value to our clients.

Billions of rupees are being spent every year on repair of concrete structures. The repairs are necessitated as the structures failed to perform adequately during its service life. This is basically due to the ingress of harmful chemical substances into the concrete thereby effecting its Durability.

This issue is about **'Effect of Pore structure on Durability of Concrete'**.

We hope you find the mailer informative and useful. ***Happy Reading!!***





Issue Highlights

- *Concrete Pore structure and its Types*
- *Pore structure of Interfacial Transition Zone*
- *Factors influencing Pore structure*
- *Transport Process*

Introduction

Concrete is one of the most widely used basic construction material for all types of constructions through out the world; and is far more produced than any other manufactured material because of its versatility and other attributes. Of all the numerous positive attributes of concrete, Durability is probably one of the most important.

Initially Concrete was regarded as having an inherently high durability, but in recent past, there is threat to the durability and longevity of concrete structures as they are built in highly polluted urban and industrial areas, aggressive environments, harmful sub-soil water in coastal areas, and other hostile conditions.

Concrete durability depends largely on the ease with which fluids in the form of liquid (Water/acids), gas (Carbon dioxide, Oxygen) or Ions (Chlorides, Sulphates) can enter the hardened concrete mass. The durability is influenced or controlled by permeability which in turn depends primarily on the number, type, size and interconnectivity of pores present. Macro-Pores - voids of 50 microns (0.05 mm or more in diameter), are detrimental to strength and impermeability whereas Micro-pores - voids smaller than 50microns, are connected to drying shrinkage and creep. Therefore understanding the characteristics of the pore structure and permeation properties of concrete is very essential to improve the durability of concrete.

Concrete Pore Structure and its Types:

The properties of concrete are affected by the manner in which the pores of various sizes are distributed within it. The major cause of durability related problems in concrete is its Permeability/Porosity. Concrete with the same total pore volume can exhibit entirely different properties, depending on whether it contains a small number of large pores or large number of small pores. Concrete is inherently a porous material and its pore structure is complex and inhomogeneous. The pore structure of cement paste close to aggregates at the Interfacial Transition Zone is different from the bulk of the Cement paste's pore structure. The fine and coarse aggregate particles in concrete may have their own pore systems, which might be completely different from the pore system of the cement paste. Pores when interconnected create fine capillaries. The various types of pores that are present in concrete include:

1. Pores in the Hydrated Cement Paste (HCP)
2. Water filled capillary voids
3. Pores in Interfacial Transition Zone (ITZ)
4. Pores in the aggregates
5. Voids due to construction deficiencies, e.g., Honeycombing due to poor compaction

The hydrated cement paste is produced when cement chemically reacts with water which contains C-S-H gel, crystals of calcium hydroxide $Ca\ (OH)_{2,}$ minor residues of unhydrated cement and water filled spaces in the fresh paste. There are four types of pores in the hydrated cement paste.

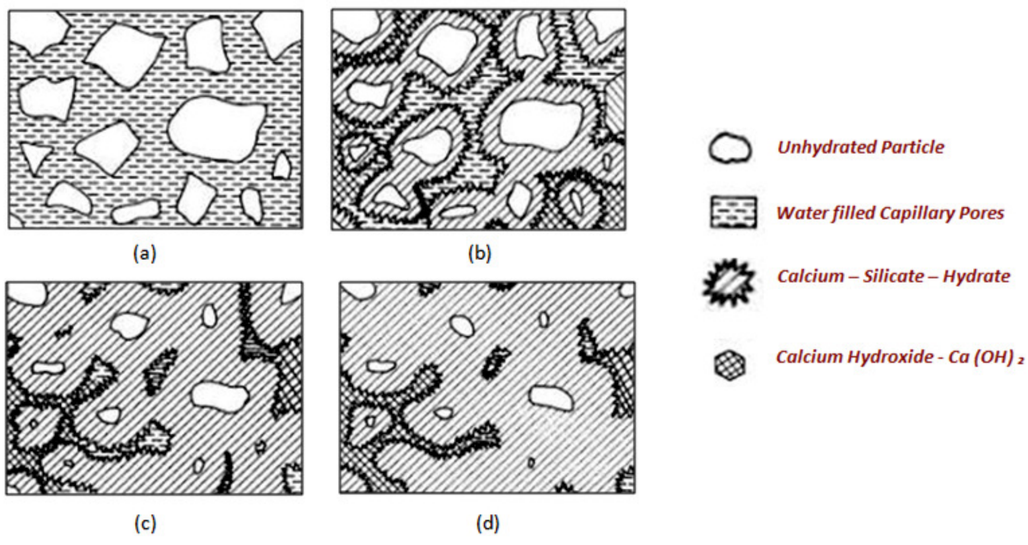
1. Gel pores: These pores do not contribute significantly to the flow of water through concrete due to its low pore size and hence don't cause water permeability. However they may contribute to drying shrinkage and creep.
2. Capillary Pores: Capillary pores are the spaces not filled by solid components of the HCP. These pores influence the permeability of concrete. The low water/ cement ratio pastes result in smaller capillary voids and high water / cement ratio pastes, at early ages of hydration result in larger capillary voids.
   In a well constituted, adequately compacted and cured concrete with low water-cement ratio, volume of capillary pores get reduced and become discontinuous due to expansive hydrated gel, which significantly reduces the permeability and hence enhances the durability. The following table shows that water/cement ratio greater than 0.5 requires longer curing time for capillary discontinuity and hence it should be below 0.5 to ensure durability of concrete.

water/cement ratio by mass	Curing time required for Capillary discontinuity
0.4	3 days
0.45	7 days
0.5	14 days
0.6	6 months
0.7	1 year
>0.7	1 year

w/c ratio vs. Curing time for Capillary discontinuity

3. Hollow-Shell Pores: These pores are closed distinct pores, which are formed from the original cement boundaries, and their size ranges from 1 micron to 15 microns. At low water/cement ratios, they can be larger than the capillary pores by more than two orders of magnitude.
4. Air Voids: These are due to either entrapped air during casting or intentional entraining of air by using an air-entraining admixture. The entrapped air cavities may be as large as 3 mm and the entrained air voids may range from 50 microns to 200 microns. They are much bigger than capillary voids and have a significant role in the permeability of concrete.

Fig 1 shows the schematically the sequence of pore structure formation in Hydrated Cement Paste as the hydration proceeds. This involves replacement of water that separates individual cement grains in the fluid paste (Fig. 1(a)) with solid products of hydration. The hydration products owing to their low specific gravity compared to cement (2.0 for Hydrated Products and 3.2 for Cement) occupy a greater volume than the original cement compounds and thus forms a dense matrix. The hydration products also bind the residual cement grains together over a period of time, as shown in fig 1(b) to 1(d).



Schematic diagram of pore structural development in Hydrated Cement Paste.

(a) Initial mix (b) 7 days (c) 28 days (d) 90 days

Pore structure of Interfacial Transition Zone (ITZ)

A water film formed around the aggregates in the fresh compacted concrete and bleed water collected underneath flaky coarse aggregates causes local increase in water/cement ratio close to them. As a result concrete becomes more porous close to the aggregates and therefore the properties of transition zone significantly affect the permeability of concrete.

Factors influencing the Pore structure

The main factors influence the pore structure of concrete are:

- Water/cement ratio
- Degree of hydration
- Use of supplementary cementitious materials
- Use of chemical admixtures
- Curing conditions

Typical pore refinement (reduction in permeability) with progress of hydration is shown in the following table:

Age (days)	Co-efficient of permeability (x 10^{-11} cm/sec)
Fresh	20,000,000
5	4000
6	1000
8	400
13	50
24	10
Ultimate	6

Reduction in permeability with progress of hydration

Use of blended cements influences the Pore structure of concrete and the concrete becomes impermeable and durable. In addition to the type of cement, age of concrete will also influence the pore structure of concrete. The volume of pores would be less with use of blended cements. The pore structure of Hydrated Cement Paste and hence the concrete largely depends on the water/cement ratio and the degree of hydration. The higher the water/ cement ratio for a given degree of hydration, the higher will be the volume of larger pores in HCP.

The use of supplementary cementitious materials, such as fly ash (Pulverized Fuel Ash), Ground Granulated Blast Furnace Slag (GGBS) and Micro silica refine the pore structure of concrete by producing additional C-S-H gel due to secondary reaction which fill the pores. The addition of superplasticisers significantly improves the pore structure of concrete by aiding proper consolidation and hence densification. Research findings have demonstrated that the inclusion of super plasticizer decreased the total intruded pore volume of HCP.

Adequate and proper curing of concrete is essential to ensure expected field performance of concrete structures. It is not only recognized as important to minimize evaporation of the mixing water but also provide a source of external or internal curing water to replace that consumed by chemical shrinkage during the hydration of the cement.

Transport Process (Permeability)

The concrete durability depends largely on the resistance it offers to fluid, gas and ion penetrations such as water, carbon dioxide, oxygen and salts from its service environment into and through its matrix. As concrete is a porous material, the transport of these substances can occur by ***capillary suction driven flow (absorption), concentration driven flow (diffusion), or pressure driven flow (permeation)***. The overall potential for the ingress of the substances into concrete by these three modes is referred to as its permeability.

Factors influencing the Transport process (Permeability):

→ Constituent Materials: Water content, Cement/Supplementary Cementitious material content, Aggregate size, shape, type and quantity, Admixtures used.

→ Method of Preparation: Mixing, Method of casting, Compacting, Trowelling.

→ Subsequent treatment: Curing.

→ Interdependence of Porosity, Pore size and strength.

Conclusion:

The Pore structure is one of the important parameters to be considered to enhance the Durability of Concrete. The durability of concrete is affected by the ingress of moisture, gases or chemical through various transport processes. The key to enhance durability is by refining the pore structure, to make concrete impermeable by controlling the w/c ratio, use of supplementary cementitious materials/blended cements, use of less porous aggregates, following the proper methods of manufacturing concrete and by giving subsequent care like curing to the concrete. Types of Pores and variations in the sizes of pores in hydrated cement paste / concrete, pore structure characteristics of cement based materials, environmental factors such as temperature and moisture variations also play a vital role in governing the transport process and the durability of the structure.

Attention should be given to the above mentioned factors to obtain durable, long lasting concrete structures which perform satisfactorily under the designed environmental conditions.

References:

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3. *'Hand book on Repair and Rehabilitation of RCC Buildings' - Published by Director General (Works), Central Public Works Department, Government of India, Nirman Bhawan – 2002.*

Our future Issue will elaborate on

"Deterioration Mechanism in Concrete and Preventive Measures"