4.8 PROPERTIES OF DURABILITY

4.8.1 WATER ABSORPTION

- The water absorption is determined by measuring the decrease in mass of a saturated and surface-dry sample after oven drying for 24 hours.
- The ratio of the decrease in mass to the mass of the dry sample, expressed as a percentage, is termed absorption.
- The assumption that oven-dry aggregate in an actual mix would absorb sufficient water to bring it to the saturated and surface-dry state may not be valid.
- The amount of water absorbed depends on the order of feeding the ingredients into the mixer and on the coating of coarse aggregate with cement paste.
- Therefore, a more realistic time for the determination of water absorption is 10 to 30 min rather than 24 hours.
- Moreover, if the aggregate is in an air-dry state, the actual water absorption will be correspondingly less.
- The actual water absorption of the aggregate has to be deducted from the total water requirement of the mix to obtain the effective water/cement ratio, which controls both the workability and the strength of concrete.

4.8.1.1 Understanding Water Transport Mechanisms in Concrete

- Moisture migration into concrete is the leading cause of concrete degradation.
- There are two primary water transport mechanisms in concrete.
- Considering water's powerful forces and then designing concrete structures to adequately resist the known effects of these two common water transport mechanisms is paramount to achieving durable structures.

- Designers, contractors, and owners need to thoroughly understand the differences in the mechanisms to ensure the structures they are building provide adequate problem-free service life.
- The two mechanisms listed by the magnitude of the challenge they impose are:

1. Capillary absorption

- Permeability
- Ignoring, or more commonly misunderstanding, this of the mechanisms provides the greatest threat to concrete leads to structures that fail to perform long-term and eventually will lead to structural failure.
- Most degradation processes encountered by concrete require water, dissolved chemicals, and the presence of oxygen.
- Dissolved salts (chlorides) or other deleterious chemicals can be rapidly transported to the steel reinforcement imbedded in the concrete through the capillary network.
- The resulting initiation of corrosion causes rebar to expand, breaking up the concrete it is embedded in.
- Additionally, in cases where water has permeated through a concrete substrate, it may damage building interiors. In each case, the presence of water is detrimental.

Rapid Deleterious Chemical Absorption through Capillaries

- As mix water required for concrete placement leaves concrete, it leaves behind a ***Porous capillary structure***.
- Capillary absorption is the primary transport mechanism for water in concrete structures.

- Capillary absorption is so powerful and rapid that it requires no pressure to function and creates far more damage potential than any of the other transport mechanisms.
- "The speed of capillary absorption is on the order of 10-6 m/s – a million times faster than pressure permeability."
- "***Capillary absorption*** is the primary transport mechanism by which water and chlorides infiltrate concrete" and that "clearly permeability is not a good indicator of resistance to chloride penetration".
- In often repeated studies and experiments, even extremely dense concrete mixes with high compressive strengths, low water cement ratios, and excellent pressure permeability readings rapidly transport water through capillary absorption.
- To ensure durable concrete it is absolutely essential to adequately address capillary absorption as the designer's primary duty.
- Permeability is the movement of water due to a pressure gradient, such as when concrete is under hydrostatic pressure.
- Performance under hydrostatic pressure is a simple function of concrete density, or cementitious content.
- Concrete's naturally dense matrix, (of even moderate quality mixes) provides an extremely difficult environment to push water through even under high pressure.
- The water pressure gradient encountered by a concrete structure is rapidly diminished by the resistance created by its relatively dense matrix.
- Concrete neutralizes the pressure gradient within the concrete very quickly and then capillary action once again becomes the primary transport mechanism and moves the water further into the structure.
- Fortunately, this transport mechanism is the least threatening, and is inexpensive to mitigate.

- Most designers overcome this challenge economically by simply increasing cementitious content (Portland cement, fly ash, slag, silica fume) or reducing the water/cement ratio to make it more difficult for water to be forced through concrete.
- Relatively small amounts of cementitious material may be added (for a small additional cost) to dramatically enhance concrete permeability performance.
- Although ***Diffusion*** is not a primary water transport mechanism it an excellent indicator of how deleterious materials can move through concrete structures.
- Chlorides can penetrate concrete by diffusion, which is the movement of chlorides in solution from an area of high concentration of chlorides to an area of lower concentration.
- Chlorides facilitate corrosion of steel reinforcement, which ultimately degrades concrete.
- Water has long been associated with deterioration processes affecting masonry materials.
- Its presence within the interior pore structure of masonry can result in physical destruction if the material undergoes wet/dry or freeze/thaw cycling.
- The latter is particularly damaging if the masonry material has high clay mineral content. Perhaps of greater importance is the fact that the presence of moisture is a necessary precondition for most deterioration processes.

4.8.2 PERMEABILITY

- Permeability is the ease with which liquids or gases can travel through concrete
- This property is of interest in relation to the water-tightness of liquid- retaining structures and to chemical attack

- Although there are no prescribed tests by ASTM and BS, the permeability of concrete can be measured by means of a simple laboratory test but the results are mainly comparative.
- In such a test, the sides of a concrete specimen are sealed and water under pressure is applied to the top surface only.
- When steady state conditions have been reached (and this may take about 10 days) the quantity of water flowing through a given thickness of concrete in a given time is measured.
- The water permeability is expressed as a *coefficient of permeability, k, given by Darcy's equation*
- The water permeability is expressed as a *coefficient of permeability, k, given by Darcy's equation*

$$\frac{1}{A}\frac{dq}{dt} = k\frac{\Delta h}{L}$$

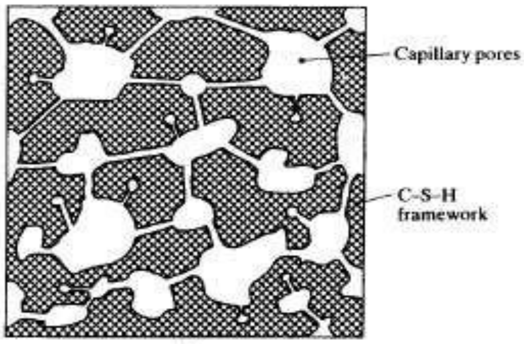
- where — is the rate of flow of water, *dt*
- *A is the cross-sectional area of the sample,*
- *Ah is the drop in hydraulic head through the sample, and*
- *L is the thickness of the sample.*
- The coefficient *k is expressed in m/sec or ft/sec.*

OTHER TESTS

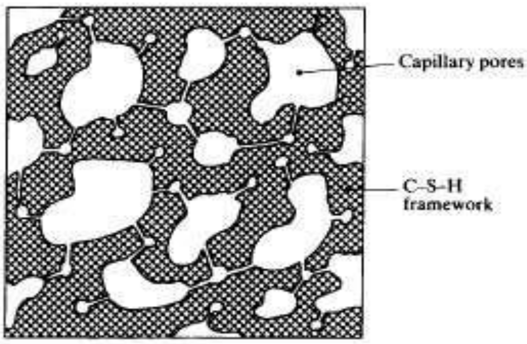
- ***INITIAL SURFACE ABSORPTION*** (BS 1881-5: 1970)
- Rate of flow of water into concrete per unit area, after a given time, under a constant applied load, and at a given temperature. This test gives information about the very thin 'skin' of the concrete only.

- Permeability of concrete to air or other gases is of interest in structures such as sewage tanks and gas purifiers, and in pressure vessels in nuclear reactors. Equation is applicable, but in the case of air permeability the steady condition is reached in a matter of hours as opposed to days.
- We should note, however, that there is no unique relation between air and water permeabilities for any concrete, although they are both mainly dependent on the water/cement ratio and the age of the concrete.
- For concrete made with the usual normal weight aggregate, permeability is governed by the porosity of the cement paste but the relation is not simple as the pore-size distribution is a factor.
- For example, although the porosity of the cement gel is 28 per cent, its permeability is very low, viz. 7×10^{-16} m/sec), because of the extremely fine texture of the gel and the very small size of the gel pores.
- The permeability of hydrated cement paste as a whole is greater because of the presence of larger capillary pores, and, in fact, its permeability is generally a function of capillary porosity.
- Since capillary porosity is governed by the water/cement ratio and by the degree of hydration, the permeability of cement paste is also mainly dependent on those parameters.
- For a given degree of hydration, permeability is lower for pastes with lower water/cement ratios, especially below a water/cement ratio of about 0.6, at which the capillaries become segmented or discontinuous.
- For a given water/cement ratio, the permeability decreases as the cement continues to hydrate and fills some of the original water space, the reduction in permeability being faster the lower the water/cement ratio.
- The large influence of segmenting of capillaries on permeability illustrates the fact that permeability is not a simple function of porosity.

- It is possible for two porous bodies to have similar porosities but different permeabilities,
- In fact, only one large passage connecting capillary pores will result in a large permeability, while the porosity will remain virtually unchanged.
- From the durability viewpoint, it may be important to achieve low permeability as quickly as possible.
- Consequently, a mix with a low water/cement ratio is advantageous because the stage at which the capillaries become segmented is achieved after a shorter period of moist curing.



(a)



(b)

- For normal weight concrete intended to have a low permeability when exposed to any type of water, the water/cementitious material ratio should be less than 0.50
- A maximum permeability of 1.5 x 10"" m/sec (4.8 x 10"" ft/sec) is often recommended.

- So far we have considered the permeability of cement paste which has been moist cured.
- The permeability of concrete is generally of the same order when it is made with normal weight aggregates which have permeability similar to that of the cement paste, but the use of a more porous aggregate will increase the permeability of concrete.
- Interruption of moist curing by a period of drying will also cause an increase in permeability because of the creation of water passages by minute shrinkage cracks around aggregate particles, especially the large ones.
- Permeability of steam-cured concrete is generally higher than that of moist-cured concrete and, except for concrete subjected to a long curing temperature cycle, supplemental fog curing may be required to achieve an acceptably low permeability.
- While a low water/cement ratio is essential for the concrete to have a low permeability, it is not by itself sufficient.
- The concrete must be dense, and therefore a well-graded aggregate has to be used, which can have a low water/cement ratio but a high permeability through passages outside the cement paste, as in the case of porous pipes.

4.8.3 SULFATE ATTACK

- Concrete attacked by sulfates has a characteristic whitish appearance, damage usually starting at the edges and corners and followed by cracking and spalling of the concrete.
- The reason for this appearance is that the essence of sulfate attack is the formation of calcium sulfate (gypsum) and calcium sulfoaluminate (ettringite), both products occupying a greater volume than the compounds which they replace so that expansion and disruption of hardened concrete take place.

4.8.4 CHLORIDE PENETRATION

- Chloride attack is particularly important because it primarily causes corrosion of reinforcement.
- Statistics have indicated that over 40 per cent of failure of structures is due to corrosion of reinforcement.
- The protective passivity layer can be lost due to carbonation.
- This protective layer also can be lost due to the presence of chloride in the presence of water and oxygen.

Measurement of Depth of Carbonation

Pink colour indicates that $Ca(OH)_2$ is unaffected by carbonation. The uncoloured portion indicates that concrete is carbonated.

Table 9.14. Limits of Chloride Content of Concrete (IS 456 of 2000)

Sl. No	*Type or Use of Concrete*	*Maximum Total acid soluble chloride Content. Expressed as kg/m³ of concrete*
1.	Concrete containing metal and steam cured at elevated temperature and prestressed concrete	0.4
2.	Reinforced concrete or plain concrete containing embedded metal	0.6
3.	Concrete not containing embedded metal or any material requiring protection from chloride	3.0

Limiting Chloride Content Corresponding to pH of concrete[9.20]

pH	Chloride content g/litre	ppm
13.5	6.7400	6740
13.0	2.1300	2130
12.5	0.6720	672
12.0	0.2130	213
11.5	0.0670	67
11.0	0.0213	21
10.0	0.0021	2
9.02	0.0002	0.2

Corrosion of Steel (Chloride induced)

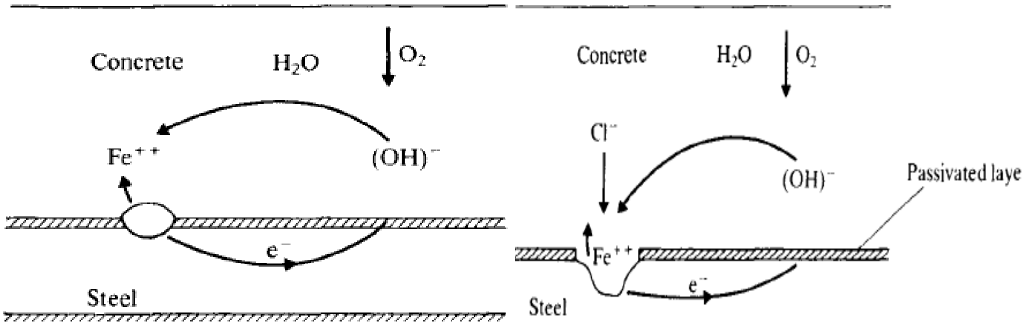
- Chloride with water and oxygen leads to corrosion of reinforcement.
- The passive iron oxide layer is destroyed when the pH falls below about 11.0 and carbonation lowers the pH to about 9.
- The formation of rust results in an increase in volume compared with the original steel so that swelling pressures will cause cracking and spalling of the concrete.
- Corrosion of steel occurs because of electrochemical action which is usually encountered when two dissimilar metals are in electrical contact in the presence of moisture and oxygen.
- However, the same process takes place in steel alone because of differences in the electro-chemical potential on the surface which forms anodic and cathodic regions, connected by the electrolyte in the form of the salt solution in the hydrated cement.
- The positively charged ferrous ions Fe^{++} at the anode pass into solution

$Fe \rightarrow Fe^{++} + 2e^-$ (anodic reaction)

$4e^- + O_2 + 2H_2O \rightarrow 4(OH)^-$ (cathodic reaction)

$Fe^{++} + 2(OH)^- \rightarrow Fe(OH)_2$ (ferrous hydroxide)

$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3$ (ferric hydroxide).



- Chloride ions present in the cement paste surrounding the reinforcement react at anodic sites to form hydrochloric acid which destroys the passive protective film on the steel.
- The surface of the steel then becomes activated locally to form the anode, with the passive surface forming the cathode; the ensuing corrosion is in the form of localized pitting. In the presence of chlorides, the schematic reactions are a

$$Fe^{++} + 2Cl^- \rightarrow FeCl_2$$
$$FeCl_2 + 2H_2O \rightarrow Fe(OH)_2 + 2HCl$$

- Thus, CI^- is regenerated. The other reactions, and especially the cathodic reaction, are as in the absence of chlorides.
- We should note that the rust contains no chloride, although ferric chloride is formed at an intermediate stage.
- Because of the acidic environment in the pit, once it has formed, the pit remains active and increases in depth. Pitting corrosion takes place at a certain potential, called the pitting potential.

4.8.5 CORROSION

4.8.5.1 Ways to Control Corrosion

- Metallurgical methods
- Corrosion inhibitors
- Coatings to reinforcement

- Cathodic protection
- Coatings to concrete
- Design and detailing

Metallurgical Methods:

- By altering its structure.
- rapid quenching of the hot bars by series of water jets, or by keeping the hot steel bars for a short time in a water bath, stainless steel reinforcements are used for long term durability of concrete structures.

Corrosion inhibitors:

- Nitrites, Phosphates, Benzoates
- The most widely used admixture is based on calcium nitrite.

Coatings to reinforcement:

- The coatings should be robust to withstand fabrication of reinforcement cage, and pouring of concrete and compaction by vibrating needle.
- Simple cement slurry coating

<u>STEPS INVOLVED….</u>

1. Derusting:

- Derusting solution.
- Cleaning the rods with wet waste cloth and cleaning powder.
- The rods are then rinsed in running water and air dried.

2. Phosphating:

- Phosphate jelly is applied to the bars with fine brush
- An inhibitor solution is then brushed over the phosphate surface.

3. Cement coating:
4. Sealing:
5. Fusion Bonded Epoxy Coating:
6. Galvanised reinforcement:
7. Cathodic Protection:

- Application of impressed current to an electrode laid on the concrete above steel reinforcement.
- This electrode serves as anode and the steel reinforcement which is connected to the negative terminal of a DC source acts as a cathode.
- In this process the external anode is subjected to corrode and the cathodic reinforcement is protected against corrosion and hence the name "Cathodic protection".

8. Coatings to Concrete:

- coated with Emcee color Flex,

9. Design and Detailing:
10. Nominal Cover to Reinforcement:

4.8.5.2 CORROSION TEST

The measurement of steel reinforcement corrosion in concrete is essential to analyze the strength and durability of structure.

Resistivity meter and Corrosion analyzing instrument which are easily available can measure these properties.

Resistivity meter for measuring corrosion

The corrosion of steel in concrete is an electrochemical reaction which generates a flow of current. Resistivity of the concrete influences the flow of this current. The lower the electric resistance, the more easily corrosion current flow through the concrete and the greater is the probability of corrosion. Thus the resistivity of concrete is a good indication of probability of corrosion.

4.8.6 ACID RESISTANCE

In general, cement concrete have low resistance to acids. It can withstand some weak acidic attacks; however, the overall acid resistance of the cement concrete is low. Following measures are used to improve concrete's resistance to acids.

1. By choosing the correct concrete composition, to make it as impermeable as possible.
2. Keeping the concrete surface, from the environment by using a suitable coating.
3. Modifying the environment to make it less aggressive to the concrete.
4. Siliceous aggregates are resistant to most acids and other chemicals and are sometimes specified to improve the chemical resistance of concrete.