Durability of Concrete

The durability of concrete signifies its ability to withstand the conditions for which it was designed, or its capacity to fulfill its required function throughout the lifespan of the structure without suffering damage or losing any resistance.

Concrete may lose its durability either due to the environmental conditions it is exposed to or due to internal factors occurring within the concrete itself.

- External factors can be **physical**, such as the influence of weather conditions like high temperatures, **chemical**, such as the attack of certain liquids and natural or industrial gases, or **mechanical**, such as the impact of abrasion that occurs in the concrete used in roads.
- Internal causes may arise from the presence of sulfates in the sand, alkali-silica reaction between reactive silica components in the aggregate and alkalis in the cement, volume instability of the cement, corrosion of the reinforcement iron, or volumetric changes resulting from differences in thermal properties between the aggregate and cement paste, or from the permeability of the concrete.

The permeability of concrete determines its susceptibility to damage from external factors. For concrete to be durable, it must be impermeable, requiring high concrete resistance to withstand harsh weather conditions.

Types of durability:

A. Chemical Durability

When dealing with durability, chemical attack which results in volume change, cracking and consequent deterioration of concrete. The types of the chemical attacks are as follows:

- ♦ Sulphate attack
- ♦ Alkali aggregate reaction
- ♦ Chloride ion attack
- ♦ Carbonation
- ♦ Acid Attack
- ♦ Seawater attack

B. Physical Durability

Physical durability is against the following actions:

- Freezing and thawing action.
- Permeability of water.
- Temperature effects.

1. Sulphate attack

- Sulfate salts do not attack concrete in their solid state, but when they are in a dissolved form, they react with cement paste compounds, leading to an increase in volume and subsequently causing concrete to crack and disintegrate.

- There are two main effects of sulfate salts on concrete: the external effect, which comes from sulfate salts present in soil or groundwater, or in seawater.

- As for the second type, it is the internal effect, which arises from sulfate salts present in the mixing materials used in concrete production such as sand and water primarily, or in very small quantities in the gravel.

- Due to the very low solubility of magnesium hydroxide, the reaction continues to completion, and under certain conditions, magnesium sulfate attack can be more severe than other types of sulfate attacks.

- The appearance of concrete affected by sulfates is usually slightly whitish, and damage typically begins at its edges and corners. This is followed by the occurrence of severe cracking and spalling, resulting in the concrete becoming soft and easily disintegrating.

Methods of controlling sulphate attack

1. Use SRC (sulphate resisting cement)

2. Quality concrete (low w/c ratio, well designed and compacted dense concrete)

3. Use of air-entrainment

4. Use of puzzolana

Sulphate attack on concrete

2. Alkali Aggregate Reaction

∗ Alkali-aggregate reaction (AAR) or alkali-silica reaction (ASR), takes place between alkali content of cement and silica content of aggregates is also a major factor effecting durability of concrete.

∗ Due to this reaction, Concrete expansion occurs which finally lead to severe cracking and concrete gets deteriorated.

∗ Its occurrence is due to :

1. High alkali content in cement (more than 0.6%)

2. Reactive silica in aggregate

3. Availability of moisture

∗ Methods of reducing alkali aggregate reaction:

1. Use non-reactive aggregates from alternate sources

2. Use low-alkali cement

3. Reduce cement content in concrete.

alkali aggregate reaction

3. Sea water attack

∗Sulfate salts present in seawater attack concrete submerged in water as well as concrete exposed above the water surface through the capillary action of water seepage.

* Chlorides in concrete increases risk of corrosion of steel (Electrochemical reaction)

∗ The drying of water (which seeps through capillary action) leaving salts inside the concrete pores leads to concrete cracking due to pressure exerted as a result of crystal formation and growth.

*Additionally, concrete located above the water surface in the tidal zone is subjected to alternating wetting and drying cycles, and this concrete is more affected chemically compared to concrete submerged in water.

*Concrete exposed to seawater may be affected by successive marine wave impacts and the movement of stones and other foreign materials, causing erosion. Additionally, marine organisms living in seawater contribute to further damage of the concrete.

∗ To minimize the effect of sea water:

1. Using dense and impermeable concrete.
2. Providing adequate concrete cover for the reinforcement steel.
3. The concrete needs to be rich in cement to achieve full compaction in mixes with low water/cement ratios.
4. It is preferable not to exceed a water/cement ratio of 0.45 in this concrete.
5. Various types of cement are used in the production of concrete exposed to seawater, such as alumina cement, sulfate-resistant Portland cement, and pozzolanic Portland cement.
6. When pouring concrete exposed to seawater, it is important to protect it from the seawater for a period of at least four days. This is achieved by leaving the temporary structural framework used to support the concrete in place.

4. Acid Attack

- In the presence SO_2 or CO_2 or any acidic vapors, especially in humid weather conditions, they can attack the concrete by dissolving or removing a portion of the cement, resulting in the formation of a loose layer that can be easily removed from the concrete surface.
- If acids or salt solutions are able to reach the reinforcing steel through cracks or porosity of concrete, corrosion can occur which will cause cracking.
- The resistance of concrete to chemical effects increases if it is allowed to dry before exposure. This allows for the formation of a thin layer of calcium carbonate (resulting from the reaction of CO_2 with lime), which closes the pores and reduces the permeability of the surface layer.

Acid attack on concrete

Permeability of Concrete

Permeability is defined as the property that allows any liquid or gas to pass through any material.

This property is of significant importance, especially in hydraulic structures such as tanks, dams, and water pipes. During their construction, special attention is given to ensuring that dams are watertight. This is not only to maintain the contents of the structure (water) and avoid its loss but also to protect the structure itself from the damage caused by water seepage. Additionally, this characteristic is crucial in concrete structures exposed to the penetration of harmful chemical substances, which could be either liquid or gaseous.

The permeability of concrete determines its susceptibility to water ingress, playing a significant role in exposing the concrete to the risk of water freezing inside its voids in cold weather conditions. It's known that the freezing of water accompanies expansion, resulting in stresses that reduce the concrete's resistance. Moreover, moisture and air ingress into reinforced concrete cause corrosion of the reinforcement steel, leading to its volumetric expansion (due to the formation of a layer of rust around it), cracking, and spalling of the concrete cover. When water enters the concrete, it may carry some salts with it, causing internal stresses within the concrete mass due to their crystallization. Additionally, water ingress into concrete affects its thermal insulation properties.

Factors affecting permeability of concrete:

1. **The effect of water and cement:**

- Permeability decreases with an increase in cement content, meaning by reducing the water/cement ratio in the mixture.
- The permeability of concrete is also affected by the properties of cement. As the fineness of the cement increases, the water tightness of the concrete improves in the same way its strength and durability do.
- Additionally, the chemical composition of cement affects permeability because it influences the rate of hydration. Generally speaking, as the resistance of the cement paste increases, its permeability decreases. This is because resistance is a function of the relative volume of gel in the available voids.

2. **The effect of aggregates:**

   If the permeability of the aggregate is low, its presence reduces the effective area through which flow occurs. Generally, the effect of aggregate in the mix is minimal, as the aggregate particles are surrounded by a layer of cement paste that prevents water penetration after a short period of mixing. In fully compacted concrete, the permeability of the cement paste is primarily responsible for the permeability of the concrete. With a constant water/cement ratio, the permeability of the concrete increases with an increase in the maximum size of the aggregate. This may be due to the formation of relatively large water-filled voids under the coarse aggregate particles. Aggregate particles must be chemically stable and have low porosity, and it is essential for them to be well-graded to make the concrete dense and water-resistant.

3. **Effect of admixtures:**

   Different materials are used as additives to improve the water resistance of concrete, and these additives are found under many brand names. However, they are generally classified into two main types according to their purposes:

   a. **Water repellant admixtures:**

      The purpose of these additives is to prevent concrete from absorbing rainwater or surface water that comes into contact with it.

   b. **Pores filler materials:**

      These additives typically include chemically active materials that form a gel through their reaction with cement, filling the voids within the concrete.

4. **Effect of uniformity of concrete:**

   Some secondary defects and conditions causing inconsistency significantly affect the initial flow during concrete placement. It's likely that most instances of inconsistency in concrete structures result from cracks and voids present in them, arising from poor consolidation or differential settling of freshly placed mass components, more so than from the permeability of the cement paste or aggregates. To reduce these defects, the mix must be workable, homogeneous, and fully compacted. Additionally, attention must be paid to prevent water from pooling on the surface of fresh concrete, forming a weak cementitious layer, and it is essential to achieve good bond strength between successive layers of concrete.

5. **Effect of surface treatment:**

   The use of surface treatments reduces water leakage, such as using fabric membrane applied to the surface of concrete along with hot asphalt, asphalt mastic, and silicone compounds.

6. **Effect of age:**

   Permeability of cement paste changes as the hydration process advances. In the case of a fluid cement paste, the size and shape of cement particles control the flow of water through it. As hydration progresses, permeability decreases rapidly because the gel gradually fills voids that were initially filled with water.

   In hardened concrete, permeability depends on the size, shape, and concentration of gel particles, as well as whether the capillary pores are continuous or interrupted by gel particles. Discontinuous capillary pores, separated from each other by gel particles, can be achieved by using an appropriate water/cement ratio and by wet curing for a sufficient period.

7. **Effect of curing:**

   As cement hydration progresses, gel forms and occupies space within the capillary pores, reducing their volume and increasing water resistance of the concrete. Generally, the permeability of concrete treated with steam is lower than that treated with moisture.