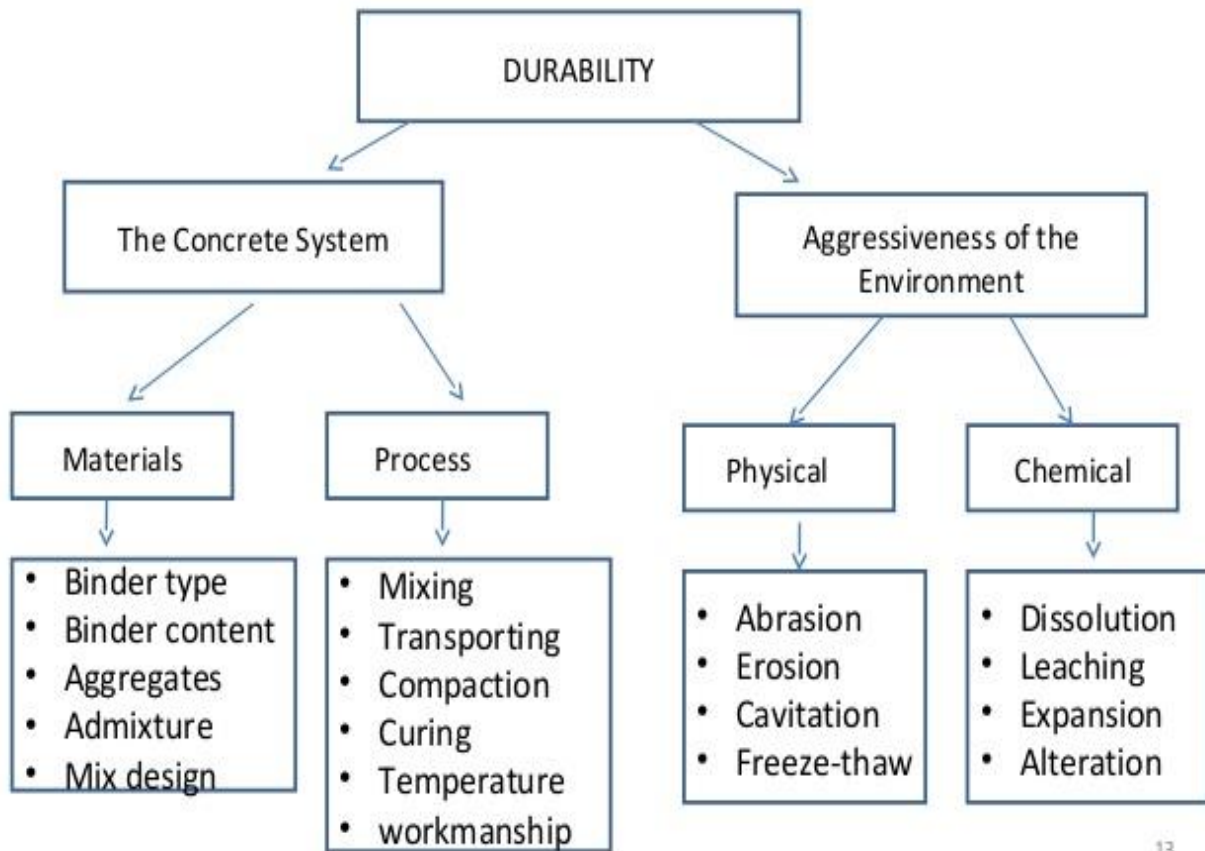


CHAPTER - 3

Durability and Serviceability of Concrete.

Durability of concrete may be defined as the ability of **concrete** to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. Different concretes require different degrees of **durability** depending on the exposure environment and properties desired.

Factors Affecting Durability



IMPORTANCE OF DURABILITY

Definition and Significance of Durability:

The durability of cement concrete can be defined as its ability to resist weathering action, chemical attack, abrasion or any other process of deterioration. A durable concrete should maintain its original form and serviceability when exposed to adverse environment.

Significance:

ADVERTISEMENTS:

It has been reported that in industrialized countries more than 40% of total resources of the building industry are spent on repairs and maintenance of concrete structures. In India also much money is spent on repair work. It is very unfortunate that not enough attention has been paid to durability aspect even in repair works.

Importance of durability in following points.

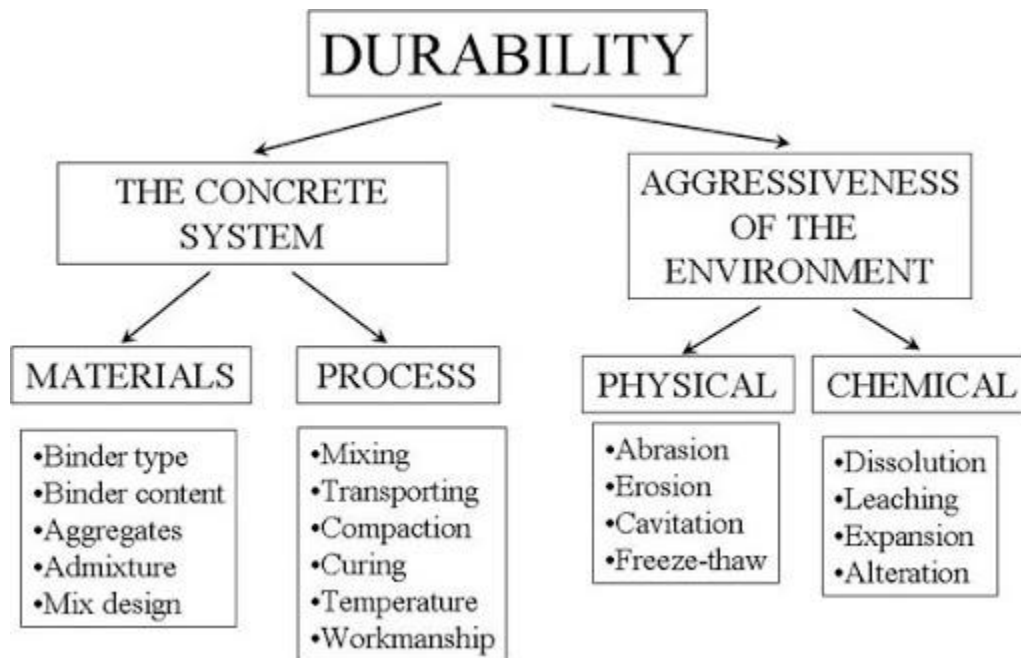
- 1) It affect economy , serviceability and maintenance of concrete
- 2) Environmental factor such as Rain, snow, humidity etc
- 3) Sulphate attack cause volume change results in expansion and disruption of concrete.
- 4) Sea shore construction like docks harbor etc concrete subjected to alternate wetting and drying ...
- 5) Fire resistance.
- 6) Acid attack
- 7) Freezing and thawing cycles
- 8) W/C ratio

Thus the construction of modern concrete structures assumes much more importance for durability than in the past. Due to these reasons in revised IS 456-2000, the approximate values for cement content, maximum w/c ratio, and minimum grade of concrete has been suggested for different exposure conditions.

These recommendations have been given in Table 17.1 below:

Table 17.1. Minimum Cement Content, Max. w/c ratio and minimum grade of concrete for different conditions of exposure as per IS 456-2000

| S. No. | Exposure | Plain Concrete | | | Reinforced concrete | | |
|--------|-------------|--|---------------------|---------------------------|--|---------------------|---------------------------|
| | | Minimum cement content kg/m^3 | Max. Free w/c ratio | Minimum grade of concrete | Minimum cement content kg/m^3 | Max. Free w/c ratio | Minimum grade of concrete |
| 1. | Mild | 220 | 0.60 | — | 300 | 0.55 | M20 |
| 2. | Moderate | 240 | 0.60 | M15 | 300 | 0.50 | M25 |
| 3. | Severe | 250 | 0.50 | M20 | 320 | 0.45 | M30 |
| 4. | Very severe | 260 | 0.45 | M20 | 340 | 0.45 | M35 |
| 5. | Extreme | 280 | 0.40 | M25 | 360 | 0.40 | M40 |



FREEZING AND THAWING EFFECT ON CONCRETE

Freeze/thaw damage occurs in **concrete** when the water molecules in **concrete** **freeze** and expand beyond the volume constraints of the **concrete**. Pavement damage due to **Freeze Thaw** Cycles. When the >91% of the pores of **concrete** are filled with water, the **concrete** is known to be saturated.

A severe exposure condition on portland cement **concrete structures** is exposure to cycles of freezing and thawing. **Air entrainment** is used to enhance the freeze-thaw resistance of **portland cement** concrete exposed to an external environment. The typical deterioration of concrete exposed to freeze-thaw conditions is random cracking, surface scaling and joint deterioration due to D-cracking. The first two are primarily due to lack of adequately entrained air in the concrete mass or the surface layer, respectively, and the latter phenomenon is primarily related to non-durable **aggregate**.

Freeze/thaw damage occurs in concrete when the water molecules in concrete freeze and expand beyond the volume constraints of the concrete.



P

avement damage due to Freeze Thaw Cycles

When the >91% of the pores of concrete are filled with water, the concrete is known to be saturated. When these water molecules freeze, they expand by 9%, and because there is no room for their increased volume, the concrete distresses. The freeze can cause the bonds in cement around the aggregate to break and the [concrete can crack](#) in those places. Thus, the higher the water/cement ratio in the concrete, the higher risk it is for freeze/thaw damage. As the seasons pass, concrete goes through the process of freezing and thawing, wearing out over time. As winters come and go from year to year, the concrete deteriorates.

Definition: Freeze-thaw weathering is a process of erosion that happens in **cold** areas where ice forms. ... The water **freezes** again as the temperature falls, and the expansion of the ice causes further expansion to the crack. This process continues until the rock breaks.



Cracked Stairs due to Freeze Thaw Cycles

Freeze-thaw weathering is **common** in regions where the temperature often drops below **freezing** at night. It does not happen much in warm climates, or in very cold places like Antarctica, where the temperature seldom rises above zero!

PREVENTION OF FREEZING AND THAWING:-

Certain measures can be taken to prevent freeze/thaw damage to pavements and any concrete structure. Prevention measures include adding deicing chemicals to the concrete during the winter in order to decrease the freezing point of precipitation as it falls onto the pavement as well as using high strength, air-entrained concrete. By reducing the freezing point of the precipitation, chemicals such as sodium chloride, calcium chloride, magnesium chloride, and potassium chloride in high concentrations work to reduce the exposure of the pavement to freeze/thaw cycles.



DAMAGE OF BRIDGE

Concrete is durable, but there's one substance that can wreak havoc on it if you aren't careful: water. Water can cause freeze-thaw damage, making it a necessary [consideration in masonry work](#). It can come in contact with concrete structures in a variety of ways — from rain to snow to dew to humidity.

Also called freeze-thaw weathering, this process has the potential to damage concrete or hardscaping elements. Luckily, there are several precautions you can take to keep your fixtures looking as good as new in the presence of cement freezing. This guide will help you understand freeze-thaw, what type of damage it causes and how you can prevent future freeze-thaw damage to your projects.

The freeze-thaw process is based on one unique characteristic of water — it [expands by nine percent when it freezes](#). The cycle occurs readily in nature and is common where temperatures reach below freezing at night and rise in the daytime. However, freeze-thaw generally doesn't happen in environments that don't freeze at all, like the tropics, or stay frozen most of the time, like the arctic. In a more moderate climate, water seeps into cracks and openings in rock during the day and freezes overnight. As the water freezes, it expands, stressing and opening the rock further and creating a wider gap. Generally, the most destructive kind of freeze-thaw action occurs in highly saturated conditions where more water is present.

You can freeze water in something like an ice cube tray, which allows the ice room to expand upward — but if water is stuck inside a non-flexible material, it will stress and eventually break it. When the ice melts as the temperature rises, it leaves a larger crack than before.

Freeze-Thaw Cycles

Once the crack has expanded, and the ice has melted, more water can fill up the gap in the rock. Since the crack is bigger, it can hold more water this time around. Once the temperature drops again, the new water freezes and the crack gets nine percent larger than before. Each time this cycle occurs, the crack gets bigger and bigger.

This process, also known as frost wedging, eventually causes the rock to break off into smaller pieces and separate from the larger stone, eroding it little by little. This erosion frequently occurs in nature in mountains and canyons. Scree slopes, which are made of fallen rock pieces, often develop at the bases of cliffs and mountains due to freeze-thaw cycles. Freeze-thaw can also affect many human-made items in a variety of climates across regions and seasons.

A freeze-thaw cycle is a form of mechanical weathering, which means it doesn't need to change the mineral makeup or molecular structure of the rock to wear away at it. Rust or oxidization, on the other hand, does cause a chemical change when they affect rock. With water, a rock is chemically identical both before and after freeze-thaw occurs. This physical weathering of concrete depends on the structure and integrity of a rock, not necessarily its chemical makeup.

Freeze-thaw cycles can occur daily in many climates where the temperature drops below freezing at night and rises above freezing during the day. If you're thinking of adding concrete installations to your home or business, you'll need to consider the possibility of freeze-thaw, as low-quality or ill-prepared concrete can be prone to more damage from freezing and thawing. Luckily, there are steps you or a contractor can take to minimize the effects of this cycle and keep the concrete in good condition.

FREEZE AND THAWING MECHANISM

<https://www.youtube.com/watch?v=1o4KojpqHxY>

Rate of freeze- thaw deterioration:

- 1) Increased porosity - Increases rate
- 2) Increased moisture saturation - Increases rate
- 3) Increased number of freeze – thaw cycles - Increases rate
- 4) Horizontal surface that trap standing water – Increases rate
- 5) Aggregate with small capillary structure and high absorption – Increases rate.
- 6) Air entrainment – decreases rate

Preventive measures against freezing & thawing :-

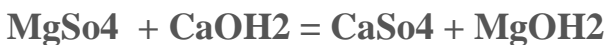
1. Use of lowest practical W/C ratio.
2. Adequate air entrainment
3. Use of durable, non porous aggregate

4. Adequate curing of concrete prior to exposure to freezing and thawing.

5. Providing proper drainage rather than flat surfaces.

Sea water Attack on concrete: -

Sea water contains 3.5% of salt by weight. It contains sulphate and some amount of CO₂.



The magnesium sulfate present in **seawater** reacts with calcium hydroxide of **cement** and forms calcium sulfate as well as magnesium hydroxide precipitation. ... The deterioration of **concrete structures** by **seawater** is more due to leaching rather than expansion of **concrete**.

Concrete exposed to seawater is wetted by a solution of salts principally sodium chloride and magnesium sulfate. Damage to concrete, if it occurs, usually results from failure to use good practices in concrete.



Sea Water Attack

- Sea water contains sulphates and hence attacks concrete in a manner similar to the sulphate attack.
- The deterioration of concrete in sea water is often is not characterized by the expansion, as found in concrete exposed to sulphate attack. Attack of sea water causes erosion or loss of constituents of concrete without undue expansion. Calcium hydroxide and calcium sulphate (gypsum) are considerable soluble in sea water, and this will increase the leaching action.
- Incase of reinforced concrete the absorption of salt results in corrosion of reinforcement. The accumulation of the corrosion product on the steel, causes rupture of the surrounding concrete. So that effect of sea water is more sevee on reinforced concrete than on plain concrete.

Steps to Improve Durability of Concrete in Sea Water

- The use of pozzolana or slag cement is advantageous under such condition.
 - Slag, broken brick bat, soft limestone, or other porous or weak aggregate shall not be used.
 - As far as possible, preference shall be given to precast members, plastering should be avoided
 - Sufficient cover to reinforcement, preferable 75 mm shall be provided
 - Care should be taken to protect reinforcement from exposure to saline atmosphere during storage, fabrication and use. It may be achieved by treating the surface of reinforcement with cement wash or by suitable methods.
-
- Use M20 grade for plain concrete and M30 for reinforced concrete for concrete in sea water or directly exposed to sea water.
 - No construction joints shall be allowed within 600 mm of the upper and lower places of wave action.

2. Carbonation process:

The process of carbonation of concrete involves the following chemical equation which clearly depicts the reaction that takes place between atmospheric CO₂ and the products of cement hydration particularly Ca (OH) 2 .

Ca (OH) 2 + CO₂= CaCO₃ + H₂O Hydration products (calcium silicate hydrate or CSH gel) and even the residual unhydrated compounds are present in all concretes. They are

1) Tricalcium silicate (C3S)

2) Dicalcium silicate (C2S)

These compounds react with CO₂ as shown in the following reactions:



3. Factors affect rate of carbonation: The following factors have a significant effect on the rate of carbonation [6].

3.1 External factors: Ambient relative humidity

Concentration of carbon dioxide

Surface protection

3.2 Internal factors: Grade of concrete

Permeability of concrete

Depth of cover to reinforcement

Water-cement ratio

3.3 Other factors:

1) Time of exposure

2) Orientation of building

The rate of carbonation is highest at relative humidity of about 50 to 75 percent..

4.6 Evaluation of Depth of Carbonation:

The phenolphthalein indicator method is a very popular method for measuring the depth of carbonation of concrete which involves spraying of solution on the concrete surface shows a change in color depending on the pH factor [22]. The measurement was carried out immediately after the broken surface was exposed and after applying phenolph

thalein indicator, which lose their color, are to be judged as carbonated but if color is pink then concrete is unaffected by carbonation.

Hand microscope is also a popular method which is being used to measure the depth of carbonation. It is necessary to record the average depth and maximum depth of penetration. The depth of carbonation is measured from the surface of the sample.

Concrete of good quality carbonates very slowly. 5 to 10 mm in 50 years.

Requirements of Durability as per IS :456-2000

- 1. Shape and size of member**
- 2. Requirement of concrete cover**
- 3. Concrete mix proportions**
- 4. Chloride in concrete**
- 5. Sulphates in concrete**

Alkali Aggregate Reaction

In most concrete, **aggregates** are more or less chemically inert. However, some **aggregates react** with the **alkali** hydroxides in concrete, causing expansion and cracking over a period of many years. This **alkali-aggregate reaction** has two forms: **alkali-silica reaction (ASR)** and **alkali-carbonate reaction (ACR)**.

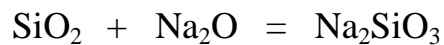
Alkali-aggregate reaction is a term mainly referring to a **reaction** which occurs over time in concrete between the highly alkaline cement paste and non-crystalline silicon dioxide, which is found in many common **aggregates**.

Alkali aggregate reactions (AAR) occur when aggregates in concrete react with the alkali hydroxides in concrete producing a hygroscopic gel which, in the presence

of moisture, absorbs water and causes expansion and cracking over a period of many years. This alkali-aggregate reaction has two forms, namely: **Alkali-silica reaction** (ASR) and **Alkali-carbonate reaction** (ACR).

Normally aggregates used in concrete are considered as inert material. But some aggregates contain reactive type of silica. This silica reacts with alkalies present in cement i.e. sodium oxide (Na_2O) and potassium oxide (K_2O).

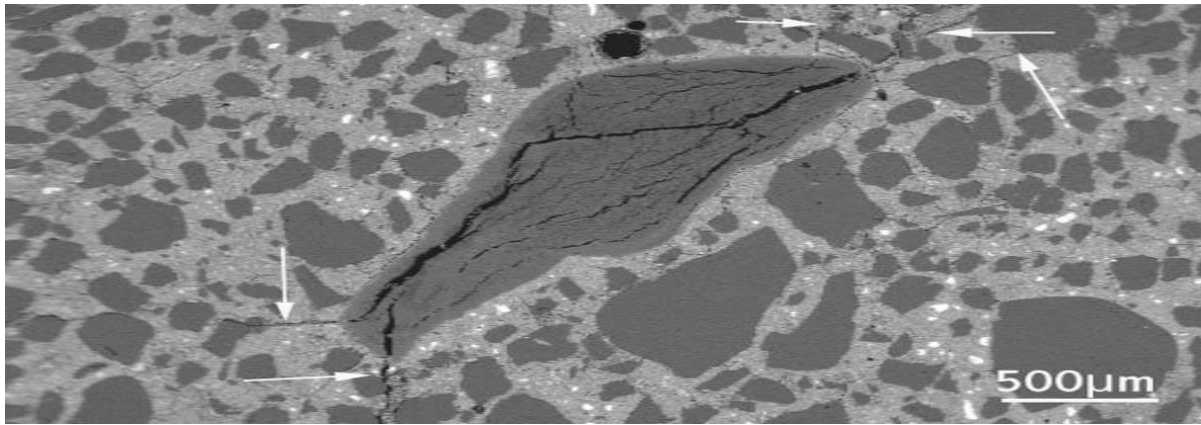
As a result alkali silicate gels of unlimited swelling type are formed. This is known as Alkali aggregate reaction.



1. Alkali + reactive silica = alkali-silica gel
2. Alkali-silica gel + moisture = expansion

The rocks which contains reactive aggregate include traps , andesite , rhyolites, siliceous limestone and certain types of sandstones.

The alkali silica gel formed by alkali aggregate reaction is confined by the surrounding cement paste and internal pressure is developed leading to expansion , cracking and disruption of cement paste. Thus it is very harmful for concrete.



Damage to concrete due to alkali aggregate reaction

Factors promoting the alkali aggregate reaction:

- a. Reactive type of aggregate
- b. High alkali content in cement
- c. Availability of moisture
- d. Optimum temperature conditions
- e. Fineness of cement particles.

To prevent the deterioration of concrete due to alkali aggregate reaction alkali content in cement should **not exceed 0.6 per cent**.

The ideal temperature for promoting the alkali aggregate reaction is in the range of 10°C to 38°C . If the temperature is below 10°C or more than 38°C it may not provide ideal situation for the alkali aggregate reaction.

Moisture content also prime reason for promoting the alkali aggregate reaction.

Fineness of cement also promoting the alkali aggregate reaction.

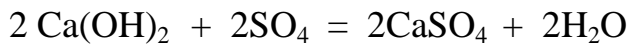
Measures to control alkali aggregate reaction :

- 1) Selection of non-reactive type of aggregate.
- 2) By restricting alkali content in cement below **0.6 per cent**.
- 3) By controlling temperature.
- 4) By controlling moisture condition.
- 5) By the use of corrective admixtures such as pozzolanas.
- 6) By controlling void space in concrete.
- 7) By not using too fine ground cement.

Sulphate Attack on Concrete

The sulphates of calcium (CaSO_4), Sodium (Na_2SO_4), Potassium (K_2SO_4), Magnesium (MgSO_4), are present in most soil and ground water. Solid sulphate do not attack concrete, but when present in solution they can react with hardened cement paste. In the hardened concrete, sulphate react with the free calcium hydroxide ($\text{Ca}(\text{OH})_2$) to form gypsum (calcium sulphate). Similarly sulphate react with calcium aluminate hydrate (C-A-H) to form calcium sulphotoaluminate, the volume of which is approximately **117%** of the volume of original aluminates. The produce of the reaction, gypsum and calcium

sulphoaluminate have a considerable greater volume than the compound they replace. So it leads to expansion and disruption of concrete.



Of all sulphates Magnesium sulphate (MgSO_4) causes maximum damage to concrete.

Sulfate attack :

Sulfate attack of concrete is a complex process, which includes physical salt attack due to salt crystallization and chemical sulfate attack by sulfates from soil, groundwater, or seawater. Sulfate attack can lead to expansion, cracking, strength loss, and disintegration of the concrete. Sulfate attack is generally attributed to the reaction of sulfate ions with calcium hydroxide and calcium aluminate hydrate to form gypsum and ettringite. The formation of ettringite leads to an increase in solid volume, resulting in expansion, cracking, and mass loss, particularly when restrained. The formation of gypsum can lead to softening and loss of mass and strength. In addition to the formation of ettringite and gypsum and its subsequent expansion, the deterioration due to sulfate attack is partially caused by the degradation of the calcium silicate hydrate through leaching calcium compounds. This process leads to loss in calcium silicate hydrate gel stiffness and an overall deterioration of the cement paste matrix. There is a general consensus that the use of fly ash, slag cement, silica fume, and metakaolin can reduce the expansion and damage due to sulfate attack.

Methods for controlling sulphate attack:

- 1) Use of sulphate resisting cement.
- 2) Addition of pozzolana.
- 3) Quality of concrete.
- 4) Use of air – entrainment.
- 5) High pressure steam curing.
- 6) Use of high –alumina cement.
- 7) Lining of polyethylene sheet.

Acid attack:

Concrete is used for the storage of many kinds of liquid some of which are harmful to concrete. In industrial plants, concrete floor comes in contact with acids, which damage the floor.

In damp condition SO_2 and CO_2 and other acid fumes present in the atmosphere affect concrete by dissolving and removing part of the set concrete. This form of attack occurs in chimneys and steam railway tunnels.

In practice acid attack occur at values of PH below 6.5 but attack is severe only at a PH value below 5.5. At a PH value below 5.5 attack is very severe.

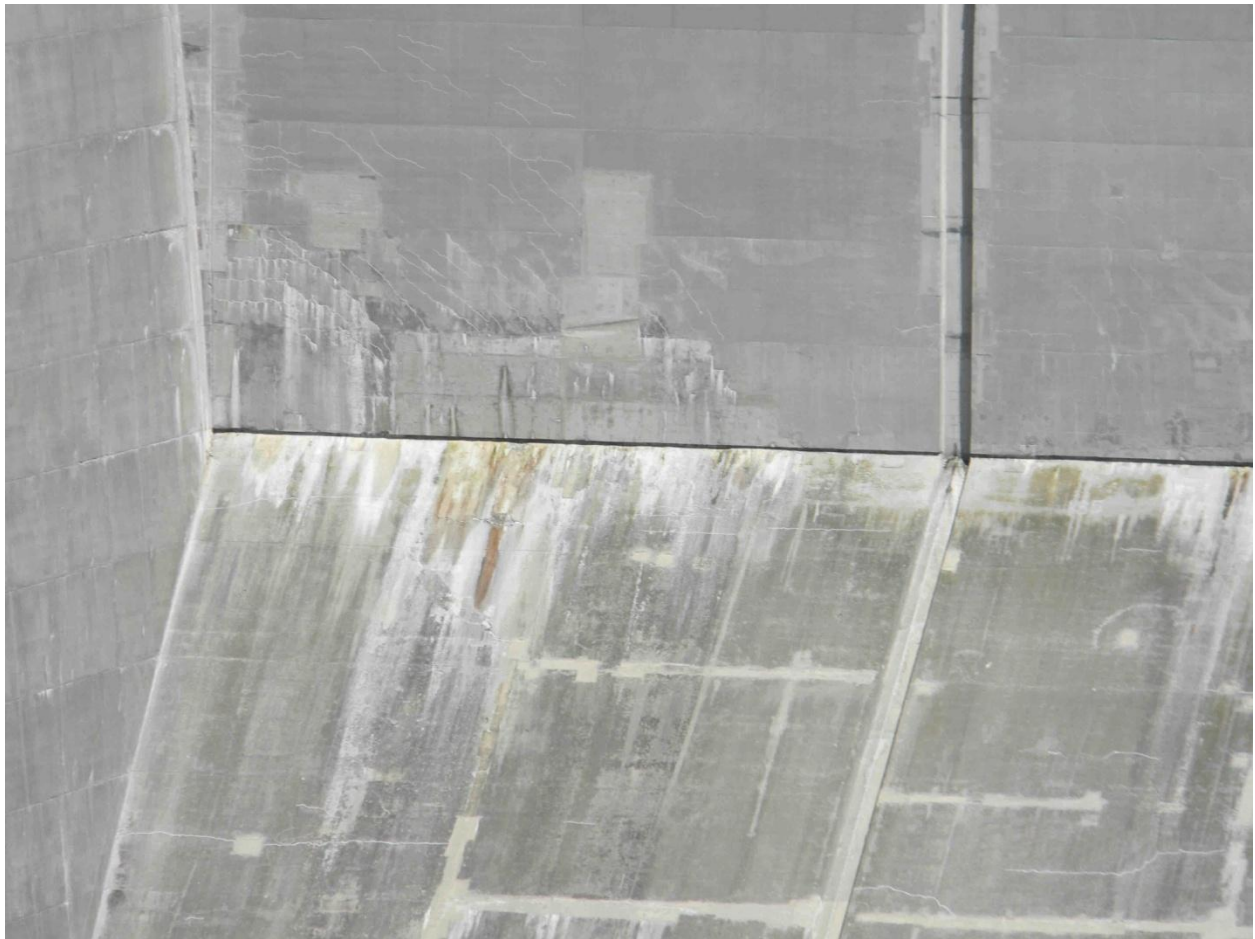
CONCRETE IS CHEMICALLY BASIC, HAVING PH VALUES RANGING BETWEEN APPROXIMATELY 12.5 AND 13.5, DEPENDING UPON THE MIXTURE PROPORTION. SINCE IT HAS HIGH ALKALINITY, IT IS READILY ATTACKED BY VARIOUS ACIDS, WHICH HAVE PH VALUES OF LESS THAN 7.

IT CAN BE ACCEPTED AS A GENERAL RULE THAT ACIDS ARE DAMAGING TO CONCRETE. THEY DO NOT ENTER INTO COMPLEX CHEMICAL REACTIONS SUCH AS THOSE THAT TAKE PLACE DURING SULFATE ATTACK, RESULTING IN EXPANSION AND CRACKING OF THE CONCRETE, BUT SIMPLY DISSOLVE THE MORE SOLUBLE CONSTITUENTS OF THE SET CEMENT, DESTROYING ITS CRYSTALLINE STRUCTURE AND LEAVING ONLY AN INCOHERENT RESIDUE. DIFFERENT ACIDS ACT PREFERENTIALLY AND AT DIFFERENT RATES ON THE CEMENT COMPOUNDS, BUT THE ULTIMATE RESULT OF SUSTAINED ATTACK IS DESTRUCTION OF THE CONCRETE. ACID ATTACK ON CONCRETE WHEN CONCRETE COMES IN CONTACT WITH ACIDIC SOLUTIONS, CONSTITUENTS OF THE CEM

ACID ATTACK ON CONCRETE CONCRETE CAN COME INTO CONTACT WITH ACIDIC SOLUTIONS FOR A WIDE RANGE OF REASONS. IN PARTICULAR, HYDROCHLORIC ACID (HCL) IS USED IN THE PICKLING OF STEEL TO REMOVE SURFACE LAYERS OF RUST. ORGANIC ACIDS ALSO ARISE IN INDUSTRIAL APPLICATIONS, BUT PARTICULARLY IN THE FOOD AND DRINK INDUSTRY. ACETIC ACID ($\text{CH}_3 \cdot \text{COOH}$) AND LACTIC ACID ($\text{CH}_3 \cdot \text{CHOH} \cdot \text{COOH}$) ARE COMMONLY ENCOUNTERED IN THIS TYPE OF ENVIRONMENT, WITH LACTIC ACID BEING PRESENT IN SOUR MILK AND CERTAIN ALCOHOLIC BEVERAGES. ACETIC ACID IS ALSO PRODUCED BY SOUR ALCOHOLIC BEVERAGES AND IS THE MAIN ACIDIC CONSTITU

Efflorescence:-

Efflorescence is a crystalline or powdery deposit of salts often visible on the surface of concrete, brick, stucco, or natural stone surfaces. It occurs when water leaves behind salt deposits on the masonry surface.





The water leaking through cracks, faulty joints or through the area of poorly compacted porous concrete dissolve some $\text{Ca}(\text{OH})_2$ compounds by leaching.

After evaporation, white deposits of calcium carbonate are left on surface of concrete. These deposits are termed as efflorescence.

- 1) The occurrence of efflorescence is greater when cool, wet weather is followed by a dry and hot spell.
- 2) When concrete is porous near the surface.
- 3) Unwashed seashore aggregate, gypsum and alkaline aggregate also cause efflorescence.

4) Type of formwork, degree of compaction, and W/C ratio also effect efflorescence.

Removal of efflorescence:-

Early efflorescence can be removed with a brush and water.

Heavy deposits of salts may require acid treatment. HCl is used for it.

The concrete surface should be washed after acid treatment.

Thermal properties of concrete

Thermal properties of concrete to understand the behavior of concrete to heating and cooling. The study of thermal properties of concrete is an important aspect while dealing with the durability of concrete.

Thermal Properties

Thermal properties of concrete to understand the behavior of concrete to heating and cooling. The study of thermal properties of concrete is an important aspect while dealing with the durability of concrete.

Concrete is a material used in all climatic regions for all kinds of structures. The important properties that will be discussed are:

- ◆ Thermal conductivity
- ◆ Thermal diffusivity
- ◆ Specific heat
- ◆ Coefficient of thermal expansion

1 Thermal Conductivity

This measures the ability of material to conduct heat. Thermal conductivity is measured in joules per second per square meter of area. Conductivity of concrete depends on type of aggregate and body when the temperature difference is 1 degree C per meter thickness of the body.

The conductivity of concrete depends on type of aggregate moisture content, density and temperature of concrete. When the concrete is saturated, the conductivity ranges generally between about 1.4 to 3.4 J/S/m²

2 Thermal Diffusivity

Diffusivity represents the rate at which temperature changes within the concrete mass. Diffusivity is simply related to the conductivity by the following equation:

$$\text{Diffusivity} = \text{Conductivity} / CP$$

Where C is the specific heat, and P is the density of Concrete. The range of diffusivity of concrete is between 0.002 to 0.006^{m²/h}

3 Specific heat

It is defined as the quantity of heat, required to raise the temperature of a unit mass of a material by one degree centigrade. The common range of values for concrete is between 840 to 1170 j/^{kg³/C}

4 Coefficient Thermal Expansion

It is defined as the change in unit length per degree change of temperature. In concrete, it depends upon the mix proportions. The coefficient of thermal expansion of hydrated cement paste varies between 11x10⁻⁶ and 20x10⁻⁶ per degree C. The coefficient of thermal expansion of aggregates varies between 5x10⁻⁶ and 12x10⁻⁶ per degree C Limestone and Gabbros will have low values and gravel and Quartzite will have high values of coefficient of thermal expansion.

Permeability of Concrete

- For completing hydration of cement about 38 % of water by weight of cement is required to fill the gel pores. If more than 38 % of water is used, than excess water will cause undesirable capillary cavities and the concrete becomes porous. Porous concrete has a higher permeability.

Importance of Permeability

- In reinforced concrete, ingress of water and air will result in corrosion of steel leading to expansion, cracking, and disruption of concrete.
- The penetration of deleterious material in solution may adversely affect the durability of concrete. $\text{Ca}(\text{OH})_2$ leaches out and aggressive liquids attack the concrete.
- If concrete becomes saturated with water due to permeability, it is more vulnerable to frost action.
- The permeability is very important in case of liquid retaining structures like water tanks and dams where water-tightness is necessary.

Factors Affecting Permeability

- The main factors affecting permeability are:
- Water/ cement ratio
- Properties of cement
- Aggregate
- Absorption and homogeneity of concrete
- Curing
- Use of admixtures
- Age of concrete

Corrosion of reinforcing steel and other embedded metals is the leading cause of deterioration in concrete. When **steel** corrodes, the resulting **rust** occupies a greater volume than the **steel**. This expansion creates tensile stresses in the **concrete**, which can eventually cause cracking, delimitation, and spalling

Corrosion is a natural process that occurs when the steel rebar within reinforced concrete structures rusts. In scientific terms, [concrete corrosion is defined](#) as the “destruction of metal by chemical, electrochemical, and electrolytic reactions within its environment.” It typically forms as the concrete ages

Why Is Concrete Corrosion a Problem?



Corrosion is initiated when materials that are harmful to steel, such as CO₂ and chloride from de-icing salt, start to penetrate concrete and reach the steel reinforcement. As an electrochemical reaction, electrons migrate from the anodic zone to the cathodic zone, releasing ferrous ions at the anode and hydroxide ions at the cathode. This will eventually lead to a potential difference between the anodic and cathodic areas at the surface of the steel reinforcement. This results in the creation of rust as a by product. Since rust occupies a larger volume than steel, it exerts internal pressure which causes the surrounding concrete to crack and become damaged. These cracks make their way to the surface of the concrete

which causes even more CO₂ and chloride to penetrate the concrete and speed up the process of corrosion.

Corrosion is responsible for up to 90% of damage to reinforced concrete structures.

Corrosion Mechanism in Concrete: Corrosion in concrete is induced by the generation of the electrochemical potentials in following ways: 1. When two different metals are present in concrete, such as steel rebars, aluminium conduit pipes, or when significant variation exist in surface characteristics of the steel, formation of composition cell can occur. 2. Concentration cells may be formed near reinforcing steel because of the differences in the concentration of dissolved ions, such as alkalis and chlorides (Figure 1)[8]. The following reactions occur at anode and cathode [9].

Anode: $\text{Fe} \rightarrow \text{Fe}^{2+} + 2\text{e}^-$ (Metallic iron)

$\text{FeO} \cdot (\text{H}_2\text{O})_x$ (Rust)

Cathode: $\frac{1}{2}\text{O}_2 + \text{H}_2\text{O} + 2\text{e}^- \rightarrow 2\text{OH}^-$ OR $\text{O}_2 + 4\text{e}^- + 2\text{H}_2\text{O} \rightarrow 4\text{OH}^-$

Some parameters are essential to initiate corrosion. Presence of oxygen, humidity (electrolyte) are the two important parameters without which corrosion is not possible.[10,11,12]. The rate of corrosion is slow if the amount of water or oxygen is limited. Presence of humidity, moisture and oxygen acts as catalyst for corrosion to occur, forming more OH⁻ thereby producing more rust component Fe(OH)₂ [8,12]. Following reactions (Eq1 to 3.) represent the formation of the rust after the iron dissolution occurs at the anodic sites in the reinforcement [10] (Table 1). $\text{Fe}^{2+} + 2\text{OH}^- \rightarrow \text{Fe}(\text{OH})_2$ (Ferrous Hydroxide) (1)

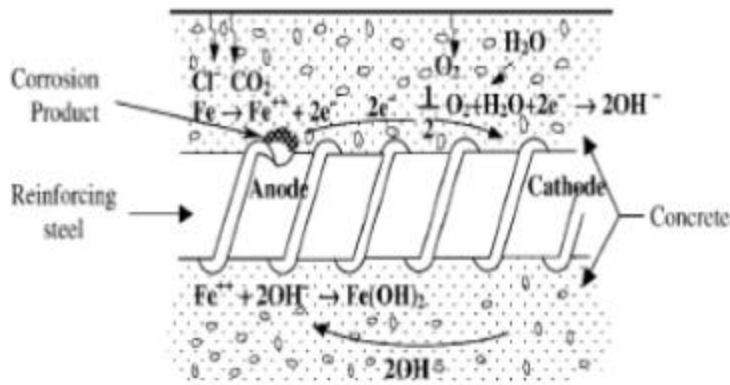


Figure 1: Electrochemical process of corrosion of steel in concrete – a simplified model.

Following are the factors which cause steel Corrosion in the concrete structure:

01. Effect of inside Moisture:

The moisture present in the pours of concrete acts like an electrolyte and it reacts with the cement which causes the corrosion of steel bars.

Hence low permeability concrete is not suitable in an area where the humidity is high in the atmosphere.

02. Leakage/Dampness:



if the concrete is highly permeable, the seepage and leakage from the toilets, plumbing pipes, terrace, damp walls, basements, etc. leads to the corrosion of steel bar in concrete. Water leakage is the main cause of early onset of corrosion and concrete deterioration as it acts as electrolyte. If the source of the water leakage or seepage is left unattended, it can cause structural damage . Hence when you repair corrosion damaged structure, it is also important that you take preventive actions i.e. stop leakage of water.

03. Inadequacy of Concrete Cover:

If the concrete cover is inadequate, then the concrete is corroded soon due to the entry of moisture. Inadequate concrete cover not only encourage the entry of moisture but also speed up the process of carbonation as well as ingress of chlorides, etc. It is advisable to provide concrete cover as recommended in IS:456.

04. Carbonation:

Hydration of cement hardens the concrete, at the same time calcium hydroxide is liberated, which set up a protective layer around the steel reinforcement. But, in the course of time, free hydroxide in concrete reacts with atmospheric carbon dioxide and form the calcium carbonate which results in shrinkage cracks. The reaction is also known as carbonation. It is the alkalinity of concrete which protects steel from corrosion. Once alkalinity is gone, there is no more protection. It reduces the alkalinity and breaks the protective layer of steel. Hence carbonation results in corrosion of steel reinforcement if the concrete has more void i.e. permeable concrete will attract more moisture from atmosphere.

05. Impurities in construction water :

The major impurities in water get added at the time of concrete mixing or concrete curing. As per the IS:456, if the total organic compounds are more than 3000 mg/l, sulphates are more than 500 mg/l, or chlorides are more than 1000 mg/l, then it leads to steel corrosion in concrete.

06. Ingress of Sea Water into Pores of Concrete:

The sea water and it contains high chlorides. If the porous concrete is permeable, the sea water in the form of moisture will enters in to the concrete from the pours surface. The sea water contains high chloride which reacts with the concrete and reduces the alkalinity of concrete. Thus the outside moisture in coastal areas also results in steel corrosion.

07. Presence of Chemical like Soluble Sulphates:

If soluble sulphate of groundwater, soil water or clay bricks react with the tricalcium aluminate of cement concrete in the presence of moisture, then this chemical reaction results in expansion of concrete as well as corrosion of reinforcement. It is also known as sulphate attack and it is also the reason of steel corrosion in concrete structure.

08. Calcium Chloride (CaCl₂) as Accelerator:

Calcium chloride reduces the electrical resistance of the concrete and promotes the electrochemical process. Calcium chloride also increases [shrinkage cracks in concrete](#). Hence use of calcium chloride as an accelerator in concrete results in steel corrosion, and it should be avoided for the excellent performance of the structure.

09. Electrolysis:

When the electrical system is not grounded correctly for high voltage or leaky current, then leakage of direct current passing through concrete or steel rebar can cause corrosion.

10. Alkali-Aggregate Reaction:

Alkalis like sodium oxide (Na₂O) and potassium oxide (K₂O) are present in the cement which react with silicious constituents of [aggregate](#) and cause the cracking in concrete. Hence, lowering of alkalinity promotes the corrosion of steel in the presence of moisture.

If you don't know the exact causes of corrosion of reinforcement steel in concrete, you are incapable to carry out repairing corrosion damaged concrete. Hence first discover the exact causes of corrosion, then prepare the reinforcement steel for repairing of concrete. Select proper repair materials and finally, apply suitable methods of repairing of concrete.

<https://www.slideshare.net/keyur30/cracks-in-concrete-and-its-remedial-measures>

