

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 Construction Industry Professionals. *In our previous issue, we discussed about how the pore structure influences the durability of Concrete. However, it is pertinent to know about other forms of concrete damage/deterioration, especially in the context of the environmental conditions in which the concrete would reside and the properties of the materials used.*

*In this issue we are bringing out information on **'Deterioration of Concrete – Types, Causes and its Preventive measures'**.*

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



Issue Highlights

- **Physical damage/deterioration**
 - Surface wear
 - Frost
 - Fire
- **Chemical deterioration**
 - Sulphate Attack
 - Acid Attack
 - Alkali Aggregate Reaction
 - Corrosion of Reinforcement

Introduction

Though concrete is quite strong mechanically, it is highly susceptible to physical and chemical attacks, which cause deterioration of concrete resulting in reduction of its strength and durability. Knowledge of most common deterioration mechanisms would help in mitigating the effects as well as adopt possible preventive measures to enhance the life of Concrete structures.

The durability of concrete is manifested in terms of its resistance to the deteriorating influences of both physical and chemical effects. Physical effects that adversely affect the durability of concrete include surface wear such as abrasion, erosion and cavitations, alternate wetting and drying, exposure to extreme temperatures such as freeze-thaw and fire. The chemical effects include expansive reactions involving sulphate attack, leaching of cement paste by acidic solutions, alkali aggregate reaction and corrosion of the embedded steel in concrete either due to carbonation or due to chlorides. It should be emphasized that the distinction between physical and chemical causes of deterioration is purely arbitrary; in practice, the two are frequently superimposed on each other.

Physical Damage/Deterioration:

Surface Wear:

It is the progressive loss of mass from the concrete surface that can occur due to Abrasion, Erosion and/or Cavitation.

- Abrasion wear occurs due to rubbing, scraping, skidding, or sliding of objects on the concrete surface. It is also known as dry attrition. This form of wear is observed in pavements, floors, or other surfaces on which friction forces are applied due to relative motion between the surfaces and moving objects. Service life of concrete gets shortened under conditions of repeated attrition cycles. Concrete abrasion resistance is markedly influenced by a number of factors including concrete strength, aggregate properties, surface finishing, and type of hardeners or toppings.
- Erosion is the wear due to abrasive action of fluids containing solid particles in suspension. Erosion takes place in hydraulic structures especially in canal linings, spillways, and concrete pipes. The rate of surface erosion depends on the porosity or strength of the concrete and on the amount, size, shape, density, hardness and velocity of the moving particles.
- Cavitation occurs due to loss of mass by formation of vapour bubbles and their subsequent collapse due to sudden change of direction in rapidly flowing water. Concrete surface affected by cavitation appears to be irregular or pitted.



Preventive Measures:

- Compressive Strength should not be less than 28MPa for Abrasion resistant concrete surfaces and 41MPa for erosion resistant concrete surfaces. (as recommended by ACI committee 201)
- Achieve suitable strength by using low water-cement ratio, proper grading of fine and coarse aggregates (limit max. size to 25mm) lowest consistency (Max.75mm slump), proper placing, consolidation and minimum air content consistent with exposure conditions.
- Use of hard aggregates for the concrete mix.
- Use of Fibre reinforced concrete improves the integrity of exposed concrete surfaces by providing enhanced tensile properties thereby improving resistance to abrasion.
- Use surface hardeners (Chemicals like Magnesium and Zinc fluosilicate, Sodium Silicate) to provide greater abrasion resistance to concrete surfaces.
- By ensuring continuous moist curing for a minimum of 7days after finishing of Concrete.
- Avoid surface misalignments or abrupt changes of slope to enhance protection from cavitation.

Additional measures for improving the properties of concrete to resist abrasion or erosion are to produce high quality surface by delaying the floating and trowelling operations until the bleed water is evaporated from the concrete surface, achieving very low water-cement ratio using super plasticizing admixtures, use of mineral admixtures in concrete to reduce bleeding, application of surface-hardening solutions to the well cured new or old surfaces.

Frost:

In cold climates, damage to concrete pavements, retaining walls, bridge decks and railings, attributable to frost action (freezing and thawing cycles) is one of the major problems requiring heavy expenditures for the repair and replacement of structures. Frost damage occurs when the moisture within the concrete expands as it freezes (typically water expands by approx. 9% when it approaches freezing), and as a result tensile stresses form near the surface. If this expansion exceeds the available volume of the pores, then the concrete gets damaged resulting in surface crazing and scaling off.



Preventive Measures:

Deterioration due to frost attack is minimized by using

- Low-permeability concrete to provide water tightness
- Air entrainment to increase the compressible volume of voids.

Air entrainment can be improved by optimizing the mixing time and reducing the concrete temperatures. Type of cement and cement content also influences the volume of air entrainment. Air entraining admixtures can prevent this type of deterioration by incorporating millions of tiny, discrete air bubbles in the concrete.

Fire:

Human safety in the event of fire is one of the considerations in the design of residential, public, and industrial buildings. Concrete has a good service record in this respect. Unlike wood and plastics, concrete is incombustible and does not emit toxic fumes on exposure to high temperature.



In the event of a fire, a very sharp rise in temperature may trigger physico-chemical changes in the concrete, such as dehydration by drying of the concrete and de-carbonation. These phenomena can cause shrinkage, losses of resistance and rigidity of the materials.

Fire introduces high temperature gradients in the concrete. As a result of these high temperature gradients, hot surface layers tend to separate and spall from the cooler interior portions of the concrete body. A dehydration and vaporization front forms from the heated surface where the temperature exceeds 100 °C. If the capillary pores are too fine, the steam pressure that builds up may generate tensile stresses in the concrete at this point such that the concrete's limit of resistance is exceeded. This phenomenon is all the more pronounced because the humidity of the concrete is high and the rise in temperature is rapid. Fragments of concrete can thus be thrown out from the surface of the element with more or less violence. For concrete, the loss of resistance results mainly from the formation of internal cracks and the degradation/disintegration of the cement paste. The paste in fact contracts, while the granulates expand. Apart from these internal cracks, at these very high temperatures cracks can be seen to form between the cement paste and the aggregates.

The cracks tend to form at joints, in poorly compacted parts of the concrete, or in planes of reinforcing steel bars. Once the reinforcement has become exposed, it conducts heat and accelerates the action of heat. Another common cause of spalling is the rapid quenching of hot fires by fire hoses. Rapid quenching of fire can cause serious structural damage.

Impact of Fire Temperature on Concrete:

Temperature	Effect on Concrete
100°C to 250°C	Normal color, slight loss in compressive strength
250°C to 300°C	Color changes to pink, strength loss increases
300°C to 600°C	Color is pink to red, strength loss continues
Above 600°C	Color changes to black, gray; very little residual strength
About 900°C	Color changes to buff; total loss of strength

Fire resistance of concrete is influenced by tensile strength, aggregate type, moisture content, permeability, density and thickness of the structural element as well as cover thickness.

Preventive measures:

A whole lot of measures are required to be taken to ensure proper fire engineering of the structure as enunciated in IS:1642-1989(reaffirmed 1994) and IS:456. Generally, concrete elements are designed for a fire rating, which is the time upto to which no significant damage occurs to the concrete element and the occupants can escape. The conditions in Fig. 1 and Table 16 A of IS 456 shall be followed.

- One factor that is seldom considered in striving for a high degree of fire or heat resistance in a concrete structure is the design of the concrete mixture itself. A study has shown that an appropriate change in the type of aggregate used can sometimes double the fire endurance of concrete. Crushed brick, charmortes, corundum and other special aggregates can be used for concrete to be exposed to fire or high temperatures.
- As far as materials are concerned, use of High Alumina cements and/or aggregates is advocated.
- Use of Pozzolans will help and so will the use of polypropylene fibres.

If designers of a concrete mix wish to achieve a high degree of fire endurance in the concrete itself without going to the use of special refractory materials, they should adopt the following:

- a) Among the aggregates available, use the one that exhibits the greatest stability at high temperatures;
- b) use a low aggregate-cement ratio;
- c) employ pozzolanic or blast furnace slag cement;
- d) design the mix for a strength in excess of what is structurally needed, to endure the greatest temperature anticipated;
- e) cure the concrete long enough to achieve the needed compressive strength

Chemical Deterioration:

Sulphate Attack:

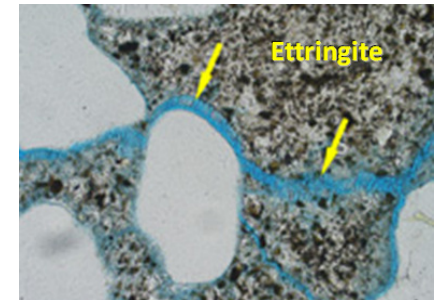
Most soils contain some sulphates in the form of gypsum (typically 0.01 to 0.05 percent expressed as SO_4); this amount is considered harmless to concrete. The solubility of gypsum in water at normal temperatures is rather limited (approximately 1400mg/lit of SO_4). Higher concentrations of sulphates in ground water are generally due to the presence of magnesium, sodium and potassium sulphates. Ammonium sulphate is frequently present in agricultural soil and water. Effluents from furnaces (that use high sulphur fuels) and from chemical industry may contain sulphuric acid. Decay of organic matter in marshes, shallow lakes, mining pits and sewer pipes often leads to the formation of hydrogen sulphide gas, which is transformed into sulphuric acid by bacterial action. The water used in concrete cooling towers may also contain high concentration of sulphates due to evaporation. Thus, it is common to find potentially deleterious concentrations of sulphates in natural and industrial water.



Degradation of concrete because of chemical reactions between hydrated Portland cement and sulphate ions from an outside source is known to take two forms that are distinctly different from each other. Which one of the deterioration processes is predominant in a given case depends on the concentration and source of sulphate ions in the contact water, and composition of cement paste in concrete.

Sulphate attack can manifest in the form of expansion and cracking of concrete. When concrete cracks its permeability increases and the aggressive water/chemicals penetrate more easily into the interiors thus accelerating the process of deterioration. Sometimes the expansion of concrete may cause serious structural problems, such as the displacement of building walls due to horizontal thrust by an expanding slab. Sulphate attack can also take the form of a progressive decrease in the strength and loss of mass due to loss of cohesiveness of the cement hydration products.

Delayed Ettringite Formation (DEF): In case of chemical sulphate attack when the source of sulphate ions happens to be internal (within the concrete) rather than external. The phenomenon is known to occur when either gypsum-contaminated aggregate or cement containing unusually high sulphate content has been used in the concrete production. DEF has been reported with steam cured concrete products. Ettringite is not a stable phase above 65°C , it decomposes to form the mono sulphate hydrate if steam curing temperatures higher than 65°C are used in manufacturing process. The sulphate ions released by the decomposition of ettringite are adsorbed on calcium silicate hydrate. Later, during the service, when sulphate ions are desorbed, the re-formation of ettringite causes expansion and cracking.



Preventive Measures:

- Sulphate resisting cement (low C_3A cement), when used, minimizes the ettringite formation after the concrete hardens. When the C_3A content is low, most ettringite will be formed in the plastic state. The use of very low C_3A content say less than 5%, however, is not good in case chlorides are present along with sulphates. In such a situation, C_3A can bind the chlorides that penetrate into concrete, thus reducing the free chloride content that can cause corrosion. Thus, it is preferable to use Slag cement or Pozzolana cement or even Ordinary Portland cement with moderate C_3A content when chlorides are present along with sulphates.
- The cement with Low C_3S also helps in improving the sulphate resistance property of concrete by reducing the amount of Calcium hydroxide.

- Concrete having low permeability provides best protection against Sulphate attack. Adequate concrete thickness, high cement content, low water cement ratio, proper compaction and curing of fresh concrete are among the important factors, which contribute to low permeability.
- Air entrained concrete produced use of air entraining agents, contains billions of microscopic air cells distributed uniformly in the body of concrete. Use of air entrainment to the extent of about 6% has found to beneficial on sulphate resisting qualities of concrete. The beneficial effect is possibly due to reduction of segregation, improvement of workability, reduction in bleeding and better impermeability of concrete. It may be noted that with 1% increase of air, the strength loss will be 4-6%. However, the loss of strength can be compensated by reducing the water-cement ratio.
- Incorporation or replacing a part of cement by a pozzolonic material reduces the Sulphate attack by converting the calcium hydroxide into C-S-H gel during the secondary reaction which imparts impermeability to concrete and makes it more denser preventing the ingress of sulphatic ions.
- High pressure steam curing improves the resistance of concrete to sulphate attack by changing C_3AH_6 (hydrates of calcium aluminates) into less reactive phase and reduction and removal of calcium hydroxide by the reaction of silica which is invariably mixed when high pressure steam curing is adopted.

IS 456 : 2000, Table 4 recommends the type of cement, minimum cement content and maximum free water cement ratios for various concentrations of sulphates in soil and ground water expressed as SO_3 . The table is given below.

Class	Concentration of Sulphates, expressed as SO_3			Type of Cement	Dense, Fully Compacted concrete made with 20 mm Nominal Maximum Size Aggregates complying with IS 383	
	In Soil		In Ground Water (g/l)		Minimum Cement Content (kg/m ³)	Maximum Free Water- Cement Ratio
	Total SO_3 (%)	SO_3 in 2:1 Water: Soil Extract (g/l)				
1	Traces (< 0.2)	Less than 1.0	Less than 0.3	OPC / PSC /PPC	280	0.55
2	0.2 to 0.5	1.0 to 1.9	0.3 to 1.2	OPC/PSC/PPC/	330	0.50
				Supersulphated Cement/Sulphate Resisting Cement	310	0.50
3	0.5 to 1.0	1.9 to 3.1	1.2 to 2.5	Supersulphated Cement/Sulphate Resisting Cement	330	0.50
				PPC/PSC	350	0.45
4	1.0 to 2.0	3.1 to 5.0	2.5 to 5.0	Supersulphated Cement/Sulphate Resisting Cement	370	0.45
5	More than 2.0	More than 5.0	More than 5.0	Sulphate resisting Cement/Supersulphated cement with protective coatings	400	0.40

NOTES:

1. Cement content given in this table is irrespective of grades of cement.
2. Use of Supersulphated cement is generally restricted where the prevailing temperature is above 40°C.
3. Supersulphated cement gives an acceptable life provided that the concrete is dense and prepared with a water-cement ratio of 0.4 or less, in mineral acids, down to pH 3.5.
4. The cement contents given in column 6 of this table are the minimum recommended. For SO_3 contents near the upper limit of any class, cement contents above these minimum are advised.
5. For severe conditions, such as thin sections under hydrostatic pressure on one side only and sections partly immersed, considerations should be given to a further reduction of water-cement ratio.
6. Portland slag cement conforming to IS 455 with slag content more than 50% exhibits better sulphate resisting properties.
7. Where chloride is encountered along with sulphates in soil or ground water, Ordinary Portland cement with C_3A content from 5% to 8% shall be desirable to be used in concrete, instead of sulphate resisting cement. Alternatively, Portland slag cement conforming to IS 455 having more than 50 percent slag or a blend of ordinary Portland cement and slag may be used provided sufficient information is available on performance of such blended cements in these conditions.

Acid Attack:

Concrete is chemically basic, having pH value ranging between 12.5 and 13.5 (approx.) depending on its mix proportion. Since it has high alkalinity, it is readily attacked by various inorganic and organic acids including sulphuric, sulphurous, carbonic, humic, hydrochloric, nitric, phosphoric, acetic and lactic acids. *Concrete can be attacked by acids (pH – less than 6.5) Attack is very severe when pH is below 4.5.*

The sources of acids include, acids present in ground water or soil, either naturally occurring or due to dumping of chemical wastes from industrial processes; acids occurring in sewers (sewage systems – sewage pipes and conduits); leakage or spillage of acids from industrial environments; disposal/burning of wastes from power plants or gasworks, in which sulphuric acid is an important component, can also make ground water acidic etc.

The primary effect of any type of acid attack on concrete is the dissolution of the cement paste matrix. This weakens the affected concrete, but unlike sulphate attack, the degradation does not involve significant expansion. The rate of attack depends more on the rate of fluid movement over the surface and on the quality of the concrete:

- Acidic ground waters that are not mobile appear to have little effect on buried concrete.
- Mildly acidic (pH above 5.5) mobile water will attack concrete significantly, but the rate of attack will be generally slow, particularly if the acids are primarily organic in origin.
- Flowing acidic water may cause rapid deterioration of concrete, therefore high quality concrete is needed.

Preventive Measures:

In order to improve the resistance of concrete to acid attacks, the following measures are to be adopted.

- Concrete must be hard and dense (non-porous) i.e it should have adequate cement content, low water-cement ratio and must be well compacted.
- Use of pozzolonic materials and silica fume in particular, increase the resistance of concrete to acids
- Use of good quality calcareous aggregates prevents concentrated acid attack on the hardened cement binder.
- Concrete pipes and conduits carrying the sewage should be impermeable to minimize the penetration by liquid.
- Sewer systems should be designed in such a manner, so as to provide sufficient flow rate, ventilation, use of chemical substances to eliminate the aerobic bacterial activity.
- Concrete can also be protected from acid attack by various surface treatments that block the pores and render the concrete less permeable.
- Surface treatment with water repelling agents, plasticized polyvinyl chloride linings can be used to control the deterioration.

In all cases, however, exposure time to acids should be minimized, if possible, and immersion should be avoided.

Alkali Aggregate Reaction:

Alkali-aggregate reaction is a chemical reaction between certain types of reactive aggregates and hydroxyl ions (OH⁻) associated with alkalis in the cement. Concrete deterioration caused by alkali-aggregate reaction is generally slow, but progressive.

In general aggregates used in concrete are considered to be inert, but under certain conditions, some components in the aggregates especially the siliceous minerals react with the alkaline pore solution (*alkalies derived from cement hydration, admixtures, or external sources and hydroxyl ions in the pore water*) of concrete to form a gel. This gel can absorb water and swells excessively exerting pressure on the hardened concrete leading to expansion resulting in Cracking. This phenomenon is called Alkali-Aggregate Reaction (AAR).

The reactivity of aggregate depends upon its particle size and porosity as these influences the area over which the reaction takes place. The expansion of cement also depends on the alkali content and fineness of cement, availability of non-evaporable water in the paste. The reaction is also accelerated under the conditions of alternate wetting and drying.



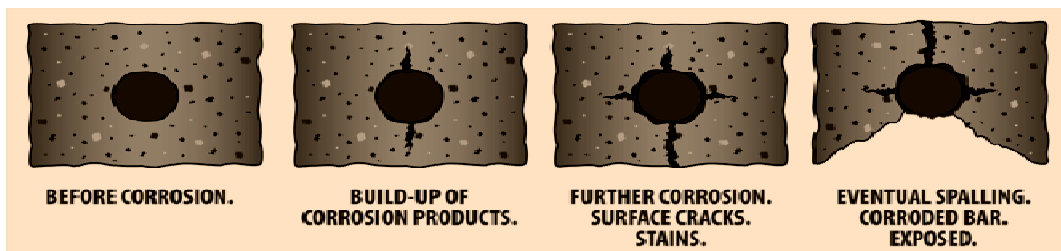
Preventive Measures:

Methods for controlling expansion due to AAR also vary on a regional basis. Many specifications do not permit the use of reactive aggregates and consequently, preventive methods are a non-issue. Generally accepted preventive methods include the use of low-alkali cement, limiting the alkali content of the concrete, the use of natural pozzolans, fly ash, slag, or silica fume, or any combination of these methods.

- Use of fly ash and slag has considerable variation in the treatment of the alkalis when considering the total alkali content of the concrete. Both fly ash and slag behave as inert diluents and do not contribute alkalis. The minimum replacement level required depends on the reactivity of the aggregate, the service life and size of the structural element, the exposure environment, and the composition of the fly ash or slag.
- Chemical admixture used to inhibit the AAR has not been widely employed by the construction industry. These include lithium salts and other salts such as barium salts, sodium silica fluoride, and alkyl alkoxy-silane.

Corrosion of Reinforcement:

It is an electrochemical process that requires an oxidizing agent, moisture, and electron flow within the metal. A series of chemical reactions takes place on and adjacent to the surface of the metal.

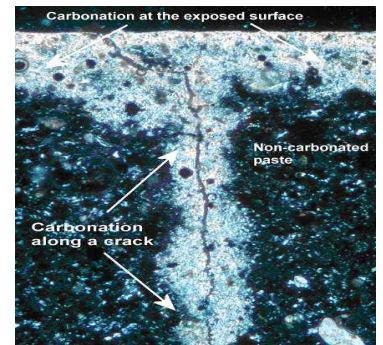


The corrosion can be induced in two ways in concrete:

- Carbonation induced corrosion
- Chloride induced corrosion

Due to Carbonation: The alkalinity to concrete is provided by hydroxides of calcium, sodium and potassium present in the hardened cement matrix. Permeation of carbon dioxide into concrete through interconnected pores and its reaction with these hydroxides causes chemical reaction that reduces the alkalinity of concrete.

This process is called Carbonation of concrete. Carbonation of concrete can be a problem in areas where the concentration of CO_2 is high and relative humidity is moderate (50-60%). Permeable concrete made with low cement content, high water-cement ratio, and inadequately moist-cured tend to suffer from serious carbonation even due to diurnal or seasonal temperature variations. Intermittent exposure to water (rain or wetting /drying cycle due to leakage from toilets) is the most favorable condition for corrosion of reinforcing steel. Once the passive film is destroyed, the affected portion of reinforcing steel is exposed to action of oxygen and water; consequently, corrosion in reinforcement steel is initiated.



Due to Chlorides: Chloride-induced corrosion causes extensive damage as the presence of salt and water creates the right conditions for rapid corrosion rates generating pits on rebars and expansive rust. Free chloride ions present in concrete, surrounding reinforcement, react with alkaline solution to form hydrochloric acid, which destroys the passive protective layer on the reinforcement steel, ultimately leading to delamination and cracking.

Presence of free chloride ions in concrete (total chloride content) promotes the continued dissolution of steel reinforcement. Chlorides may be present in the fresh mix or may penetrate from external source (salts in ground water, soil, chemical admixtures, contaminated aggregates etc.) into the hardened concrete. The most important is Sea water.



The rate of penetration depends both on the diffusion property of the concrete and on its binding capacity. The composition

of binder plays important role for the penetration resistance of concrete than the amount of cement used and the water/cement ratio.

Chlorides not only cause corrosion of reinforcement but also impart harmful effects on concrete as well. The chloride ions penetration brings about concrete swelling of 2 to 2.5 times larger than that of water penetration. This causes slight reduction of concrete strengths as well as leaching making concrete more porous and vulnerable.

Preventive Measures:

In order to increase the service life of any structure it is important to prolong the initiation of corrosion in the reinforcement. The various means to prolong the initiation of corrosion are:

- Increased cover to concrete – The time required for the chloride ions or carbonation effect to reach the reinforcement is more with increase in the cover of concrete.
- Reduced water-cement ratio – The permeability of concrete reduces with reduction in water-cement ratio, thereby making it impervious preventing the ingress of chloride ions into concrete.
- Use of supplementary cementitious materials like Fly ash, Ground Granulated Blast furnace Slag, silica fume etc. makes the concrete matrix denser.
- Use of corrosion inhibitors in concrete – The corrosion inhibitors provides resistance to corrosion either by forming an oxide film on the surface of the reinforcing bar or by reducing the rate of chloride ion migration depending on the nature of inhibitor used. Calcium nitrite is an inorganic inhibitor.
- Use fusion bonded epoxy coated reinforcement, hot dip galvanized reinforcement or stainless steel.
- Cathodic protection prevents corrosion by converting all of the anodic (active) sites on the metal surface to cathodic (passive) sites by supplying electrical current (or free electrons) from an alternate source. Usually this can be done by fixing of galvanic anodes (which are more active than steel) to the reinforcement,. This practice is also referred to as a sacrificial system, since the galvanic anodes sacrifice themselves to protect the steel. Alternatively Impressed Current Cathodic Protection (ICCP) is used to mitigate the effects of corrosion, especially in marine atmosphere. Impressed current systems use anodes (ICCP anode) of a type that are not easily dissolved into metallic ions, but rather sustain an alternative reaction; oxidization of the dissolved chloride ions. Power is supplied by an external DC power unit.

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