MODULE-4

DURABILITY OF CONCRETE - Introduction, Permeability of concrete, chemical attack, acid attack, efflorescence, Corrosion in concrete. Thermal conductivity, thermal diffusivity, specific heat. Alkali Aggregate Reaction, IS456-2000 requirement for durability

DEFINITION:

A long service life is considered synonymous with durability. Since durability under one set of conditions does not necessarily mean durability under another, it is customary to include a general reference to the environment when defining durability. According to ACI Committee 201, durability of Portland cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration; that is, durable concrete will retain its original form, quality, and serviceability when exposed to its environment. No material is inherently durable; as a result of environmental interactions the microstructure and, consequently, the properties of materials change with time. A material is assumed to reach the end of service life when its properties under given conditions of use have deteriorated to an extent that the continuing use of the material is ruled either unsafe or uneconomical.

Materials Related Failures

Concrete Deterioration can be caused by:

- The use of inappropriate materials.
- Poor construction practices.

Environmental Related Causes of Concrete Durability Problems The inferior durability characteristics of concrete may be caused by the environment that the concrete is exposed to. The following environmental condition can affect the concrete durability:

- Temperature.
- Moisture.
- Physical factors.
- Chemical factors.
- Biological factors

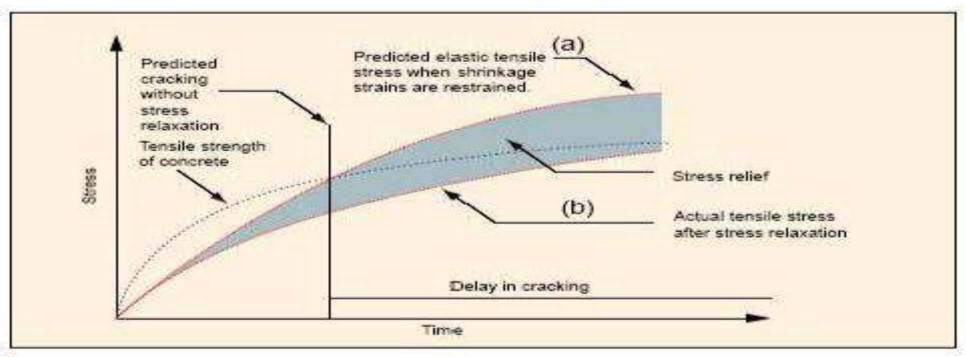
These factors may be due to weathering conditions (temperature, and moisture changes), or to abrasion, attack by natural or industrial liquids and gases, or biological agents. Durability problems related to environmental causes include the following: steel corrosion, delamination, cracking, carbonation, sulfate attack, chemical attack, scaling, spalling, abrasion and cavitation.

Dimensional Stability

The influence of shrinkage and creep on concrete cracking: under restraining conditions in concrete, the interplay between the elastic tensile stresses induced by shrinkage strains and the stress relief due to the viscoelastic behavior is at the heart of the deformations and cracking in most structures. To understand the reason why a concrete element may not crack at all or may crack but not soon after exposure to the environment, we have to consider how concrete would respond to sustained stress or to sustained strain. The phenomenon of a gradual increase in strain with time under a given level of sustained stress is called creep.

The phenomenon of gradual decrease in stress with time under a given level of sustained strain is called stress relaxation. Both manifestations are typical of visco elastic materials. When a concrete element is restrained, the visco elasticity of concrete will manifest into a progressive decrease of stress with time (Fig. 4-1 curve b from Mehta textbook). Thus under the restraining conditions present is concrete, the interplay between elastic tensile stresses induced by shrinkage strains and stress relief due to visco elastic behavior is at the heart of deformations and cracking in most structure

Figure 4-1



THERMAL SHRINKAGE

In general, solids expand on heating and contract on cooling. The strain associated with change in temperature will depend on the coefficient of thermal expansion of the material and the magnitude of temperature drop or rise. Except under extreme climatic conditions, ordinary concrete structures suffer little or no distress from changes in ambient temperature. However, in massive structures, the combination of heat produced by cement hydration and relatively poor heat dissipation conditions results in a large rise in concrete temperature within a few days after placement. Subsequently, cooling to the ambient temperature often causes the concrete to crack.

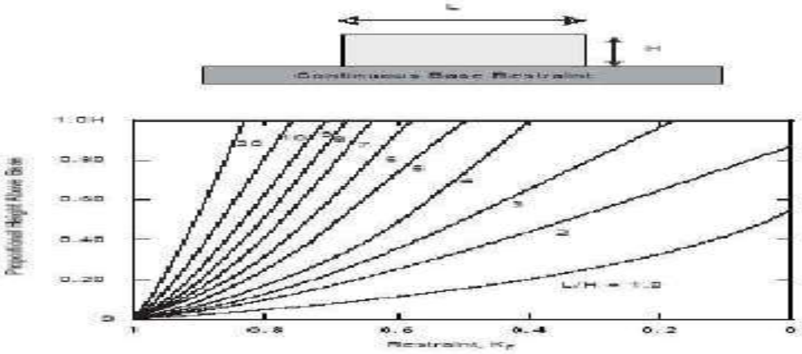
Since the primary concern in the design and construction of mass concrete structures is that the completed structure remains a monolith, free of cracks, every effort to control the temperature rise is made through selection of proper materials, mix proportions, curing conditions, and construction practices.

With low tensile strength materials, such as concrete, it is the shrinkage strain from cooling that is more important than the expansion from heat generated by cement hydration. This is because, depending on the elastic modulus, the degree of restraint, and stress relaxation due to creep, the resulting tensile stresses can be large enough to cause cracking. For instance, assuming that the coefficient of thermal expansion of concrete is 10 × 10−6 per °C, and the temperature rise above the ambient from heat of hydration is 15 °C, then the thermal shrinkage caused by the 15 °C temperature drop will be 150×10−6. The elastic modulus (*E*) of ordinary concrete may be assumed as 3 × 106 psi. If the concrete member is fully restrained (*Dr* = 1), the cooling would produce a tensile stress of 450 psi. Since the elastic tensile strength of ordinary concrete is usually less than 450 psi, it is likely to crack if there is no relief due to stress relaxation.

Factors Affecting Thermal Stresses

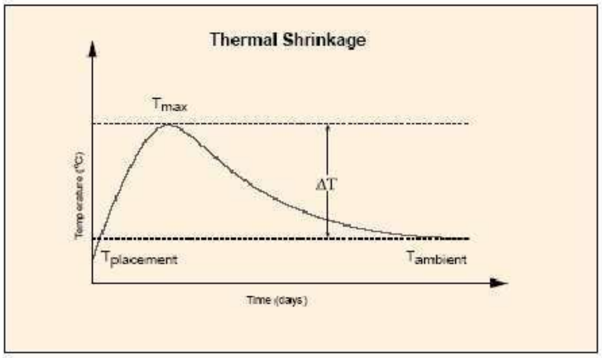
Degree of restraint (*Kr*) . A concrete element, if free to move, would have nostress development associated with thermal deformation on cooling. However, in practice, the concrete mass will be restrained either externally by the rock foundation or internally by differential deformations within different areas of concrete due to the presence of temperature gradients. For example, assuming a rigid foundation, there will be full restraint at the concrete-rock interface (*Kr* = 1.0), however, as the distance form the interface increases, the restraint will decrease, as shown in the following Figure

Figure 4-16



Temperature change. The hydration of cement compounds involves exothermicreactions which generated heat, and increase the temperature of concrete mass. Heating causes expansion, and expansion under restraint results in compressive stress. However, at early ages, the elastic modulus of concrete is low and the stress relaxation is high, therefore, the compressive stress will be very small, even in areas of full restraint. In design, to be conservative, it is assumed that a condition of no initial compression exists.

Figure 4-19



THERMAL PROPERTIES OF CONCRETE

Coefficient of thermal expansion is defined as the change in unit length per degreeof temperature change. Selecting an *aggregate with a low coefficient of thermalexpansion* when it is economically feasible and technologically acceptable, may,under certain conditions, become a critical factor for crack prevention in mass concrete. This is because the thermal shrinkage strain is determined both by the magnitude of temperature drop and the linear coefficient of thermal expansion of concrete; the latter, in turn, is controlled primarily by the linear coefficient of thermal expansion of the aggregate which is the primary constituent of concrete.

The reported values of the linear coefficient of thermal expansion for saturated Portland cement pastes of varying water/cement ratios, for mortars containing 1:6 cement/natural silica sand, and for concrete mixtures of different aggregate types are approximately 18, 12, and 6 to 12 × 10^{-6} per °C, respectively. The coefficient of thermal expansion of commonly used rocks and minerals varies from about 5 × 10^{-6} per °C for limestones and gabbros to 11 to 12 × 10^{-6} per °C for sandstones, natural gravels, and quartzite. Since the coefficient of thermal expansion can be estimated from the weighted average of the components, assuming 70 to 80 percent aggregate in the concrete mixture, the calculated values of the coefficient for various rock types (both coarse and fine aggregate from the same rock) are shown in Fig. 4-24. The data in the figure are fairly close to the experimentally measured values of thermal coefficients reported in the published literature for concrete tested in moist condition, which is representative of the condition of typical mass concrete.

Specific heat is defined as the quantity of heat needed to raise the temperature of aunit mass of a material by one degree. The specific heat of normal weight concrete is not very much affected by the type of aggregate, temperature and other parameters. Typically the values of specific heat are in the range of 0.22 to0.25 Btu/lb.F.

Tensile strength. The higher the tensile strength, the lower is the risk that thetensile stress will exceed the strength and crack the material.

The combination of factors that are desirable to reduce the advent of cracking in concrete can be described by a single term called **extensibility**. Concrete is said to have a high degree of extensibility when it can be subjected to large deformations without cracking. Obviously, for a minimum risk of cracking, the concrete should undergo not only less shrinkage but also should have a high degree of extensibility (i.e., low elastic modulus, high creep, and high tensile strength).

In general, high strength concretes are more prone to cracking because of greater shrinkage and lower creep; on the other hand, low strength concretes tend to crack less, probably because of lower shrinkage and higher creep.

ENVIRONMENTAL-RELATED CAUSES OF CONCRETE DURABILITY PROBLEMS

The inferior durability characteristics of concrete may be caused by the environment that the concrete is exposed to or by internal causes within the *Thermal conductivity* gives the flux transmitted through a unit area of a materialunder a unit temperature gradient. The thermal conductivity of concrete is influenced by the mineralogical characteristics of aggregate, and by the moisture content, density, and temperature of concrete. Typical values of thermal conductivity for concretes containing different aggregate types range between 23-25 25 Btu in/h.ft2.F.

EXTENSIBILITY AND CRACKING

As stated earlier, the primary significance of deformations caused by applied stress and by thermal and moisture-related effects in concrete is whether or not their interaction would lead to cracking. Thus the magnitude of the shrinkage strain is only one of the factors governing the cracking of concrete. From 4-1 it is clear that the other factors are:

- **Modulus of elasticity**. The lower the modulus of elasticity, the lower will be theamount of the induced elastic tensile stress for a given magnitude of shrinkage.
- **Creep**. The higher the creep, the higher is the amount of stress relaxation andlower the net tensile stress.

The following environmental conditions can affect the concrete durability:

− Temperature

− Moisture

− Physical factors

− Chemical factors

− Biological factors

These factors may be due to weathering conditions (temperature and moisture changes), to *abrasion,* attack by natural or industrial liquids and gases, or biological agents. Durability problems related to environmental causes include the following: steel corrosion, delamination, cracking, *carbonation,* sulphate attack, chemical attack, scaling, *spalling,* abrasion and *cavitation.*

TEMPERATURE

Temperature variations will cause changes in the concrete volume. When temperature rises, the concrete slightly expands, and when temperature falls, the concrete contracts. If the concrete wasunrestrained, these normal volume changes in concrete would have little consequences. Since concrete is usually restrained by foundations, subgrades, reinforcement, or connecting members, volume changes in concrete can produce significant stresses in the concrete. Tensile stresses can cause the concrete to crack.

Thermal expansion and contraction of concrete are influenced by its coefficient of thermal expansion. An average value for the coefficient of thermal expansion is about 10 millionths per degree Celsius or 0.000010/°C (5.5 millionths per degree Fahrenheit or 0.000055/°F), although values ranging from 3.2 millionths to 7.0 millionths per °F have been reported in the literature.

Temperatures greater than 95°C (203°F) can have significant effects on concrete. The total volume change in concrete is the sum of the volume changes of the cement paste and aggregates. At high temperatures, the cement paste will shrink due to dehydration of the calcium silicate hydrate (C-S-H), while the aggregate will expand. For normal aggregate concrete, there is a net expansion. Therefore, exposure to very high temperatures (i.e. fire) will result in concrete spalling, particularly when the concrete is exposed to high temperatures for a long time.

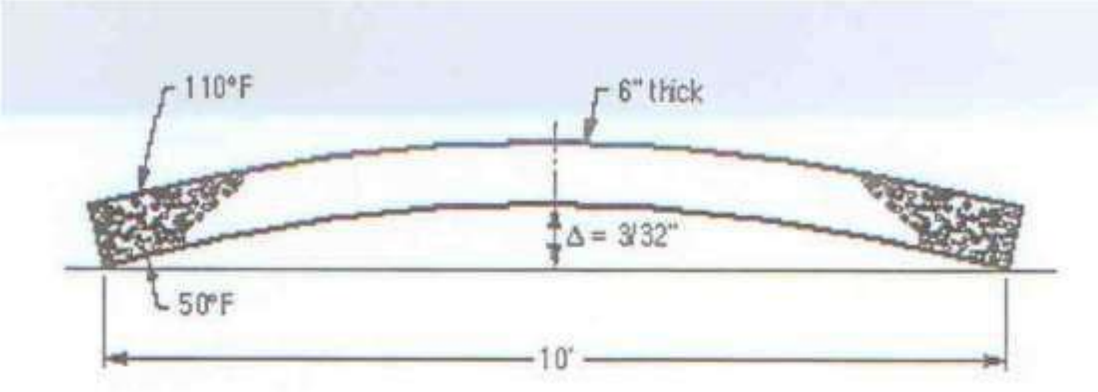


Figure 1. Warping of Concrete due to Temperature Difference

Several factors influence the behavior of concrete at high temperatures. These factors include concrete moisture content, aggregate type and stability, cement content, duration of concrete exposure, the rate that temperatures raise, the age of the concrete, and any restraint.

The Environmental-related Problems of Temperature

Environmental problems are ascribable to the daily and seasonal changes in temperature.

Daily Changes in Temperature

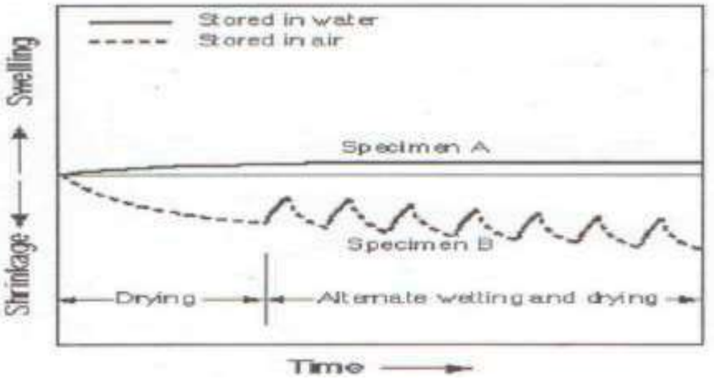
Daily changes in temperature can be up to 20°C (36°F) at the coast and somewhat higher inland. The limiting tensile strain for concrete is frequently quoted to be between 10-4 and 2X10-4. If the coefficient of thermal expansion of concrete is assumed to be 10 millionths per degree Celsius (5.5 millionths per degree Fahrenheit), a temperature change of 10°C to 20°C (18°F to 36°F) would be sufficient to cause the restrained concrete to crack. Repeated tensile stresses cause the cracks to grow and lead to scaling, spalling, and delamination. If the cracks develop to the level of the reinforcing steel, ingress of salt and moisture will cause the steel to corrode.

Seasonal Changes in Temperature

Seasonal changes in temperature are considerably greater than the daily fluctuations. Seasonal changes in temperature range up to 50°C (90°F) between the summer and winter. Seasonal temperature changes cause higher stresses than daily temperature changes, and they result in more extensive cracking. In, some cases, cracks developed at low temperatures may close when the concrete temperature increases in the summer. If dirt or debris enters the cracks when the openings are at their maximum, an increase in temperature will cause the compressive stresses to develop. In slabs on grade and sidewalks, if large compressive stresses are developed due to the expansion of the concrete, the slab may buckle upward and crack.

MOISTURE

Changes in the moisture content in concrete will result in either concrete expansion or contraction. When concrete gains moisture, the concrete will slightly expand or swell. When concrete loses moisture, the concrete will contract or shrink. The effects of moisture gains and losses on the volume of concrete are illustrated in Figure 2.



Concrete will slightly expand if the concrete is kept continuously wet, however, concrete drying causes the concrete to shrink. Further, wetting and drying of the concrete can cause the concrete to alternately swell and shrink. As concrete drying occurs, the portion of concrete near the surface will dry and shrink faster than the inner portion of the concrete. This drying and shrinking of the concrete surface will cause the concrete surface to develop tensile stresses and possible cracks. If a section of the concrete is restrained, and if concrete joints are not provided, major random cracks may develop.

Shrinkage of reinforced concrete is less than the shrinkage of plain concrete. The difference depends on the amount of reinforcing steel used. Steel reinforcement restricts but does not prevent drying shrinkage. The concrete will crack if the shrinkage strain of the concrete exceeds the limiting tensile strain of the concrete.

Environmental-related Problem of Moisture

The three main problems with moisture and concrete are as follows:

− Carbonation

− The moisture cycle

− Contaminants

Carbonation

In addition to shrinkage upon drying, concrete undergoes shrinkage due to carbonation. Carbon dioxide ($CO2$) present in the atmosphere reacts in the presence of moisture with the hydrated cement minerals (i.e. the agent usually being the carbonic acid). Carbonation may lead to crazing. The extent of carbonation depends on the permeability of the concrete and on the concentration of carbon dioxide in the air. The penetration of carbon dioxide beyond the exposed surface of concrete is extremely slow. The alkaline conditions of hydrated cement paste are neutralized by carbonation. This neutralization, by dropping the pH from over 12 to about 9, affects the protection of reinforcing steel from corrosion. Thus, if the entire concrete cover to steel were carbonated, corrosion of steel would occur in the presence of moisture and oxygen.

Moisture Cycles

Stresses caused by changes in moisture content of the concrete may be additive to stresses caused by temperature changes. Tensile stresses usually increase the tendency for cracking, scaling, spalling, and delamination. Rapidly fluctuating humidity (up to 70% in one day) can lead to moisture changes in the concrete. Condensation on concrete surfaces enters surface cracks and is absorbed into the concrete. Although the surface of the concrete may dry off rapidly, the water in the concrete and in the micro-cracks takes longer time to evaporate. If the moisture level at the reinforcing steel reaches 60% to 90% and sufficient chlorides are present, the steelwill .corrode. The influence of the relative humidity on steel corrosion is shown in Table.

Table 1. Influence of Relative Humidity on the Corrosion of Steel in Concrete

Relative Humidity	**Remarks**	**Corrosion Risk**
Concrete sub-merged in water	Capillaries filled with calcium hydroxid solution. Oxygen must diffuse throug solution-filled capillaries to steel.	No-corrosion to small risk
90% to 95%	Pores filled with pore solution throug which oxygen must diffuse.	Small to medium risk.
60% to 90%	Pores only partially filled. Water an oxygen reach steel easily.	Great risk.

below 60%	No or very little solution in pores.	No risk.

If the relative humidity is maintained at 80% and the temperature surrounding the reinforced concrete is increased, there will be a resulting increase in the rate of steel corrosion. Concrete that is subjected to moisture cycles may accumulate salts in the capillaries near the evaporating surface. This accumulation of salt may contribute to the chemical attack and/or salt scaling. Moisture movements in concrete may result in the concentrations of chlorides and sulphates in the concrete. Concentrations of chlorides in the concrete will cause the reinforcing steel to corrode and will also cause the concrete to crack and disintegrate.

Contaminants

Contaminants in the water that is absorbed into the concrete may cause staining,steel corrosion, or sulphate attack. Contaminants include: chloride and sulphate salts, carbonates, etc. Alternate cycles of wetting and drying allow the concentration of salts to increase and thereby increase the severity of their attack.An increase in the size of salt crystals in the capillaries near the evaporating surface causes cracking and scaling. If the salts are drawn to the surface and deposited at places where water evaporates, efflorescence will occur. The build-up of soluble salts depends on many factors, including the permeability of the concrete and the concentration of salts in the water that is being absorbed.

PHYSICAL FACTOR

Under many circumstances, concrete surfaces are subjected to wear. Concrete wear may be caused by the sliding, scraping or impact of objects that fall onto the concrete. In hydraulic structures, the action of the abrasive materials carried by flowing water generally leads to erosion of the concrete. Another cause of damage to concrete in flowing water is cavitations. Abrasion damage to concrete may be caused by the sliding or scraping of equipment across the concrete. Abrasion damage to concrete may also be caused by subjecting the concrete to abrasive materials (such as sand) that are carried by wind or water. Test results indicate the following facts;

− That abrasion resistance is clearly related to the compressive strength of the concrete.

− Strong concrete has more resistance than weak concrete.

− Since compressive strength depends on the water-cement ratio and adequate curing, a low water-cement ratio and proper curing of the concrete are necessary for abrasion resistance.

− Hard aggregates are more abrasion resistant than soft aggregates.

− Steel trowelled surfaces resist abrasion more than a surface that is not trowelled. Cavitation occurs when a high-velocity, flow of water (or any other fluid) suffers an abrupt change in direction or velocity. This change in direction or velocity in flowing water causes a zone of lowpressure to occur at the surface of the concrete that is immediately downstream from the direction or velocity change. This low pressure zone may allow pockets (or cavities) of vapor to form. When leaving the low pressure zone, these pockets of vapor collapse. The collapse of these vapors causes a localized highenergy impact on the concrete surface. This localized high-energy impact leads to erosion of both the cement paste and aggregate.

Concrete that is affected by cavitation has an irregular, jagged, and pitted surface. In contrast, concrete that is eroded by water-borne solids has a smooth surface. Damage to the concrete surface does not progress steadily. After an initial period of small damage, rapid deterioration will occur. This rapid deterioration is followed by damage to the concrete at a slower rate.

Fire around concrete structures can weaken the superstructure and decrease the concrete strength tremendously. Damage by fire may include total or partial collapse of the structure, distortion, excessive deflection and expansion, buckling of the steel, spalling and shattering of the concrete, discoloration, and reduction of the physical properties of the steel and concrete.

Environmental-related Physical Problems

Concrete may be subjected to fire or other forms of physical contact, such as wear caused by sliding, scraping, impact, or cavitation. Physical contact with concrete surfaces may result in spalling, scaling; and disintegration.

Cavitation

Cavitation can be a problem in any open channel where the velocity of the flowing water is higher than 12 *mls* (39.4 *ft/s).* In a closed pipe or conduit, cavitation can occur at velocities as low as 7.5 *mls* (24.6 *ft/s).* Concrete damage that is due to cavitation can be minimized if irregularities in the flow of the water are eliminated or if the velocity of the flowing water is reduced. Concretes that have the best resistance to cavitation damage have a high strength, a low water-cement ratio, a small aggregate size that does not exceed 20 mm (3/4 inch), and a good paste aggregate bond.

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 thigh temperature.

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. Cracks; then; 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. The effect of increased temperatures on the strength of concrete is small and somewhat irregular below 250°C (482°F). A reduction in compressive strength begins soon after 100°C (212°F) has been reached. This loss increases with an increase in the concrete temperature. When heated above 600°C (1112°F), concrete has little residual strength. When mild steel or hot-rolled, high-yield reinforcing steel is heated to about 200°C (392°F), there is a significant increase in strength. On further heating, the strength starts to decrease. At 400°C (752°F), the strength is approximately the same as the strength at normal temperatures. At 550°C (1022°F), the residual strength is only about 50% of the original. Above 550°C (1 022°F), the strength drops rapidly.

Factors that tend to promote spalling include the high moisture content, restraint to expansion (e.g., panels within a frame), low porosity and low permeability, closely spaced reinforcement, and rapid temperature rise. Spalling can also result from differential expansion of the mix constituents. Another common cause of spalling is the rapid quenching of hot fires by fire hoses. Rapid quenching of fire can cause serious structural damage. Concrete that is made with various types of siliceous or limestone aggregate shows a change in color with temperature. These color changes are due to the presence of iron oxide in the concrete; however, these color changes are not always apparent.

The effects of the high temperatures caused by fires are shown in Table 2.

Table 2. Impact of Fire Temperature on Concrete

Temperature	Effect on Concrete
100°C to 250°C (212°F to 482°F)	Normal color, slight loss in compressive Strength
250°C to 300°C (482°F to 572°F)	Color changes to pink, strength loss increases
300°C to 600°C (572°F to 1112°F)	Color is pink to red, strength loss continues
Above 600°C (1112°F)	Color changes to black, gray; very little residual Strength
About 900°C (1652°F)	Color changes to buff; total loss of strength

A key factor in the amount of damage that is caused to concrete is the duration of the fire. Because of the low thermal conductivity of concrete, it takes considerable time for the interior of concrete to reach damaging temperatures. For instance, damage commonly does not extend to more than about 10 to 30 mm (3/8 to 1 1/4 inches) below the surface of the concrete. Note that the interior of the concrete can never be more damaged from fire than its surfaces.

BIOLOGICAL FACTORS

Concrete may be damaged by live organisms such as plants, sponges, boring shells, or marine borers. **Mosses** and **lichens**, which are plants of a higher order, cause insignificantdamage to concrete. These plants produce weak acids in the fine hair roots. The roots enable mosses and lichens to adhere to the concrete. The acids that are produced from mosses and lichens will attack the cement paste and cause the concrete to disintegrate and scale. In some cases, carbonic acids are produced from plants, such as mosses and lichens, when substances from these plants decompose. The carbonic acid that is produced will attack the concrete.

Rotting seaweed has been known to produce sulfur. Sulfur can be easily converted to sulfuric acid. The presence of sulfuric acid on concrete leads to concrete disintegration. The growth of seaweed may also create a problem if the seaweed is exposed at low tide. When the seaweed is exposed at low tide, the seawater that is retained by the seaweed becomes more concentrated by evaporation. The effect of seawater on concrete increases as the concentration of seawater increases.

Rock boring mollusks and sponges, which are common in reefs or areas where the seabed is composed of limestone, may invade underwater concrete structures and piles containing limestone aggregate. The pattern of infestation greatly differs between organisms. When mollusks attack concrete, their pattern of infestation is widespread and relatively deep. The holes that the mollusks create tend to extend through both the aggregate and cement paste. Boreholes created by mollusks are located perpendicular to the outer surface of the concrete and can measure up to 10 mm (3/8 inch) in diameter. Although the depths of boreholes from mollusks vary, growth measurements indicate a rate of borehole penetration of about 10 mm (3/8 inch) per year. Boreholes serve solely as protective enclosures for the mollusks.

The pattern of infestation created by boring sponges are shallow, closely spaced, with small diameter holes that average 1 mm (1/25 inch) in diameter. The boreholes created by boring sponges are often interconnected. The attack of boring sponges on concrete is generally concentrated in small areas. As the degree of honeycomb in the concrete increases, the surface material of the concrete crumbles. Rock boring mollusks and sponges were discovered in the concrete piles of the Juaymah NGL Trestle in April 1982. This discovery took place about four years after the construction of the Juaymah NGL Trestle. The Juaymah NGL Trestle is approximately 10 kilometer (6.2 miles) long and is supported on 1500 precast, post-tensioned concrete cylinder piles. These concrete cylinder piles have outside diameters that range from 1.37 to 1.68 meters (4.5 to 5.5 feet). To stop the penetration of these mollusks and sponges, the concrete piles of the Juaymah NGL Trestle were encapsulated from about 1.2 meters (4 feet) to about 6 meters (20 feet) below the Indian Spring Low Water datum.

Environmental-related Biological Problems

Marine borers, such as mollusks and sponges, tend to form bore holes into underwater concrete structures. Marine borers reduce the concrete's load-carrying capacity as well as expose the concrete's outer reinforcing steel to the corrosive seawater. Boring sponges produce interconnected bore holes. As the degree of interconnection increases, the surface material of the concrete crumbles. Disintegration of the surface layer exposes a new substrate of the concrete to the boring sponges. Deterioration of concrete due to a boring sponge attack is relatively slow. Rock boring mollusks and sponges will also chemically bore holes into concrete containing calcareous substances.

CHEMICAL FACTORS

Chemical Corrosion

The resistance of concrete to deterioration processes triggered by chemical reactions involves generally, but not necessarily, chemical interactions between aggressive agents present in the external environment and the constituents of the cement paste. Among the exceptions are alkali-aggregate reactions which occur between the alkalies in cement paste and certain reactive materials when present in aggregate, delayed hydration of crystalline CaO and MgO if present in excessive amounts in portland cement, and electrochemical corrosion of embedded steel in concrete. In a well-hydrated portland cement paste, the solid phase, which is composed primarily or relatively insoluble hydrates of calcium (such as C-S-H, CH, and C-A-SH), exists in a state of stable equilibrium with a high-pH pore fluid.

Large concentrations of Na+, K+, and OH− ions account for the high pH value,12.5 to 13.5, of the pore fluid in Portland cement pastes. It is obvious that portland cement concrete would be in a state of chemical disequilibrium when it comes in contact with an acidic environment. Again, it needs to be emphasized that chemical reactions manifest into detrimental physical effects, such as increase in porosity and permeability, decrease in strength, and cracking and spalling. In practice, several chemical and physical processes of deterioration act at the same time and may even reinforce each other. For the purpose of developing a clear understanding, the chemical processes can be divided into three subgroups shown in Fig. 5-10, and discussed one at a time.

Special attention will be given to sulfate attack, alkali-aggregate attack, and corrosion of embedded steel, as these phenomena are responsible for deterioration of a large number of concrete structures. Finally, the last section of this chapter is devoted to durability of concrete in seawater, because coastal and offshore structures are exposed to a maze of interrelated chemical and physical processes of deteriorate which aptly demonstrate the complexities of concrete durability problems in practice.

Chemical corrosion results from the breaking down and dissolution of the cement paste and/or the chemical action of the aggressive agent. Combined physical and chemical corrosion may occur in cases where the aggressive agent combines with the cement or aggregate to form compounds that have a volume greater than the volume of the original constituents. This expansion may lead to a disruption in the concrete. The nature, concentration, and rate of replenishment of aggressive agents affect the rate of concrete deterioration that is caused by exposure to the aggressive agents. If an aggressive agent is carried by a flowing stream over the concrete surface of a pipe or canal, the replenishment of this aggressive agent will be maintained indefinitely. Indefinite replenishment of an aggressive agent will result in greater damage than would occur if the concrete were in contact with a limited quantity of the aggressive agent.

When the concrete is in direct contact with aggressive soils, the aggressive solution may be drawn into the concrete by capillary action. If evaporation at the surface of the concrete is possible, the concentration of salts in the capillaries may become dangerously high. A similar situation may occur when one surface of the concrete is exposed to an aggressive solution under hydrostatic pressure and the other surface is dry. The solution is forced into the capillaries of the concrete and, if evaporation at the exposed face is possible, a heavy build up of salts may be expected in the pores of the concrete surface. Chemical corrosion in Saudi Aramco is manifested by steel corrosion, alkali aggregate reactivity, sulphate attack, and acid attack. Salt in the surrounding ground, ground water, or air diffuses into the concrete. Steel corrosion results in an increase in the volume of the corroded portion (Le. surficial layer) of the reinforcing steel bar.

This increase in steel volume causes the concrete to crack and to disintegrate. The first evidence of steel corrosion may be the appearance of a brown stain on the concrete surface. The appearance of this brown stain is followed by the development of a fine crack running through the stain and roughly following the line of the steel. The increase in the volume of the steel corrosion products eventually bursts the concrete cover. Pieces of concrete are spalled off.

The spalling of concrete leaves the steel exposed. . The pieces of concrete that are spalled are usually sound and show no evidence of concrete deterioration. Temperature and relative humidity play an important part in determining the rate of steel corrosion in concrete, as was explained in Table 1 under the topic of "Moisture".

Chemical Attack

Solid salts do not attack concrete, but when they are in the form of a solution, they can directly react with the hardened cement paste. Some soils contain alkali, magnesium and calcium sulphates. When these sulphates come into contact with groundwater, they form a sulphate solution. Seawater may also contain significant sulphate content.

Attack of the hardened cement paste can occur when the sulphates react with the Ca(OH)2 and the calcium aluminate hydrates. This reaction is called **sulphate attack**. Due to the increase in volume, these expansive reactions can produce a sufficient pressure that disrupts the cement paste. This disruption of the cement paste results in concrete cracking and disintegration. Over a period of time, excessive amounts of sulphates in soil or water can attack and destroy concrete that is not properly designed and protected.

The rate of a sulphate attack increases with an increase in the strength of the sulphate solution. The concentration of the sulphates is expressed as the number of parts of the weight of S04 per million parts of the solution (ppm). 1000 ppm is considered to be a moderately severe sulphate content. 2000ppm is considered to be a very severe sulphate content, especially if MgSO4 is the predominant constituent. The parallel values of soluble sulphates in the soil itself are 0.2 and 0.5 percent. The movement of the groundwater must be known in order to estimate the danger of a sulphate attack. A high rate of attack may occur because the sulphate that is removed by the reaction with the cement hydration products can be replenished. Likewise, alternating saturation and drying of the concrete can lead to rapid deterioration by sulphate attack.

Sulphate attack conditions are less severe when the concrete is completely buried and a channel for the groundwater does not exist. Concrete that is attacked by sulphates has a characteristically whitish appearance.

Sulphate damage usually starts at the edges and corners of the concrete member and is followed by a progressive cracking and spalling of the concrete. Cracking and spalling of the concrete reduces the concrete to a friable or even soft state.Some concrete structures may be subjected to chemical attack on one or more surfaces. Concrete can be attacked by water, acids, alkali, salt solutions, or a wide variety of organic chemicals. Damage may be limited to only surface discoloration or surface roughening.

Damage could be as catastrophic as acid attack, with the resulting loss of structural integrity. The affected surfaces are generally covered with barrier materials. A barrier material separates the concrete surface from the environment.

In damp conditions, SO2 CO2, SO3 and other acid forms that are present in the atmosphere may attack concrete by dissolving in water and removing parts of the cement paste. These acids will leave a *soft* and mushy mass behind. This form of attack occurs in sewers, chimneys, and in/around sulfur pits. Almost all types of mineral acids will have a destructive effect on concrete. The rate of an acid attack is determined by some factors such as the amount and concentration of acid, the cement content, the type of aggregate used in respect to the aggregate's solubility in acids, and the permeability of the concrete. When the hydrated cement reacts with an acid, the lime in the cement tends to neutralize the acid. If the concrete is made with a siliceous aggregate, neutralization can only be affected by the breaking down of the cement binder. If a calcareous aggregate, such as

limestone, is used in the concrete, the aggregate is also active in the neutralization of the acid.

The aggregate is referred to as a "sacrificial" aggregate. Even when the acid is constantly being replenished on concrete, the rate of deterioration by an acid attack can .be considerably retarded through the use of limestone or dolomite aggregates in the concrete. The constant replenishment of acids on concrete can be observed in hydraulic structures, footings, or piles that are in direct contact with acid ground waters, cooling towers, and other structures that are exposed to acid atmospheres. In some environments (such as flash distillation chambers of desalination plants), the continuous exposure to mineral-free water will rapidly dissolve any available lime or other soluble compounds of the cement paste. When lime or other soluble compounds of the cement paste dissolve, concrete will deteriorate and eventually disintegrate. Environments, such as the flash distillation chambers of desalination plants, can cause concrete deterioration and disintegration because the' concrete is constantly exposed to condensing water vapors or the resulting flow or dripping of distilled water.

ALKALI AGGREGATE REACTION IN CONCRETE (AAR)

INTRODUCTION

AAR is a chemical reaction of alkali in concrete and certain alkaline reactive minerals in aggregate producing a hygroscopic gel which, when moisture present, absorbs water and expand. Gel expansion causes cracking in the concrete.

The number of structures affected by AAR is relatively small comparing to the total number of concrete structure built, but the problem has been found in many countries around the world. In Hong Kong, occurrence of AAR have been identified for some structures [Stanley,1992]. See photos in the Teaching Web Page for cases of AAR in

Hong Kong and around the world. Most of the structures severely cracked by AAR are exposed to the whether or underground in contact with damp soil. This is because for significant expansion to occur sufficient presence of moisture is essential. Apart from the moisture, high content of alkali in the concrete is also essential. No case as been found where the alkali content, in terms of equivalent sodium oxide (Na2Oequi), is below 3-4 kg per cubic meter of concrete.

It is also found that, when there are sufficient moisture and alkali, maximum expansion of concrete due to AAR occurs when the content of reactive minerals in aggregate is within a sensitive region, some refer to this as "pessimum" content. Content of reactive minerals below or greater than the pessimum value, AAR expansion reduces. From the above, it can be seen that, for a damage AAR expansion to occur, it is necessary to have

- sufficient moisture supply,

- high content of alkali in concrete, and

- pessimum amount of reactive minerals in aggregate.

SOURCES OF ALKALIS IN CONCRETE

a. Cement

All ingredients of concrete may contribute to the total alkali content of the concrete, the major source of alkali is from cement. The chemical composition of cement is usually expressed in terms of oxides. In relation to AAR, alkali content in cement is determined from Na2O and K2O. Alkali content is described as total mass of "equivalent sodium oxide", Na2Oequ, which is determined from the following expression. Na2Oequ = Na2O + 0.658 K2O Alkali content of the cement commonly used in Hong Kong is, in terms of Na2Oequ, less than 1%. In some regions of China, e.g. in Tianjin and Beijing area, alkali content of

local cement is relatively high, above 1.5%, owing to the raw material of cement.

b. Pozzolans

A pozzolan is a siliceous or siliceous and aluminous material which react with lime released from cement hydration forming a compound possessing cementitious properties. Pozzolanic materials are used as a cement replacement or as part of cenmentitious material to modify or improve properties of concrete, sometimes for economical consideration. Common pozzolanic material used in concrete include PFA (palverized fuel ash, or fly ash), silica fume, GGBS (ground granulated blastfurnace slag). Other pozzolans include volcanic ash (the original pozzolan), opaline shale and chert etc. PFA is the most common pozzolan used in concrete. The use of silica fume in concrete is on the rising. Pozzolan consumes alkali when react with lime. When considering pozzolan contribution of alkali to concrete, a reduction to the alkali content of the pozzolan should be allowed for.

c. Aggregate

Aggregate containing feldspars, some micas, glassy rock and glass may release alkali in concrete. Sea dredged sand, if not properly washed, may contain sodium chloride which can contribute significant alkali to concrete.

d. Admixtures

Admixture in the context of AAR in concrete means chemical agents added to concrete at the mixing stage. These include accelerators, water reducers (plasticizers), retarders, superplasticizers, air entraining, etc. Some of the chemicals contain sodium and potassium compounds which may contribute to the alkali content of concrete.

e. Water

Water may contain certain amount of alkali. PNAP 180 states that acid-soluble alkali content of water be determined in accordance with American Public Health Association (APHA) (17ed. 1989) Sections 3500-K and 3500-Na.

f. Alkalis from outside the concrete

In area of cold whether, de-icing salt containing sodium compounds may increase alkali content on the surface layer of concrete. Soils containing alkali may also increase alkali content on the surface of concrete.

ALKALI CONTENT AND AAR

Research show that when the total alkali content, in terms of equivalent sodium oxide, is less than 3 kg/m3, damage expansion due to AAR is unlikely to happen, provide that known highly alkali-reactive minerals, such as opal and glass, are not present in the concrete. Because of the above research findings, and also because no reliable universal testing method have been established for the determination of reactivity of an aggregate, limiting alkali content in concrete has become the most widely used approach for the control of AAR. In Hong Kong, PNAP 180 specifies that, in the absence of alternative approach for AAR control, the alkali content of concrete expressed as the equivalent sodium oxide shall not exceed 3.0 kg per cubic meter of concrete.

REACTIVE AGGREGATE

General types of AAR

There are mainly three types of AAR found in concrete. These are

- alkali-silica reaction
- alkali-silicate reaction and
- alkali-carbonate reaction

Alkali-silica reaction is a reaction between alkali hydroxides and free silica in aggregate form a alkali-silica gel.

SiO2 + 2NaOH + H2O _ Na2SiO3×2H2O

Silica Alkali Water Alkali-silica gel Alkali-silicate reaction is the same as alkali-silica reaction except that in this case the reactive constituent is not free silica present in the combined form of phyllosilicates. Alkali-carbonate reaction occurs in concrete when alkalis react with certain dolomitic lime stones containing clay. Reaction causes cracks allowing water to enter which causes the clay to swell and disrupt the aggregate. Majority of the structures affected by AAR is found due to alkali-silica reaction. Alkalisilicate and alkali-carbonate reaction is relatively rear.

Tests for aggregate reactivity

Many test methods have been proposed by researchers for identifying potential reactivity of aggregate all over the world. These may be classified into three types.

- Petrographic examinations
- Chemical tests
- Expansion tests

Petrographic examination is the process of identifying the types of minerals in aggregate or concrete section by observation using microscope or other aids. This method can identify types of minerals in the aggregate and give suggestions as for whether the aggregate is potentially reactive or not. Because the uncertainties involved in the test, the method is generally used as a screening test as a part of an investigation. Many proposed test methods using chemical analyses to identify potential reactivity of aggregate. ASTM C389-87 chemical test (ASTM 1987a), for example, evaluates aggregate reactivity by measuring the amount of dissolved silica and the reduction of alkalinity in the reaction alkali solution. In an expansion tests, mortar bars or concrete prisms are made using the aggregate to be investigated. There specimens are then put in to a specified condition and the expansion of the specimens are measured. Since at normal climate conditions the reaction will take a few years or even longer to complete, measures to accelerate the reaction sometimes adopted for such tests.

One of such measures is to place the specimens at 38°C or 40°C and 100% relative humidity. In such a condition the AAR and its expansion complete within a few months time. In another such test using mortar bar as specimens, the mortar bars are immersed in a NaOH solution at 80°C. This method is also referred to as Accelerated Mortar Bar Test.

It should be noted that the methods that have been proposed so far have their limitations. Some succeeds in identifying reactivity for certain aggregates whereas fails for others. Therefore it is difficult to ascertain an aggregate is absolutely non-reactive using the currently available testing methods.

Concrete in Seawater

For several reasons, effect of seawater on concrete deserves special attention. First, coastal and offshore sea structures are exposed to the simultaneous action of a number of physical and chemical deterioration processes, which provide an excellent opportunity to understand the complexity of concrete durability problems in practice. Second, oceans make up 80% percent of the surface of the earth; therefore, a large number of structures are exposed to seawater either directly or indirectly (e.g., winds can carry seawater spray up to a few miles inland from the coast). Concrete piers, decks, breakwater, and retaining walls are widely used in the construction of harbors and docks. To relieve land from pressures of urban congestion and pollution, floating offshore platforms made of concrete are being considered for location of new airports, power plants, and waste disposal facilities. The use of concrete offshore drilling platforms and oil storage tanks is already on the increase. Most sea waters are fairly uniform in chemical composition, which is characterized by the presence of about 3.5 percent soluble salts by weight. The ionic concentrations of Na^+ and Cl^- are the highest, typically 11,000 and 20,000 mg/liter, respectively. However, from the standpoint of aggressive action to cement hydration products, sufficient amounts of Mg^{2+} and SO_4^{2-} are present, typically 1400 and 2700 mg/liter, respectively.

The pH of seawater varies between 7.5 and 8.4, the average value in equilibrium with the atmospheric CO_2 being 8.2. Under exceptional conditions (i.e., in sheltered bays and estuaries) pH values lower than 7.5 may be encountered; these are usually due to a higher concentration of dissolved CO_2, which would make the seawater more aggressive to Portland cement concrete.

The following Table shows the concentration of major ions in some of the world seas.

Major Ions	**Concentration (mg/l)**								
	Black Sea	**Marmara Sea**	**Mediterranean Sea**	**North Sea**	**Atlantic Ocean**	**Baltic Sea**	**Arabian Gulf**	**BRE** Exposure**	**Red Sea**
Sodium	**4,900**	**8,100**	**12,400**	**12,200**	**11,100**	**2,190**	**20,700**	**9,740**	**11,350**
Magnesium	**640**	**1,035**	**1,500**	**1,110**	**1,210**	**260**	**2,300**	**1,200**	**1,867**
Chloride	**9,500**	**14,390**	**21,270**	**16,550**	**20,000**	**3,960**	**36,900**	**18,200**	**22,660**
Sulfate	**1,362**	**2,034**	**2,596**	**2,220**	**2,180**	**580**	**5,120**	**2,600**	**3,050**
TDS	**17,085**	**26,409**	**38,795**	**33,060**	**35,370**	**7,110**	**66,650**	**32,540**	**40,960**
TDS Ratio*	**3.90**	**2.52**	**1.72**	**2.02**	**1.88**	**9.37**	**1.00**	**2.05**	**1.63**

Concrete exposed to marine environment may deteriorate as a result of combined effects of chemical action of seawater constituents on cement hydration products, alkali aggregate expansion (when reactive aggregates are present), crystallization pressure of salts within concrete if one face of the structure is subject to wetting and others to drying conditions, frost action in cold climates, corrosion of embedded steel in reinforced or pre stressed members, and physical erosion due to wave action and floating objects. Attack on concrete due to any one of these causes tends to increase the permeability; not only would this make the material progressively more susceptible to further action by the same destructive agent but also to other types of attack. Thus a maze of inter woven chemical as well as physical causes of deterioration are found at work when a concrete structure exposed to seawater is in an advanced stage of degradation. The theoretical aspects, selected case histories of concrete deteriorated by seawater, and recommendations for construction of concrete structures in marine environment are discussed next.

Theoretical Aspects

From the standpoint of chemical attack on hydrated Portland cement in unreinforced concrete, when alkali reactive aggregates are not present, one might anticipate that sulfate and magnesium are the harmful constituents in seawater. It may be recalled that with groundwaters, sulfate attack is classified as *severe* when the sulfate ion concentration is higher than 1500 mg/liter; similarly, Portland cement paste can deteriorate by cation exchange reactions when magnesium ion concentration exceeds, for instance, 500 mg/liter.

Interestingly, in spite of the undesirably high sulfate content of seawater, it is a common observation that even when a high C3A Portland cement has been used and large amounts of ettringite are present as a result of sulfate attack on the cement paste, the deterioration of concrete is not characterized by expansion; instead, it mostly takes the form of erosion or loss of the solid constituents from the mass. It is proposed that ettringite expansion is suppressed in environments where (OH)− ions have essentially been replaced by Cl− ions. Incidentally, this view is consistent with the hypothesis that alkaline environment is necessary for swelling of ettringite by water adsorption.

Irrespective of the mechanism by which the sulfate expansion associated with ettringite is suppressed in high C3A Portland cement concretes exposed to seawater, the influence of chloride on the system demonstrates the error too often made in modeling the behavior of materials when, for the sake of simplicity, the effect of an individual factor on a phenomenon is predicted without sufficient regard to the other factors present, which may modify the effect significantly.

It may be noted that according to ACI Building Code 318-83, sulfate exposure to seawater is classified as *moderate*, for which the use of ASTM Type II Portland cement (maximum 8 percent C3A) with a 0.50 maximum water/cement ratio in normal-weight concrete is permitted. In fact, it is stated in the ACI 318R-21
Building Code Commentary that cements with C3A up to 10 percent may be usedif the maximum water/cement ratio is further reduced to 0.40. The fact that the presence of uncombined calcium hydroxide in concrete can cause deterioration by an exchange reaction involving magnesium ions was known as early as 1818 from investigations on disintegration of lime-pozzolan concretes by Vicat, who undoubtedly is regarded as one of the founders of the technology of modern cement and concrete Vicat made the profound observation:

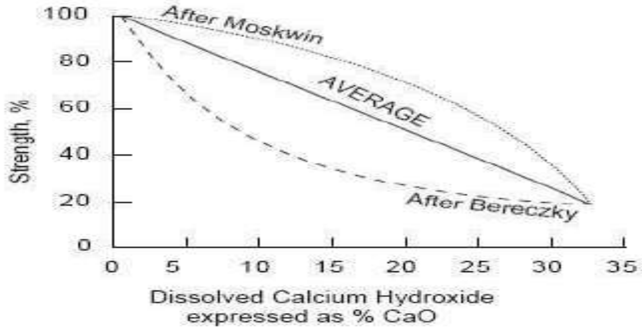
On being submitted to examination, the deteriorated parts exhibit much less lime than the others; what is deficient then, has been dissolved and carried off; it was in excess in the compound. Nature, we see, labors to arrive at exact proportions, and to attain them, corrects the errors of the hand which has adjusted the doses. Thus the effects which we have just described, and in the case alluded to, become the more marked, the further we deviate from these exact proportions. Several state-of-the-art reviews on the performance of structures in marine environments confirm that Vicat‟s observation is equally valid for Portland cement concrete.

From long-term studies of Portland cement mortars and concretes exposed to seawater, the evidence of magnesium ion attack is well established by the presence of white deposits of Mg(OH)2, also called *brucite*, and magnesium silicate hydrate. In seawater, well-cured.

concretes containing large amounts of slag or pozzolan in cement usually outperform reference concrete containing only Portland cement, partly because the former contain less uncombined calcium hydroxide after curing. The implication of loss of lime by cement paste, whether by magnesium ion attack or by CO2 22 attack, is obvious from Figure.

Since seawater analyses seldom include the dissolved CO2 content, the potential for loss of concrete mass by leaching away of calcium from hydrated cement paste due to carbonic acid attack is often overlooked. According to Feld, in 1955, after 21 years of use, the concrete piles and caps of the trestle bends of the James River Bridge at Newport News, Virginia, required a $ 1.4 million repair and replacement job which involved 70 percent of the 2500 piles. Similarly, 750 precast concrete piles driven in 1932 near Ocean City, New Jersey had to be repaired in 1957 after 25 years of service; some of the piles had been reduced from the original 550 mm diameter to 300 mm. In both cases, the loss of material was associated with higher than normal concentrations of dissolved CO2 present in the seawater.

It should be noted that in *permeable concrete* the normal amount of CO2 present in seawater is sufficient to decompose the cementitious products eventually. The presence of thaumasite (calcium silicocarbonate), hydrocalumite (calcium carboaluminate hydrate), and aragonite (calcium carbonate) have been reported in cement pastes derived from deteriorated concretes exposed to seawater for long periods.



READY MIX CONCRETE

RMC concrete - manufacture, transporting, placing, precautions, Methods of concreting- Pumping, under water concreting, shotcrete, High volume fly ash concrete concept, properties, typical mixSelf compacting concrete concept, materials, tests, properties, application and Typical mix

RMC industry is about 12 years old in India, while it was introduced in other countries much earlier

- PATENTED IN GERMANY

• 1913- FIRST DELIVERY OF RMC (BALTIMORE)
• 1926- BIRTH OF TRANSIT MIXER
• 1931- ERECTION OF FIRST COMMERCIAL PLANT IN LONDON
• 1950-1974 REMARKABLE GROWTH OF RMC – 31 MILLION CUBIC
METRE OF CONCRETE PER YEAR

Factors Delaying Entry of RMC in India:

• RMC is highly mechanized activity and entails initial high cost. Especially dueto import of basic equipment and machinery.Smaller size of construction in unorganized sector highly competitive and cost conscious.Availability of abundant cheap labour for making and transporting concrete.Differential taxation between RMC and SMC. Especially before 1997 whenexcise duty @16% also existed.

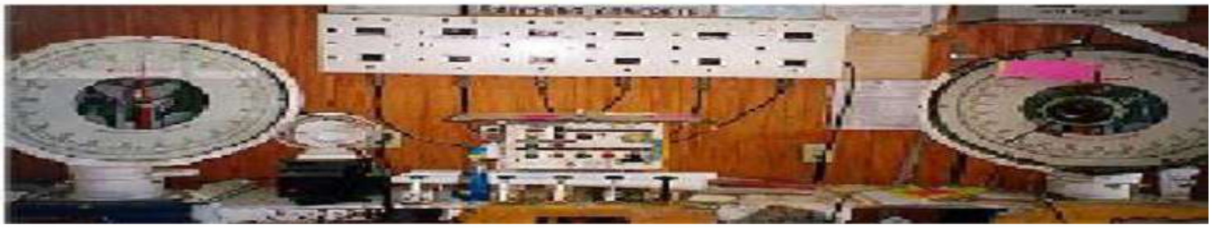
Factors that Prompted Introduction of RMC

- Increasing stakes in the reliability and durability of construction of emerging users.

- Decreasing share of construction cost in overall cost of the facility.

- Increasing awareness on environmental factors and convenience.
- Globalization – adoption of best practices across the globe.
- Bigger size of projects and Time is recognised as a cost factor.

A TYPICAL 'RMC READYMIX' PLANT



RMC- MAJOR ADVANTAGES

• Assured And Uniform Quality Of Concrete
• Speedier Construction Through Mechanised Operations
• Need For Ordering And Storing Cement, Aggregates And Sand On Site Totally Eliminated
• Lower Labour And Supervisory Costs
• Minimisation of cement wastage through bulk handling and storage

• Cleaner working environment
• -Eco-friendly product

COMMON QUALITY PROBLEMS: Quality problems of various natures which

May get reported arelisted below:

- Delay in setting of concrete beyond 24 hours.
- Development of cracks when the concrete is still in fresh state.
- Development of cracks in hardened concrete.
- Non-compliance of concrete cube strength (cast at site) to specifications at 7-days.
- Non-compliance of concrete cube strength (cast at site) to specifications at 28-days.
- Concrete supplied to site either has more slump than specified or has becomestiff making it difficult to pump. Reasons for above problems to occur at construction site are many. It is necessary to understand the behaviour of each and every constituent of concrete and construction techniques adopted at site before arriving at any conclusion regarding quality problems of RMC.

In many cases, information regarding Concrete Mix Design adopted for the type of material available in the plant may not be available. Properties of the constituents may not be available due to lack of testing facilities at RMC plant 1. Delay in setting of concrete beyond 24 hours:

Delay in setting of concrete is mainly due to excess dosage of set retarding admixture used to retain pumpable slump for longer durations. These admixtures are used to prolong the plasticity of concrete. Useful to counter the effects of high temperature, eliminate cold joints, and reduce cracking associated with form deflections. Basically, retarding admixtures increase dormant stage in the C3S hydration process. Too large a dose of admixture than specified by the manufacturer will cause the hydration reaction never to proceed resulting in cement that will never set.

Remedies:

1. It is important to carryout extensive trials while using set retarding admixture to arrive at optimum dosage without delaying setting of concrete than required. This also establishes the compatibility between cement and admixture. It is important to note that when a particular brand of cement is found to be compatible with a particular admixture, results may not be reproducible when cement is from a factory at a different location even though brand of cement is same. It is necessary to have a good quality control practices as properties of constituent materials vary to a large extent.

2. Development of cracks when the concrete is still in fresh state:

Cracks which appear when the concrete is still in fresh state are called plastic shrinkage cracks. These are caused by rapidly evaporating surface moisture. While some evaporation occurs all the time, its rate is increased by high ambient air temperature, elevated fresh concrete temperature, low humidity and strong winds. All four factors are in full force on warm summer days. Evaporation may be so strong; it actually pulls moisture from the concrete. Cracks are also caused by plastic settlement. Horizontal reinforcing bars may put restraint to overall settlement of concrete. Due to this thin plastic settlement cracks can occur. Vertical cracks form along line of the bars, penetrating from surface to bars. Remedies: It is essential to keep the concrete surface moist always to prevent cracks being developed when the concrete is still in fresh state. Adoption of good curing techniques that stops moisture loss from surface as soon as after placing of concrete. Use of curing compounds can be a good solution wherever it is not possible to monitor effective curing of concrete.

3. Development of cracks in hardened concrete:

Early-age thermal cracking is caused by restraint to contraction on cooling from a temperature peak, which is associated with the release of the heat of hydration of the binders. Early-age thermal cracking occurs within few days in thin sections, but it may take several weeks to develop in massive sections. Because of fast track constructions taking place to meet demands of infrastructure development, the trend towards large continuous pours of concrete with the requirements of high early strength and shorter striking times and problems of heat of hydration are mainly responsible for early-age cracking in hardened concrete. This type of cracks occurs when the restrained thermal contraction strain exceeds tensile strain capacity of concrete. The concrete temperature rise depends on number factors such as cement and addition type and content, type of aggregate, as well as ambient temperature, formwork used and section thickness.

Restraint is a function of the construction sequence and the constraint of neighbouring elements. Non-compliance of concrete cube strength (cast at site) to specifications at 7-days: Concrete cubes are cast both at plant and at site to determine compressive strength of concrete at various ages viz. at 7-day and 28 day. Even though specifications do not exist for 7-day strength in IS 456-2000, concrete cubes are tested at 7-day to check progressive development of strength. Normally expected strength at 7-days is about 2/3 of the 28-day compressive strength for a particular grade of concrete. Getting 80%-90% of 28-day compressive strength can easily be achieved when 53- Grade OPC is used.

However with addition of fly ash as a partial replacement to cement, strength at 7-day may not reach a value of 2/3 of the compressive strength at 28-days. In such cases, concrete cubes are certain to reach the required value at 28-days provided mix design is in order and standard procedure of cube ,curing and testing are followed. Non-compliance of concrete cube strength (cast at site) to specifications at 28-days When concrete cubes cast at site do not comply with specifications of 28-day compressive strength, then it becomes necessary to resort to non-destructive testing methods.

Of all the non-destructive testing methods determination of in-situ strength of concrete using concrete core extraction is most relied upon method. Reasons for failure of concrete cubes at 28-day can be many. Concrete supplied to site either has more slump than specified or has become stiff making it difficult to pump: Doubts will always be raised if the concrete supplied at site has more slump than specified. Addition of water during transit can be suspected which is bound to affect the quality of concrete. On the other hand it could be due to defects in carrying out trial mixes to assess the slump retaining characteristics of concrete using a particular admixture. Concrete loosing workability making it difficult to pump is another area of concern. In such cases, water added to make concrete pumpable which again affects quality of concrete. Re-dosing of admixture, if adopted, has to be done under technical supervision following recommendation of manufacturer of admixture. Otherwise it may lead to delayed setting of concrete SAMPLING AND TESTING OF READY-MIXED CONCRETE (As per IS 4926-2003):

For the assessment of compliance of ready-mixed concrete, the point and the time of sampling shall be at the discharge from the producer"s delivery vehicle or from the mixer to the site or when delivered into the purchaser"s vehicle.

Time in Transport:

The general requirement is that concrete shall be discharged from the truck mixer within 2 hours of the time of loading. However, longer period may be permitted if retarding admixtures are used or in cool humid weather or when chilled concrete is produced.

Workability:

Workability is measured in terms of slump of concrete using the standard procedure laid down in IS 1199: 1959- Methods of sampling and analysis of concrete.

Acceptance criteria for workability:

The workability shall be within the following limit on the specified value as appropriate: Slump: ±25 mm or ±1/3 of the specified value whichever is less. Sampling of concrete for assessment of compliance to strength: Unless otherwise agreed between the parties involved, the minimum testing frequency to be applied by the producer in the absence of a recognized ready-mixed concrete industry method of production control, should be one sample for every 50 m3 production or every 50 batches, whichever is the greater frequency.

Three test specimens shall be made up for each sample for testing at 28 days. The purchaser shall inform the producer if his requirements for sampling and testing are higher than one sample every 50 m3 or 50 batches, whichever is the greater frequency Acceptance criteria as per IS 456-2000: The test results of the sample shall be average of the strength of the three specimens. The individual variation should not be more than ±15% of the average.