RMCMA

Bulletin No.5

# Cracks in Fresh and Hardened Concrete

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## Causes and Preventive Measures

## PRESIDENT'S MESSAGE

Concrete is most extensively used material in construction worldwide. Concrete is strong in compression but weak in tension and has limited ductility, and cracks in concrete are inevitable. The consequences of cracks can be from trivial to catastrophic and their repairs are expensive and complex.

The Bulletin on "Cracks in fresh & hardened concrete - causes & preventive measures", is deliberated to understand the causes of concrete cracks and circulated among all the stake-holders across supply chain, to take preventive measures to avoid them.

I would also like to emphasis on the use of latest materials/technologies, in the process of making concrete structures more durable and sustainable. Amongst - the first comes, use of lower water-cement ratio concrete mixes, use of PP fibers as mandatory ingredient in all mixes, followed by application of curing compound irrespective of type of application of concrete . These measures will help in minimising the cracks both at wet & hardened state.

I urge construction Industry to graduate to self-healing & bacterial concrete that are new innovations and offers solution to long term cracks and to avoid major repair of concrete structures. It is time to bring relevant specifications of the same for larger field application.

Industry needs to focus more on sustainability by eliminating water as curing material, minimize cracks in concrete, thus enhance the service life of the structures beyond their design life, so that the natural materials can be saved for the future generation.

Hope that, future of concrete lies in the crack free concrete structures that are produced by using right materials and following correct construction practices.

Er. Ramesh Joshi
(President, RMCMA)

# INTRODUCTION:

The durability of concrete is mainly affected by 3 major factors, namely permeability, volume changes and cracks. Cracks appear in concrete due to reasons such as use of improper materials, inadequate design and construction practices, chemical attack and environmental factors like, temperature, humidity and wind. In this bulletin the causes and preventive measures of non-structural cracks in concrete in fresh and hardened state are discussed. The cracks are mostly unpredictable occurrence but the consequences can be from trivial to catastrophic.

Normally it is not possible to conclusively attribute the causes of cracks on the basis of visual observation alone. However, cracks will appear in concrete when tensile stress exceeds the tensile strength of concrete. Cracks appear as a solitary or in a pattern phenomenon. Cracks can be characterised by certain features that help to identify the cause. These includes width, depth, length, taper, direction and size. In the case of pattern cracking, spacing of the cracks is also significant.

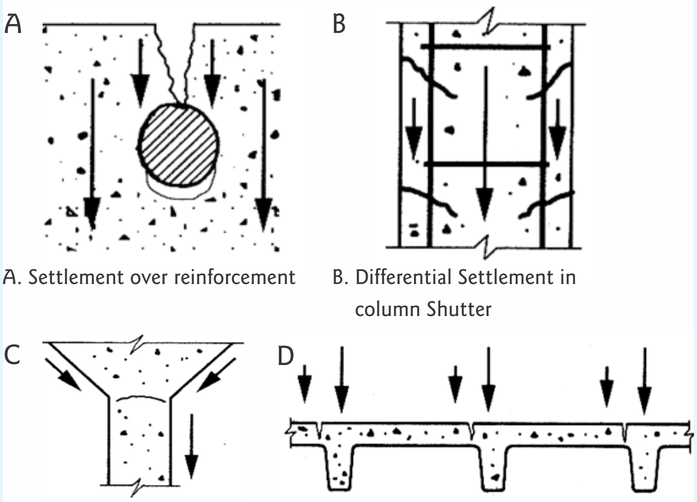
## Cracks in Fresh Concrete:

The following types of cracks are generally found in fresh concrete;

1. Plastic Settlement Cracks
2. Plastic Shrinkage Cracks
3. Early Thermal Contraction Cracks
4. Crazing
5. Drying Shrinkage Cracks

## 1. Plastic Settlement Cracks:

Plastic Settlement cracks are appeared in the first place and caused by inability of the concrete to settle uniformly. These cracks may appear where there is variation in the depth of the member or where there is significant restraint from reinforcement near the surface or bleeding of concrete




A. Settlement over reinforcement
B. Differential Settlement in column Shutter
C. Settlement in Column Differs from Flared Head
D. Settlement in rib differs from slab

Fig. 1 Plastic Settlement Cracking

### 1.1. Settlement Cracks due to Change in Section:

In slabs an insufficient amount of cover to large diameter top steel bars can cause the concrete to break its deck over the reinforcement. In such cases, plastic settlement cracks will occur along the reinforcement and their depth will extend from the top surface to the top of the reinforcement. The settlement cracks generally happen in deep beams or at change of section such as in T-beam or tapered columns and conical shaped structures as shown in fig. 1. (a) to (d).

If the cover to the top steel is minimal, say 20 mm, the settlement cracks can occur as early as 10 to 20 minutes after compacting the concrete. If the cover is increased, the time to cracking is also increased. If the concrete has settled around the steel bar there is lightly to be a crescent shape void under the steel, which initially will be filled with bleed water. The effect of this void is to reduce the area of bond between steel and concrete. The possibility of reduced bond strength in top bars is recognized by many international design codes

### 1.2. Settlement cracks due to bleeding:

Water being the lightest ingredients of concrete moves upward when either the heavier ingredients settles due to their own weight or concrete is compacted through vibration. The bleeding water in certain cases emerge at the surface or in some other cases may remain within the concrete. But bleeding always takes place when concrete is compacted. All concretes are subject to settlement but bleed water is seen on the surface if the rate of evaporation is less than the rate of bleeding.

The bleeding water gets trapped by flaky or flat pieces of aggregates and also by reinforcement and gets accumulated below such aggregates and reinforcement. In internal bleeding water trapped below flat pieces of aggregate and reinforcement affects the bond between cement paste and aggregate or reinforcement on account of increase in w/c ratio. The interface becomes prone to micro-cracking due to shrinkage stresses caused by dissipation of heat of hydration and drying shrinkage. The interface thus becomes a weak link in concrete. The micro-cracks propagates further and increases in width and depth over a period of time. The bleeding water on top surface of concrete when evaporate makes top surface porous and reducing abrasion resistance of concrete. The excessive working of the top surface presses coarse aggregate down and brings up the particles of cement and water. Such top surface made up of fine material with excess water develops cracks and craziness on the concrete surfaces.

Bleeding is mainly influenced by rate of evaporation, water content, use of retarders, temperature at placing time, depth of section, air entrainment and use of ultrafine materials in concrete.

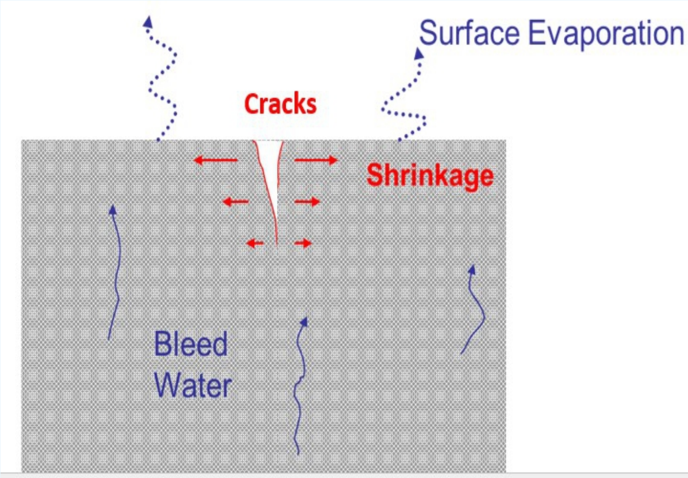



Fig. 2 Cracks due to bleeding

### 1.3. Preventive Measures:

i. Use of low w/c mixes, preferably using water reducing superplasticizers.

ii. Revibration of concrete within its initial settling time to eliminate cracks developed due to plastic settlement. Revibration should not be applied too soon as a second phase of bleeding can still cause settlement cracks. The correct time of revibration will be the least time that a vibrator poker can be inserted into the concrete and removed without leaving a significant trace. Revibration is often the only way to eliminate plastic settlement cracks particularly in deep sections.

iii. Use of self-compacting concrete where reinforcement is congested.

iv. Proper grading of coarse and fine aggregates as per IS: 383 to achieve optimum density of concrete.

v. Avoid over compaction of concrete to minimize segregation and under compaction of concrete to minimize air voids and air pockets in concrete.

vi. Use of even small quantity of fibers will reduce bleed water and settlement.

vii. Use of air entraining admixtures and ultrafine materials also reduce bleeding and settlement significantly.

## 2. Plastic Shrinkage Cracks:

Water from fresh concrete can be lost by evaporation, absorption by aggregate, formwork and rehydration process. When the loss of water from the surface of concrete is faster than the migration of water from interior to the surface, the surface dries up. This creates moisture gradients which results in surface cracking while concrete is still in plastic condition. The magnitude of plastic shrinkage and cracks depend upon the ambient temperature, relative humidity and wind velocity. Basically it depends upon the rate of evaporation of water from the surface of concrete. The rate of evaporation in excess of 1 kg/m$^2$ per hour (ACI Report[4]) is considered critical. The possibility of plastic shrinkage cracks increases, if any of the following conditions exists at the site of work.

a. The ambient temperature above 40˚C.

b. Wind velocity more than 30 km per hour.

c. The relative humidity is below 50%.

Plastic shrinkage cracks occur within a few hours of placing concrete, although they are not noticed until at least the next day. Plastic shrinkage cracks are most common in slabs, but they can also occur in the exposed top faces of walls and columns. Concrete slabs which are correctly power trowelled should not exhibit plastic shrinkage cracks because the action of trowelling is a form of re-compaction and tends to close them as fast as they occur.

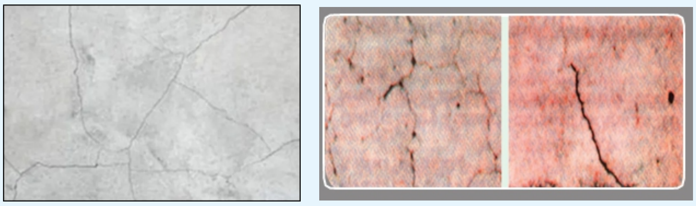


Fig. 3 Plastic Shrinkage Cracks in concrete

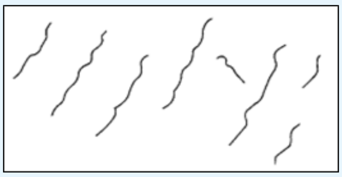
### 2.1. Types of Plastic Shrinkage Cracks:

Usually plastic shrinkage cracks take one of the three forms;

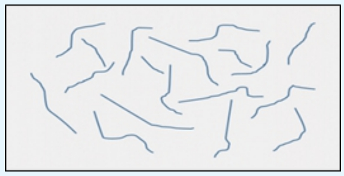
a. Diagonal cracks at approximately 45 degree to the edges of the slab. The cracks being 0.2 to 2.0 m apart.

b. A large random map pattern.

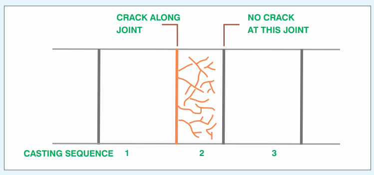
c. Cracks following the pattern of the reinforcement or other physical features, such as a change of section.



a) Diagonal cracks



b) Random




c) In Restrained Bay

Fig. 4 Types of Plastic Shrinkage Cracks

Although, the cracks can be wide at the top (upto 2-3 mm), they rapidly diminish with the depth. Nevertheless, in all but minor cases, they will usually pass through full depth of a slab in contrast with settlement cracks.

## 2.2. Preventive Measures:

The effective ways to avoid plastic shrinkage cracks is to reduce the rate of evaporation by means of early curing. The rate of evaporation of water from concrete is a function of the dryness of the air and wind speed. The dryness of the air is affected by temperature and humidity. The effect of wind speed on the rate of evaporation is very significant even a light wind 8 km/h will double the evaporation and in a 32 km/h wind the rate will exceed 1 kg/$m^2$ per hour.

The temperature difference between concrete and air may also have a significant effect on evaporation. Large differences may occur in winter when air temperature may be 5°C - 10°C and concrete temperature may vary between 20°C to 25°C. The phenomena of plastic shrinkage therefore is not limited to hot or windy days alone. It is essential to limit the rate of evaporation of water from the concrete during the critical time when the strain capacity is minimum namely from about 2 to 3 hours after placing, perhaps earlier in hot conditions. Early curing is essential to avoid plastic shrinkage cracks. If resin based curing compounds are used, they should not be applied until the concrete has lost its free surface water. The silicate-based curing compounds can be applied to wet concrete but they need considerable period of time before they react with the free line in the concrete, thus they cannot prevent plastic shrinkage cracks.

The application of windbreak is impracticable on most sites. The effective way to avoid plastic shrinkage cracks is to start wet curing with hessian or cover it by polyethylene sheet before the bleed water disappears.

i. Moisten, sub-grade and formwork before starting concreting.

ii. Reduce the time gap between placing and finishing. If there is a delay, cover the concrete with polyethylene sheet.

iii. Minimize evaporation of water by covering concrete surface with burlap, fog spray and curing compound.

iv. Erect temporary wind breakers to reduce the wind velocity if it is an excess of 20 km per hour.

v. Sprinkle water in the surrounding of construction site to increase the relative humidity.

vi. Cover the concrete surfaces with polyethylene sheet immediately after finishing to prevent evaporation of water.

vii. Commence water curing of concrete immediately after the final set of concrete.

Fig. 5 Early Curing

The plastic shrinkage cracks are common occurrence especially in flat surfaces like, roof slabs and concrete pavements. Once they have appeared, it is difficult to satisfactorily rectify these cracks. However, a mixed cement slurry is poured over the cracks while concrete is still green (less than 10 hours old) and well worked by trowel after striking each side of the cracks to seal them. The low viscosity polymer formulations are also used to fill the fine plastic shrinkage cracks within 2 to 3 days of their occurrence. The best way is to take precautions to prevent evaporation of water from fresh concrete, finish it fast and cure it as early as possible.

# 3.Early Thermal Contraction Cracks:

The reaction of cement with water is exothermic which produces heat. If an element of concrete is big enough which is isolated by the formwork or other materials, then the rate of heat development in the first 24 hours is likely to exceed the rate of heat loss to the atmosphere and the concrete temperature will rise.

After a few days, the rate of heat development falls below the rate of heat loss and the concrete will cool. The cooling will cause contraction of the element. There will be no cracking if this contraction is unrestrained, but in practice there is bound to be some restraint which causes tensile strains and consequently surface cracking. The main factors affecting core area are due to either external restraint or internal restraint or both. The internal restraint is generally caused in thick elements. The surface of the element cools quicker than the core. Therefore there will be differential strains across the section and where this differential is large, cracks may develop. This internal restraints cannot be avoided but the risk of cracking can be avoided by taking suitable measures. The formation of cracks largely depends on the geometry of the element, the nature of the formwork and its striking time.

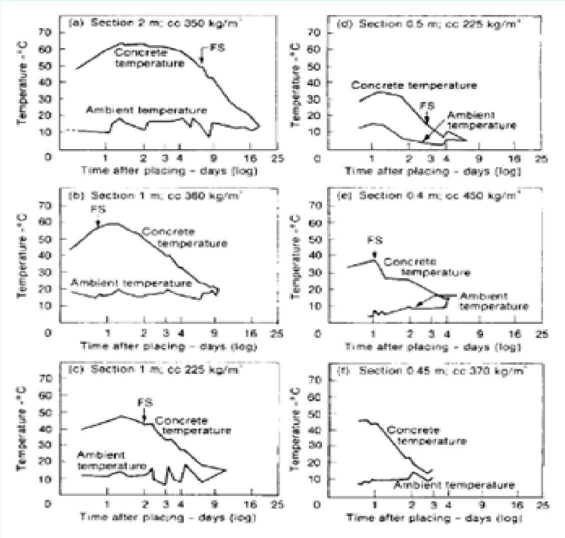



Fig. 6. Early temperature history of various concrete walls showing section thickness and cement content. FS indicates formwork struck

In most cases, the temperature of the core cools down to ambient in about 7 to 14 days. Therefore, the thermal contraction cracks must occur during this period. The cracks are most likely to form when the core temperature has dropped about 10°C - 20°C from the peak temperature. A crack which forms in the first 2 weeks is unlikely to be drying shrinkage unless the elements is a thin slab subjected to extreme drying condition. Similarly the cracks which forms after the period of several weeks or months cannot be early thermal contraction cracks.

### 3.1. Factors Affecting Temperature Rise in Concrete:

a. **Initial temperature:** Initial temperature of materials especially that of aggregates and water.

b. **Ambient temperature:** During hot weather concrete will develop a high peak temperature but there may be a greater differential between peak and ambient in the colder seasons.

c. **Size of the Element:** Large sections produce more heat but there are limits above which the problem does not become worst.

d. **Curing:** After the formwork has been removed concrete should not be cured by spraying with water as this will increase temperature differences known as thermal shock. Instead, concrete should be kept warm for a suitable time.

e. **Formwork Striking Time:** Early striking may reduce peak temperatures but will increase temperature differences.

f. **Types of Formwork:** Timber formwork will produce warmer concrete than steel or GRP but the temperature difference will be reduced.

g. **Admixtures:** Accelerators will produce heat more quickly, retarders may delay the process of hydration but will not reduce the total heat generated.

h. **Cement Content:** More cement means more heat.

I. **Cement type:** There will be increase of heat when OPC is used as compare to blended cement.

### 3.2. Factors Affecting Early Thermal Contraction Cracks:

a. **Types of Aggregates:** Limestone and, to a lesser extent, granite aggregate concretes have lower co-efficient of thermal expansion than other dense aggregate like basalts.

b. **Tensile strain capacity:** Lightweight aggregate concretes have a high tensile strain capacity and their use can be beneficial.

c. **Reinforcement:** Cracks width can be reduced by increasing the amount of reinforcement.

d. **Use of Fibers:** Currently there is little evidence of the use of synthetic or steel fibers to control early thermal contraction cracks. However, the use of steel fibers in industrial floors may help to control cracks caused by warping of thin slabs.

### 3.3. Preventive Measures:

The major factors which shall be considered and specified for control of thermal cracks are;

i. Design and specifications

ii. Restraint (size of pore, spacing of movement joints)

iii. Distribution steel, section thickness, cement content, cement type and the aggregate type.

### 3.4. Construction Methods:

Restraint (sequence and timing of pours, additional movement joints) heat development (choice of concrete materials and formwork type) cooling (striking of formwork, curing and insulation).

## 4. Crazing:

Crazing is the cracking of the surface layer of concrete into smaller irregularly shape contiguous areas. The cracks formed by crazing are very shallow and do not affect the structural integrity of the concrete and in themselves should not lead to subsequent deterioration of the concrete. The crazing is generally caused due to the floated or troweled surface layers of concrete slabs and formed surface of cast concrete. The crazing pattern is often hexagonal form with a distance of 5 to 75 mm across each "map". The small dimensional pattern is typical of wet-cast vibrated concretes, especially concrete cast against smooth formworks or moulds. The larger pattern is more typical of cast stone compacted by hammer. The surface crazing cracks are typically between 0.05 and 0.50 mm wide and down to 2 or 3 mm depth at the most. Crazing may be present but not noticeable until the cracks are filled with dirt. As long as crazing cracks have no perceptible depth, they should be of no consequence other than aesthetically.

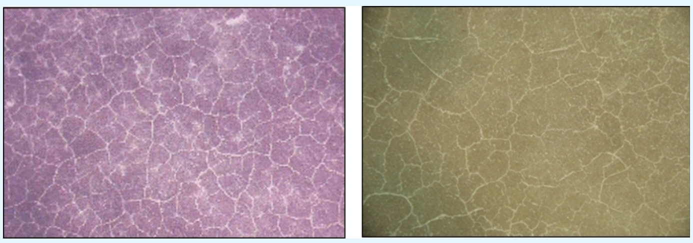


Fig. 7. Crazing

## 4.1. Causes of Crazing:

### 4.1.1. Moisture Gradient:

Crazing is caused by stresses resulting from differential moisture movement due to;

a. A high moisture concentration gradient. The porous materials as well as the impermeable materials will not craze because they cannot support moisture concentration gradients.

b. A discontinuity in composition near the exposed surfaces. When a material whose surface is different than the underlined material due to laitance has been brought out to the surface as a result of over trowelling will craze.

### 4.1.2. Climatic conditions:

The most important climatic factors governing crazing are the relative humidity and the air temperature during a drying period. The lower the relative humidity and temperature, the more severe the conditions. It follows that in a "normal" year the most severe condition occur in about April and May and the least severe around November. Crazing is often apparent within 1 to 7 days of casting but may happen later if the climate is severe enough.

### 4.1.3. Type of formwork:

The type of formwork affects the permeability of the formed concrete surface and is a most important factor. Generally, smooth formwork surfaces of low permeability (steel, plastic) will increase the incidence of crazing.

### 4.1.4. Concrete Mix:

In general, rich or wet mixes have a greater risk of crazing.

### 4.1.5. Preventive Measures:

Floated or troweled or formed concrete surfaces:

a. **Mixes:** Avoid over-rich or excessively wet mixes. Mixes with high cement contents may result in surface laitance which will allow differential moisture movements and hence prone to crazing.

b. **Compaction:** Compaction should remove trapped air and leave a concrete surface ready for the surface finish. If vibration continues for too long, the surface layer will be too rich and too wet and crazing may result.

c. **Finishing:** Avoid excessive finishing or any procedure which will depress coarse aggregate and produce a concentration of cement paste and fine aggregate at the surface. Remove bleed water before performing finishing operation. Do not dust fine materials on to the flat surface to absorb bleed water. Delay steel trowelling until the water sheen has disappeared from the slab surface.

d. **Curing:** Apply adequate and continuous curing as soon as finishing has been completed. On no account should a surface be subjected to wetting and drying cycles by inefficient curing.

e. **Formwork:** Avoid the use of formwork with a face of low permeability. Such formwork is much more likely to produce a concrete surface which has a different porosity from the body of the concrete.

f. **Making good:** If it is necessary to make good the surface because of blow holes or voids then, the process of bagging up should be carried out on a limited basis to the area of the defects only. If it is necessary to make good large surfaces, there is a great risk that the applied materials will craze.

# 5. Drying Shrinkage:

Drying shrinkage may be defined as the reduction in volume of concrete caused by the chemical and physical loss of water during the hardening process and subsequent exposure to unsaturated air. The reduction in volume can cause cracks only if the concrete is restraint in some way. The strain caused by the drying shrinkage occurs at a very slow rates in concrete members and therefore relaxation due to creep is of significant benefit.

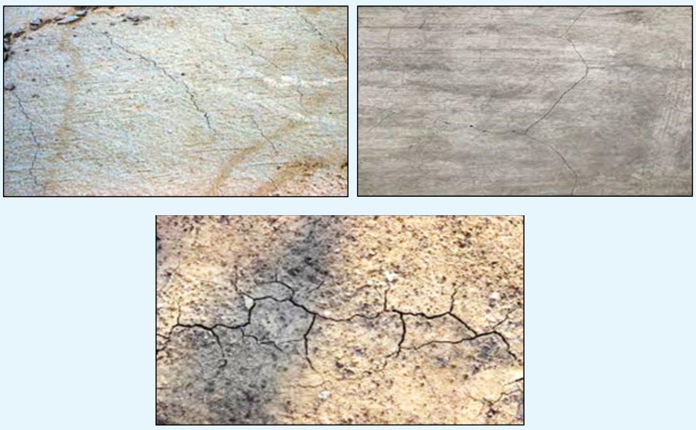


Fig. 8. Drying Shrinkage

## 5.1. Factors Affecting Shrinkage:

All constituents of concrete influence drying shrinkage either individually or as a result of their interaction. The shrinkage of a particular concrete mix is also affected by additional factors such as temperature history, curing methods, relative humidity and ratio of volume to exposed surface. Whether or not the drying shrinkage is sufficient to cause cracks mainly depends on the properties of the detailing of reinforcement.

a. **Water:**

Complex physical and chemical changes occur in the cement gel during hydration but the major contribution to drying shrinkage is the contraction of the concrete in response to loss of water to the surrounding unsaturated air. The more water evaporates from the concrete, higher the tendency to shrink on drying and lower the capacity to resist possible stress. Consequently the water content of a concrete (note w/c ratio) has the most significant effect on its drying shrinkage.

b. **Cement:**
In general, it can be assumed that the influence of cement is minimal, however it is of importance so far as the amount of cement is used affects the water content of a particular mix. The fineness of cement has little effect on drying shrinkage cracks. This may be because, as the fineness is increased, the tendency to shrink more is offset by the earlier development of tensile strain capacity to resist drying shrinkage.

c. **Blended Cement:**
Both GGBS and PFA used to produce concretes which after 28 days have a higher modulus of elasticity than OPC concrete. They will also have slightly reduced creep properties. Both these effects will tend to offset the benefits of reduced water content and shrinkage.

d. **Aggregates:**
Sound, normal weight aggregates for concrete have low shrinkage compare to cement paste. By maximizing the quantity of aggregates will reduce the effect of cement paste's high drying shrinkage. Drying shrinkage can further be reduced by using aggregates of lowest specific area.

e. **Admixtures:**
An admixture affects drying shrinkage because it either changes the water requirement of a mix or influences in some other way the behavior of the cement paste. A reduction in water content is usually possible and it has positive effects on drying shrinkage. But the accelerating admixtures like calcium chloride increases drying shrinkage and the risk of reinforcement corrosion.

f. **Relative humidity:**
Loss of water by evaporation is primary cause of drying shrinkage. The relative humidity of the air surrounding the concrete plays an important part in determining the amount of shrinkage. As relative humidity decreases, the rate and amount of water loss from a concrete surface increases, windy conditions increases the rate of evaporation even more. At relative humidity at 95%, the moisture movement virtually stops. If the relative humidity is maintained above 95%, the concrete may absorb water and expand.

g. **Curing:**
Curing will have a significant beneficial effect on tensile strain capacity and it is for this reason that curing reduces the risk of cracking. Curing also provides insulation against heat loss, thus reducing thermal gradients especially in large units and helping to reduce thermal contraction.

## 5.2. Preventive Measures:

i. **Restraint:**
The effect of external restraint can be reduced or eliminated by careful designed measures such as provision of slip layers, suitable bearings, free movement joints etc. The core of a large element of a concrete may never dry out but any exposed faces tend to shrink if they are subjected to a drying environment. This differential drying shrinkage will tend to cause cracks at the surface and such cracks can be avoided by taking suitable precautions as discussed earlier.

ii. **Provision of Reinforcement and Joints:**
The ability of reinforcement to control the width of the cracks at the surface of concrete is a direct function of cover. Therefore crack control steel should be placed as near to the surface as possible, subject to the usual requirements of cover from durability consideration.

The amount of crack control reinforcement required must be related to the provision of movement joints. If sufficient reinforcement has been provided to control early thermal contraction, then this reinforcement will also control subsequent long term drying shrinkage.

iii. **Use of Fibres:**
Fibres have insignificant effects on unrestrained long-term drying shrinkage of concrete. Steel fibres (0.5% by volume) are found much more effective than polypropylene fibres. Use of fibres to avoid drying shrinkage is very beneficial in industrial floors, the cost can be partially offset by reducing the thickness of a slab and avoiding the movement joints.

The concrete elements with exposed upper surfaces such as slabs and pavements must be protected soon after placing the concrete, both to eliminate the problems due to plastic or early thermal movements and to improve the properties of the hardened concrete. However, for elements such as beams and columns, formwork will provide sufficient curing so long as it is not removed too early. The curing improves the hydration process and mechanical properties of the concrete and its tensile strain capacity. It is, for this reason that curing helps to reduce cracks due to drying shrinkage.

## 6. Cracks in Hardened Concrete:

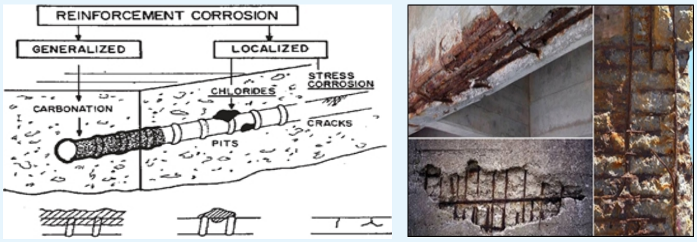
Cracks in hardened concrete may occur due to the following reasons;

1. Corrosion of reinforcement due to carbonation and chlorides.
2. Alkali aggregate reaction
3. Chemical attack, mainly due to sulphates

Cracks in the hardened concrete may also happen due to settlements, overloading natural calamities such as earthquake, floods, etc. other structural reasons. The cracks caused due to such reasons are not covered in this bulletin.

## 6. 1. Corrosion of Reinforcement:

The reinforcing steel in concrete normally does not corrode because, in the inherently alkaline environment, a protective passive layer forms on its surface. However, if the depth of cover is insufficient or the concrete is permeable, then the concrete may carbonate as deep as the reinforcement and the protective layer may be at risk.




a). Carbonation b). Chloride Attack c). Stress Corrosion

Fig. 9. Corrosion of Reinforcement

The chlorides either from the ingredients of the concrete or ingress from environment may also initiate electro-chemical process leading to corrosion of reinforcement. IS: 456 - 2000 lays down the permissible limits of chlorides in concrete as under;

i. Concrete containing metal and steam cured at elevated temperature and pre-stressed concrete - 0.4 kg/$m^3$

ii. Reinforced concrete or plain concrete containing embedded metal - 0.6 kg/$m^3$

iii. Concrete not containing embedded metal or any material requiring protection from chloride - 3.0 kg/$m^3$

Corrosion may take place at a rate dependent on the cover thickness and the quality of concrete. Corrosion may be further increased by migration of chlorides salts as they are very soluble in water. If any moisture movement takes place in concrete, chloride ions may migrate with the moisture and result in high concentration in certain locations exceeding the permissible limits. The size of the steel bars increases manifold due to corrosion and causes tensile stresses within the concrete and consequently causing cracks and spalling of concrete.

The technique of half-cell potential measurement to assess the condition of reinforcement is normally used in such cases.

### 6.1.1. Preventive Measures:

i. The permeability of concrete will be reduced by the use of blended cement, GGBS and fly ash.

ii. Concrete materials should not contribute chlorides to the mixture, this may exceed the permissible chloride limits.

iii. Corrosion inhibiting admixture delay the onset-of corrosion. Water repellent material may reduce the progress of moisture and chlorides to a limited extent in low permeability concrete.

iv. Use of Ultrafine materials like silica fume, ultrafine slag, ultrafine fly ash, etc. 5% by weight of these materials make concrete dense and impermeable.

v. Avoid excessive cementitious materials as they increase the volume of paste and the potential for shrinkage and cracking.

vi. Concrete must be adequately compacted and cured. Curing should be performed preferably for at least 7 days.

vii. Concrete temperature should be maintained above 5°C and below 40°C.

viii. Early age curing is especially important for concrete mixtures containing SCM's. Many study shows that concrete porosity is reduced significantly with increased curing times and, correspondingly corrosion resistance is improved.

ix. ACI-318 recommended maximum WC of 0.4 and minimum strength of concrete 35 MPa for concretes that will be exposed to moisture and external source of chlorides in service.

## 6.2. Alkali Aggregate Reaction Cracks:

Alkali aggregate reaction is found in two forms namely ACR (Alkali Carbonate Reaction) and ASR (Alkali Silica Reaction). ACR is very uncommon and some pockets in North America are found to have such aggregates. In this bulletin, ASR will be discussed which is more common. ASR is a reaction which takes place between hydroxyl ions in the pore fluid within a concrete and certain forms of silica occasionally present in significant quantities in the aggregate. The product of the reaction is a gelatinous silicate hydrate containing sodium, potassium, calcium and water. Its formation and growth produces internal stresses within the concrete which are large enough to induce micro-cracking, expansion and visible cracks.

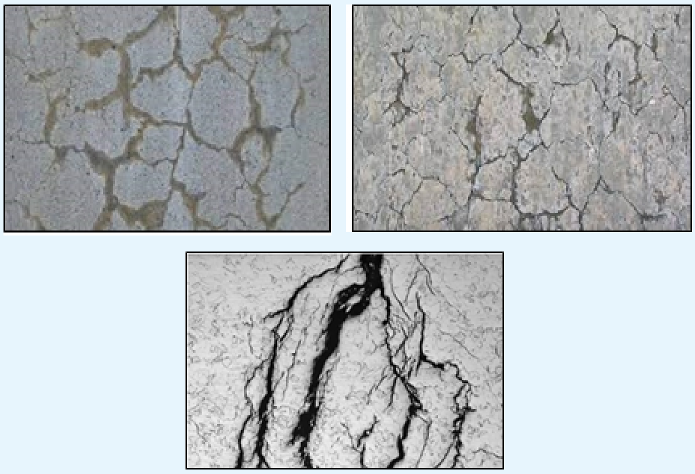


Fig. 10. Alkali Aggregate Reaction Cracks

In a concrete member affected by ASR, a network of micro-cracks can be found in the heart of the member connecting cracked aggregate particles. This micro-crack system is absent in the surface layers. As a consequence, the heart concrete expands more than the exposed surface of the member. The micro-cracks occur perpendicular to the surface and are generally 25 to 45 mm deep. Diagnosis of cracking due to ASR is not easy because ASR gel can be found infilling micro-cracks in concretes unaffected by ASR. To establish that the ASR is the primary cause of cracking, it is necessary to rule out other causes of cracking and expansion. It shall be established that substantial quantities of ASR gel are present in the concrete and the crack distribution pattern is typical of that induced by ASR.

#### 6.2.1. Preventive Measures:

To minimize the risk of cracking due to ASR, a number of approaches are used;

i. Use an aggregates with a long history of satisfactory performance.

ii. Test the aggregate for reactive silica

iii. Place an alkali limit on the concrete or the cement.

iv. In the UK, the total alkali limit ($Na_2O$ equivalent) is 3kg/$m^3$ and on cement 0.2 to 0.6%.

v. Use blended cements with blends of fly ash and GGBS.

vi. Limiting the cement content in the concrete mix and thereby limiting total alkali content in the concrete mix.

vii. Measures to reduce the degree of saturation of the concrete during service such as use of impermeable membranes.

The Concrete Society of UK has recommended that where PFA or GGBS is used, the effective alkali content of these materials will be taken to be one-sixth and one-half respectively of their total alkali contents.

### 6.3. Chemical Attacks Mainly due to Sulphates:

Most soils contain some sulphate salts in the form of calcium, sodium, and magnesium. They occur in soil or ground water or in chemical environments. Because of solubility of calcium sulfate is low, ground water contain more of other sulphates and less of calcium sulphates.

The soluble sulphates find entry into porous concrete and react with the hydrated cement products. Of all the sulphates, magnesium sulphates causes maximum damage to concrete. A characteristic whitish appearance is the indication of sulphate attack, prompting spalling and erosion of concrete. In the hardened concrete, calcium aluminate hydrate (C-A-H) can react with the sulphate salts and the product of reaction is calcium alumino sulphates forming within the framework of hydrated cement paste. Because of the increase in volume of the reaction products, which can go upto 2.27 times, a gradual disintegration of concrete takes place.

Fig. 11. Resistance against Sulphate Attack

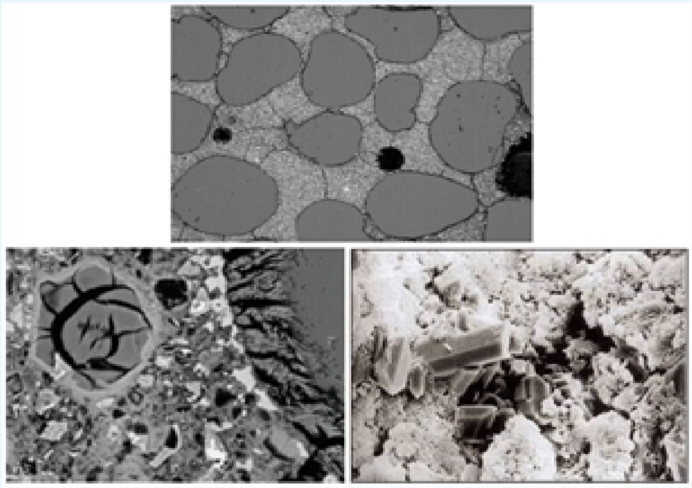


Fig. 12. Sulphate Attack on Concrete

The rate of sulphate attack increases with the increase in the strength of solution. A saturated solution of magnesium sulphate can cause serious damage to concrete with higher w/c ratio within a short time. However, if the concrete is made with low w/c ratio the concrete can withstand the action of magnesium sulphate for 3 to 4 years or even more. The concentration of sulphate is expressed as the number of parts by weight of $SO_3$ per million parts. 1000 ppm is considered moderately severe and 2000 ppm is considered severe. The permissible limits of $SO_3$ in soil and water are given in Table - 4 of IS: 456 - 2000.

#### 6.3.1. Preventive Measures:

i. **Use of sulphate resisting cement:** Use of cement with low $C_3A$ content of 5% to 8% gives a reasonable resistance against sulphate attack as well as corrosion of reinforcement.

ii. **Use of good quality of concrete:** Well-designed placed, compacted and cured. The concrete with low w/c ratio, dense and impermeable provides high resistance to sulphate attack.

iii. **Use air entrainment:** Use air entrainment to the extent of 3% to 4% in concrete. The beneficial effect is due to improvement in workability, reduction in bleeding and permeability.

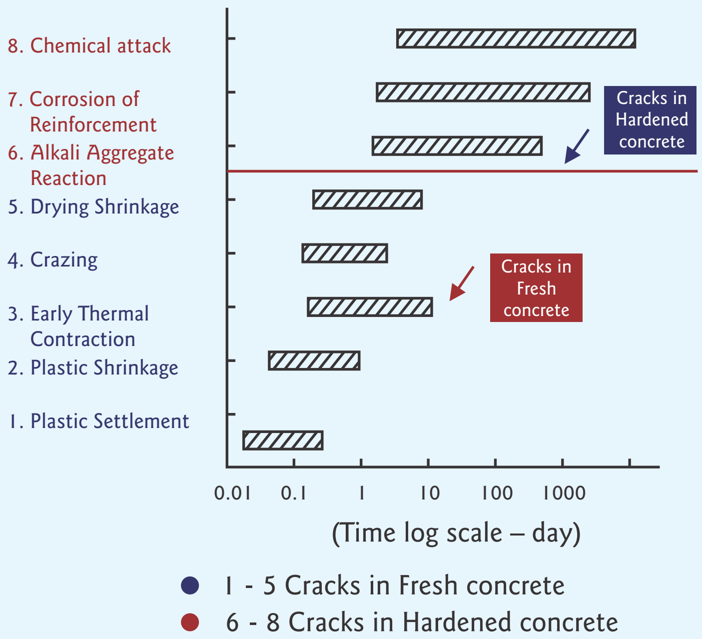
iv. **Use cementitious materials:** Use supplementary cementitious materials like fly ash, GGBS as part replacement of cement.

v. The use of SCM's is beneficial on two accounts, due to lowering down $C_3A$ content in total cementitious materials and refining the pore structure of the concrete to make it denser and impermeable.

High pressure steam curing improves the resistance of concrete to sulphate attack. This improvement is due to the change of $C_3A\ H_6$, compound into a less reactive phase and accelerated reaction to block the capillary pores thereby reducing the permeability of concrete.

## 7. Chronological Order or Cracking:

The appearance of cracks in a material indicates that the material has been stressed beyond its strained capacity. Concrete is stressed through the enforced external loads and also by the reaction of the material to the environment. The response of concrete to these effects depends on its age. Freshly mixed concrete is in a quasi-liquid state when placed and is capable of withstanding large deformation. Rapidly it begins to harden and the tensile strain capacity decreases before making a slight recovery with the time. The occurrence of cracks is related to time scale as illustrated in fig. 13.




Note: First five (1 – 5) are cracks developed in Fresh Concrete and last three (6 – 8) are cracks developed in Hardened Concrete

Fig. 13 Chronological characteristics of crack-inducing phenomena

The cracks happen in the sequence in fresh concrete and hardened concrete which are given as under;

**In Fresh Concrete**

a. Plastic settlement
b. Plastic shrinkage
c. Early thermal contraction
d. Crazing
e. Drying shrinkage

**In Hardened Concrete**

a. Restrained settlement
b. Alkali Aggregate Reaction
c. Corrosion of Reinforcement and Chemical attack.

## 8. Conclusion:

Cracks in fresh and hardened concrete are frequently observed. The cracks in fresh concrete like plastic shrinkage are caused due to evaporation of water and inadequate early curing. The settlement cracks are mainly due to bleeding of concrete and localized restraints. Thermal contraction is related to the size of concrete elements, environment, and concrete mix design. Crazing is mainly due to over finishing, use of impermeable formwork. The shrinkage in concrete at different time periods is due to excessive use of water in the mix and inappropriate practices followed during construction.

Cracks in hardened concrete are caused due to structural and non-structural reasons. The major causes of non-structural cracks are carbonation of concrete, corrosion of reinforcement, alkali aggregate reaction and chemical attack due to acids and sulphate as described above. Though it may not be possible to completely eliminate the cracks but these can be minimized by taking appropriate preventive measures suggested in this bulletin.

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## About RMCMA

The Ready Mixed Concrete Manufacturer's Association (RMCMA), India is a non-profit industry organisation of leading ready mixed concrete producers from India established in March 2002. The vision of RMCMA is to make Ready-Mixed concrete the preferred building material of choice as the best environment-friendly material of construction. The RMCMA is committed to provide leadership to the Ready Mixed Concrete industry in India. It promotes the interests of the entire Ready Mixed Concrete industry in India, without sacrificing the interest of end users, designers, specifiers, owners and other stakeholders.

RMCMA strongly supports the Quality Scheme for RMC Plants as spearheaded by Quality Council of India (QCI) and BIS. RMCMA through its efforts have already brought about 350 RMC plants throughout the country under certification scheme. RMCMA is endeavouring that all RMC plants in India shall be brought under the umbrella of 3rd party certification. RMCMA is focused on following activities

1) Organising Training Program for "Concrete Technologist of India" at different cities.
2) Creating Awareness about advantages of quality concrete in construction.
3) Certification of RMC Plants through QCI and BIS
4) Participation at National and International level to promote RMC
5) Formulation and revision of Codes pertaining to concrete and RMC
6) Safety, Health and Environment requirements at RMC Plants.
7) Dissemination of Knowledge amongst Civil Engineers and QC professionals.
8) Participation in Seminars/ Conferences and Exhibitions for promotion of RMC.

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