



READY MIXED CONCRETE MANUFACTURERS' ASSOCIATION – (RMCMA)

(Bulletin No. 15)

Shrinkage in Concrete – Causes and Preventive Measures

PRESIDENT'S MESSAGE

Dear RMCMA Members,

I am pleased to present this month's bulletin on *Shrinkage in Concrete - Causes and Preventive Measures*. In our country, where concrete builds everything from bustling highways to towering skyscrapers, shrinkage remains a silent challenge that can lead to cracks and shorten the life of structures. But with the right knowledge, we can turn this into a manageable issue. This bulletin shares practical insights to help our members produce concrete that stays strong and durable, even in India's varied climates-from hot and dry summers to humid monsoons.

Shrinkage, whether plastic, autogenous, drying, or thermal, is a natural part of concrete's journey from fresh mix to hardened form. As the bulletin explains, it starts with water loss creating tensile stresses in the paste, which can cause cracking if not controlled. For us in the ready-mixed concrete sector, understanding these causes is key, especially with modern low w/b ratio mixes that demand higher grades but bring risks like early autogenous shrinkage. The good news is that simple steps-like fog nozzles for plastic shrinkage, internal curing with super absorbent polymers (SAP) or nano-silica suspension for autogenous control, and low-heat cements for thermal gradients-can make a big difference. And let us not forget the role of aggregates: increasing their volume restrains shrinkage effectively, as shown in the bulletin's figure.

This resource draws from our IS codes, like IS:456-2000 and IS:16700-2023, which set clear limits on total shrinkage strain (0.03% to 0.04%). It also reminds us to balance mix design with curing practices to boost sustainability and avoid premature aging. At RMCMA, we believe in moving from reactive fixes to proactive planning-using tools like high-range water reducers and mineral admixtures to keep concrete performing well over time.

I encourage all our members to use this bulletin as a handy guide in your plants and sites. Let us commit to mixes that not only meet strength needs but also fight shrinkage head-on, ensuring safer and longer-lasting builds across India.

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1. Introduction

Shrinkage is the volumetric contraction of non-loaded concrete element, while creep is the volumetric contraction of a concrete element under constant load. Shrinkage is major shortcoming in the use of concrete because if it gets out of control, it can result in severe cracking that facilitates the penetration of aggressive ions and renders the reinforcing steel more vulnerable to rusting. Similarly, creep can have potential effect on concrete crack occurrence due to stresses generated by the restrained volume change or sustained load applied. In general creep deformation is much higher than the elastic strain of normal concrete under sustained load.

Shrinkage and creep both can have significant damaging effect on durability of concrete structures and can shorten their life cycle drastically when they result in severe cracking. This premature aging adversely impacts the sustainability of concrete structures. Therefore, it is important to know how to control the cracking due to shrinkage and creep. To know this, it is important to understand the nature and origin of shrinkage and creep. Once the phenomenon that generates shrinkage and creep is understood, then the technical methods to mitigate their effects can be devised. In this bulletin the causes of shrinkage and steps to reduce its effect on concrete structures is discussed. The causes and mitigation of creep are not dealt in this bulletin.

2. Types of Shrinkage

Shrinkage refers to the contraction of either fresh or hardened concrete upon a loss of water. When this loss of water occurs in fresh concrete, the resulting shrinkage is called the plastic shrinkage. When it occurs in hardened concrete, it is called drying shrinkage. In both cases the water is usually lost by evaporation to the atmosphere but the loss can also result from the suction of an underlying dry concrete or from soil, or from dry forms. They have the same physical origin, when water evaporates from the concrete menisci are created in the capillary pore-system and it is the tensile stresses created at the level of the menisci that results in contraction of the paste. Depending upon the severity and the rapidity of this loss of water, the size distribution of the capillary pores and the degree of connectivity, the concrete surface can crack more or less severely. Any restraint to concrete contraction concentrates the cracking around the restraint.

2.1 The third type of shrinkage which is well known is the thermal shrinkage. The hydration reactions of cement are exothermic, the concrete temperature first increases until the heat loss through the forms, bottom and top surfaces equals the heat generated inside the concrete by hydration, then the concrete

temperature decreases. The temperature decrease causes a contraction which is called thermal shrinkage or thermal contraction.

2.2 The other two types of shrinkages, autogenous shrinkage and carbonation shrinkage are not so much known and popular. Autogenous shrinkage is mainly developed in low w/c concretes. Carbonation shrinkage from practical point of view is negligible as compared to autogenous and drying shrinkage and normally does not cause any damage to concrete.

Autogenous shrinkage was first observed by Lynam in 1934. Autogenous Shrinkage is a physical consequence of cement hydration, so that all concretes experience some degree of autogenous shrinkage but it is more prominent in low w/c ratio concretes. Earlier concretes had a w/c ratio 0.50 or greater and thus had more water than required to hydrate the cement. They had relatively large capillary porosity composed of large pores in which large menisci developed on self-desiccation. Large menisci means low tensile stresses and low tensile stresses means low contractions.

Autogenous Shrinkage can no longer be ignored because more and more concretes are now cast with low w/c or w/b ratio, lower than 0.40. In such concretes, autogenous shrinkage may be higher magnitude than drying shrinkage and it starts to develop as soon as hydration begins, at a time when the tensile strength of paste is very low. In concretes having w/c or w/b ratio lower than 0.35, uncontrolled autogenous shrinkage can result in very rapid and severe cracking. All the four types of shrinkages are described in detail in subsequent paragraphs.

3. Plastic Shrinkage

Water evaporates from any fresh concrete that is exposed to hot weather or windy conditions, with the result that the surface cracks more or less severely depending upon the evaporation rate. It is menisci developed in the capillary system of the fresh concrete by the evaporation of water that creates the tensile stresses, that causes the concrete surface to crack. The prevention of plastic shrinkage can be done by controlling or minimising the loss of water of evaporation.

3.1 Plastic shrinkage is becoming more critical

Concretes having a high w/b ratio greater than 0.50, contain more water than the binder can hold, so that after compaction concrete tends to bleed. Concrete surface becomes covered with a thick or thin layer of water depending upon the w/b ratio used. The bleed water evaporates first and that prevents the formation of Menisci within the paste, usually, when the evaporation conditions are not severe, the layer of bleed water protects the surface

of concrete from bleeding. But as the w/b ratio of concrete decreases, the mix contains more cement and less water, so that low w/b concretes bleed very little or not at all, the lower the w/b ratio, the less the bleeding and the greater the risk of cracking. The situation is further exacerbated if the mix contains micro-fine materials like silica fume, metakaolin, ultrafine slag or ultrafine fly ash. As a result, for all practical purposes, below a w/b ratio of 0.35, concrete no longer bleeds, and if the evaporation conditions are severe, concrete surfaces crack rapidly. With the use of High Range Water Reducing Admixtures, majority of concretes have w/b ratio less than 0.35, therefore plastic shrinkage becomes more critical in modern concretes.

3.2 Methods to Control Plastic Shrinkage

There are several ways to prevent plastic shrinkage. The easier and best method is to start early curing by fogging or lightly sprinkling water after finishing of concrete. To prevent loss of water by evaporation, the concrete surface shall be covered by impervious layer of a membrane of suitable material. These methods are described as under;

3.2.1 Fog Nozzles

Fog nozzles similar to those used in nurseries to cultivate flowers can be used to saturate the ambient air above the concrete surface, so that necessary condition for evaporation does not exist. This technique is simple and not costly to implement. It is more beneficial in the months of summer. Fog nozzles can be used to prevent plastic shrinkage in any type of concrete irrespective of its w/b ratio. It is more suitable for horizontal surfaces than vertical surfaces of concrete.

3.2.2 Impervious Layer or Membrane

There are 3 ways to protect the surface of fresh concrete against evaporation with an impervious layer. The first one is to cover the concrete surface with an evaporation retarder, second one is the use of curing compound/membrane, and the third one is covering the concrete surface with an impervious sheet/covering.

3.2.2.1 Evaporation Retarders

Evaporation retarders are aliphatic alcohols that cover the concrete (i. e. the layer of bleed water) with a monomolecular film that prevents water evaporation. An evaporation retarder can

be spread over the concrete surface as soon as it has been placed and finished. Usually, the protection lasts long enough. Evaporation retarders can be used with any concrete, whatever its w/b ratio.

3.2.2.2 Curing Compounds

When sprayed on the surface, curing compounds form impervious layer that prevents water evaporation and avoids the risk of cracking. This technique is well known and has been commonly used for many years. When used with concretes that contain more water than required for full hydration ($w/b > 0.42$), they eliminate the need for water curing. However, if the membrane is torn water can evaporate.

It is important to note that curing membranes have limitations for use in concrete having a w/b ratio lower than 0.42, because later on this membrane will prevent the penetration of additional water to mitigate autogenous shrinkage and early cracking risks, except when some form of internal curing is provided. In such cases, it is internal curing that will mitigate the development of early autogenous shrinkage and the risk of cracking associated with it. Therefore, curing compounds can be used with concretes having w/b ratio greater than 0.42. In case of concrete having w/b ratio less than 0.42, the use of curing compounds must be accompanied with internal curing. Internal curing to ensure the proper hydration of cover concrete through external water curing.

4. Autogenous Shrinkage

Autogenous shrinkage is a consequence of chemical and physical transformations that occur in cement paste during its hydration. The hydration reaction creates strength, heat at the same time and absolute reduction in volume. Le Chatelier and Powers have shown that when Portland cement hydrates, the absolute volume of the hydrated cement paste is about 8% to 10% smaller than the absolute volume of the cement and water, this phenomenon is called "chemical contraction".

As long as cement paste behaves like a soft material, it contracts, but when the newly formed hydrates generate the first physical link between the cement

particles, the cement paste starts behaving like a solid that restrains the chemical contraction. Consequently, the absolute volume reduction is physically transformed into empty capillary pores distributed throughout the hydrating cement paste. This phenomenon is called "self-desiccation". Self-desiccation results in the formation of menisci within the hardening cement paste and menisci generate tensile stresses. It is these tensile stresses that generate the contraction of the apparent volume of the concrete referred to as "Autogenous Shrinkage".

When there is an external source of water that can fill the porosity developed by the self-desiccation as soon as it is created, menisci are no longer formed, and tensile stresses are no longer developed within the hydrated cement paste, and so the cement paste does not contract. The concrete no longer shrinks. The source of water is external to the cement paste but it can be either external to the concrete (usual water curing) or internal to the concrete (internal curing).

4.1 Methods to Control Autogenous Shrinkage

The autogenous shrinkage is not a serious problem with concrete having w/b ratio more than 0.42. However, it is important to take appropriate precautions for concrete having w/b ratio lower than 0.42 to control autogenous shrinkage. In case of such concretes, it is necessary to provide additional water to cement paste as soon as it starts its hydration either by external sources or by using internal curing agents.

4.1.1. External Curing

Water spraying or the use of water saturated hessian cloth/ burlap/ blankets/geo-textiles can be used to avoid the autogenous shrinkage of concrete surfaces. The penetration of this additional water inside the concrete surface is limited especially in low w/b ratio concretes. Penetration may reach only about 50 mm in a concrete having w/b ratio of 0.35. This external water not only avoids the formation of menisci in the porosity created by the hydration reaction in this zone but also hydrates some unhydrated cement particles and fills the porosity. It is very important to water cure the concrete skin in order to increase the protection of outer layer of reinforcing steel.

4.1.2 Internal Curing

Internal curing is also used to control autogenous shrinkage. It is normally done by following methods.

4.1.2.1 Use of Super Absorbent Polymers (SAP)

Super absorbent polymers can absorb from 50% to 100% of water of their volume, depending on the purity of the water. SAPs absorb water from the fresh concrete and release it during hydration of the paste and help in avoiding formation of menisci and consequently autogenous shrinkage. However, proper adjustment of water in the concrete mix is to be made to allow for absorption of water by SAP. In addition, SAP are costly and in powder form, which creates difficulty in accurate dosing in automated system. The mixing of SAP in mix needs special care, as it may lead to segregation due to 'floating' effect. These difficulties can however, be overcome by proper planning.

4.1.2.2. Use of Nano-size Silica Suspension

Nano-size Silica particles suspended in a liquid are also used for internal curing of concrete. The nano particles adsorb water, similar to SAP and release it during hydration process of paste and subsequently to control formation of menisci and consequent autogenous shrinkage. They have advantage over SAP being in liquid form, which facilitates easy and accurate dosing in automated system. In addition, mixing is more uniform and easier as compared to SAP. They are now available in the market under different brand names and ready to use. Being in nano-size, the addition also helps in achieving higher early strength as compared to controlled concrete.

4.1.2.3 Use of Light Weight Fine Aggregate

It has been reported that by substituting about 20% of fine aggregate of an equal volume of saturated light weight sand, the autogenous shrinkage can be controlled or eliminated due to continuous wetting of concrete

for first 24 hours. This method has been found useful and selectively used in pre-cast industry. However, the w/b ratio for concrete mixes is recommended to be 0.35 to 0.40 to have adequate water for hydration and wetting of concrete. It is not expensive and ecological friendly as carbon foot-prints are minimized because there is no emission of CO².

5. Drying Shrinkage

Drying shrinkage is the contraction of concrete as it dries the water in capillary pores and is lost to environment, causing the concrete to shrink and potentially crack. This occurs over months as water evaporates from the cement paste, creating internal tensile stresses, which may lead to cracking of concrete. The problem of drying shrinkage is more acute in concretes with w/b ratio more than 0.5. To reduce dryings shrinkage, it is essential to control w/b ratio preferably not exceeding 0.4. In addition, adequate and proper curing of concrete is major requirement. Dry, hot conditions accelerate drying shrinkage. Aggregate size also plays important role in controlling drying shrinkage. Larger size of aggregates mixes have lower shrinkage as compared to smaller size aggregates mixes. Apart from low w/b ratio, use of bigger size aggregates, proper curing, the use of shrinkage compensating agents is also recommended, but it should be done with care to avoid damage to dimensional integrity of concrete.

5.1 Curing of Concrete to Mitigate Drying Shrinkage

Drying shrinkage cracking is only a concern with concretes having w/o ratio more than 0.42. Such concretes have water content more than required for full hydration. As the w/b ratio increases beyond 0.42, the drying shrinkage also increases. First the water evaporates from larger capillaries and subsequently from finer capillaries. Continued evaporation of water creates menisci and surface tension on walls of menisci creates tensile stresses within the concrete. If tensile strength of concrete is lower than the tensile stresses caused due to drying shrinkage, cracks develop within the body of concrete. When the crack propagates inside the concrete, it opens new zones to drying and crack length further increases. If the w/b ratio is more than 0.42 in concrete, the water curing may only delay drying shrinkage but it would happen over a period. In such concretes, drying shrinkage can be avoided or reduced by effective coating the concrete surface by a suitable material like tar or silane.

5.2 Use of an Expansive Additive

Expansive additives such as magnesia are used in requisite quantity in composition of concrete to compensate the shrinkage. Different types of shrinkage compensating additives are available for autogenous and drying shrinkage. For autogenous shrinkage, the hydration of additive should happen in first 48 hours, while for drying shrinkage, slow hydrating agents like magnesia are used. Coarse aggregates volume in concrete has appreciable effect on drying shrinkage. With increasing volume of coarse aggregate, the shrinkage reduces and at higher percentage of aggregates ranging above 55% to 60% reduces shrinkage appreciably.

6. Thermal Shrinkage

The reaction between cement and water releases heat and the amount of heat released depends upon various factors, such as chemical composition of cement, initial temperature of fresh concrete, ambient temperature, etc. At the same time some heat is also lost through the forms, top and bottom surfaces of concrete. All things being equal, heat loss is more through steel forms as compared to wood forms. Due to hydration reaction, the concrete temperature first increases and then decreases and eventually reaches equilibrium with the ambient temperature. This release and consequent loss of heat has several rheological consequences on the hardening concrete.

- The initial homogeneity of concrete is rapidly lost, because very quickly the temperature of the hardening concrete varies across the cross-section of the structural element.
- Close to the forms and to the top surface, heat losses are greater than the center of the concrete element, therefore, temperature differences are quickly developed within the mass of concrete (temperature gradients).
- In the warmer parts cement hydrates, more rapidly than in the colder ones, which means that microstructure of the hardened cement pastes changes according to the location within a concrete element.

6.1 Limiting Cracking due to Thermal Gradients

The existence of excessive thermal gradients within hardened concrete can generate cracking, depending upon the tensile stresses reached by the concrete. Therefore, when casting large concrete elements, it is important to limit as much as possible the temperature of the hardening concrete, in order to decrease temperature gradient as much as possible. The temperature gradient, normally is limited by;

- a) Decreasing the temperature of the fresh concrete, by use of cold water/ice/ice flakes, sprinkling water over coarse aggregates and concreting during night hours or when ambient temperatures are low.
- b) Using low heat of hydration cement. Coarsely ground cement like 33 grade or cement having low C³S and high C²S are preferred. BIS has issued a code on Low Heat Cement under IS:12600-2009, which can also be used.
- c) Using mineral admixtures like Fly ash, GGBS, Calcined Clay, limestone powder, etc. as part replacement of OPC cement. The amendment number 6 of IS:456-2000 permits replacement of OPC up to 60% (including 5% microfine materials) by ggbs in mass concrete works. It would be possible to decrease the temperature of concrete with large replacement levels of OPC by mineral admixtures.
- d) Using high volume fly ash concrete, replacement of OPC up to 50%. Such concretes shall be proportioned at low w/b ratio normally (0.25 to 0.30) with high dose of PC based admixtures. If the heat of hydration of OPC is 100, then heat of hydration of ggbs is about 70 to 80 and that of fly ash 20 to 30. Fly ash is more effective in limiting the temperature of mass concrete as compared to ggbs.
- e) Using insulating forms to reduce heat emission from the surface of concrete near to forms. Thermocol sheets are commonly used for this purpose. Over the top concrete surfaces, thermocol sheets are sprayed to reduce emission of heat. Other suitable measures can also be used.
- f) Consequently, on stripping of formwork, the exposed concrete surfaces may feel thermal shock, if the temperature differential of concrete surface and ambient is more than 20°C. Traditionally the temperature difference is limited to 20°C to avoid thermal cracks.

It is therefore essential to continuously monitor the temperature of concrete surface and allow adequate time for opening of forms so that temperature differential is within 20°C.

The above precautions are essential to limit temperature gradient and consequent risk

of cracking. Presently several mathematical models are also used to predict the peak temperature in mass concrete works.

The weakest part of these models is the proper evaluation of the thermal expansion of the hardening concrete, since it varies during hardening from the time of addition of water to the hardened state. However, it is easy to measure the coefficient of thermal expansion properly just at the time of setting.

7. Effect of Aggregates on Shrinkage

A simple and effective way to decrease shrinkage as well as creep is to increase aggregate content in concrete. It has been reported that if the aggregate volume is 50% of total volume of cement paste matrix, the shrinkage is reduced by a factor of three, compared to the shrinkage of only cement paste. It should however, be realised that whatsoever is the aggregate content in the mix, the shrinkage of cement paste stays same. It is only the shrinkage of concrete that is reduced. The aggregate skeleton only restrains the shrinkage of cement paste and distributes it more evenly to form microcracks within the cement paste, rather than macrocracks that would have been otherwise developed. Aggregates play a key role in reducing the shrinkage and creep, however, a trade-off is to be achieved between rheology requirements of concrete and the volume of aggregates used in the mix.

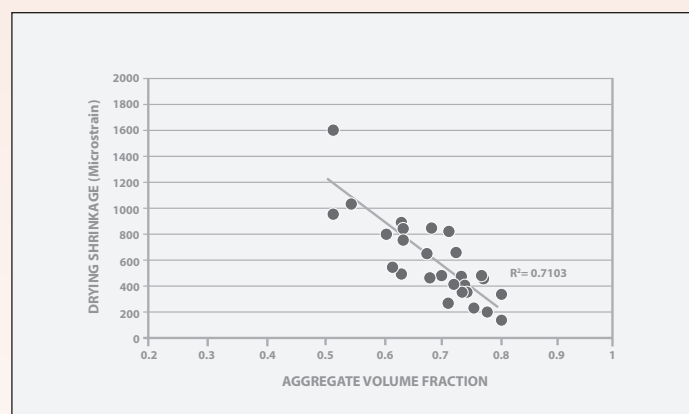


Fig-1 Relationship between concrete drying shrinkage and aggregate volume (Ref -3)

8. Codal provisions on shrinkage

Shrinkage of concrete has been a subject of great importance to consider in design of concrete structures in order to avoid cracks at different ages of concrete and to enhance its life and sustainability. Different national and international codes have made provisions on limiting and measuring shrinkage in concrete. The important provisions are given below;

- a) IS:456-2000 - Under clause 6.2.4.1, the code has made the provision that total shrinkage of concrete for design may be taken 0.0003 or 0.03 percent.
- b) IS:16700-2023 - The code is for design of Tall Buildings and under para (m) **Annex 'C'** specifies that total shrinkage strain of concrete shall not exceed 0.04 percent.
- c) ACI:318 - ACI:318 in general RCC works, permits total shrinkage strain in concrete 0.04 percent.
- d) ASTM C157 - The code permits 28 days shrinkage strain up to 0.05 percent.
- e) IS:516-2018 - The part 6 of the code deals with determination of drying shrinkage and moisture movement in concrete samples.

The various codes generally permit total shrinkage of hardened concrete even at later age to limit within 0.03% to 0.05%. The total shrinkage depends on constituents of concrete, exposure conditions such as temperature, humidity, wind velocity and period of exposure. The values given in various codes are in general, however, for a more accurate value, same shall be determined for a given concrete mix in a given exposure and duration conditions.

9. Conclusions

The shrinkage in concrete is a matter of great concern in its fresh as well as hardened state. Shrinkage creates tensile stresses which may cause cracks in concrete depending

upon its tensile strength at that age. The problem is equally faced by low w/b ratio concretes as well as high w/b ratio concretes. In low w/b ratios which are normally used these days for higher grades of concrete, of the plastic and autogenous shrinkage are more prominent resulting in cracks in fresh as well as hardened concrete. In higher w/b ratio especially exceeding 0.42, the drying shrinkage is more prominent resulting in cracks at a later date, even beyond six months.

Shrinkage is inherent property of cement paste. When water is lost from cement paste (non-rigid porous material) by evaporation to environment, shrinkage will take place, irrespective of whether concrete is in fresh or hardened state. However, the magnitude of shrinkage is not equal to volume of water lost. Free water lost from the larger pores does not generate significant shrinkage, but as the capillary pores begin to empty, menisci form on the surface of the remaining water. Surface tension forces in the water, exert stresses on the walls of the pores, leading to overall shrinkage of the paste. Further drying can lead to removal of the absorbed water from the cement hydrate gel resulting in additional shrinkage. Therefore, shrinkage is a continuous process in the concrete, however, appearance of cracks happens when tensile strength of concrete is lower than the tensile stresses caused by the shrinkage. Adequate study of environment to which concrete will be exposed, its constituent materials and proper mix proportioning including suitable curing regime can help to mitigate the shrinkage problems in concrete.

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