

Internal Curing: Curing Concrete Inside Out

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Abstract: *The use of huge quantity of fresh water in making and curing of concrete is an area of major concern in the construction industry today. In many big cities the desired quality and quantity of water is not available at reasonable price and some municipal corporations have imposed sanctions on the use of fresh water for construction purpose. This has led to the exploitation of natural resources like pond and tube wells. Literature since early 20th century suggests that the curing is the basis of development of all properties of hydrated concrete. Internal curing, the emerging area in concrete technology which has created interest amongst many researcher across the world have reported the enhancement in concrete durability and performance by virtue of better hydration. The paper is a literature review of more than 50 research papers on the topic and is an attempt to explain the mechanism of internal curing and list out the advantages of internal curing at various stages of concrete. Internal curing cannot replace the conventional curing, but works internally to increase the effectiveness of curing and make concrete more durable and less permeable.*

Keywords: Concrete, Curing, Internal curing, light weight aggregates, sustainability, shrinkage, self desiccation.

1. Introduction

The long term performance of concrete structures primarily depends upon of effective curing. Literatures emphasize on importance of curing but due to lack of awareness or situational circumstances in site, early age curing lacks due attention in Indian construction industry. Poor field curing along with concrete's inability to fully cure internally resulting in a fraction of unhydrated cement within the matrix thus depriving the industry with maximum potential that concrete can offer. This can be minimized by the age-old internal curing technology that dates back to concrete constructed during the Roman Empire using volcanic LWA materials.

1.1 Concern on use of potable water for curing

Construction industry is one of the major consumers of water resource in the world. The construction of a 100,000 sq. ft. multi-storey structure can require about 10 million litres of water for production, curing and site development activity. A double lane flyover can consume 70 million litres of water on the same scale.

The loss of precious fresh water during pond curing or wastage during intermittent sprinkling of water is an area of concern where availability of water is scarce. Researchers across the world are engaged in finding methods to reduce the use potable water in construction work, without sacrificing quality? Other practical issues related to curing water at construction site

- The quality water resource available for construction is less.
- Cost of obtaining water of desired quality at site is expensive or otherwise disturbing the natural sources like tube well or pond around.
- Hot weather regions like most part of India where large quantity of water is needed for curing owing to evaporation losses etc. Then also proper internal curing is not achieved.

Many new techniques are being applied to save water in construction industry to increase sustainability in

construction. Performance-based specifications quantify curing for acceptance and payment in addition; effective sealants and compounds that prevent the loss of water and promote moist curing conditions of concrete will be in high demand.

1.2 Curing & its importance

Curing is the process of controlling the rate and extent of moisture loss from concrete during cement hydration. Curing also control the ambient temperature of hydrating concrete since this affects the rate of hydration.

Concrete that is allowed to dry out quickly also undergoes considerable early age drying shrinkage. Inadequate or insufficient curing is one of main factors contributing to weak, powdery surfaces with low abrasion resistance. The durability of concrete is affected by a number of factors including its permeability and absorptivity, result of lack of curing. These are related to the porosity of the concrete and whether the pores and capillaries are discrete or interconnected. Whilst the number and size of the pores and capillaries in cement paste are related directly to its water-cement ratio, they are also related indirectly to the extent of water curing. Long time water curing cause hydration products to fill the pores and capillaries present either partially or completely in turn to reduce the porosity of the paste.

Curing is designed primarily to keep the concrete moist by preventing the loss of moisture from the concrete during the period in which it is gaining strength. Curing must be done for a reasonable period of time if the concrete is to achieve its potential strength and durability.

1.3 Definition of Internal Curing (IC)

In 2013, ACI-308 changed the definition of IC states that "internal curing refers to the process by which the hydration of cement occurs because of the availability of additional internal water that is not part of the mixing Water."

1.4 Difference between Internal and External Curing

In essence, the existing curing techniques require 'external actions' involving curing concrete from 'outside in'. On the other hand 'internal curing' is the one where curing is from 'inside out' (C. S. Viswanatha 2008).

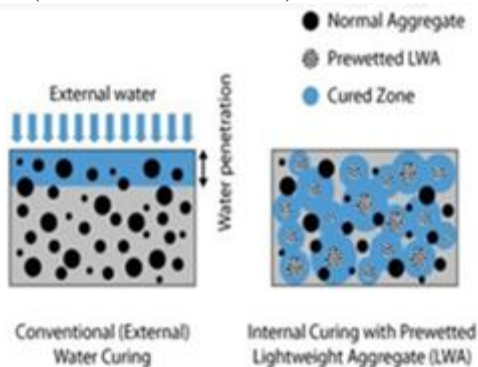


Figure 1: Illustration of difference between external and internal curing (Castro, De La Goliás & Weiss, 2010)

Conventionally, curing concrete means creating conditions such that water is not lost from the surface i.e., curing is taken to happen 'from the outside to inside'. In contrast, 'internal curing' is allowing for curing 'from the inside to outside' through the internal reservoirs (in the form of saturated lightweight fine aggregates, superabsorbent polymers, or saturated wood fibers) Created. They inhibit moisture loss and thereby improve long term strength and reduce drying shrinkage. Differences between conventional (external) curing and internal curing are shown in Figure While external curing water is applied at the surface and its depth of penetration is influenced by the quality of the concrete, internal curing enables the water to be distributed more equally throughout the cross section.

1.5 Materials used for internal curing

Internal water curing or self curing could be achieved using one of the following materials or one or two in combination

- Natural or Synthetic Light Weight Aggregate Fines, expanded shale with higher water absorption capacity.
- Super Absorbent Polymers (SAP) (60-300 mm size) - Sodium salts of poly-acrylic acid, polyacrylamide copol., ethylene maleic anhydride copol., cross-linked carboxy-methyl-cellulose, polyvinyl alcohol copol, etc.,
- Coarse aggregate of nominal maximum size and gradation (Water absorption = 20%)
- Shrinkage Reducing Admixture - SRA polyethylene-glycol.
- Saturated Wood powder / fibres.

2. Mechanisms of Internal Curing

(Bentz et al. 1999; Bentz et al. 2005) SSD prewetted LWA has been commonly used as an internal curing agent. Water is released from water-filled prewetted LWA due to drop in the RH within the hydrating cement paste due to self desiccation. To understand the mechanism of IC, the water involved in it needs to be sub divided into following heads:

- (1) the volume of water available for IC, (Absorption capacity of the agent)

- (2) the ability of the water to leave the LWA when needed for IC(desorption ability of agent), and
- (3) The effect of particle size, content and distribution of the LWA in the matrix for better dispersion of IC water in the paste.

2.1 The volume of water available for IC / Self-curing

Absorption can be defined as the ability to take in water by means of capillary suction. Where as diffusion is the movement of ions due to a concentration gradient. In LWA absorption is taking place which occurs on a faster time scale than diffusion. Water required for internal curing depends upon chemical and autogenous shrinkages expected during hydration reactions. Water/moisture required for internal curing is supplied by incorporating saturated-surface dry (SSD) lightweight fine aggregates (LWA). Bentz and coauthors (Bentz et al. 1999; Bentz et al. 2005) presented an equation to determine the amount of LWA needed to counteract the effects of self desiccation. The LWA can be used for internal curing without considerable detrimental effects on strength when added in the amounts just required to eliminate self-desiccation.

$$M_{LWA} = (Cf \times CS \times \alpha_{max}) / (S \times \Phi_{LWA})$$

Where:

M_{LWA} (kg/m³ or lbs/yd³) is the mass of LWA (in a dry state) that needs to be prewetted to provide water to fill in the voids created by chemical shrinkage,

Cf (kg/m³ or lbs/yd³) is the cement content of the mixture, CS (g of water per g of cement or lb of water per lb of cement) is the chemical shrinkage of the cement,

α_{max} (unit less) is the expected maximum degree of hydration (0 to 1),

S (unit less) is the expected degree of saturation of the LWA (0 to 1)

And be taken to be 1 when the LWA was soaked for 24 h,

Φ_{LWA} (kg of water/kg of dry LWA or lb/lb) is the absorption capacity of the LWA (taken here as the 24 h absorption).

A more correct approach to determining Φ_{LWA} is to use the measured desorption capacity of the LWA from saturation down to 92 % RH. Since in an actual concrete the LWA is initially "saturated" and undergoes desorption during IC. (Bentz et al. 2005).

2.2 The ability of the water to leave the LWA when needed for IC

Water leaves the LWA due to the suction (under pressure) that develops in the pore fluid within the hydrating cement paste due to its chemical shrinkage and self-desiccation. The consequence of this water movement from LWA to surrounding paste is frequently quantified in mortar as an increase in internal relative humidity and an increase in the critical pore size that remains prewetted (Lura 2003; Henkensiefken et al. 2008).

The basic principle for internal curing is that the largest pores will lose water first as the capillary stress that develops will be minimized when pores are emptied in this order. As the specimen ages, the hydrating paste pull water out of successively smaller pores of the LWA.

The Young-Laplace equation can be used to relate the size of the menisci to the capillary pressure:

$$\sigma_{cap} = -\frac{2\gamma\cos\theta}{r}$$

Where:

σ_{cap} (Pa) is the capillary pressure,
 γ (N/m) is the surface tension of pore fluid,
 θ (radians) is the liquid-solid contact angle (assumed to be 0 radians), and r (m) is the radius of curvature of the meniscus or the pore size.

The smaller meniscus radius in the low w/c mixtures corresponds to a higher capillary pressure, resulting in higher shrinkage

Following factors establish the dynamics of water movement to the unhydrated cement particles:

1. Thirst for water by the hydrating cement particles is very intense,
2. Capillary action of the pores in the concrete is very strong, and
3. Water in the properly distributed particles of (fine) LWA is very fluid.

A majority of water is lost at a high relative humidity (RH>96 %) implying the pores in the LWA are large (>25 nm) and the water is available to be lost at high relative humidity, which is preferred for internal curing. The samples release almost all (96 %) of their moisture when a relative of humidity of 92 % is reached, which implies that the water will leave the pores of the LWA if a large enough suction pressure (or a low enough internal relative humidity) exists. It should be noted that this favorable desorption behavior is not characteristic of all LWA (Lura 2003).

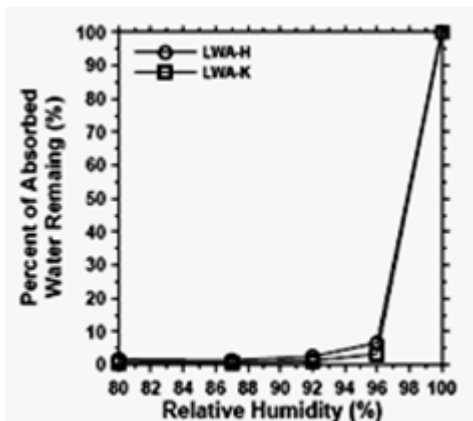


Figure 2: Desorption isotherm of two different LWA (P.Lura et. al.,2003)

2.3. Effect of Particle Size and Content of LWA

The fine lightweight aggregate, in saturated condition, produce a more uniform distribution of the water needed for curing throughout the microstructure. The grain size of the LWA used as curing agent should be less in order to minimise the paste– aggregate proximity, i.e. the distance to which the internal curing water could diffuse. The grain size of down to 2–4 mm is found to be beneficial. However, the further reduction of grain size could result in a decrease of curing efficiency. The coarse LWA proved to be less effective than the fine LWA even though they had the same volume of water because of the increased spacing between

the aggregate. (van Breugel et al. 2000; Zhutovsky et al. 2002).

The effectiveness of internal curing depends not only on whether there is sufficient water in the LWA, but also on whether it is readily available to the surrounding cement paste as well. Hence, if the distance from some location in the cement paste to the nearest LWA surface is too great, water cannot permeate fully within an acceptable time interval. This distance can be called the paste– aggregate proximity. The finer the aggregate size, the closer will be the paste– aggregate proximity.

Crushed LWA could provide a better surface for binder interaction as the pelletising process often produces LWAs with sealed surface. The vesicular surface resulting from the crushing operation allows paste penetration and provides more surface area for reaction between the aggregate and paste. The transition zone associated with a crushed aggregate has advantages over a more smooth and sealed surface.

3. Internal Curing - Benefits

Internal curing can make up for some of the deficiencies of external curing, both human related and hydration related with in critical curing period between 12 to 72 hours because hydration products clog the passageways needed for the fluid curing water to travel to the cement particles thirsting for water.

The benefit from IC can be expected when

- Cracking of concrete provides passageways resulting in deterioration of reinforcing steel,
- low early-age strength is a problem,
- permeability or durability must be improved,
- Rheology of concrete mixture, modulus of elasticity of the finished product or durability of high fly-ash concretes are considerations.
- Need for: reduced construction time, quicker turnaround time in precast plants, lower maintenance cost, greater performance and predictability.

3.1 Improvements to Concrete due to Internal Curing

- Reduces autogenous cracking,
- largely eliminates autogenous shrinkage,
- Reduces permeability, thus improving durability,
- Protects reinforcing steel,
- Increases mortar strength,
- Increases early age strength sufficient to withstand strain,
- Provides greater durability,
- Higher early age (say 3 day) flexural strength
- Higher early age (say 3 day) compressive strength,
- Lower turnaround time,
- Improved rheology
- Greater utilization of cement,
- Lower maintenance,
- use of higher levels of fly ash,
- Less micro-cracking as a result higher modulus of elasticity, or
- through mixture designs, lower modulus

- sharper edges,
- greater curing predictability,
- higher performance,
- improves contact zone,
- does not adversely affect finishability,
- does not adversely affect pumpability,
- Reduces effect of insufficient external curing.

4. Conclusion

The internal curing (IC) is an effective means of reducing autogenous shrinkage. Since autogenous shrinkage is a main contributor to early-age cracking, it is expected that IC would also reduce early age cracking. As internal curing maintains saturated conditions within the hydrating cement paste, the magnitude of internal self-desiccation stresses are reduced and long term hydration is increased. IC is particularly effective for the high performance concretes containing mineral admixtures.

Apart from the benefits and improvements in concrete which has been already discussed IC is useful when 'performance specifications' are important than 'prescriptive specifications' for concrete. Prime applications of IC could be: concrete pavements. Precast concrete operations, parking structures, bridges, HPC projects, and architectural concretes.

Internal curing compounds are technology yet to get popularized and care should be taken when utilized. With significant research contributions in to this area, Internal curing is an assured futuristic technology which is going to gain popularity and to continue to prevail in the industry for long. Instead of relying only on external applications of water, concrete quality will be engineered through the incorporation of water absorbed within the internal curing agent.

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