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Utilizing Porous Light Weight Aggregates for Self-Curing Concrete: Mechanism & Practical Considerations in Ready-Mixed Concrete Plant

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Abstract - *Concrete needs adequate curing in order to exhibit desired strength & durability properties. If the concrete receives insufficient curing, the cement will not hydrate fully. It is well known fact that higher fraction of cement getting hydrated produces the desirable compounds in the concrete. Moreover, it leads to an enhanced field performance of the concrete. Development of concrete with self curing (internal curing) ability can be the solution. Internal curing (IC) is curing the concrete from inside. The additives like Super-absorbent Polymer (SAP), Shrinkage Reducing Admixture (SRA) viz., Polyethylene glycol, propylene glycol, polyvinyl alcohol, paraffin wax, acrylic acid & pre-wetted light weight aggregates can be used as self curing agents. These materials facilitate extended hydration of the cement & cause lesser shrinkage. The research in the field of Self-Curing Concrete indicates the encouraging effects of these additives on degree of hydration, interface transition zone (ITZ), micro structure & other properties of concrete. The studies in the field show that Internal Curing has advantages such as reduction in shrinkage cracking, plastic shrinkage crack formation, water absorption, etc. The effectiveness of self curing has been proved in the laboratory, but the implementation on the field is yet not so common & encouraging. In this paper, an attempt has been made to discuss the mechanism & advantages of internal curing by incorporating Light Weight Aggregates. The paper also throws some light on how the internal curing can be practiced in the construction field. The practical considerations at the RMC plant are discussed.*

***Key words*: Concrete, plastic shrinkage, w/c ratio, autogenous shrinkage, internal curing, ITZ, chemical shrinkage, RMC plant.**

1. INTRODUCTION

Chemical shrinkage is an important mechanism to be considered in order to deal with the internal curing. Products of a reaction occupy smaller volume than the reactants in the process of chemical shrinkage [1, 2]. During hydration, chemical reaction takes place which leads to the reduction of volume. Before the concrete sets, the process of volume change will not pose any problem. As chemical shrinkage takes place, the concrete is still in fresh sate, sufficiently fluid & the particles have ability to re-arrange themselves. They can fill in the space which gets created by the chemical shrinkage. But, once the concrete sets, it becomes a rigid mass. The particles will not be able to re-arrange themselves. This eventually leads to the creation of vapor-filled voids in the body of the concrete [3].

The voids generated by the chemical shrinkage can be filled by supplying the water from the prewetted porous Light Weight Aggregates (LWAs). These LWAs act as self curing agents & bring about the internal curing process [4, 5]. In the laboratory, internal curing is shown to be beneficial for reducing self-desiccation & autogenous shrinkage [6, 7]. The research work across the world has shown that internal curing can also decrease plastic shrinkage cracking [8], shrinkage cracking [9] & water absorption [10]. The current paper discusses about the use of Light Weight Aggregate as potential internal curing material. It also focuses on the need of implementing internal curing on the field.

1.1 Importance of Curing

Curing is the process of controlling the moisture movement from the concrete mass during the process of hydration of cement. For the concrete to be strong & durable enough, it must be cured properly. The hydration of cement must be adequate to ensure that the concrete porosity is reduced to such an extent that the required strength & durability are obtained; moreover, the volume changes in the concrete because of shrinkage are also reduced [11]. Early age drying shrinkage is due to rapid drying of concrete. It leads to the formation of powdery surfaces which have low resistance against abrasion. The insufficient curing leads to the increase in absorptivity & permeability. In other words, the durability of concrete gets hampered badly. These two important parameters are a function of concrete porosity. The durability is dependent upon whether the pores & capillaries are interconnected or discrete. The size & the quantity of the capillaries & pores present in the cement paste are a function of water curing & water-cement ratio. The capillaries & pores are partially or completely filled by the hydration products. Therefore, proper curing becomes vital for the concrete to have required properties [11, 12, 13].

1.2 Age old Curing Methods: Limitations & Difficulties

The curing methods involving external application of water or curing compounds are not sustainable solutions for the problem. The water curing also leads to the wastage of large quantity of water, owing to the considerable evaporation & run-offs. The concrete quality affects the effectiveness & penetration depth of externally applied curing water, to a large extent. The external curing water is unable to supply in-depth hydration to the cement in the first 2 to 3 days, as the concrete permeability reduces. The hydration products fill-in & disconnect the capillary pore network [14].

2. SELF - CURING OF CONCRETE

The phenomenon of increase in the cement hydration by using the Light Weight Aggregates was brought to light by Paul Klieger [15] in 1950s. He quoted, "LWAs absorb considerable water during mixing which apparently can transfer to the paste during hydration". This was affirmed by Campbell & Tobin [16] in 1967, the absorbed moisture presence in LWAs produced a concrete which was less sensitive to the poor field curing conditions. Research work on deliberately incorporating LWAs for internal curing of concrete started in 1990s. Robert Phileo [17] made a statement, "Either the basic nature of Portland cement must be changed so that self-desiccation is reduced or a way must be found to get curing water in to the interior of high-strength structural members. The latter is possible by incorporating saturated LWAs in the concrete". ACI-308 gives revised definition of IC as, "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". [18].

The basic difference between the conventional curing & IC is depicted in fig. 1 [19]. In external curing, water is applied on the surface. The water penetration depth is influenced by the number of factors such as quality of concrete, age. The advantage of IC is that the water gets distributed throughout the concrete mix.

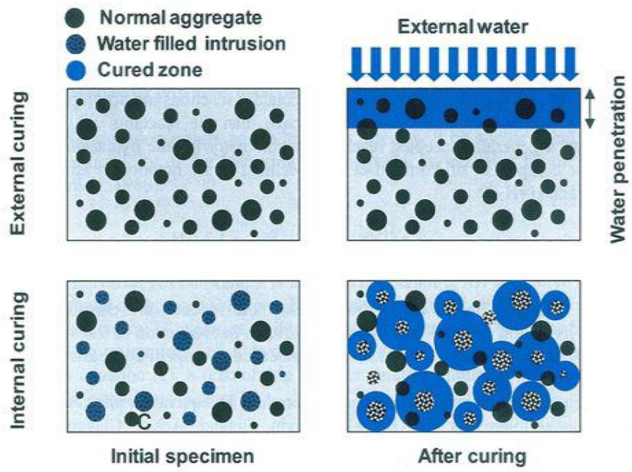

Fig. 1: Difference between External Curing & Internal Curing.

Owing to the chemical shrinkage, empty pores get created in the concrete mix during the process of hydration of cement paste. This results in to the reduction of internal Relative Humidity (RH) within the cement paste. The formation of micro-cracks & capillary pores occurs because of the self-desiccation & non-availability of moisture within the hydrating cement paste [20-25]. The weak planes within the matrix are these micro-cracks. Internal Curing helps to provide extra water throughout the concrete mix. This results in to maintaining the RH, avoiding the self-desiccation & reducing the autogenous shrinkage. The supplementary Cementitious Materials (SCMs) need extra water for their reaction in later age. Internal curing is appropriate for concrete with SCMs [19-28].

2.1 Light Weight Aggregates (LWAs) as Potential Self Curing Agents

The ready mix concrete producer is concerned about the amount of pre-wetted LWAs to be incorporated in to concrete mix for internal curing from practical considerations. An equation for mixture proportioning [29, 30] was given by working out a balance between the water demand by the cement for hydration process & the water supplied by the pre-wetted LWAs.

The following equation, by considering Ordinary Portland Cement (OPC) was given

$$M_{LWA} = (C_f \text{ X } CS \text{ X } \alpha_{max}) / (S \text{ X } \Phi_{LWA}) \text{ ------------ (i)}$$

Where, M_{LWA} = mass of (dry) LWAs required per unit volume of concrete (kg/m^3)
C_f = cement factor or binder content (kg/m^3)
CS = chemical shrinkage of concrete (g of water / g of cement)
α_{max} = maximum expected degree of cement hydration
S = degree of saturation of LWAs (0 to 1)
Φ_{LWA} = absorption (desorption) capacity of LWAs (kg water / kg dry LWAs)

Correct approach to get Φ_{LWA} is to use the measured desorption capacity of the LWAs at Relative Humidity of 92%. Practically, LWAs are saturated initially. Afterwards, they undergo desorption during the internal curing (Bentz et al. 2005) [30]. Typical coefficients for chemical shrinkage for an OPC concrete are between 0.06 & 0.08 at room temperature. The maximum expected degree of hydration of cement under saturated condition (α_{max}) can be considered as [(w/c)/0.36], for w/c ratio below 0.36. However, the maximum expected degree of hydration can be estimated as 1 for (w/c) ratio > 0.36. It is necessary that the LWAs should be distributed throughout the concrete mass. Therefore, Fine Light Weight Aggregates (FLWAs) are preferred to Coarse Light Weight Aggregates (CLWAs). The advantage of FLWAs is the lesser distance between the aggregates. It will provide beneficial effects of IC to a large paste volume.

2.2 Role of Water-Filled LWAs

Plastic shrinkage cracking is reduced due to IC because water from the LWAs replenishes the water which is lost due to evaporation (fig. 2). Immediately after the concrete gets placed, the system is in a fluid state. Cement grains & aggregates try to settle because of gravity. The pore fluid (water) is forced to the surface. During the initial period, this bleed water forms a thin layer over the concrete surface. Water evaporates from the concrete surface at a fairly constant rate (provided the environmental exposure conditions are constant). This is known as constant rate period of drying [31]. During this period, the concrete continues to consolidate in the vertical direction. This results in to the settlement of surface. However, after certain period, the rate of settlement drastically reduces because the particles begin to come in each other's contact. Assuming that the evaporation rate is relatively high, the bleed water layer will be lost from the concrete surface.

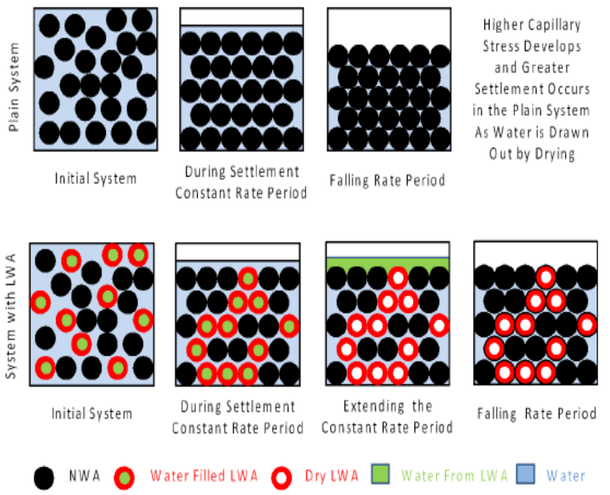

Fig. 2: A conceptual illustration of the role of water-filled lightweight aggregate at the surface of a concrete exposed to drying immediately after placement (Henkensiefken, Briatka, Bentz, Nantung, & Weiss, 2010).

A slower rate of evaporation is seen when the water available to evaporate reduces. This is referred to as the falling rate period [31]. During this period, water between the particles is drawn because of evaporation. This results in to capillary stress development. This leads to further consolidation & it may subsequently cause concrete cracking. In the case of conventional concrete, the stresses will increase drastically during this period; however, in the system with IC, water is supplied by the pre-wetted LWAs to compensate for the evaporating water from the concrete surface. Due to this, capillary stresses are low during the falling rate period. Low consolidation & lower potential for plastic shrinkage cracking are the results. National Institute of Standards & Technology (NIST) [8] verified the water removal from LWAs while the surrounding cement paste remains saturated, using 3-dimentional x-ray absorption microtomography measurements. On the other hand, it is seen that in a sealed system which was not exposed to drying, the water remained in the LWAs until it was drawn out to the surrounding cement paste due to capillary forces generated during hydration [32].

Though pre-wetted LWAs are useful in decreasing the potential for cracking due to plastic shrinkage & reducing the crack width, any water consumed in this phase will not be available later to decrease the autogenous &/or drying shrinkage. Water lost at a high RH (RH > 96%) corresponds to the pores in the LWAs as large as > 25 nm. Water lost at high RH is preferred for self-curing. The water leaves the pores of the LWAs provided that enough suction pressure exists. However, this favorable desorption behaviour is not characteristic of all the LWAs (Lura 2004) [33]. The distance of water travelled from the surfaces of internal reservoirs was estimated by Bentz et. al. [34] in terms of hydration age. Early age (< 1 day): 20 mm, middle age (1day to 3 days): 5 mm, late (3 to 7 days): 1mm, worst case (> 28 days): 0.25 mm.

Self-curing results in to producing a denser microstructure with fewer & smaller unhydrated cement particles & fewer & smaller capillary pores. The microstructure of the Interfacial Transition Zones (ITZ) around LWAs & normal weight aggregates (NWAs) are different (Fig. 3). In the case of NWAs, a wall effect exists because of inherent size differences between cement particles & aggregates. There is a deficiency of cement particles & a surplus of water (porosity) near the aggregate surface; so, a higher (w/c) within the ITZ.

Sel-curing is useful for mitigating autogenous shrinkage (chemical shrinkage), which decreases the internal RH in the hydrating concrete. This increases shrinkage & early age cracking (Bentz et.al., 2005) [34].

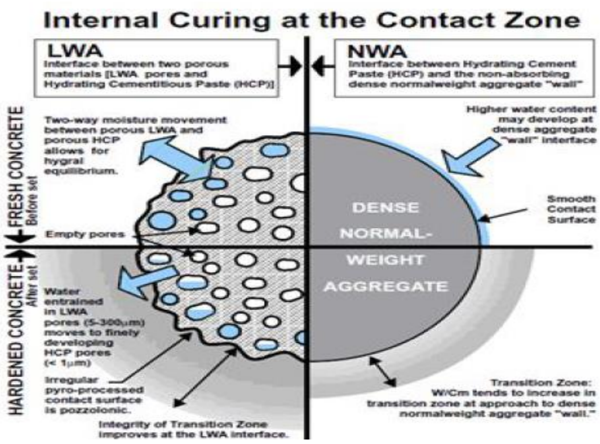

Fig. 3: Diffrence in the moisture movement between Porous Light Weight Aggrgates (LWAs) & Normal Weight Aggregates (NWAs).

Due to this, strength & durability get hampered badly. To combat the shrinkage that results from self-desiccation & the associated drop in internal RH, the minimum amount of water needed to supply IC is equal to the volume of water that is needed to fill the empty pore space that results from autogenous shrinkage associated with cement hydration. Internal RH is a measure of the amount of internal water that is available for cement hydration in the cement paste. Concretes containing LWAs have increased internal RH. They reduce autogenous shrinkage & therefore reduce total shrinkage. Due to this, there is a decresaed potential for cracking. IC are suited for the concrete mixes with relatively low w/cm ratios (ratios < 0.36) (Villarreal and Crocker, 2007). [35].

2.3 Ready Mixed Concrete (RMC) Plant: Practical Feasibility of LWA Concrete for Internal Curing

The Ready-Mixed Concrete producers find it difficult to use LWAs . The practical challenege for them is to maintain a proper saturation to ensure that lightweight concrete will pump. However, this diffuclty can be overcome by using a sprinkler system, a saturation pit, a pug mill or by vacuum saturating the aggregate. Fine Light Weight Aggreagtes (FLWAs) are preferred over Coarse Light Weight Aggreates (CLWAs). But, FLWAs exhibit cohesive properties when they are wet. This may lead to a difficulty of handling them in a batching plant owing to the fact that they may stick or make a bridge over the gate. However, an auger-screw gate on the hopper instead of the typical clam-gate can be used. Alternatively, batching the material as received & determining water absorption before concrete sets, can be carried out. But, this raises many questions. If the assumed amount of water absorption by LWAs is wrong, the (w/c) ratio of the concrete mix would be wrong. This would lead to the concrete with much different properties than expected. There is another issue of pumping the concrete. The water quantity to be forced into the LWAs during pumping needs to be determined at first. As the LWAs absorb water until set, the slump test may not indicate the normal slump. Since extra water would be placed in the mixture for absorption, this water would increase the concrete slump & appear wetter than it would be if the LWAs were pre-soaked. This may necessitate a proper correction to be applied to the observed slump value.

3. CONCLUSIONS

The benefits of Internal Curing using LWAs are as below:

- The use of LWAs decraseses the water absorption. This leads to a good quality concrete.
- Shrinkage cracking can be delayed or prevented if a sufficient volume of LWAs is incorporated in to the concrete.
- Plastic shrinkage cracking can be reduced or eliminated by adding the required amount of LWAs.

In order to effectively utilize the advantages of IC & making it practically feasible for producing such a concrete on large scale in RMC plant, certain aspects need attention for further development.

- IC is normally used for High Performance Concrete (HPC) with low (w/c) ratio, to mitigate autogenous shrinkage. For high (w/c) ratio concretes, problems other than autogenous shrinkage such as plastic shrinkage cracking & water absorption exist. More research is required to extend IC to high (w/c) ratio mixes.
- Mixture proportioning methods have focused on the autogenous shrinkage caused by the chemical shrinkage of cement. This consideration is vital in internal curing applications. But this should not be the only consideration.
- Aggregate desorption needs more attention rather than aggregate absorption.
- Volume of LWAs is an important factor. Along with it, aggregate size & grading must also be given due importance while proportioning the mix.
- Issues related to utilizing the pre-wetted LWAs in a concrete batching plant must be given due importance. The materials can be batched dry.
- In RMC plant, a method for finding the quantity of water absorbed (& subsequently desorbed) needs to be developed.
- During pumping, the water will be absorbed by the LWAs. So, an extra amount of water has to be added to the concrete mix.
- This addition of extra amount of water makes it imperative to develop a new worakability test or modify the slump test to cater to the practical requirement.

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