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Internal Curing in High Performance Concrete

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Abstract: This research aims at studying the prospects of using the sawdust for internal curing of high performance concrete (HPC). Sawdust is used as a lightweight aggregate to replace the normal weight fine aggregate. Thus it is a two-pronged research which investigates the optimum content of sawdust which when added to HPC gives a lightweight concrete with an internal source of curing. Several concrete specimens with different sawdust content and a control set of concrete specimen were produced in the laboratory. The variable studied is the different sawdust content in different sets of concrete specimens. The compressive strength is established as the measure of best sawdust content. It is concluded that a proper content of sawdust may be efficiently used to replace the normal weight fine aggregate and as a source of internal curing for HPC.

Keywords: *High Performance Concrete, Internal Curing, Sawdust, Compressive Strength*

Introduction:

High performance concrete (HPC) is characterized by early age strength. long term high strength, low permeability, high durability, resistance to freeze thaw, resistance to chemical attacks, toughness and impact resistance, compaction without segregation and high modulus of elasticity. Currently, experimental research studies are oriented towards making good concrete a better one by recognizing the fact that durability results from better choice of materials and procedures and also the embrace of the concept of HPC and its enhancement by using innovative concept of internal curing [1].

Internal curing (IC) is a method of curing in which extra water is supplied to the concrete by using internal curing agent. IC agent can be pre-wetted lightweight aggregate (LWA), superabsorbent polymers, pumice, expanded clay, shale etc. [2]. Pre-wetted sawdust is used as an IC agent in this research. In most of the HPC concretes, a low w/c ratio is adopted that is the reason these concretes hold inadequate mixing water to sustain water-filled coarse capillaries required to keep pozzolanic reactions and cement hydration. This makes internal curing more effective for such types of concrete [3].

Many definitions exists for HPC, typical HPC mixtures are characterized by low w/c ratio (<0.40) [4]. When w/c ratio is less than 0.30, self-desiccation occurs, which leads to bulk or autogenous shrinkage. The reason is that internal drying occurs as the concrete curing continues. For this purpose IC agents are used which cures concrete from internally and provide water to the hydration process. By this way, cement waste can be mitigated as in low w/c ratio concrete mixtures where less water is available to hydrate cement fully [5]. Most of the research work done on internal curing is oriented towards prevention of self-desiccation and autogenous shrinkage. But the challenging task is to reduce the self-weight of concrete and meanwhile increasing the compressive strength [6]. Internal curing in this regard can be very helpful by placing tiny reservoirs in the form of pre-wetted sawdust which will release water when concrete will dry [7]. Also a dense microstructure is formed in HPCs in a few days, holding the externally cured water to completely hydrate the cement [8]. This research is designed to investigate the effectiveness of lightweight aggregate (LWA) at varied amount as an internal curing agent to increase the compressive strength. Most of the work on HPC has been concentrated on self-desiccation and early age cracking. This research is designed to investigate the effectiveness of lightweight aggregate at varied amount as an internal curing agent to increase the compressive strength. Recent researches used sawdust as an internal curing agent to improve the compressive strength of concrete by fully pre-saturating it [6, 7, 9]. Quantity of internal curing water is not quantified in researches where sawdust is used as an IC agent. In this research, efforts are made to quantize the amount of sawdust and internal curing water. The chemical shrinkage of the hydrated water empty the pores due to which self-desiccation accrued. Since lightweight aggregate have tiny reservoirs, the amount of water required to completely eliminate self-desiccation in these reservoirs can be computed as [10]:

$$W_{cur} = C_f \times \alpha_{max} \times CS \qquad (1)$$

Where:
W_{cur} = water content (kg/m3 or lb/yd3)
C_f = cement content (kg/m3 or lb/yd3)
α_{max}= maximum degree of hydration
CS= chemical shrinkage (kg water/kg cement hydrated or lb/lb)

Cement content (C_f) is calculated from mix designing while the maximum degree of hydration for mixes with w/c ratio less than 0.36 is calculated by dividing w/c ratio by 0.36. The chemical shrinkage (CS) is taken to be 0.07 based on literature.

Recent researches have shown that the amount of curing water needed is actually higher than that predicted in Equation (1). Equation (1) predicted curing water contents in the range of 30 to 39 lb/yd^3 from, whereas levels of 50 to 67 lb/yd^3 were needed to prevail self-desiccation because of the reason that all the water is not immersed in the lightweight aggregate is useful against self-desiccation [11]. The explanation for this apparent discrepancy is that not all the water in the aggregates can become effective to counteract self-desiccation. Several other factors can be taken into account such as:

(a) If the pore size of Aggregate is very fine, water will not drift easily into the paste surrounding the aggregate.

(b) If the spacing amid the aggregate particles is excessively large the paste surrounding the aggregates will not be reachable to the water in the aggregate in a suitable time. [10]

The property of aggregate that explain how simply the rapt water contained by the aggregate is able to be released back into the mix is termed as desorption. Aggregate desorption is greatly affected by the aggregate pore size and the spacing between aggregate particles. Equation (1) is adapted by researchers in order to account for some of these influences [12]. Accordingly the amount of lightweight aggregate for elimination of self-desiccation by the internal curing water can be calculated as:

$$M_{LWA}=\frac{Cf\,x\;CS\;x\;\alpha max}{S\;x\;\varphi LWA} \qquad (2)$$

Where;

M_{LWA} = quantity of lightweight aggregate required to eliminate self-desiccation (kg/m^3 or lb/ft^3)

S = degree of saturation of aggregate (0 to 1)

φ_{LWA} = absorption of lightweight aggregate (kg water/kg dry or lb/lb)

The aim of the present study is to study the effectiveness of sawdust as an efficient source of internal curing by quantifying the amount of water and sawdust using Equation (1) and Equation (2). Since the sawdust have absorptive nature, so it can absorb large quantity of water for the purpose of internal curing and the permeability of sawdust to release the water when concrete dries with time.

Experimental Program:

1 Lightweight aggregate:

The absorption test of sawdust is performed according to ASTM C-128 by oven drying the sample and then soaking it in water for 72-h [13]. The sawdust absorbed water up to 400% of its own oven dry mass and is calculated according to ASTM C1761 [14]. As a general recommendation, the sawdust should pass through 0.25 in. sieve size. A few types of sawdust contain extractable materials that can thwart with hardening properties, particularly lean concrete mixes [9]. The setting of concrete is additionally influenced by a few types of sawdust. Therefore, sawdust is pretreated before utilizing it as a part of concrete by soaking and washing it in water.

The fine and coarse aggregates are obtained from local quarries. The fineness modulus of fine and coarse aggregates is 2.58 and 3.67 respectively.

The physical properties such as specific gravity (SSD), moisture content and water absorption of coarse and fine aggregates are shown in table 1.

Table 1: *Physical properties of aggregates*

Physical properties	***Coarse aggregate***	***Fine aggregate***
Specific gravity (SSD)	2.682	2.523
Moisture content	0.1%	0.96%
Water absorption	0.683%	1.567%

2 Variables Studied:

The water theoretically needed to fully compensate for self-desiccation can be calculated from Equation (1). While the amount of dry mass of sawdust i.e. LWA can be calculated from Equation (2) and then fine aggregate are replaced from the mixture using the same amount.

Four types of trial mixes are produced during this experimental study, keeping the w/c to be 0.30:

1) Control mix is prepared for comparison purpose. The control mix is proportioned in ratio of 1:1:1.81 by weight based on actual data obtained from the tests on fine and coarse aggregates.

2) Mix in which sawdust is added by calculating its amount using Equation (2). The amount of internal curing water required for this mix is calculated using Equation (1). The mix is designated as SI1.

3) Mix in which internal curing water and sawdust amount calculated using Equation (1) and Equation (2) respectively, is provided 3 times of the amount calculated. The mix is designated as SI2.

4) Mix in which internal curing water and sawdust amount calculated using Equation (1) and Equation (2) respectively, is provided 5 times of the amount calculated. The mix is designated as SI3.

Since the densities of the normal aggregates and the dry lightweight one are not same, the replacement in the concrete mixture is executed on volume basis with the mass of LWA determined from Equation (1) [12].

3 Testing procedure:

To evaluate the effectiveness of sawdust as a source of internal curing, compressive strength tests are done according to ASTM C-39 procedure [15]. Standard cylindrical specimens of 6” x 12” for compressive strength are tested at 3,7,14 and 28 days. The cylindrical specimens are kept in water after demolding from the cylinders. The test results are the average of three cylindrical specimens. The control mix is used as a reference for comparison.

Test Results & Discussion:

A. Test results for SI1, SI2 and SI3 mixes:

Fig. 1 shows the compressive strength of control mix, SI1, SI2 and SI3 at 3,7,14 and 28 days.

The compressive strength tests reveal that by incorporation of sawdust, the strength increases. At all the ages, the strength of SI1 mix is greater than control mix. Early age strength gain is clearly shown by SI1 mix. The 3, 7 and 14 days strength is 25%, 35% and 33% greater than the control mix respectively. While the final strength of SI1 mix is almost 14% greater than the control mix.

The 3, 7 and 14 days strength of SI2 mix is 50%, 52% and 54% greater than the control mix. While the final 28 days strength is 25% greater than the control mix. High early strength gain is observed by other researchers using sawdust and Liapor as IC agents [6, 16]. The final strength gain achieved in this research is 25% greater than the control mix, which is so far greater strength achieved while using sawdust as an IC agent. The mix SI2 has the highest early age strength gain both from control mix, SI1 and SI3 mixes. While the 28-days strength of SI2 is also greater than the other three mixes.

The higher early age strength and final strength combines the favorable effects of the internal curing with a relatively low w/c ratio (i.e. 0.30) [17]. The strength development is very fast in early ages, but the strength at 28 days decreases in SI1 and SI2 mixes, possibly due to less internal curing water available at 28-days age.

Various factors influenced the compressive strength of sawdust lightweight concrete:

1) The bond between sawdust and matrix, and the quality of interfacial transition zone could contribute to the concrete's strength. It is observed that the bond between cement paste and lightweight aggregate like sawdust in this case is strengthened by the saturation of cement paste into lightweight aggregate. [18, 19].

2) The increase in strength is due to stress homogeneity in sawdust concrete. The limited elastic mismatch between the cement paste and aggregates can minimize the occurrence of internal micro cracking, therefore, intensifying the compressive strength [20].

3) Since concrete gains strength by the process of hydration. The extra water stored in the IC agent i.e. sawdust, might also contribute in the increased compressive strength. Similar observations were made by other researchers [6]. By the use of small angel x-ray diffraction and thermal gravimetry, it was observed by other researchers that there was considerable rise in the amount of hydration products at later ages in lightweight aggregate concrete [17].

The increase in the sawdust percentage results in the decrease of the compressive strength of the concrete. The early age strength of 3, 7 and 14 days of SI3 mix is 13%, 19% and 22% less than the control mix respectively. While the final 28-days strength of SI3 is almost 34% less than the control mix.

The decrease in compressive strength of concrete is due to the following crucial factors:

1) The mechanical properties of normal weight aggregate are generally superior to lightweight aggregate like sawdust. The aggregate's strength provides ceiling strength to the concrete, after which the addition of any cementitious material to the mix doesn't increase the compressive strength [21].

2) Moist concrete usually exhibits lesser strength as compared to the partially dried concrete. This can be a reason for the decreased strength of concrete in SI3.

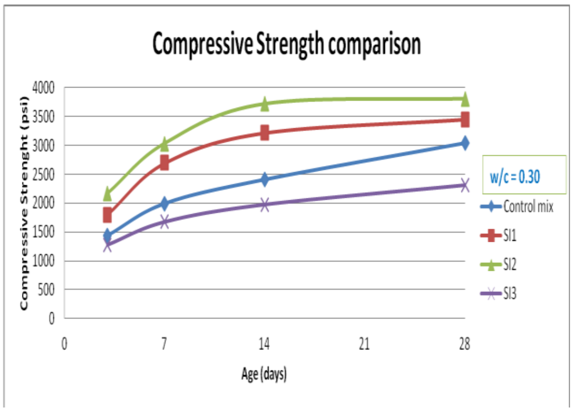

***Figure 1**: Compressive Strength comparison*

Conclusions:

The researchers have formulated the following findings from this experimental study:

- SI2 mix proves to be an effectual source of internal curing as the final strength is 25% greater than the control mix.
- Sawdust is found as an excellent and effective source of internal curing when used in optimum amount.
- The effects of sawdust on the concrete's strength are higher for early strength and lower for later strength.
- The compressive strength decreased as the sawdust amount is increased.

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