Center for By-Products Utilization

SELF-CURING CONCRETE

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Report No. CBU-2006-11
REP-610
April 2006

A CBU Report

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Introduction

Most of the concrete that is produced and placed each year all over the world already does self-cure to some extent. Some of it is not intended to have anything done to its exterior surface, except perhaps surface finishing. Yet the concrete's ability to serve its intended purpose is not significantly reduced [1].

"Curing is the maintaining of a satisfactory moisture content and temperature in concrete during its early stages so that desired properties (of concrete) may develop. Curing is essential in the production of concrete that will have the desired properties. The strength and durability of concrete will be fully developed only if it is cured. No action to this end is required, however, when ambient conditions of moisture, humidity, and temperature are sufficiently favorable to curing. Otherwise, specified curing measures shall start as soon as required." [1]

Most of the concrete in the world is placed in quantities that are of sufficient thickness such that most of the material will remain in satisfactory conditions of temperature and moisture during its early stages. Also, there are cases in which concrete has been greatly assisted in moving toward a self-curing status either inadvertently or deliberately through actions taken in the selection and use of materials [1].

To achieve good cure, excessive evaporation of water from a freshly cast concrete surface should be prevented. Failure to do this will lead to the degree of cement hydration being lowered and the concrete developing unsatisfactory properties. Curing can be performed in a number of ways to ensure that an adequate amount of water is available for cement hydration to occur. However, it is not always possible to cure concrete without the need for applying external curing methods [2].

Most paving mixtures contain adequate mixing water to hydrate the cement if the moisture is not allowed to evaporate. It should be possible to develop an oil, polymer, or other compound that would rise to the finished concrete surface and effectively seal the surface against evaporation [3].

New developments in curing of concrete are on the horizon as well. In the next century, mechanization of the placement, maintenance, and removal of curing mats and covers will advance as 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 will be in high demand. Self-curing concrete should become available in the not-too-distant future [4].

Efficiency of light-weight aggregates for internal curing of high-strength concrete to eliminate autogenous shrinkage

High performance concretes (HPC) with extremely low water to binder (w/b) ratios are characterized by high-cracking sensitivity, which is a consequence of increased autogenous shrinkage. The major reason for autogenous shrinkage – self-desiccation – cannot be eliminated by traditional curing methods. The application for the concept of internal curing by means of saturated lightweight aggregate was applied and shown to be effective in eliminating autogenous shrinkage. Zhutovsky et al. [5] described an approach to optimize the size and porosity of the lightweight aggregate to obtain effective internal curing with a minimum content of such aggregate. In this study the primary emphasis was placed upon an investigation of the effects of the replacement level of normal weight coarse aggregates by saturated lightweight ones, and the degree of water saturation of lightweight aggregate. These parameters provided the means to control the effectiveness of autogenous curing [6, 7]

Self-desiccation is reduced by the emptying of pores in the cement hydration products due to chemical shrinkage of the hydrated water. Hence, the amount of water required in the internal reservoirs of the lightweight aggregates to completely eliminate self-desiccation may be calculated from chemical shrinkage as follows.

$$W_{cur} = C.\alpha_{max} . CS \qquad (1)$$

where:

W_{cur} – water content (kg/m^3);

C – cement content (kg/m^3);

α_{max} – maximum degree of hydration; and,

CS – chemical shrinkage (kg water/kg cement hydrated).

Several factors affect to counteract self-desiccation (and, therefore, autogenous shrinkage). Such as: (i) aggregate pore size: If it is very fine, water may not migrate readily into the surrounding paste. (ii) The spacing between the aggregate particles: if it is too large, the paste surrounding the aggregates may not be accessible to the water in the aggregate within a reasonable time. These influences may be expressed in a simplified engineering approach in terms of an efficiency term, η, which is a factor in the range of 0 to 1, describing the portion of water in the aggregates that can become available for internal curing. Accordingly, the content of lightweight aggregate, LWA, in units of kg per m^3 of concrete required to eliminate self-desiccation by the internal water in the aggregates may be calculated:

$$LWA = \frac{W_{cur}}{\phi . S . \eta} \qquad (2)$$

where:

ϕ – aggregate water absorption by weight (kg water per kg of dry aggregate)

S – degree of saturation of aggregate;

η – efficiency factor (i. e., the fraction of water absorbed in saturated aggregate that can become effective to counteract self-desiccation).

Ideally, one would like to develop aggregates for internal curing where the efficiency factor, η, is 1, and the water absorption is as high as possible, to minimize the aggregate content required to obtain effective internal curing [6, 7].

The experimental study [6, 7] showed the benefits of using fine lightweight aggregate for autogenous curing. The efficiency of fine pumice aggregate, i. e. the fraction of absorbed water available for internal curing, can approach 1, i. e. 100% efficiency [6, 7].

An Investigation into the feasibility of formulating "self-cure" concrete

A feasibility of curing concrete by adding water-soluble chemicals during mixing that reduce water evaporation during setting and hardening of the concrete, making it "self-curing", was discussed by Dhir et al. [2]. The chemicals' abilities to reduce evaporation from solution and to improve water retention in hydrating portland cement was monitored by measuring weight-loss, X-Ray powder diffraction, and thermogravimetry measurements to assess whether any improvement in water retention was matched by an increase in degree of the cement hydration. Initial surface absorption tests and compressive strength measurements were made to assess whether any improvement in water retention was matched by an increase in degree of cement hydration. Tests were also made to determine surface permeability and strength development. A scanning electron microscope was used to determine the influence of the admixture on cement paste microstructure. It was found that two of the chemicals studied had a significant ”self-curing” effect. One of these chemicals enhanced hydration further than simply water retention [2] and ”self-curing”.

To achieve the most beneficial properties of a concrete, it is necessary for it to be cured properly because poor curing can reduce the performance expected from the specified water/cementious materials ratio and cement content. Although the codes of practice and other specifications make provisions for “adequate curing”, it is generally recognized that there are major practical difficulties in achieving even the minimum specified curing on-site [2].

When concrete is left in air, water evaporates from its surface. A number of factors influence the rate of evaporation. These factors include air temperature, wind speed, relative humidity, type of cement, w/cementious materials ratio, and the initial temperature of the concrete. Evaporation of water from freshly placed concrete results in detrimental features such as plastic cracking and friable surface [2].

After the concrete has set, evaporation can lead to shrinkage cracking. However, the main problem is that of “self-desiccation”. The unhydrated cement particles rely on capillary pathways running throughout the concrete to supply them with water. If the concrete loses water, the capillaries within it can dry out or become cut off by shrinkage. The reduction in the water transportation capability of the concrete is never fully reversed by the addition of more water for curing [2].

Poor concrete strength and surface quality can be avoided by good curing practices. This can be achieved in a number of ways, with varying degrees of effectiveness. Curing methods involve either the introduction of water after placing or the reduction in the rate of evaporation from the surface [2].

Water may be introduced by ponding (the immersion of the exposed concrete surface), spraying or by using coverings of wet burlap. Ponding and spraying are the most effective curing techniques, although they present a number of practical problems. The use of coverings is an expensive technique both in terms of the materials used and labor [2].

A common feature of all the existing curing techniques is that they require “external action” to ensure that they are correctly applied for the curing of concrete. An “internal curing system would have several advantages, primarily the production of a better quality concrete surface, greater turnover and the reduction in costs of operatives. It is conceivable that such a system could be created by the introduction during the mixing state of a chemical that would reduce water evaporation in the set concrete and make the concrete effectively “self-curing” [2].

Durability of “self-cure” concrete

Dhir et al [8] reported results of several durability tests conducted on self-cure concrete specimens. It was found that initial surface absorption, chloride ingress, carbonation, corrosion potential and freeze/thaw resistance characteristics were all better in air cured self-cure concrete than in the air cured control concrete. This improvement appears to be dependent on the admixture dosage, although the durability properties obtained in the study were not as good as the film cured concrete. It may be possible to achieve such properties with higher quantities of self-cure chemical.

Concrete that is capable of retaining greater quantities of water then ordinary concrete when cured in air has been developed by means of an addition of a “self-cure” chemical (SCC) which was a water-soluble polymeric glycol identified as the chemical. The water retention leads to a greater degree of cement hydration and hence improved properties of concrete in comparison to control test specimens. One particular feature of self-cure concrete is its good durability properties.

The SCC dosages were used as the molar concentration of the chemical in the mix water. 0.005M and 0.100M. Two sets of control specimens (specimens containing no self-cure chemical) were cast, kept under damp hessian polythene for 24 hour and then stripped. One set was cured in air at 20^{o} C and 60 % RH for 28 days. The other set was kept for the same amount of time in the same conditions, but sealed in a water-resistant plastic film to ensure that no moisture was lost. The self-cure concrete specimens were also cured in air at 20^{o} C and 60 % RH. Initially a surface absorption test was carried out on 150 mm cubes. After the 28-day curing period these specimens were left in air at 20^{o}C and 60 % RH for 7 days before testing (the film sealed specimens were unwrapped for this period). The test was conducted on three faces of each cube [8].

Initial Surface Absorption Test (ISAT)

Figure 1 shows the 10-minute ISAT values obtained from concrete test specimens. The surface of the air cured control specimens absorbs water at a highest rate, the least permeable surfaces are those of the time cured specimens. The higher dosage of the self-cure chemical provided a greater improvement in surface characteristics, but at both concentrations the chemical decreases the rate of absorption at the surface [8].

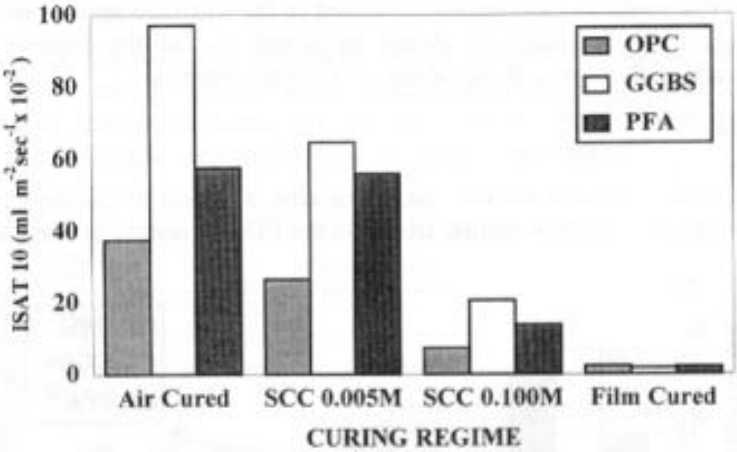

Figure 1. 10 Minute Initial Surface Absorption Test Results.

With respect to surface quality, chloride diffusion, carbonation, corrosion potential and freeze thaw, resistance self-cure concrete provides improved performance when compared to air cured specimens. The improvements in concrete durability properties are dependent on chemical dosage. At the highest dosage used in this study properties, approaching, and in some cases as good as, those characteristics of the film cured control were achieved. It is conceivable that higher dosages could produce air-cured concrete with properties rivaling those achieved in the film-cured situation [8].

Protected paste volume in concrete: Extension to internal curing using saturated lightweight fine aggregate.

One difficulty in the field use of high-performance concrete is the potential for self-desiccation and autogenous shrinkage that may occur due to its low water/cementious materials ratio and addition of silica fume to the mixture proportions. Several researchers have proposed the use of saturated lightweight aggregates to provide “internal” curing for the concrete. Simple equation was developed for concrete for the replacement level of needed to ensure adequate water retention for complete curing of the concrete. Additionally a three-dimensional concrete microstructural was model is applied to determine the fraction of the cement paste within a given distance from the lightweight aggregate surfaces. The simulation results were compared with analytical approximation developed previously. This new concept for curing is similar to the protected paste volume concept applied to characterizing air-void systems in air-entrained concrete [9].

High performance concrete (HPC) has moved from the laboratory to field use. One problem sometimes encountered is its propensity for undergoing self-desiccation and autogenous shrinkage. Due to the chemical (and/or autogenous) shrinkage that occurs as the cement hydrates, empty gel pores are created within the cement paste, leading to a reduction in its internal relative humidity and a measurable shrinkage that may cause early-age cracking. This situation is intensified in HPC (relative to conventional concrete) due to its generally higher cement content, reduced water/cementious materials (W/Cm) ratio, and any pozzolanic mineral admixtures incorporated, such as silica fume. The empty pores created during self-desiccation not only induce autogenous shrinkage stresses but also influence the kinetic of the hydration process, limiting the degree of hydration, and thus strength, that can be achieved relative to that obtainable under saturated curing conditions [9].

Prevention of autogenous shrinkage in high-strength concrete by internal curing using wet lightweight aggregates

Restrained autogenous shrinkage in high-strength lightweight aggregate concrete was investigated by Batur et al [10]. Effects of a partial replacement of normal weight aggregate by lightweight aggregate on autogenous shrinkage were also studied. The concrete with saturated lightweight aggregate exhibited no autogenous shrinkage, where as the normal weight concrete with similar matrix exhibited large shrinkage. A partial replacement of normal-weight aggregate by 25% by volume of saturated lightweight aggregate was very effective in eliminating the autogenous shrinkage and restrained stresses of the normal-weight concrete. It should be noted that the internal supply of water from the saturated lightweight aggregate to the high-strength cement matrix caused continuous expansion, which may be related to continuous hydration [10].

The effect of lightweight aggregate and their absorbed water content on the reduction in the autogenous shrinkage and restraining stresses in high-strength concrete is a clear manifestation of their effectiveness as a means of internal curing. This behavior demonstrated that the internal drying of the concrete pores due to hydration generated a driving force by which water was transported from the pores of the lightweight aggregate into the partially dried gel-pores of the cementitious matrix. The mechanisms of this transport process may be associated with capillary effects since the gel-pores in the paste matrix are considerably smaller than those of the lightweight aggregates, and, as a result, capillary suction may take place. It should be noted that the use of lightweight aggregate as a full or partial replacement of normal weight aggregate to eliminate autogenous shrinkage and restraining stresses was accompanied as expected by lower strength. This is a typical characteristic of the lightweight concrete [5, 10].

Influence of microstructure on the physical properties of self-curing concrete

Dhir et al [11] reported that during the development of "self-curing" concrete, it was found that one particular self-curing admixture produced a number of effects with respect to particular physical properties and powder x-ray diffraction characteristics. Two computer models were used to illustrate the influence the admixture was thought to have on hydrated cement microstructure. At low dosages, good strength and improved permeability characteristics were observed. At high dosages it appears that the admixture has a detrimental effect on the concrete's compressive strength due to an alteration of the nature of calcium hydroxide and the C-S-H gel structure was altered beneficially producing a highly impermeable concrete. It is suggested that although a lowering of strength did occur at high dosage, a much lower permeability for a given strength could be obtained [11].

Potential benefits from concrete using lightweight aggregate, include:

- Better thermal properties;
- Better fire resistance;
- Improved skid-resistance;
- Reduced autogenous shrinkage;
- Reduced chloride ion penetrability;
- Improved freezing and thawing durability;
- An improved contact zone between aggregate and cement matrix; and,
- Less micro-cracking as a result of better elastic compatibility.

Water absorbed within the internal aggregate pores provides internal curing (often referred to as self-curing or water entrainment) that improves the hydration of cementious materials [12].

Concrete made with lightweight aggregates has less shrinkage than normal aggregates. “The reason for this is that lightweight aggregate has higher moisture content, hence, as the concrete hydrates, the concrete is supplied with water from the aggregate (internal curing) making the specimen less susceptible to shrinkage” [12].

“Lightweight aggregate improved the autogenous shrinkage tremendously,” autor concluded. “However, again the strength will be reduced” [12].

Barrita et al. [13] evaluated high performance concrete mixtures that can be used successfully in hot dry climates. In this research magnetic resonance imaging (MRI) was used to measure the effectiveness of extending the moist curing period by incorporating some saturated lightweight aggregates into a concrete mixture being placed in hot dry climatic conditions. A series of concrete mixtures were prepared and moist cured for either 0, 0.5, 1 or 3 days, or by using a curing compound, followed by air drying at 38°C and 40% relative humidity. To accomplish this, 11% by volume of the total aggregate content was replaced with lightweight aggregate.

Type I white portland cement and quartz aggregate plus the lightweight aggregate were all selected for their low iron content to minimize adversely affecting the MRI measurements. The concrete mixtures were low strength concrete (W/C=0.60), self-consolidating concrete (W/C=0.33 containing 30% fly ash), and high strength concrete (W/ C=0.30 containing 8% silica fume) [13].

Specimens prepared with these mixtures were cast in triplicate. After curing, the specimens were dried in one direction in an environmental chamber at 38°C and 40% relative humidity. As the specimens were drying, magnetic resonance imaging was used to determine the evaporable water distribution. After the drying period, the specimens were conditioned in an oven at 105°C and water absorption tests were undertaken to determine their sorptivity [13].

The profiles obtained during drying indicated a reduced moisture loss with increasing length of moist curing. Also the use of saturated lightweight aggregate does not eliminate the need to provide some external moist curing for a reduced period of time. The results from water uptake experiments indicated that the addition of lightweight aggregate particles substantially increases the sorptivity in low strength concrete while it has only a marginal effect in both self-consolidating and high strength concrete, when compared to the same concrete mixtures containing only normal-weight aggregate [13].

Swamy and Bouikni [14] presented a simple method to obtain a 50 Mpa 28-day strength concrete having 50 and 65 percent by weight cement replacement with slag having a relatively low specific surface. The method enables slag concrete with strengths comparable to ordinary portland cement concrete from 3 days onward to be produced. The compressive and flexural strengths and the elastic modulus of these two concretes as affected by curing conditions are then presented. Prolonged dry curing is shown to affect adversely tensile strength and elastic modulus and create internal microcracking, as identified by pulse-velocity measurements. High swelling strains at high slag-replacement levels showed the need for longer wet curing for such concretes. Without any water curing, concrete with 50 percent slag replacement reached nearly 90 percent of its target strength of 50 MPa at 28 days and continued to show modest strength improvement up to 6 months. The results emphasized that even 7-day wet curing was inadequate for high levels of slag replacement, and that continued exposure to a drying environment can have adverse effects on the long-term durability of inadequately cured slag concrete [14].

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