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# Effect of internal curing on internal relative humidity and shrinkage of high strength concrete slabs

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## HIGHLIGHTS

- Internal relative humidity in high strength concrete slabs with and without internal curing is experimentally measured.
- Efficiency of internal curing on shrinkage reduction in high strength concrete slab is evaluated.
- Internal curing can greatly improve moisture status and shrinkage development in high strength concrete slab.

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## ABSTRACT

In the paper, the moisture content, in terms of relative humidity, inside of high strength concrete slab, with and without addition of pre-soaked lightweight aggregate (PSLWA), exposed to normal indoor environment is investigated by continually measuring the interior humidity of concrete immediately after slab casting until 28 days. The effects of internal curing on the developments of internal relative humidity and free shrinkage in high strength concrete slab are analyzed. The experimental results show that the internal relative humidity of high strength concrete decreases with concrete age since casting. The developing tendency of the relative humidity inside of concrete with age follows a vapor-saturated stage with 100% relative humidity (stage I) and a stage that relative humidity gradually decreases (stage II). A humidity gradient along the thickness of slab exists in early age high strength concrete. As PSLWA is added, the reduction rate of interior humidity in stage II is obviously reduced and the reduction trend with age changes from non-linear pattern to almost linear pattern. The duration of the internal humidity-saturated stage I is noticeably prolonged by addition of PSLWA. The humidity gradient together with the corresponding shrinkage gradient along the thickness of the slab is reduced also. The highest reduction on internal humidity at 28 days since casting in high strength concrete slab is changed from 46.5% to 26.2% with a medium PSLWA addition ratio, and finally to 7.9% with a high PSLWA addition level. Within present addition range, the more the PSLWA added, the stronger the above positive internal curing effects.



## 1. Introduction

The moisture content in the concrete pores is a critical parameter for most of the degradation processes suffered by concrete, for example concrete shrinkage and shrinkage related cracks. Concrete shrinks as moisture is lost to the environment or by self-desiccation. As concrete shrinks, tensile stresses will develop in the structure due to restraints from adjacent materials, connected members or shrinkage gradient. The stresses may overcome the tensile strength and lead the concrete to crack. The magnitude of shrinkage strain is normally proportional to the amount of moisture lost [1–4]. The evaluation of the shrinkage induced stresses in the structure requires the knowledge of the distribution of shrinkage strain, which, in turn needs the information of moisture distribution first. The local shrinkage can directly relate to the pore humidity [5–7].

Normally, the autogenous shrinkage of concrete is inversely proportional to water to cement ratio. The higher the water to cement ratio, the lower the autogenous shrinkage. High strength concrete generally has a low water to cement ratio, therefore marked autogenous shrinkage may occur in high strength concrete structures [6,7]. In addition, a similar problem may emerge in high performance concrete due to its high content of cementitious

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materials normally. In order to avoid the shrinkage induced cracking in high strength concrete or high performance concrete structures, it is necessary to compensate for the moisture loss resulting from cement hydration. Use of pre-soaked lightweight aggregate (PSLWA) as an internal reservoir to provide water as the concrete dries is an effectual method to reduce autogenous shrinkage of high strength concrete [8,9]. Furthermore, moisture content in pores directly affects strength, thermal properties and the rate of cement hydration. It plays a role in the durability problems and fire resistance [10]. In addition, frequent cracking of concrete structures at early ages has indicated that the early-age is one of the most critical periods of the life time of the cementitious materials [11]. Therefore, the moisture content and its distribution inside of concrete, with and without taking the action of internal curing with pre-soaked lightweight aggregate, are critically needed in order to evaluate the effectiveness of internal curing on the mitigation of shrinkage induced cracking and on the improvements of durability and service-life of concrete structures.

The purpose of this paper is to investigate the effect of internal curing using PSLWA on moisture content and its distribution of high strength concrete and to contribute to the understanding and designing of concrete mixtures including the consideration of internal curing. In the paper, the moisture content, in terms of relative humidity (RH), inside of high strength concrete slab, with and without the addition of PSLWA, exposed to normal indoor environment was investigated by continually measuring the interior humidity and temperature of concrete immediately after slab casting until 28 days. The effect of internal curing on the developments of internal relative humidity and free shrinkage as well in high strength concrete slab is analyzed.

## 2. Experimental program

### 2.1. Details of materials and specimen

Basic concrete mixture with water to cement ratio of 0.33 was used in the experiments. Based on the above basic mixture, two mixtures with different contents of PSLWA were utilized. Mixtures of concrete containing lightweight aggregate were designed according to the required amounts of internal curing water based on the above basic mixture proportion. Slightly different water to cement ratios compared to the reference was used for the mixtures with PSLWA in order to maintain a comparable compressive strength among the three mixtures. Fly ash based lightweight aggregate with the particle size of 2.5–6.5 mm, porosity of 0.37, water absorption in weight of 21% after 7 days' soaking, dry density of 1375 kg/m$^3$ was used as the carrier of internal curing water. Fig. 1 is the photograph and sieving curve of the lightweight aggregate used in experiments. All mixtures were made with the same normal Portland cement. Natural sand and crushed limestone with a maximum particle size of 5 mm and 20 mm, respectively, were used as normal fine and coarse aggregates. The concrete mixture proportions used in the present work are listed in Table 1, where $W_{IC}/C$ is the mass ratio between the introduced water in PSLWA and the cement. A polycarboxylate superplasticizer with 30% solid content was used in all three mixtures to guarantee the fresh concrete having a comparable slump of 90–120 mm. In the slab tests, one dimensional heat and moisture transportation in concrete were created. Waterproof plywood mold with net inner dimensions of 200 × 200 × 800 mm was used. To ensure the heat and moisture to transfer only along the specimen thickness direction, the bottom and the inner transverse and longitudinal sides of the mold were covered with five polystyrene boards to prevent heat loss and further with plastic sheets to prevent moisture loss. The casting face was immediately suffered to dry after finishing the surface.

### 2.2. Devices for measuring the relative humidity

In this study, a digital resistance based sensor that can measure humidity and temperature at the same time was used for relative humidity and temperature measurements. The measuring accuracies of relative humidity and temperature are 3% and 0.5 °C respectively. The signals from the sensor can automatically be recorded by a computer. The humidity and temperature were recorded every 10 min. In order to keep the sensor to be at the appointed location in concrete, a PVC tube with an inner diameter of 15 mm was used to hold the sensor. One end of the PVC tube was covered with a plastic sheet glued to the end. To keep the moisture exchanging with surrounding concrete, three rectangular holes were made on the surface of the PVC tube. In order to prevent the fresh cement paste flowing into the PVC tube from

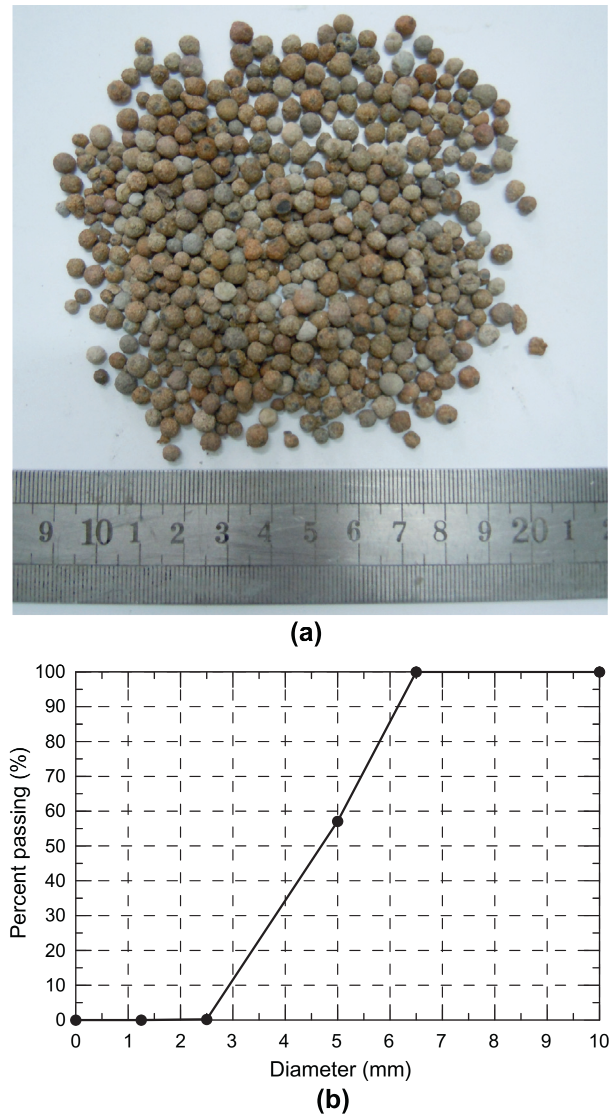


**Fig. 1.** Lightweight aggregate used in experiments, (a) photographer and (b) sieving curve.

these oblong holes, a steel bar with a diameter a little smaller than the plastic tube was filled into the tube first during concrete casting. After a few minutes of concrete casting, the steel bar was removed from the tube and the sensor was put in. To ensure the measured humidity reflecting the real values inside concrete, two O-rings with a 2 mm thickness were used to isolate the unoccupied space between the PVC tube and the sensor bar. The O-ring was slightly above the sensory section of the sensor (about 1 cm in length). In the mean time, at the top of the tube, the gap between the PVC tube and the sensor bar was sealed by an industry sealant to double isolate moisture loss through the gap. Thus, the sensory section is only connected to the concrete where we wish to measure the humidity. The detailed positions of the sensors and the PVC tubes in the specimen are shown in Fig. 2.

### 2.3. Concrete mixing and specimen casting procedures

The LWA was soaked in water for 7 days. Before concrete mixing, the pre-soaked LWA was surface dried with a wet towel in the laboratory and kept in a sealed container for use. The concrete mixing procedure can be described as follows. First, the fine and coarse aggregates were mixed together. Next, the cement was added followed by the required water with the supperplasticizer mixed in and the mixing was continued for 3 min. Then prepared LWA were added and continued for another 2 min of mixing. Afterwards the fresh concrete was cast into the mold in two layers and consolidated by a needle vibrator. After compacting, the PVC tubes with steel bar filled in were put into concrete at appointed depths from the casting surface. While inserting the tubes, the vibration hammer was started again to ensure that the PVC tube surfaces were well contacted with the surrounding concrete. After about 30 min of concrete casting, the steel bars were removed from