MONITORING MATERIAL PROPERTIES OF HIGH PERFORMANCE CONCRETE COLUMNS DURING ITS EARLY CURING PERIOD BY FIBER BRAGG GRATING SENSORS

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ABSTRACT:

With the rapid development of our society, more and more special structures such as high-rise buildings, large span structures, offshore structures etc. have been arising in the past decades of years. . As a new developing construction material in these years, High performance concrete has attracted great attentions of civil engineers and researchers due to its paramount merits. Fiber Bragg grating (FBG) sensing technique fits the deformation monitoring of concrete structure especially at its early age due to their distinguished merits. In this paper, properties of HPC columns during the early curing period are studied by FBG embedded strain sensors. Since FBG senses both strain and temperature simultaneously, FBG temperature sensors are used to compensate temperature effect of FBG strain sensors for accurate measurement of strain. Meanwhile FBG temperature sensors can monitor inner temperature changes of concrete. Simultaneous measuring of strain and temperature has been realized here. The results show that early age autogenous shrinkages of HPC concrete columns during the early curing period are pretty high. Also the content of water reducing agent on autogenous shrinkage has been analyzed.
Keywords: HPC columns, early-age Properties, FBG sensors, temperature compensation

1. INTRODUCTION

Concrete shrinkage is of increasing concern when focusing on maintaining durable structures. Over time, the shrinkage induces cracking which can severely decrease concrete life expectancy. These volume changes are often attributed to drying of the concrete over a long period, though recent observations have also focused on early age or plastic drying problems. At early ages the concrete is still moist and there are difficulties in measuring the fluid material. These difficulties have hindered comprehensive physical testing and understanding of the factors influencing plastic shrinkage. The most common solution to reduce early age volume changes is to avoid drying by proper handling of the concrete for the first few hours after placement. It is imperative that the concrete curing begins immediately and follows correct methods.

A supplementary problem to drying shrinkage at early ages is the change that occurs when no moisture transfer is permitted with the environment. This volume reduction is called autogenous shrinkage and is attributed to chemistry and internal structural changes. Typical values of autogenous shrinkage of ordinary concrete are about 40×10^{-6} at the age of 1 month and 100×10^{-6} after 5 years, which are relatively low compared with those of drying shrinkage. Therefore, the contribution of autogenous shrinkage has previously been regarded as “insignificant” in ordinary concrete mixtures due to the dominant role of drying shrinkage. However, in recent years, the increasing application of high strength concrete (HSC) and high performance concrete (HPC) has lead to the re-introduction of autogenous concerns as the mixtures are using more special cements and multiple admixtures while reducing water to cement ratio. The combination of a variety of material properties provides a basis for evaluating and quantifying the contribution of early age autogenous shrinkage to the total performance of concrete. Overall, early age concrete shrinkage is of increasing concern, as it can be responsible for cracking when the concrete has not gained significant strength to withstand internal stresses.

Shrinkage of concrete takes place in two distinct stages: early age and later age. The early stage is commonly defined as the first day, while the concrete is setting and starting to harden. Later age, or long term, refers to the concrete at an age of 24 hours and beyond. During this later stage the concrete is demolded and standardized shrinkage measurements are conducted. The long-term shrinkage is typically the only part that is identified and addressed in literature, as well as being the portion that is accommodated in structural design. Within each of these two stages of shrinkage there are also various types of linear change which can be physically measured on a specimen, mainly drying and autogenous. Both of these types can occur during either shrinkage stage. In addition to drying and autogenous shrinkage, the concrete is also subjected to volume reductions due to thermal changes and carbonation reactions. Both thermal and carbonation shrinkage are noted here, though they are not as significant as the other two and their full analysis is outside the scope of this thesis..

2. Fiber Bragg Gratings and Its Sensing Mechanism

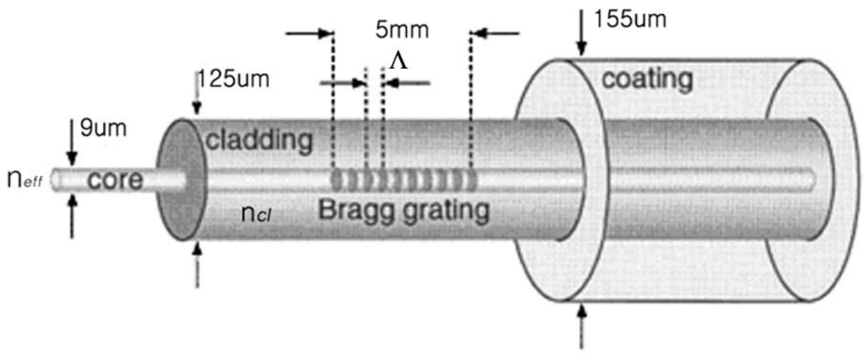


Fig.1 Schematic structure of a fiber Bragg grating (FBG)

A fiber Bragg grating is a periodic or aperiodic perturbation of the effective refractive index in the core of an optical fiber (see Fig.1). Typically, the perturbation is approximately periodic over a certain length of e.g. a few millimeters or centimeters, and the period is of the order of hundreds of nanometers, or much longer for long-period fiber gratings. Schematic structure of a fiber Bragg grating (FBG) is shown in Fig. 1.The refractive index perturbation leads to the reflection of light (propagating along the fiber) in a narrow range of wavelengths, for which a Bragg condition is satisfied:

$$\lambda_B = 2n_{eff}\Lambda \qquad (1)$$

where Λ is the grating period, λB is the vacuum wavelength, and neff is the effective refractive index of light in the fiber. Essentially, the condition means that the wavenumber of the grating matches the difference of the (opposite) wave vectors of the incident and reflected waves. In that case, the complex amplitudes corresponding to reflected field contributions from different parts of the grating are all in phase so that they can add up constructively; this is a kind of phase matching. Even a weak index modulation (with an amplitude of e.g. 10−4) is sufficient for achieving nearly total reflection, if the grating is sufficiently long (e.g. a few millimeters). Light at other wavelengths, not satisfying the Bragg condition, is nearly not affected by the Bragg grating, except for some side lobes which frequently occur in the reflection spectrum (but can be suppressed by apodization of the grating). The Schemes of sensing mechanism for fiber Bragg gratings is displayed in Fig 2.

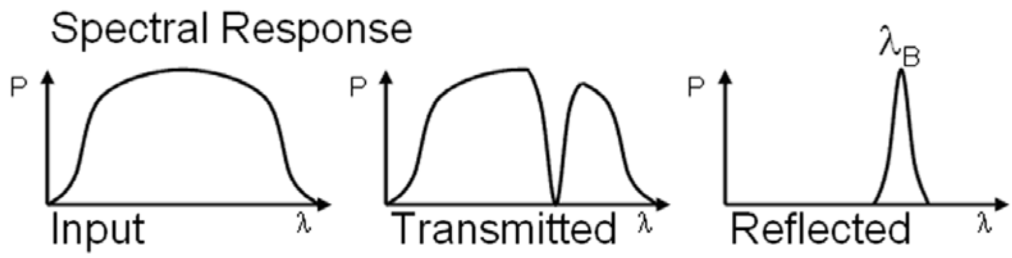


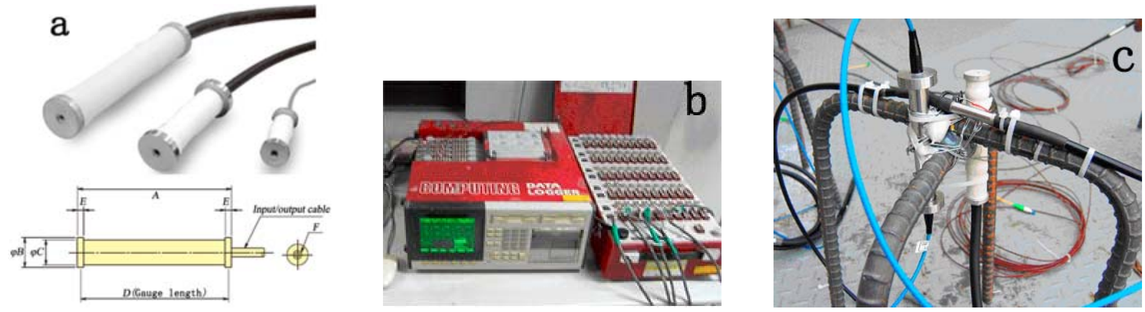
Fig. 1 Schemes of sensing mechanism for fiber Bragg gratings

The reflection bandwidth of a fiber grating, which is typically well below 1 nm, depends on both the length and the strength of the refractive index modulation. The narrowest bandwidth values, as are desirable e.g. for the construction of single-frequency fiber lasers or for certain optical filters, are obtained for long gratings with weak index modulation. Large bandwidths may be achieved with short and strong gratings, but also with aperiodic designs. As the wavelength of maximum reflectivity depends not only on the Bragg grating period but also on temperature and mechanical strain, Bragg gratings can be used in temperature and strain sensors.

3. Experimental Programs

3.1 Embedded Strain Transducer and Concerned Data Logger

The embedded strain transducer used in our experiment is KM-100B belonging to KM series made by Tokyo Sokki Kenkyujo, which can measure the strain of concrete that undergoes a transition from compliant to hardened state. Its low elastic modulus is close to that of fresh concrete before hardening, and its waterproof construction is suitable for internal strain measurement during the very early stages of curing. In addition, they are impervious to moisture absorption; thus, they can produce stability for long-term strain measurement as well. As shown in Fig.3 (a), the sensor is small, light and strong enough to be installed easily without influencing the strain distribution of measured object. Concerned data-logger used here is TDS-602 static data collecting system (Fig.3.b) made by the same company, which can collect data with high resolution. This equipment can connect strain sensor and thermocouple simultaneously, and it is fit for long-term measurement with small-sized battery by sleep interval timer.



(a) Used embedded strain transducer-KM-100B　　(b) Data logger TDS-602　　(c) Sensor installing technique

Fig.3 Used KM-100B strain transducer, data logger and installing technique

3.2 Specimen Making and Transducer Installing

Table.1 Concrete mixture proportion (Unit weight: kg/ m3)

w/c	S/a	w	c	S	G[a]	Ad[b] (%)
0.27(0.30)	0.37	171	633	591	1000	0.2

a. Maximum coarse aggregate size is 20mm.
b. Super plasticizer (high-range water-reducing admixture), ratio of cement weight.

Table 1 lists the concrete mixture proportion selected for the AS test and the 28-day compressive strength cylinder specimens. Two w/c ratios were adopted to study their effect on AS of HPC.

As there is still no specification on monitoring HPC AS in very early age, and in order to simulate the actual column member in construction site, the real size specimens were made (Table 2). Four same size specimens were used in this experiment, one was reinforced HPC specimen (RHPC3 specimen 3), and the other three were plain HPC specimens (PHPC1, 2, 4--specimen1, 2, 4), from which the influence of reinforced bars on AS can be obtained.

Fig.3 (c) shows the installation technique of embedding sensor. Inside the specimen, two “U” steel bars intersected in perpendicular style, and then the strain gauge was bound at that intersection with its axial orientation along the longitudinal direction of the specimen.

Table 2. The specification for experiment specimens

Specimen No	Size (cm)	Reinforcing or not	w/c
PHPC 1	40x40x100	Plain	0.27
PHPC 2*		Plain	/
RHPC 3		Reinforced	0.30
PHPC 4		Plain	0.30

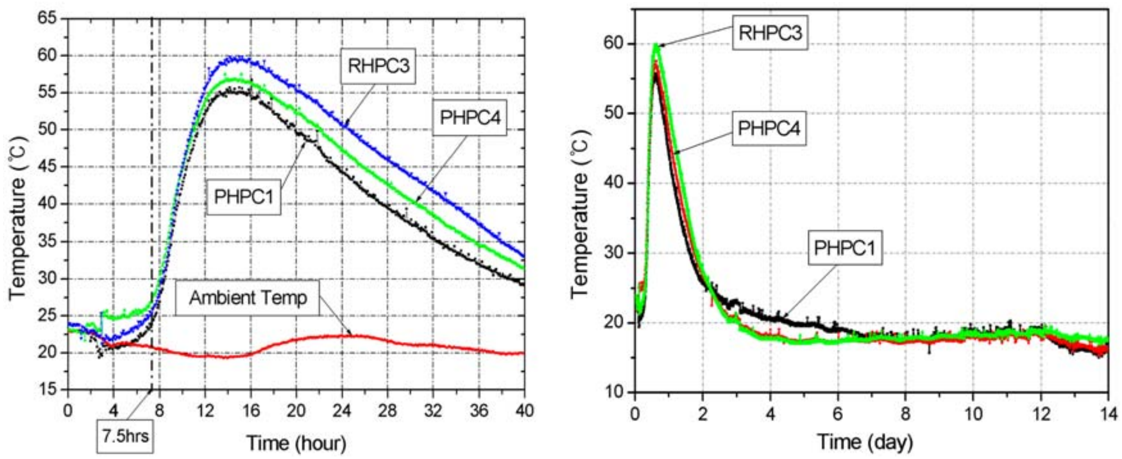
*. The plastic sheet covering PHPC2 was damaged during curing, drying shrinkage maybe occur.
As PHPC2 and PHPC4 has the same condition such as w/c ratio, curing condition et al., only monitoring data for PHPC4 used　in results and discussions has no influence on our experiment objective

4. Results and discussions

Generally, before initial setting of concrete, the elastic modulus tends to zero. During this liquid concrete phase there is no structure to hold the body firmly in place. Any movement due to applied stresses will be immediately corrected by a shift in the position of the body. Therefore, during this stage, the deformation of concrete (also called chemical shrinkage) can be neglected for long term durability of structures.

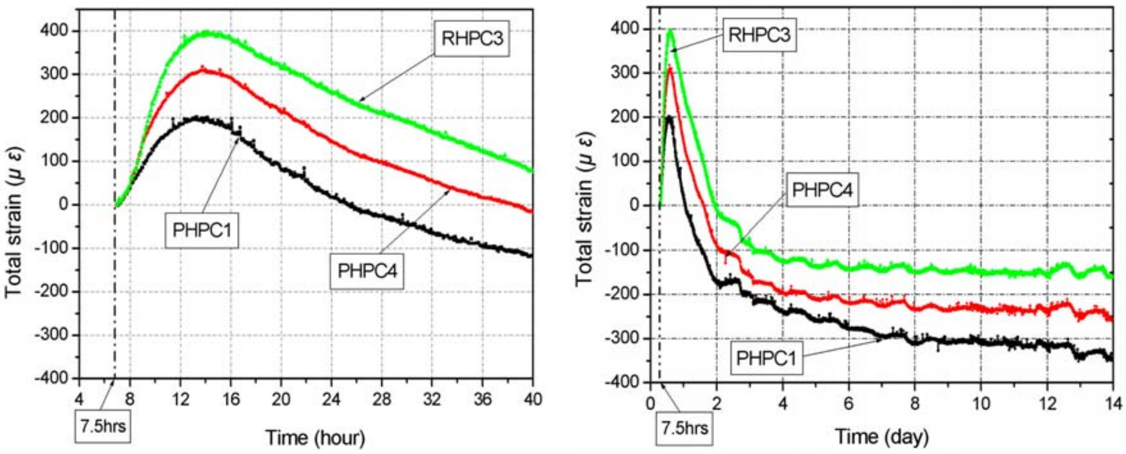
In this experiment, the reference point (initial setting time) is chosen as the 7.5 hours after mixing. From initial setting time, concrete temperature increases rapidly due to large hydration heat, and peak temperature value occurs at about 14 hours after concrete pouring (Fig.4.a) which is most likely to correspond to the final setting of the concrete. Then as most hydration reaction finishes, temperature decreases slowly. According to Fig.4. (b), concrete temperature almost tends to constant after about 2 days. Namely, temperature deformation is invertible which only occurred during first 2 days, and then it reverts with decreasing temperature.

Fig.5 shows the total deformation including temperature deformation, which is expansion during first one day or so. That is because the pretty high temperature deformation due to concrete hydration exceeds autogenous shrinkage. After temperature deformation reversion, concrete specimens display shrinkage in succession. Part reason for the highest total strain of RHPC3 is the higher temperature deformation than other two specimens. Based on Fig.6.(b), the increasing rate of AS within the first day is pretty high for whatever specimens. And the absolute values within the first day are also very large. According to Fig.6.(a), AS values for RHPC3, PHPC4 and PHPC1 are 85με, 155με and 250με respectively. After about one day, the increasing rate of AS decreases remarkably. Until two weeks later as shown in Fig.6.(b), AS values for RHPC3, PHPC4 and PHPC1 are up to 130με, 210με and 300με, respectively. This demonstrates that first day AS values for all specimens are 60% larger than those for 14 days correspondingly. Therefore, autogenous shrinkage of HPC within the first day after concrete pouring should be surveyed and taken into account while other literatures ignore it.



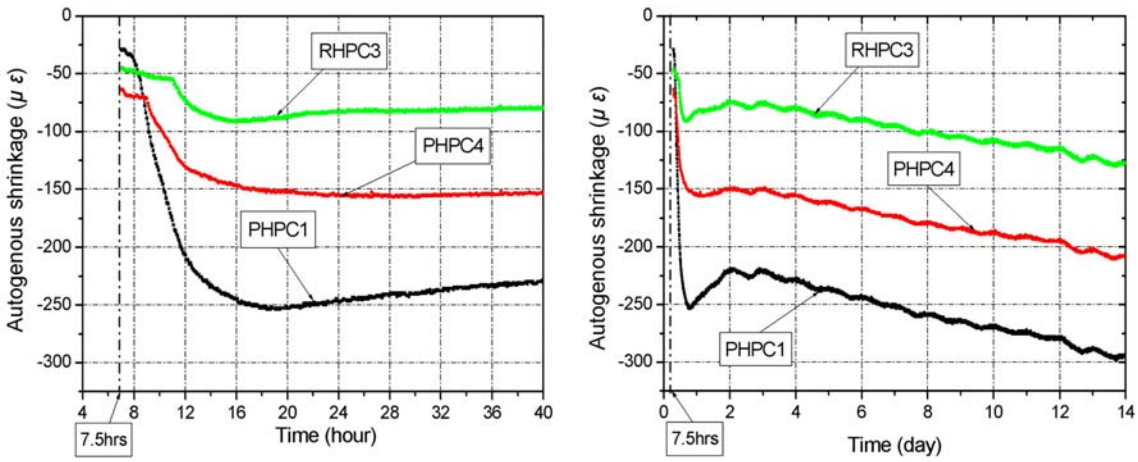
(a) Within 40 hours (b) Extending to 14 days

Fig.4 Temperature distribution of specimens within 40 hours and 14 days



(a) Within 40 hours (b) Extending to 14 days

Fig.5. The total deformation of HPC within 40 hours and 14 days



(a) Within 40 hours (b) Extending to 14 days

Fig.6. Autogenous shrinkage of HPC specimens within 40 hours and 14 days

5. Summaries

Autogenous shrinkage of HPC is caused by self-desiccation in pore structure of concrete, and it has much effect on the cracking of HPC structures. Early age AS of HPC column specimens has been monitored by KM-100B embedded strain transducer under construction-site conditions in our experiment, and following conclusions can be reached:

The increasing rate of HPC autogenous shrinkage is rapidly large within the 1 day after concrete mixing; also the absolute value is large. First day AS values for all specimens in this test are 60% larger than those for 14 days correspondingly. Therefore, autogenous shrinkage of HPC within the first day after concrete pouring should be investigated and taken into account for structure durability research. Reinforced bars restrict autogenous shrinkage of HPC due to the restraint of the rigid frame composed of reinforced bars. Further it can be predicted that the larger reinforcement ratio will result in the less HPC AS. However, it does not influence the temperature distribution of HPC columns. The w/c ratio is most influential parameter on AS when its value is less than 0.4. For most HPC, the w/c is under 0.4, so the less of w/c ratio, the larger of the AS under the same conditions.

Regarding the early-age deformation data of HPC columns measured by KM-100B strain transducer as exact value, FBG monitoring system grasped the very early age property and its varying trend (within the first day just after concrete casting) successfully and accurately by comparison of FBG data and KM data. And the data including strain and temperature from FBG monitoring system are much more stable and accurate than those from KM transducers. I.e. the reliability of monitoring data from FBG sensor is demonstrated.

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