The Exploration on Early Age Deformation of HPC by FBG Strain Sensor

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Abstract

For high performance concrete, due to its low water cement ratio (water binder ratio) and addition of mineral admixtures, pretty high autogenous shrinkage and thermal deformation occur at very early age of casting (especially before hardening). This may lead to early age cracking of HPC structures, and then may influence the durability of HPC. This paper has monitored the early age properties of HPC successfully by embedded FBG strain sensor. The results showed that the deformation increased rapidly within the first day after HPC casting. And its value is up to 85 $\mu\varepsilon$, which is the 30% of two-month deformation (280 $\mu\varepsilon$). Considering the durability and permeability of HPC, the first-day deformation is pretty high and can not be neglected. Also the superior capability of FBG sensors such as continuity, stability and multiplexed technique etc, has been demonstrated.

요 약

고강도 콘크리트는 낮은 물-시멘트 비와 혼화제의 첨가로 인해 타설 후 극 초기재령에서 큰 자기수축과 온도변형이 발생한다. 이것은 고강도 콘크리트 구조물의 초기재령에서의 균열을 초래할 것이고, 고강도 콘크리트의 내구성에 영향을 미칠 것 이다. 그러므로 고강도 콘크리트의 초기재령 특성에 집중할 필요가 있다. 이 논문에서는 매설형 FBG 센서를 이용하여 고강도 콘크리트의 초기재령 특성을 모니터링 하였다. 결과에서는 고강도 콘크리트 타설 후 하루동안 변형이 급격히 증가함을 보여 주었다. 그리고 변형량의 값은 85με 이상이며, 두달간의 변형량(280με)의 30%에 해당한다. 고강도콘크리트의 내구성과 침투성을 고려하면, 첫째날의 변형률은 꽤 높아 무시할 수 없는 수치이다. 또한 연속성, 안정성, 다양한 복합기술 등 FBG 센서의 보다 높은 성능이 증명 되었다.

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1 Introduction

HPC is more and more widely used in construction field all over the world. While it may develop considerable AS (autogenous shrinkage) due to self-desiccation at early age. Cracking due to AS will occur and possibly result in premature corrosion of the steel reinforcement, and spalling of the concrete. For concrete with a low w/c ratio, AS may be of significance. According to Aitcin et al. [1], the AS will develop rapidly if the w/c ratio is lower than 0.42. To acquire high durability and strength, low w/c, also mineral admixtures are used for making HPC. i.e, the AS of HPC is an important part constituting total deformation of HPC at early age.

This paper aims to monitoring the early age deformation of HPC specimen by FBG embedded strain sensor immediately after concrete mixing. Firstly, the FBG technique is introduced in this paper. Then the monitoring experiments are carried out. The results show that FBG sensor can measure very early age deformation of HPC precisely especially the first day after HPC mixing which can not be measured by traditional strain gauges.

2. FBG sensing technique

Meltz et al. [2] produced fiber Bragg gratings by "burning" a series of equidistant lines into the glass core of a standard single-mode telecommunication fiber by using an excimer laser. These lines comprising the Bragg grating are characterized by a refraction index different from the one of the regular fiber core.

Light propagating in the glass fiber core will be reflected by the interfaces between the regions having different refraction indices. For a certain wavelength, the Bragg wavelength, the light reflected by the periodically varying refraction index will be in equal phase and amplified [3]. These result in a characteristic peak at this wavelength in the transmission as well as in the reflection spectrum. As the peak wavelength depends on the spacing between the lines forming the gratings, this can be used for measuring strains. Fig.1 illustrates the working principle of a Bragg grating sensor. Upon illumination with light, Bragg gratings reflect the Bragg wavelength

$$\lambda_B = 2 \cdot n \cdot \Lambda \qquad (1)$$

Where n=average refractive index; and Λ=period of change of the refractive index [4].For a uniform strain change $\Delta\varepsilon$ and temperature increments ΔT over the grating length, the Bragg wavelength changes [2] according to

$$\Delta\lambda_B = \lambda_B \cdot (1-p_e) \cdot \Delta\varepsilon + \lambda_B \cdot (\alpha+\xi) \cdot \Delta T \qquad (2)$$

Where pe is effective elastooptic coefficient [3], a is thermoelatstic coefficient; and ξ is thermooptic coefficient [4]. For the present experiments, temperature effects can be neglected, because ΔT here had a pretty small value.

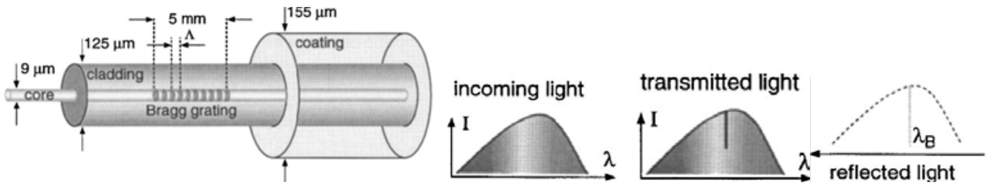

Fig.1.The schematic diagram of FBG monitoring principle

3. Experiment program

3.1 Mixture proportions and curing conditions

Table1. Concrete mixture proportion (Unit weight: kg/m^3)

28-day strength	*w/c*	*S/F*	*w*	*c*	*S*	*G*	*F/A*	***PC***
60MPa	*0.30*	*60*	*152*	*495*	*738*	*986*	*68*	*8.4*

Table 1 lists the HPC mixture proportion selected for the AS test. In the mixture, KS type I Portland cement was used. For good workability and consolidation of the concrete, PC type super plasticizer, which meets the KS requirements, was also used. Two AS specimens with size 40mm×10mm×10mm base on KS F2595 were made, due to the small specimen size, the maximum size of coarse aggregate is limited within 20mm. All the surface of AS specimens are covered by plastic films just after concrete casting to prevent dry shrinkage occurring. However the malfunction of constant temperature and humidity system, the temperature and humidity outside the specimens can not be controlled effectively, i.e. natural temperature and humidity.

3.2 FBG sensors and Demodulation

Steel-tube packaged Embeddable FBG strain sensor is used in this research; its picture is shown in Fig.3. Based on wavelength division multiplexing (WDM) technique, an optical sensing interrogator- sm130-500 made by Micron Optics, Inc is used (Fig.4). This instrument can resolve a wavelength shift of 1 pm, which corresponds to a strain and temperature resolution of about 1 ε and 0.1 ℃, respectively.

Fig.2.Specimens with covering polyethylene

Fig.3. FBG embedded sensor

Fig.4. Sm130-500 Interrogator

Early age deformation is measured just after casting by the embedded FBG sensors inside and the temperature is measured by embedded thermocouple. Inside FBG sensor is set along the longitudinal direction of the specimen in the middle part. Simultaneously, the thermocouple was put the vicinity of strain gauges to measure concrete temperature. To ensure the proper position of FBG sensor inside the specimen, the sensors are set inside the mould after casting 1/2 of all concrete quantity, then remained concrete are cast.

4. Results and Discussion

The measured data included thermal deformation and AS. To decrease the experimental error, the mean value of the two specimens' data is used to analyze and discuss. To grasp the variation of AS, the temperature data from thermocouple is used. Fig. 5 shows the early-age deformation of HPC during the first day after casting. Just after concrete casting, due to the low stiffness of cement paste, its deformation can not be transferred to sensor effectively. However, the sensor can get the exact deformation of concrete after initial setting time for its enough stiffness. The initial setting time usually corresponds to the start time that rapid rise of concrete temperature arises during hydration. Referring to Fig.6, the initial setting time is determined—about 4.5 hours after casting. Correspondingly, the early age deformation data in Fig.5 is exact from point “S”. As the peak temperature-- point Q occurs---about 10 hours after casting, simultaneously, the deformation also arrive at its peak value--- point P in Fig.6. And the deformation near point P is shown as expansion, during this period, the hydration temperature is highest, and the thermal expansion is a little larger than autogenous shrinkage. After P, concrete shrinkage increased sharply and quickly until point C--- about 20 hours after casting. Afterward, the shrinkage also increased slowly, relevant ΔT in Fig.6 decreased. The total deformation during 8 days is 80με, and the first day deformation value (57με) is about 70% of it.

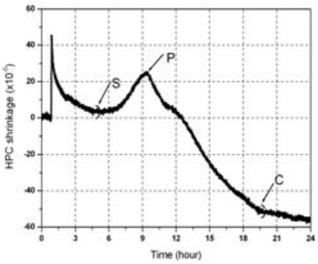

Fig.5. First day deformation

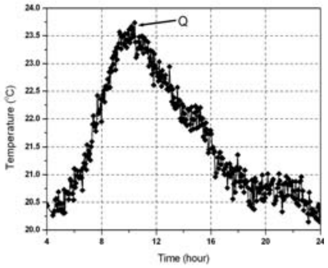

Fig.6. First day temperature

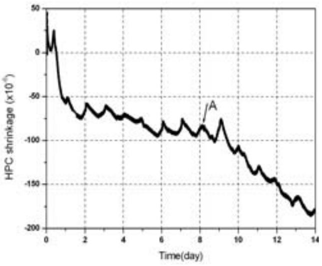

Fig.7 14-day deformation

There are some unstable fluctuates in surrounding temperature due to the malfunction of constant temperature and humidity instrument. Ambient humidity and temperature influence on experiment results can be seen in Fig.7. After 8-day curing by covering polyethylene films, deformation is nearly constant, i.e., concrete temperature tends to be constant and most autogenous shrinkage has occurred. Then film was discovered, and deformation is monitoring until 14 days. During this period, shrinkage increases extremely fast---- due to the happening of drying shrinkage, the total shrinkage value is up to 165με at the 14th day. It is three times as the 1st day-deformation (57με).

5. Conclusions

In this research, FBG embedded strain sensor was used to monitor early age deformation of HPC specimens successfully. FBG sensors monitored the deformation before concrete hardening precisely and continuously. The early age deformation of HPC within the first day much rapidly increases and reaches a pretty high value; in this research the first day deformation(57με) is 35% of that(165με) of 14th day, therefore, as considering the durability and permeability of HPC structures, the pretty high first day deformation can not be neglected. The research on early age and very early age properties of HPC is important for improving the durability and service life of HPC structures.

References

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