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Early-age shrinkage and temperature optimization for cement paste by using PCM and MgO based on FBG sensing technique

Huafu Pei [a,*], Zongjin Li [b,*], Ying Li [b]

[a] Dept. of Geotechnical Engineering, Dalian University of Technology, State Key Lab of Coastal and Offshore Engineering, Dalian 116024, China
[b] Dept. of Civil and Environmental Engineering, The Hong Kong Unviersity of Science and Technology, Hong Kong, China

HIGHLIGHTS

- Phase change of paraffin can offset the hydration heat in the fresh cement paste.
- Volumetric expansion of the paraffin can compensate early-age shrinkage in cement.
- MgO and paraffin can reduce the influence of early-age shrinkage and thermal accumulation.

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ABSTRACT

Accompanying with hydration progress, early-age performance involving drying shrinkage and thermal expansion are becoming big challenges for ordinary Portland cement. Stress concentration induced by shrinkage can lead to cracking which definitely affect durability of engineering structures especially for large volume concrete structures such as dams, tunnels, nuclear reactor and deep foundation. To overcome this issue, a large amount of studies have been conducted to eliminate the influence of early-age shrinkage and thermal expansion in concrete after casting. Cooling tubes are generally embedded in a large volume concrete before casting. Stress concentration will occur around the pipe which is becoming a potential risk to the in-service structures. In this study, the authors proposed a new method to add paraffin and magnesium oxide in fresh matrix. A relatively new sensing technology was employed to measure the internal strain and temperature simultaneously. A series of test was executed to determine the addition of phase change materials and expansive. Finally, the experimental results were analyzed and discussed. It can be concluded from the test results that paraffin and magnesium oxide can be used as admixtures which can significantly reduce early-shrinkage and thermal accumulation.

1. Introduction

Owing to the low tensile strength, early-age shrinkage and thermal accumulation are big issues for ordinary Portland cement (OPC) especially for big volume concrete structures with low water–cement ratio. As well known, cracking and degradation of concrete induced by early-age shrinkage and thermal accumulation definitely affect structural integrity and durability in harsh environment. The shrinkage can cause internal stress concentration in big volume concrete structure while the force balance is not reached. Early age shrinkage is a big issue for cement-based materials especially for large-scale concrete structures such as dams, shearing wall, and nuclear reactor [12,4]. To study the early age shrinkage in cementitious materials, researcher focused on the measurement of early age shrinkage by using different sensing technologies [1,2].

1.1. Previous studies on the early age shrinkage measurement

Loukili et al. [14] initiated a new method to measure early-age shrinkage in mortar by using thermocouple. Krauss and Hariri [13] used ultrasonic wave to detect the early age shrinkage, however, it is impossible for ultrasonic technique to provide quantified strain values in cementitious materials. The measurement accuracy cannot be kept to a high level as the transmission of elastic wave in liquid changes slightly with the variation of Young's modulus.

Glisic and Simon [10] used low-coherence interferometry (LCI) technique to monitor the early age shrinkage of concrete. However, the LCI sensor can merely measure the averaged early-age shrinkage in cementitious materials. Slowik et al. [22] used fiber Bragg gratings to investigate early-age shrinkage of cement paste. How-

* Corresponding author.
E-mail address: huafupei@dlut.edu.cn (H. Pei).

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ever, the temperature compensation for the FBG strain sensor was accomplished by using a traditional temperature gauge which has lower sensitivity than FBG sensor does. Pei et al. [20,21] successfully used FBG strain and temperature sensors to measure strain and temperature in mortar specimens. The temperature compensation was accomplished by using a FBG temperature sensor. The strain and temperature in mortar specimens had been record and analyzed in very early age once the specimens were cast in the molds. Thus, the previous work makes the measurement of early age performance for cement paste possible.

In the past few decades, the expansion based on CaO, MgO and Aft have been studied. It was found that MgO reacts with water to form $Mg(OH)_2$ that causes volume expansion about 118% [3,4,5,6,7,16,18].

A successful case is the Baishan Dam constructed in 1973 in China. In fact, at that time, high-MgO cement was not chosen specially. Some years later, it was found no impenetrating cracking was observed in this dam, then in turn to investigate the reason, and finally considered that the main effect is the high content MgO (4.5% ca.) contained in the cement. For various constructions, to get the cement with suitable content of MgO to obtain the required expansion rate and expansion ratio are much difficult [8,9].

1.2. Working principle of fiber Bragg grating sensor

Hill et al. discovered photosensitivity and fabricated the first fiber Bragg grating (FBG) with a visible laser beam along the fiber core in 1978, FBGs have already been widely applied in civil engineering. The main reason for the popularity is that FBGs can be used to measure temperature and strain at multiple points simultaneously. FBG sensors have several advantages over the traditional electric based strain gauges. As shown in Fig. 2, FBG can reflect a specific light of a certain wavelength, which depends on the refractive index of fiber and the grating period [26] when a broadband source of light was injected into the optical fiber according to Bragg's law. For reflected spectrum of a typical FBG, the wavelength at which the reflectivity peaks is called Bragg wavelength λ_B:

$$\lambda_B = 2n_{eff}\Lambda \tag{1}$$

where n_{eff} is the effective core index of refraction; and Λ is the periodicity of the index modulation.

For a standard single mode silica fiber, the relationship between the Bragg wavelength change $\Delta\lambda_B$, strain change $\Delta\varepsilon$, and temperature change ΔT can be simplified as [11,19]:

$$\frac{\Delta\lambda_B}{\lambda_0} = c_\varepsilon\Delta\varepsilon + c_T\Delta T \tag{2}$$

where λ_0 is the original Bragg wavelength of released FBG; c_ε and c_T are the calibration coefficients for temperature and strain. In order to measure actual strains due to force, temperature compensation of FBG sensors is required. This can be easily achieved by adding an additional FBG into an empty copper tube and placed in the same temperature field. Once the temperature is measured, the mechanical strain can be corrected to be:

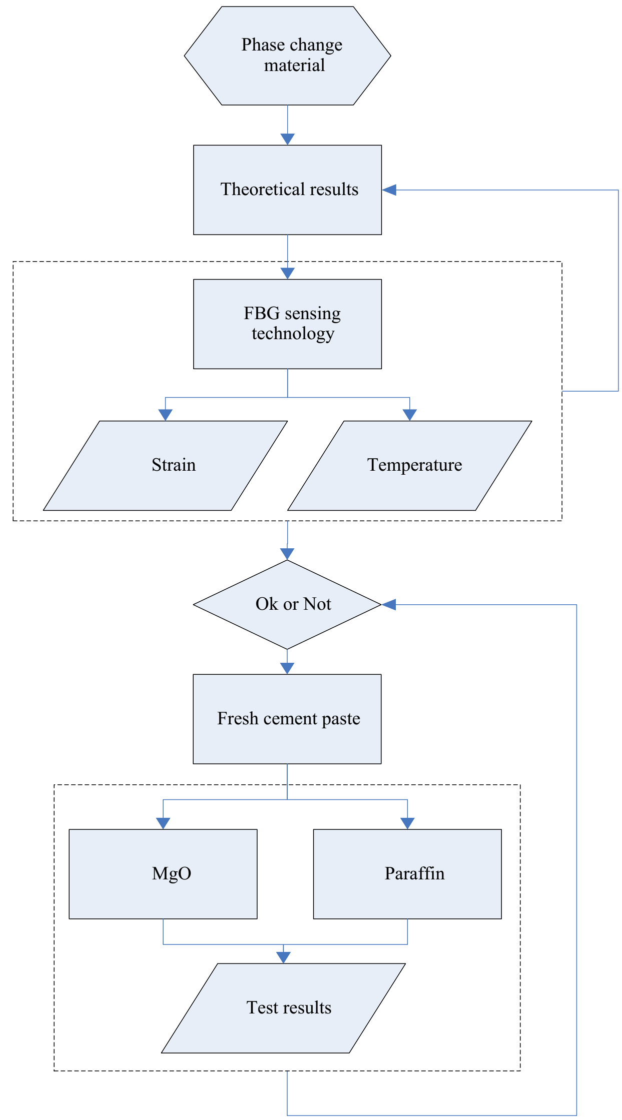

Fig. 2. Flowchart of the studies in this paper.

$$\Delta\varepsilon = \frac{1}{c_\varepsilon}\left(\frac{\Delta\lambda_B}{\lambda_B} - c_T\Delta T\right) \tag{3}$$

A fiber with a series of FBGs with different original wavelengths is normally fixed along a soil nail by using methods of cement grouting, clamps, etc. Using Eq. (4), the mechanical strains along the fiber fixed along the soil nail can be obtained.

The shrinkage and thermal expansion of cement paste is detrimental to the workability of cementitious materials after casting especially for large volume concrete structures. As one of the most widely used phase change materials (PCM), paraffin has already

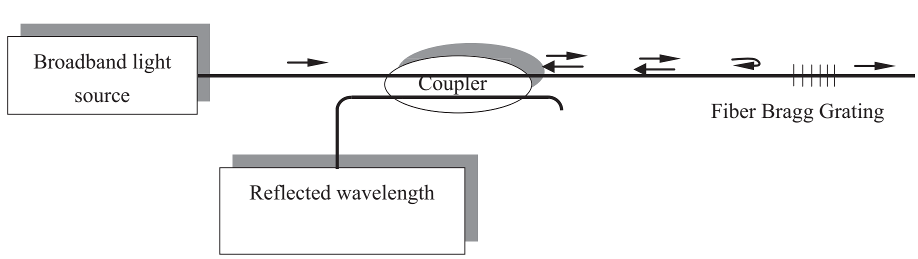

Fig. 1. Working principle of FBG sensor.