Pergamon

Cement and Concrete Research 30 (2000) 1251–1253

CEMENT AND CONCRETE RESEARCH

A study on thermal self-diagnostic and self-adaptive smart concrete structures

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Received 15 July 1999; accepted 6 April 2000

Abstract

Smart structures are made by embedding sensors, actuators, and controllers into the structure during manufacture. Carbon fiber reinforced concrete (CFRC) can be used as both thermal sensor and thermal actuator because of the Seebeck effect and electrothermal effect, which have been reported. In this paper, two kinds of thermal smart concrete structure are designed using CFRC. First, the smart concrete beam embedded with four CFRC sensors is studied. Experimental results show that the smart concrete beam with CFRC sensors can monitor the process of the heat transfer and temperatures inside concrete. Then, embedding a CFRC sensor into a CFRC plate and connecting it to a controller result in a smart concrete system. Results show that it operates in situ, in-line temperature measurement and control with excellent stability.

Keywords: Fiber reinforcement; Cement; Composite; Electrical properties; Temperature

1. Introduction

Smart structures are made by embedding sensors, actuators and controllers into structures during manufacture. In these structures, information is observed by sensors and analyzed with controllers where a decision is made whether or not action is required; then actuators respond to a given excitation. That is, they have the ability of self-diagnosis and self-adaption.

Smart concrete structures capable of nondestructive healthy monitoring in real time are of increasing importance due to the need to maintain the functions of critical civil infrastructure structures, such as bridges and dams. Thermal load is very important in bulk concrete structures. Cement hydration, the sun radiation, the temperature change of water and air may produce tensile stress, which can cause cracking of structure. Therefore, it is necessary to study smart concrete structures, which possess thermal self-diagnostic and a self-adaptive function.

Carbon fiber reinforced concrete (CFRC) is an intrinsically smart material. It cannot only sense compressive or tensile stress both in elastic and inelastic regimes [1–4], but also temperature [5–7]. In addition, it has an electrothermal function [8]. So, CFRC can also be used as the thermal sensor and the thermal actuator. In this new smart structures technology, concrete itself is the sensor and the actuator, so there is no need to embed strain gages, optical fibers, PZT, SMA, etc., within concrete structures.

In this paper, two kinds of thermal smart concrete structure are designed using CFRC. First, a concrete beam embedded with four CFRC sensors is studied. The objective is to investigate thermal self-diagnosis smart concrete structures. Then, a CFRC sensor is embedded into the CFRC plate and connected with a controller to form a smart concrete system. The objective is to investigate thermal self-diagnostic and self-adaptive smart concrete structures.

2. Thermal smart concrete beam

2.1. Experiment procedure

CFRC sensors are prepared according to Ref. [7]. Four CFRC sensors (4 × 4 × 4 cm) are embedded in a concrete beam along its axis, and the interval between sensors is 5

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0008-8846/00/$ – see front matter
PII: S0008-8846(00)00284-2

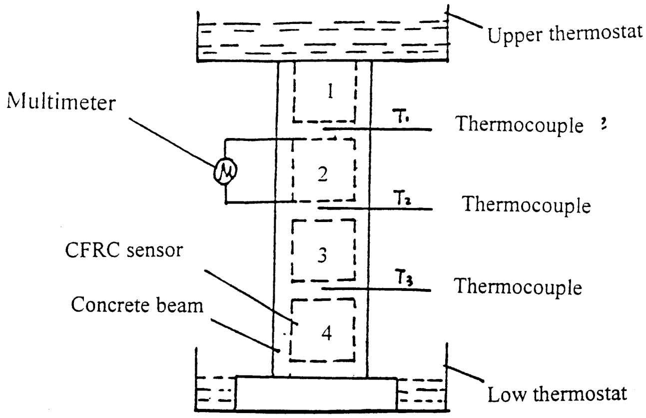

Fig. 1. The experimental model of thermal smart concrete beam.

mm. The beam is 6 × 6 × 20 cm. Then the beam is fixed between an upper thermostat and a lower thermostat, and the in-site measurement of thermoelectric force (TEF) is performed by digital multimeters. Thermocouples are inserted in the interval between sensors to measure the temperature. The experimental model is illustrated in Fig. 1. During measurement, temperatures of the upper thermostat, the lower thermostat and air were 45°C, 15°C, and 15°C, respectively.

2.2. Results

A typical plot of TEF vs. time of sensor 1–sensor 4 is shown in Fig. 2. As shown in Fig. 2, when the top of beam touches the upper thermostat, sensor 1 makes response to heat at once, and TEF increases very quickly. After about 20 min, heat reaches the top surface of sensor 2, and sensor 2 begins to produce TEF. After another 20 min, sensor 3 starts to sense heat. And sensor 4 hardly outputs TEF, implying that no change of temperature has taken place in this section. Thus, the concrete beam can monitor the process of the heat transfer; that is, from the top of the beam to the bottom gradually.

When the temperature field becomes stable, TEF keeps a certain value, therefore CFRC sensors embedded in concrete beam display good stability.

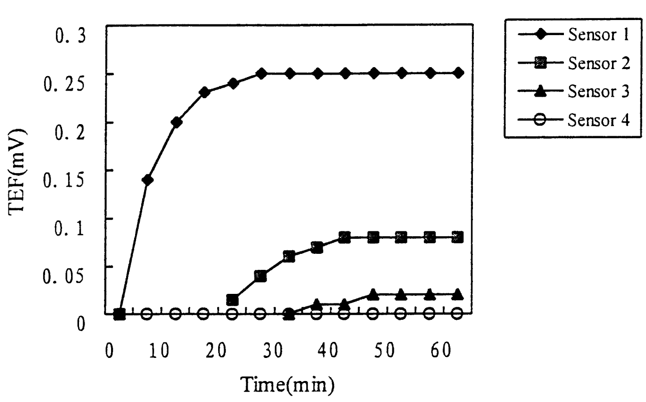

Fig. 2. The relationship between TEF and time of sensor 1–sensor 4.

Table 1
The temperature of concrete beam based on CFRC sensors and thermocouples

	CFRC sensors	Thermocouples
T_1 (°C)	25	24
T_2 (°C)	17	16
T_3 (°C)	15	15

The thermoelectric power (TEP) of the CFRC thermal sensors (content of carbon fibers is 0.5 wt.%) is about 12 μV/°C [6]. Therefore, using values of the TEF, we could estimate temperatures T_1, T_2, T_3 indicated in Fig. 1. They are compared with values obtained by thermocouples. Results are in agreement with values obtained by thermocouples (See Table 1).

3. Thermal smart concrete plate

3.1. Experiment procedure

The CFRC sensor and the CFRC plate are prepared according to Ref. [8]. The CFRC plate works as thermal actuator. CFRC sensor (1 × 1 × 20 cm) are embedded in the CFRC plate (1 × 20 × 35 cm). Then they are connected with the system of controller made up of A/D converter, single-chip microcomputer, relay, display and power, etc. The experimental system is shown in Fig. 3.

3.2. Results

The results show that the above-mentioned concrete structure can perform thermal self-diagnosis and self-adaption. When the system starts to work, the output of CFRC sensor is fed to a single-chip microcomputer through A/D converter; the single-chip microcomputer then performs data analysis and compares the current temperature with the installing temperature. The feedback information is sent out to excite CFRC actuator to work or not. When the present temperature is lower than the installing temperature, power is applied to actuator, conversely, power is switched off. Thus, the structure is always under the situation of in situ, in-line temperature measurement and control. Although this smart concrete plate was made two and a half years ago,

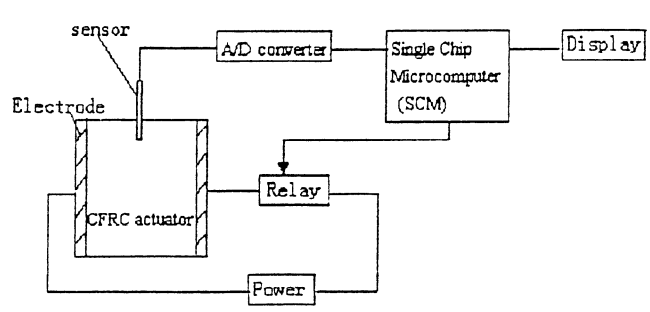

Fig. 3. The experimental system of thermal smart concrete plate.

it works well now showing that such kind of thermal smart structure has excellent stability.

4. Conclusion

1. CFRC can be used as both the thermal sensor and the thermal actuator. Especially it is suitable for making thermal self-diagnostic and self-adaptive smart concrete structures.
2. The smart concrete beam with CFRC sensors can monitor the process of the heat transfer through the beam and CFRC sensors in the beam display an excellent stability.
3. The smart concrete beam with CFRC sensors can monitor temperature inside concrete, and results are in agreement with that obtained by thermal couples.
4. The smart concrete plate associated with the system of controller has realized in situ, in-line temperature measurement and control.
5. The CFRC smart concrete plate has excellent stability.

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