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Communication

A study on thermal self-monitoring of carbon fiber reinforced concrete

Sun Mingqing *, Li Zhuoqiu, Mao Qizhao, Shen Darong

Dept. of Engineering Mechanics, Wuhan University of Technology, Wuhan 430070, People's Republic of China

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Abstract

Carbon fiber reinforced concrete (CFRC) is an intrinsically smart material that can sense not only compressive or tensile stress, but also temperature. The thermal self-monitoring ability is associated with the Seebeck effect. An experimental study was made to examine the relationship between the temperature differential (ΔT) and thermoelectric force (TEF)—its sensitivity and repeatability, its response time and the influence of ambient temperature (T_a) on TEF. The results show that TEF is proportional to ΔT over a wide range of temperature, and the thermal self-monitoring CFRC possesses high sensitivity and good repeatability. The T_a has no influence on TEF. Although the response time of CFRC is not fast enough because of its low heat conductivity, it can be used as a thermal sensor embedded in massive concrete structures, such as water dams and bridges, where the temperature changes slowly.

Keywords: Fiber reinforced; Concrete; Composite; Electrical properties

Smart structures capable of nondestructive health monitoring in real- time are of increasing importance, due to the need to maintain the functions of critical civil infrastructure systems, such as bridges and dams. Carbon fiber reinforced concrete (containing fiber in amounts as small as 0.2 volume-percent) is an intrinsically smart material that can sense compressive or tensile stress both in elastic and inelastic regimes. This capability is based on the notion that the volume resistance of CFRC changes with the outward stress. This is the basis for a new sensor technology for insitu health monitoring of concrete structures. In this technology, the concrete itself is the sensor, so there is no need to embed strain gages, optical fibers or other sensors in the concrete [1–5].

A recent study shows that CFRC can also sense temperature because of Seebeck effect [6–8]. Thermal load is very important in such bulk concrete structures as dams. Cement hydration, sun radiation and the temperature change of water and air may produce tensile stress which can cause cracking of the structure. Therefore, it is necessary to conduct internal thermal self-monitoring in order to diagnosis the safety of dams. Through thermal self-monitoring, the change of tensile stress can be observed and the cooling of the dam can be performed.

Results of an experimental study on the thermal self-monitoring of CFRC, which include the relationship between the temperature differential (ΔT) and thermoelectric force (TEF), its sensitivity and repeatability, its response time and the influence of ambient temperature (T_a) on TEF, are reported.

1. Experiment procedure

1.2. Materials and specimens

The short carbon fibers (Shanghai Carbon Ltd. Co.) are 5 mm; the fiber properties are given in Table 1. The matrix was Portland cement (525#). The compound of cellulose and chloroform was added to disperse the fibers. The mix proportion was provided in Table 2. Water, carbon fiber and disperser were mixed by hand for about 2 min; then this

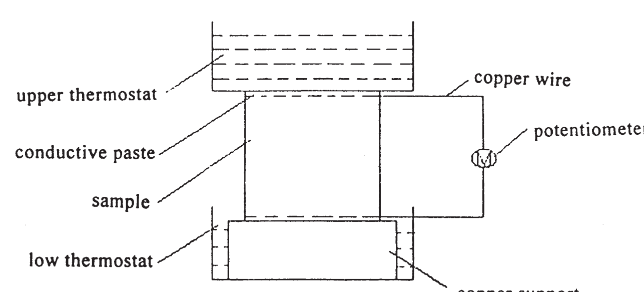

Fig. 1. The experimental set-up.

* Corresponding author. Tel.: 86-027-87651970; E-mail: sunmingqing@163.net.

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Table 1
The properties of carbon fiber

Item	Diameter/μm	Tensile strength/GPa	Tensile modulus/GPa	Resistivity/Ω .m	Density/g. cm^{-3}
Target	7 ± 0.2	⩾ 1.95	⩾175	25.0×10^{-5}	⩾1.75

mixture and cement were mixed in the mixer for 2 min. After pouring the mix into oiled molds (4 × 4 × 4 cm), a vibrator was used to decrease the amount of air bubbles. The specimens were de-molded after 1 day, and then allowed to cure at room temperature for 28 days. The electrode constituted graphite-conductive paste applied on the upper and the low surfaces, respectively.

1.3. Testing procedure

A DT9203 multimeter was used to measure the thermoelectric force (TEF). The experimental setup is illustrated in Fig. 1. The temperature differential, controlled by means of the upper thermostat and the lower thermostat, does not exceed 15°C during measurements of thermoelectric power (TEP). The highest temperature differential was 50°C, to investigate thermal self-monitoring of CFRC over a wide range of temperatures. The ambient temperature during measurement was 25°C, unless noted otherwise.

2. Results and discussion

A typical plot of TEF vs ΔT is shown in Fig. 2. The smart behavior of CFRC was observed, and its origin was described previously [6]. The TEF was confirmed to be proportional to ΔT. Thus, the thermoelectric power (TEP) can be obtained from the slope of the line. The TEP is about 12μ V/°C. It is apparent that CFRC can sense temperature with high sensitivity. Without fibers, no smart action was observed. This means that carbon fibers are required for the smart behavior to occur. The TEF increases with ΔT and the relationship is linear (see Fig. 3).

The plots of ΔT vs TEF (Fig. 4) obtained from three measurements are similar. It shows that the smart behavior of CFRC has excellent repeatability, which is one of the most important requirements for the sensors.

Fig. 5 shows the relationship between time and TEF. TEF reaches 80% of the final value within 1 min and becomes steady in 4 min. So, it can be used as thermal sensor embedded in massive concrete structures, such as water dams and bridges, where the temperature changes slowly.

Table 2
Mix proportions of the specimens

Fiber/cement (wt.%)	0.5
Water/cement (%)	30.0
Disperser/cement (%)	0.4

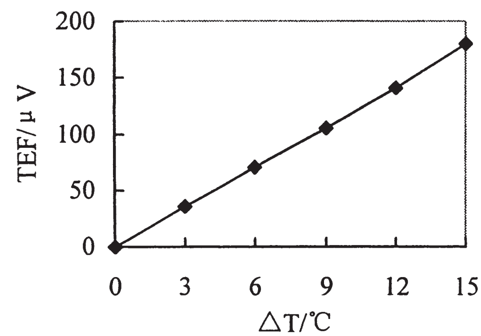

Fig. 2. The relationship between smaller ΔT and TEF.

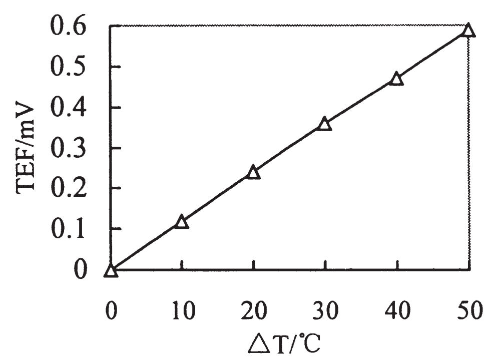

Fig. 3. The relationship between larger ΔT and TEF.

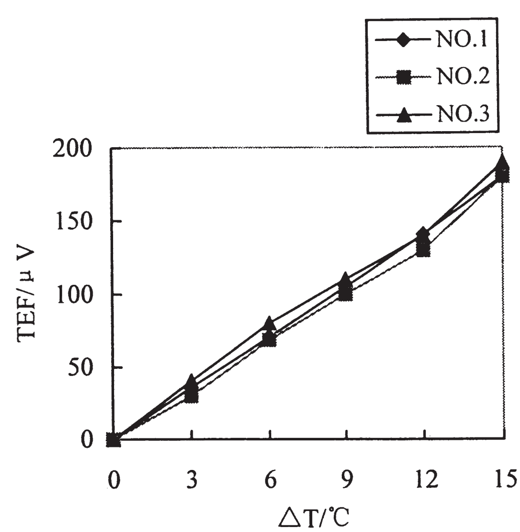

Fig. 4. The repeatability of ΔT vs TEF.

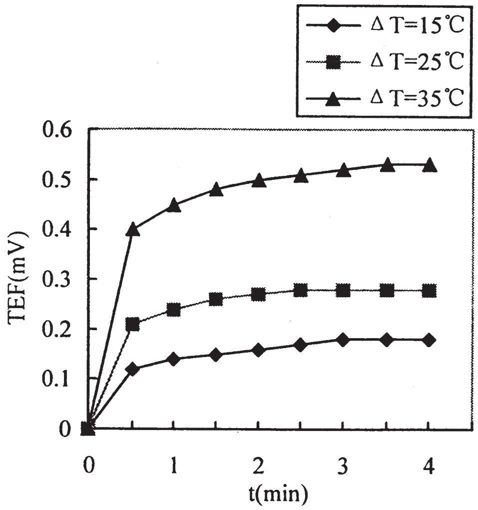

Fig. 5. The relationship between time and TEF.

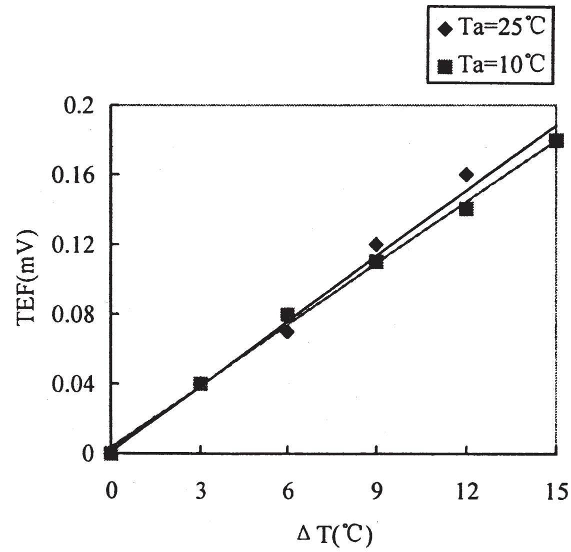

Fig. 6. The influence of ambient temperature on TEF.

From Fig. 6, it can be seen that ambient temperature does not significantly influence the TEF value.

3. Conclusions

1. The CFRC is an intrinsically smart material that can sense temperature.
2. The TEF values are proportional to ΔT over a wide range of temperature. Thermal self-monitoring CFRC possesses high sensitivity and good repeatability.
3. The response time of CFRC is not fast enough because of its low heat conductivity. The CFRC can be used, however, as the thermal sensor embedded in the massive concrete structures.
4. The T_a has little influence on the TEF.

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