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Deformation adjustment of concrete beams laminated with carbon fiber mats

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Abstract

A carbon fiber mat is a sheet composed of intercrossing short carbon fibers, which has more stable and lower electrical resistivity compared with dispersed short carbon fiber mixed in cement. Thereby carbon fiber mats can be used in cement and then make cement structures exhibit obvious electro-thermal effect. In this paper, Electro-thermal properties of carbon fiber mats and an elementary strengthening experiments against deformation of carbon fiber mat cement laminated beams were researched. Firstly, electro-thermal properties of carbon fiber mats were studied. Secondly, carbon fiber mat laminated beams are designed and experiments were conducted to get temperature and deformation responses driven by the electro–thermal effects of the carbon fiber mat cement laminated beams. Finally, some experiments of deformation adjustment were done according to the above experimental results. The results show that deformation of concrete beams upon loads can be reduced even removed, and the beams can be strengthened against deformation.

Keywords: Deformation adjustment; Concrete beams; Carbon fiber mats; Electro-thermal effects

1. Introduction

Cement is one of the most popular materials used in construction engineering. Cement structures such as bridges and dams often come into being distortion due to the sun radiation, cycle of frost and thaw, creep, or shrinkage, which affects their normal work. MAGLEV railway is a good example. The flatness of MAGLEV railway is one of the most important factors restricting speed of MAGLEV trains. So the deflection of MAGLEV railway should be limited strictly [1]. Therefore, sometimes deformation of structures must be controlled to restrain deformation development or crack pregnancy, and then to improve the loading capacity of structures. All of these requirements are very difficult to be satisfied relying on some peripheral materials or equipments, because concrete structures are all bulky and weighty. How to control deformation of a concrete structure without exterior auxiliaries? How to improve flexural loading capacity against deformation of concrete beams by means of cement–matrix composites? Some Japanese researchers have proposed the actuating system by means of partial heating of plastic-matrix composites (CFRP/Al laminates). They described fabrication and evaluation of the laminate [2]. But few reference can be found to study deformation control or adjustment on concrete structures by the aid of cement–matrix functional materials. In this paper, an elementary method of deformation adjustment is introduced using electric-thermal effect of carbon fiber mat-concrete laminates. This method can eliminate or reduce the need for peripheral non-structural materials. As structural materials such as concrete are inexpensive and durable, this method results in reduced cost and enhanced durability.

Carbon fiber cement–matrix composite is known to decrease the drying shrinkage and increase the flexural toughness [3,4], to increase the flexural strength of concrete and renders the composite the ability to sense its own strain, damage and temperature. The strain-sensing

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ability is due to the effect of strain on the volume electrical resistivity of the composite. The temperature-sensing ability is due to the Seebeck effect. During the past 20 years, Carbon fiber cement–matrix composites has evolved to provide better performances such as highway traffic monitoring, weighing of vehicles in motion, and structural vibration control [5–14]. In thermal engineering, electrically conductive concrete with high content of carbon fiber is used to roadway deicing system due to the high conductivity of the carbon fibers compared to cement [15,16]. However, carbon fibers are difficult to disperse [17], which probably leads to unsteadiness of the resistivity.

A carbon fiber mat is a sheet of short carbon fibers contacting with each other, which has more stable and lower electrical resistivity compared with dispersed short carbon fiber when mixed in cement. Therefore carbon fiber mat reinforced cement has obvious electric–thermal effect, making it more attractive for thermal engineering.

In this paper, cement mortar beams were coated with two thin carbon fiber mat mortar layers on the top and bottom to adjust its deformation. When electrified, temperature of carbon fiber mat reinforced cement rises rapidly. As the electrical resistance of the carbon fiber mortar layer is much lower than that of the plain cement mortar layer, the temperature field in the beam is not uniform, generated temperature difference will cause the beam to deform. The deformation could be designed to reduce even remove some original deformation. Based on such idea, it is hopeful for success of structures to have the ability of deformation self-adjustment and of self-improvement.

2. Structure and properties of carbon fiber mats

In this paper, carbon fiber mat from Kaifeng Ltd. was used. Technical parameters of the carbon fiber mat are shown in Table 1. Fig. 1 indicates the micrograph of the mat. Carbon fiber mat has high electro-thermal efficiency due to its low electrical resistivity. A mat sized $40 \times 500\ mm^2$ was used and the resistance was 46 Ω (measured by four-probe method). In order to fix the mat and to prevent the heat dissipation, a board was used to cover the mat, and the mat was electrified by four-probe method. The experimental results of the raised temperature of the mat electrified with three different electrical powers are shown in Fig. 2. It can be found that carbon fiber mat exhibits obvious electro-thermal effect that can be used in thermal engineering.

Table 1
Technical parameters of the carbon fiber mat

Mass (g/m^2)	Fiber diameter (μm)	Glue content (%)	Density (kg/m^3)	Fiber modulus (GPa)	Water content (%)
22	6 and 7	1–20	75	207	⩽0.5

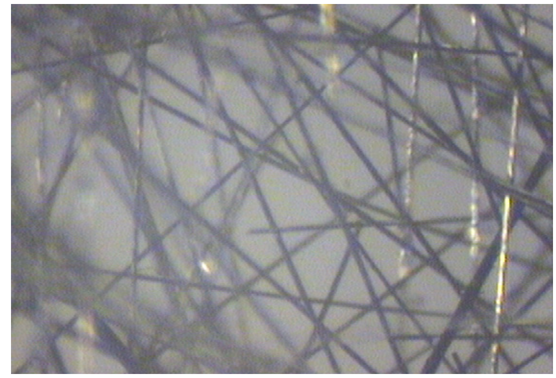

Fig. 1. Micrograph of carbon fiber mat.

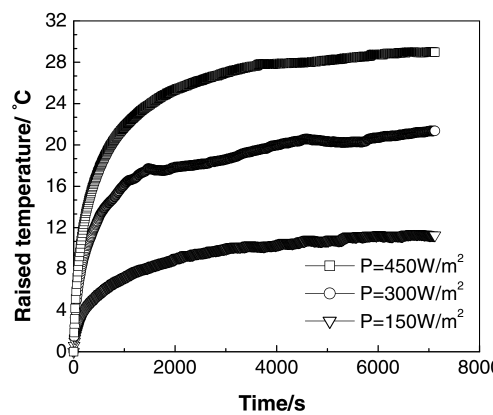

Fig. 2. Raised temperature of the mat in the course of being electrified.

3. Fabrication of laminated beam specimens

The specimens were in the form of a rectangular beam of size $500 \times 60 \times 40$ mm (shown in Fig. 3). The matrix was the mixture of Portland 425# cement (from Huaxin Corp. China) and median-top sand (from Wuhan, China), mass proportion was one to one. The water/cement ratio was 0.35. The mixture of water, cement and sand was placed in a rotary mixer with a flat beater for 5 min. After the substrate mix (cement mortar) was poured into a mold, a vibrator was used to decrease the amount of air bubbles and facilitate compaction. Then a piece of carbon fiber mat (20 g/m^2, Shanghai Carbon Ltd. Co.) was spread on the surface, which was coated with some cement mortar (5 mm thick). Four copper clips (0.1 mm thick) welded with copper wire as electrodes enclosed the carbon fiber

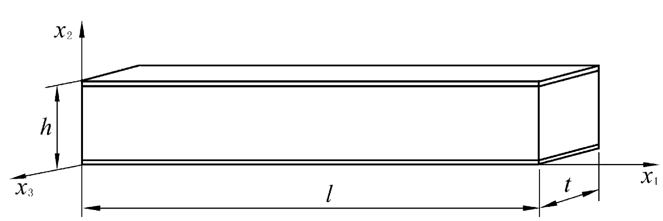

Fig. 3. Schematic diagram of a concrete beam laminated carbon fiber mats.

mat. To make it contact with the mortar fully, the vibrator was used again. Finally the samples were de-molded after 24 h, and then another piece of carbon fiber mat was spread on the other surface in the same way. Finally the sample was cured in a curing box for 28 days, then in air at room temperature.

4. Experimental electro-thermal effects of the laminated beams

When used, the sample beam was supported with two hinges at the left and right end (Fig. 4). Adjusting the power supply, the lower mat of the beam was electrified. The temperature of the lower part of the beam is much higher than that of the upper part. Through heat conduction, the temperature of the upper part rose gradually. But from top to bottom, temperature difference existed, which resulted in deformation of the beam. Four-probe method for measurement (shown in Fig. 4) was used in the experiments. The outer two contacts (for passing current) were 490 mm apart. The inner two contacts (for voltage measurement) were 480 mm apart. A Keithley 2700 multimeter/data acquisition system was used for DC voltage, current and temperature measurements. In addition, a F1212M-3 DC adjustable steady-voltage power supply, two copper-constantan thermocouples and a DA-2 LVDT deformation transducer were used too.

The beam was electrified by proper power supply ($P = 13$ W). The results are shown in Figs. 5 and 6. Fig. 5 shows temperature at the top and bottom surface in the course of electrifying (Fig. 5(a)), temperature difference between the top and bottom surface (Fig. 5(b)) and the mid-point deflection on the bottom surface (Fig. 5(c)). Fig. 6(a) shows stable temperature differences with different electrical powers. Fig. 6(b) shows the largest values of deflection with different electrical powers. From Fig. 6, it can be found that temperature difference between the top and bottom surface and the largest deflection are proportional to input powers. The temperature field in the beam and deformation response of the beam was derived theoretically in our former paper [18]. All the experimental results are similar to theoretical ones.

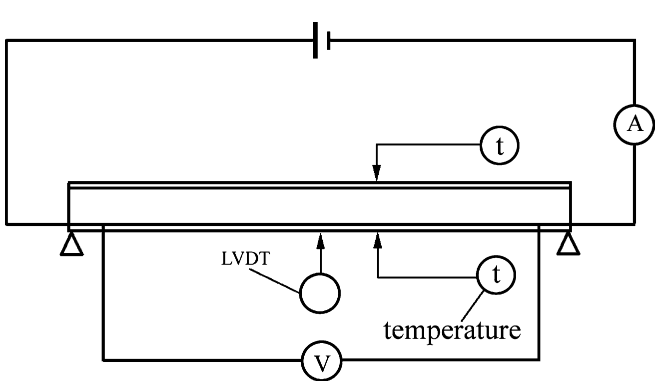

Fig. 4. Test setup.

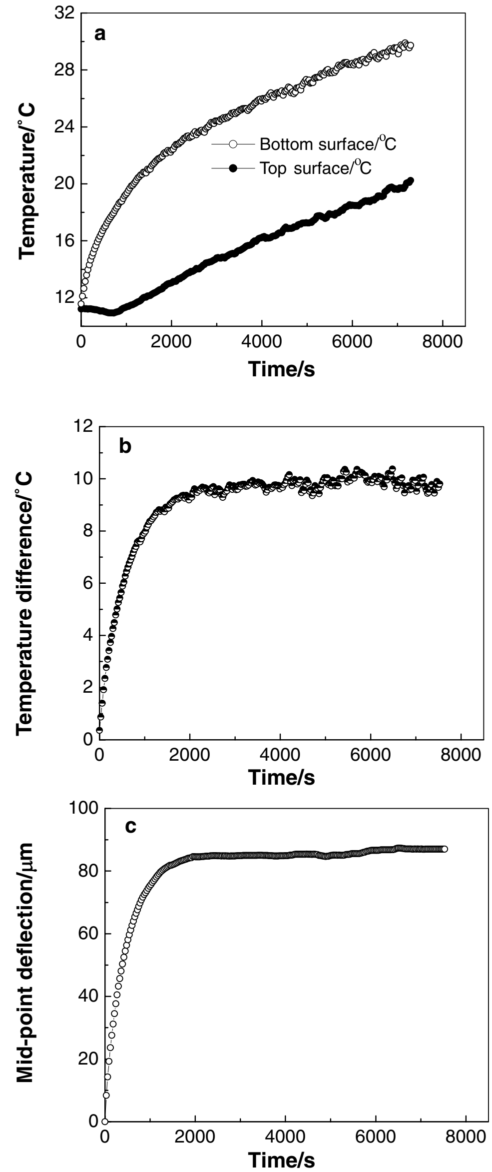

Fig. 5. Experimental results: (a) temperature of the top and bottom surface against time; (b) temperature difference between the top and bottom surface against time and (c) deflection of mid-point at the bottom surface of the beam against time.

5. Experiments of deformation control

From the above results, it can be seen that with a certain electric power displacement tends to be stable after a period of time, and the stable displacement is proportion to the input electric power. Therefore, the input electric power can be adjusted to control or regulate the deformation of the beam without any adscitious forces.

The experiment is aimed to eliminate original deflection generated by loads. The experiment is conducted using INSTRON5882. The experiment setup is shown in Fig. 7. The span of the beam used here is 400 mm. The results of deformation adjustment is given in Fig. 8. Fig. 8(a) shows the mid-point deflection at the bottom surface in

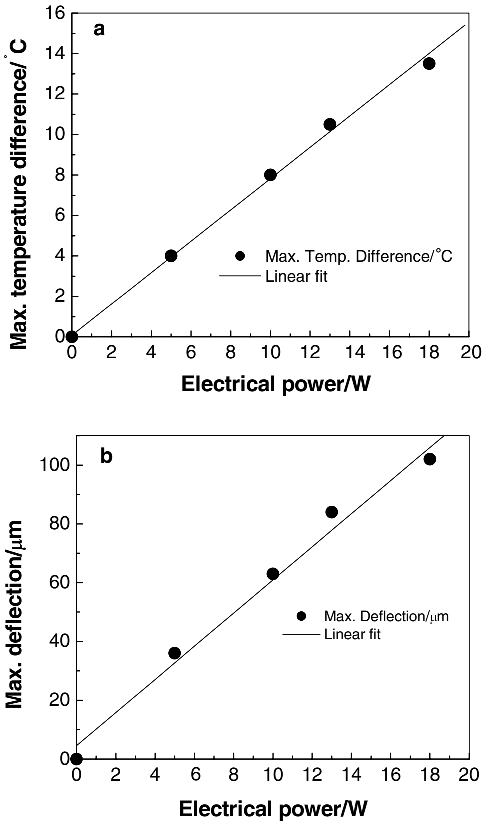

Fig. 6. Max. temperature difference and Max. deflection vs. electrical power: (a) stable temperature difference between the top and bottom surface vs. electrical power and (b) mid-point deflection at the bottom surface vs. electrical power.

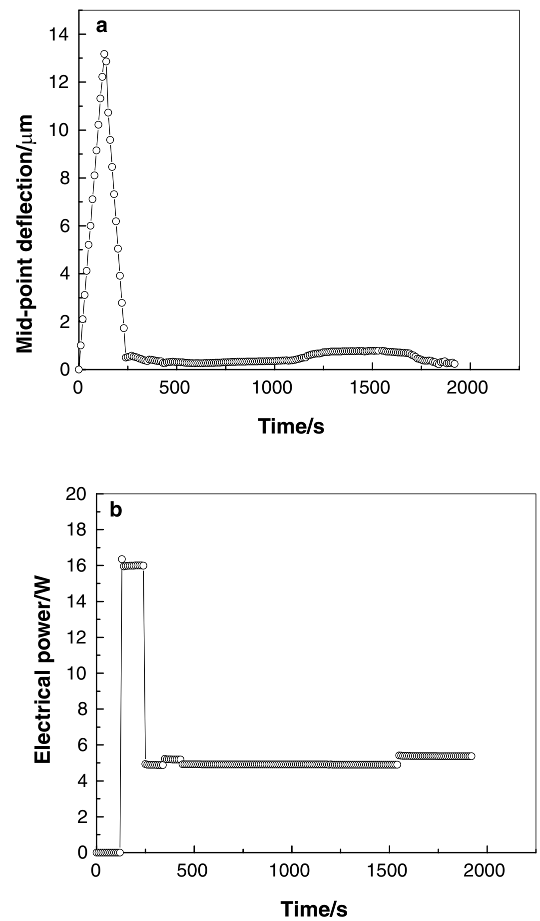

Fig. 8. Results of deformation adjustment: (a) input electric power against time and (b) deflection of the mid-point on the bottom surface against time.

the course of adjustment. Fig. 8(b) indicates the electrical power at the same time. Firstly, a 3-point bending experiment of the beam was done to make the beam deform. Then, keeping the load constant, we electrified the top layer mat cement. The thermal deformation increased gradually, so the deflection of the mid-point on the bottom surface decreased correspondingly. When it was close to zero, the electrical power was adjusted to keep the deflection zero. This course was lasted for 30 min to verify the effectiveness of the deformation adjustment.

Fig. 7. Three-point load experiment setup.

6. Experiments for increasing flexual loading capacity

Last but not least, some experiments were done to increase the flexual loading capacity of the beam. The instruments and the sample are just like the above. In the first place, the beam was loaded a force valued 200 N and the greatest deflection was 20 μm. Secondly, keeping the deflection constant, we electrified the top layer mat cement. Then the thermal deformation increased gradually, and the load should be increased to keep the deflection. In other words, the flexual loading capacity of the beam was improved by the electro-thermal effects. The experimental results are shown in Fig. 9. Fig. 9(a) shows the temperature differential between the top and bottom surface of the beam due to the electrifying courses. Fig. 9(b) shows the flexual loading capacity of the beam versus the input power of the beam when the deflection of the mid-point is kept 20 μm.

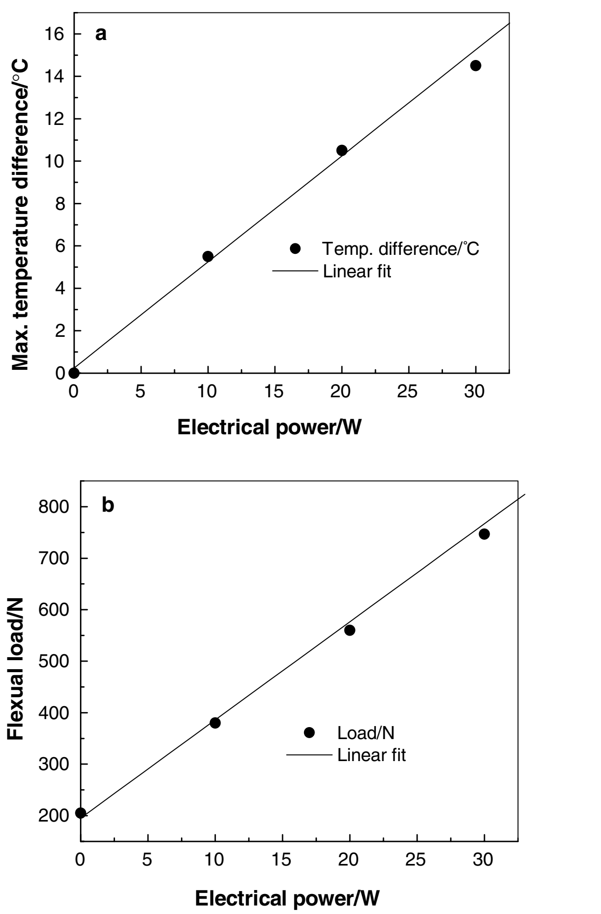

Fig. 9. Results of the experiments for increasing the carrying capacity of the beam.

7. Conclusions

The electro-thermal response of concrete beams laminated with carbon fiber mats is studied through experiments. It is found that stable electrical power produces stable temperature difference and deflection in the end, and the temperature difference between the top and bottom surface and the largest deflection are proportional to input powers. According to the above experimental results, experiments of deformation adjustment are conducted. With the help of the adjustment method, deformation of concrete beams can be reduced even removed, and the bending stiffness or flexual loading capacity of beams can be improved. The method in this paper can be used to adjust not only deformation but also temperature of concrete beams.

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