EFFECT OF CURING AGE ON THE SELF-MONITORING BEHAVIOR OF CARBON FIBER REINFORCED MORTAR

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Introduction

Self-monitoring refers to the ability of a structural component to monitor its dynamic strain and damage without the need for embedded or attached sensors. Concrete containing short carbon fibers (as little as 0.2 vol.%) is self-monitoring [1-5]. The DC volume electrical resistivity of the concrete changes reversibly upon reversible strain.

Although the curing age affects the mechanical properties of concrete, it has little effect on the electrical resistivity [6]. On the other hand, the bond strength between steel fiber and cement paste decreases with increasing curing age from 7 to 28 d, while the contact electrical resistivity increases, due to the drying shrinkage of the cement paste [7]. As the self-monitoring ability of carbon fiber reinforced concrete stems from fiber pull-out and the accompanying change in the contact resistivity between fiber and matrix [1-4], the effect of the curing age on the bond strength and contact resistivity suggests that the curing age affects the self-monitoring character. Indeed, this paper reports so.

Experimental Methods

The carbon fibers were isotropic pitch based and unsized, as obtained from Ashland Petroleum Co. (Ashland, KY). The diameter was 10 µm; the nominal length was 5 mm. Fibers in the amount of 0.5% by weight of cement (0.24 vol.% of mortar) were used. Cement paste made from Portland cement (Type I) from Lafarge Corp. (Southfield, MI) was used with water/cement ratio 0.35. The aggregate was natural sand [1]; sand/cement ratio = 1.0. No large aggregate was used. The water reducing agent used in the amount of 3% by weight of cement was TAMOL SN (Rohm and Haas Co., Philadelphia, PA), which contained 93-96% sodium salt of a condensed naphthalenesulfonic acid. Methylcellulose and silica fume were added to help disperse the fibers. Silica fume (EMS-965, Elkem Materials Inc., Pittsburgh, PA) was used in the amount of 15% by weight of cement. Methylcellulose (Methocel A15-LV, Dow Chemical, Midland, MI) in the amount of 0.4% by weight of cement was used together with a defoamer (Colloids 1010, Colloids, Inc., Marietta, GA) in the amount of 0.13 vol.%.

Simultaneous to mechanical testing, DC electrical resistance measurements were made. For compressive testing according to ASTM C109-80, specimens were prepared by using a 2 x 2 x 2 in. (5.1 x 5.1 x 5.1 cm) mold. The strain was measured by the crosshead displacement, while the resistance R along the stress axis was measured using the four-probe method (with silver paint electrical contacts). R was essentially proportional to the resistivity. In addition to static loading to failure, testing was performed under cyclic loading within the elastic regime. Each cycle took 38.1 s.

Results and Discussion

R decreased during compressive loading in each cycle and increased during unloading in each cycle, due to fiber push-in during loading and fiber pull-out during unloading. At the end of the first cycle, R was larger than the initial value, due to damage of the fiber-cement interface. As cycling progressed, both the maximum and minimum R in a cycle decreased, due to damage of the cement matrix separating adjacent fibers at their junction; this damage increased the chance for adjacent fibers to touch each other, thereby decreasing the resistivity. This decrease from cycle to cycle persisted for the first ~ 150 cycles. Fig. 1(a) shows the fractional resistance increase

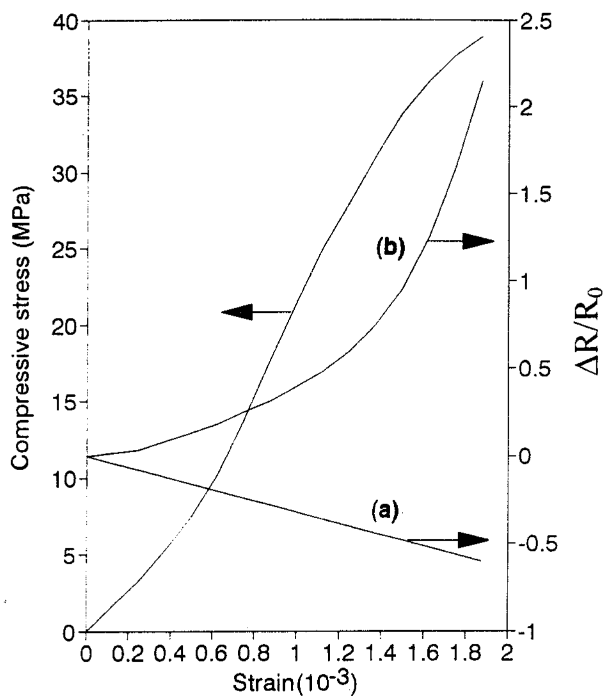

Fig. 1 $\Delta R/R_0$ vs. strain and stress vs. strain during first static compression up to failure at (a) 28 d, (b) 7 d.

($\Delta R/R_0$) vs. strain and stress vs. strain during first static compression up to failure at 28 d. R decreased monotonically up to failure.

Similar results were obtained at 14 d, except that the decreases in maximum R and minimum R from cycle to cycle were less. However, at 7 d the resistance increased monotonically upon first static compression up to failure (Fig. 1(b)). Consistent with the static compression result of Fig. 1(b) is the cyclic compression result. During the first cycle, the resistance increased upon loading, increased further upon subsequent unloading (due to fiber pull-out), decreased upon loading in the second cycle (due to fiber push-in), and increased upon unloading in the second cycle (due to fiber pull-out); the behavior was similar in second and subsequent cycles, but was different in the first cycle. The behavior at 7 d is attributed to the relatively strong fiber-matrix bonding at 7 d and the consequent need to weaken the bond prior to fiber pull-out. Bond weakening is accompanied by irreversible increase in the contact electrical resistivity [8], which results in the irreversible resistance increase observed in the first cycle [3]. The fiber-cement bond strength decreased with increasing curing time from 7 to 14 d, while the contact resistivity increased, as shown for stainless steel fiber [5]. At 14 or 28 d, the bond strength was weak to start with, so bond weakening was not necessary prior to fiber pull-out. The monotonic resistance increase up to failure at 7 d is due to the bond weakening at least in the low stress regime; in the high stress regime, it is probably due to damage. At 7 d the maximum $\Delta R/R_0$ and minimum $\Delta R/R_0$ did not change from cycle to cycle, in contrast to the decrease in these quantities at 14 and 28 d. This effect of the curing age is attributed to the decrease in ductility with increasing curing age and the resulting increased tendency for repeated fiber pull-out and push-in during cyclic loading to cause damage to the cement matrix separating adjacent fibers.

Conclusion

The self-monitoring behavior of carbon fiber reinforced mortar was affected by the curing age. The electrical resistance increased with compressive strain during first loading at 7 d, but at 14 and 28 d it decreased; this effect is due to the weakening of the fiber-cement interface as curing progresses. The resistance decreased slightly and irreversibly at the end of each cycle at 14 and 28 d, but not at 7 d; this effect is due to the decreasing ductility of the cement matrix as curing progresses.

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