Pergamon

Cement and Concrete Research, Vol. 25, No. 3, pp. 491-496, 1995

0008-8846/95 $9.50+.00

0008-8846(95)00037-2

IMPROVING THE BONDING BETWEEN OLD AND NEW CONCRETE BY ADDING CARBON FIBERS TO THE NEW CONCRETE

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(Communicated by D.M. Roy)
(Received December 5, 1994)

ABSTRACT

The addition of short carbon fibers in the amount of 0.35 vol.% resulted in mortars that bonded more strongly to old mortars. The increase in shear bond strength was up to 89%. This effect is attributed to the lowering of the drying shrinkage by the fiber addition. The effect is largest when the fibers were used with latex, which was in the amount of 20% of the cement weight.

I. Introduction

The most widely used method of concrete structure repair [1,2] is the bonding of new concrete to the old concrete needing repair. The success of this method is limited by the insufficient bonding between the old and new concretes, in spite of the use of admixtures such as silica fume and latex [3-7] in the new concrete. In this paper, by the addition of short carbon fibers to the new concrete, the bond strength between the old and new concretes was increased by up to 89% beyond the levels achieved by the use of the admixtures mentioned above. This effect of the fiber addition is attributed to the decrease in drying shrinkage [8,9] and the resulting decrease in the stress at the interface between the new and old concretes.

II. Experimental Methods

(1) Materials

The carbon fibers used were short (nominally 5 mm in length), unsized and made from isotropic pitch. Their properties are shown in Table 1. They were provided under the trade name Carboflex by Ashland Petroleum Co., Ashland, Kentucky. The dispersion of the carbon fibers requires the use of additives, such as latex, methylcellulose and/or silica fume [10].

The cement used was Portland cement (Type I) from Lafarge Corp. (Southfield, MI). The sand used for all specimens except the drying shrinkage test specimens was natural sand (100% passing 2.36 mm sieve, 99.9% SiO_2). The sand used for drying shrinkage test specimens was silica sand #2 (crystalline, 99.91% SiO_2). The sand/cement ratio was 1 for all specimens other than the drying shrinkage test specimens and 1.5 was the drying shrinkage test specimens. Table 2 describes the five types of mortar studied. They were (i) plain mortar, (ii) mortars with methylcellulose, (iii) mortars with methylcellulose and silica fume, (iv) mortars with latex, and (v) mortars with epoxy. In all cases (other than plain mortar), mortars with and without carbon fibers in the amount

Table 1. Properties of carbon fibers

Filament diameter	10 μm
Tensile strength	690 MPa
Tensile modulus	48 GPa
Elongation at break	1.4%
Electrical resistivity	$3.0 \times 10^{-3}\ \Omega$ cm
Specific gravity	1.6 g cm $^{-3}$
Carbon content	98 wt.%

of 0.35 vol.% (corresponding to fibers in the amount of 0.5% by weight of cement) were compared. Both the water/cement ratio and the water-reducing agent (WR)/cement ratio were chosen to maintain the slump at 160-170 mm. The required water/cement ratio and the WR/cement ratio varied with the dispersant used. The water reducing agent powder used was TAMOL SN (Rohm and Haas), which contained 93-96% sodium salt of a condensed naphthalene sulfonic acid. The latex (Dow Chemical, 460NA) was a styrene butadiene copolymer emulsion; it was used in the amount of 20% of the weight of the cement. An antifoam agent (Dow Corning 2410, an emulsion) used was in the amount of 0.5% of the weight of the latex; it was used whenever latex was used. Methylcellulose (Dow Chemical, Methocel A15-LV) in the amount of 0.4% of the cement weight was used. A defoamer (Colloids 1010) was added in the amount of 0.13 vol.%; it was used whenever methylcellulose was used. The silica fume (Elkem Materials, EMS 960) was used in the amount of 15% by weight of cement.

A Hobart mixer with a flat beater was used for mixing. For the case of mortars containing latex, the latex, antifoam agent and carbon fibers first were mixed by hand for about 1 min. Then this mixture, sand, cement, water and the water reducing agent were mixed in the Hobart mixer for 5 min. In the case of mortars containing methylcellulose, the methylcellulose was dissolved in water and then the carbon fibers and the

Table 2. Mix Proportions (by weight unless indicated otherwise) of various types of mortar.

Sample	Fiber vol.%	Water/cement ratio		Latex/ cement ratio	Meth/ cement (%)	SF/ cement ratio	WR/ cement (%)
		All specimens other than drying shrinkage test specimens	Drying shrinkage test specimens				
Plain mortar	0	0.475	0.45	0	0	0	0.5
Mortar with Meth	0 0.35	0.475 0.475	0.45 0.45	0 0	0.4 0.4	0 0	1 1
Mortar with Meth and SF	0 0.35	0.475 0.475	0.45 0.45	0 0	0.4 0.4	0.15 0.15	2 2
Mortar with latex	0 0.35	0.23 0.23	0.35 0.35	0.2 0.2	0 0	0 0	0.5 1.5

Meth = methylcellulose; SF = silica fume; WR = water reducing agent.

defoamer were added and stirred by hand for about 2 min. Then this mixture, sand, cement, water and the water reducing agent (and silica fume, if applicable) were successively added and then mixed in the Hobart mixer for 5 min. After pouring the mix into oiled molds, a vibrator was used to facilitate compaction and decrease the amount of air bubbles. The specimens were demolded after 1 day and then allowed to cure at room temperature (25°C) and room humidity (10% relative humidity) in air.

(2) Bond strength measurements

The bond strength between new and old mortar was measured using a shear test configuration (Fig. 1). Two mortar pieces labeled A (poured first) sandwiched a mortar piece labeled B (poured 28 days after pouring A) and the A-B joints were subjected to shear when B had been cured for 28 days. Six specimens of each type were tested.

(3) Drying shrinkage testing

The drying shrinkage was investigated by measuring the length change in accordance with ASTM C490-83a. The specimen size was 25.4 x 25.4 x 286 mm (1 x 1 x 11.25 in). The accuracy in the length change measurement was ± 0.0025 mm (0.0001 in.).

(4) Compressive testing

Compressive strength testing was conducted on mortar specimens of size 50.8 x 50.8 x 50.8 mm (2 x 2 x 2 in), in accordance with ASTM C109-80. Six specimens of each type were tested. The specimens had been cured for 28 days at the time of testing.

III. Results and discussion

(1) Bond strength

Table 3 gives the shear bond strength of joints between old mortar (plain) and new mortar, such that the curing age difference was 28 days between old and new mortars. The fibers increased the shear bond strength by up to 89%. Their effectiveness was greatest when latex was used. When fibers were absent, the use of methylcellulose + silica fume gave the highest shear bond strength. When fibers were present, the use of latex gave

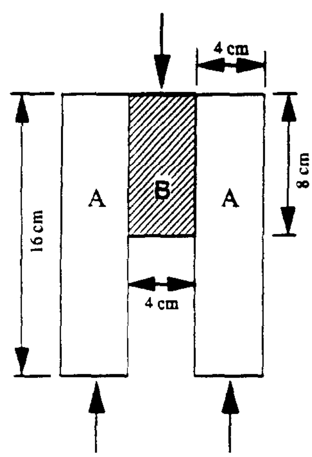

Fig. 1

Configurations for measuring shear bond strength between old mortar (A) and new mortar (B).

Table 3. The results of shear debonding tests conducted on joints between an old mortar and a new mortar such that the curing age difference was 28 days between the old and new mortars. Debonding tests were conducted at a curing age of 28 days for the new mortar.

Joint (old-new)	Shear bond strength (MPa) Without fibers	With fibers	Fractional increase due to fibers
Plain-Plain	0.22±0.02	-	-
Plain-M	0.39±0.05	0.63±0.02	62%
Plain-M+SF	0.84±0.02	1.40±0.10	67%
Plain-Latex	0.76±0.03	1.44±0.15	89%

Note: M = methylcellulose; SF = silica fume

the highest shear bond strength. However, the difference in bond strength between the case with methylcellulose + silica fume and the case with latex is small, whether the fibers were present or not.

(2) Drying shrinkage

Fig. 2 shows the plots of the drying shrinkage strain vs. curing time. The drying shrinkage was decreased by the fiber addition. Among the three dispersants used with the fibers, namely (i) methylcellulose, (ii) methylcellulose + silica fume, and (iii) latex, latex gave the largest drying shrinkage, as shown by comparing the curves labelled 6, 4 and 2 in Fig. 2.

(3) Compressive strength

The fiber addition slightly decreased the compressive strength at 28 days (Table 4). The use of methylcellulose + silica fume gave the highest compressive strength.

(4) Correlation between bond strength and drying shrinkage

The fiber addition increased the bond strength and decreased the drying shrinkage. The use of latex + fibers gave the highest bond strength, but it gave the largest drying shrinkage, compared to the case of methylcellulose + fibers and the case of methylcellulose + silica fume + fibers. This means that the quality of the concrete-concrete interface is not only governed by the drying shrinkage, but also by the adhesion ability of the concrete. Latex appears to help the adhesion ability, so that the use of latex + fibers resulted in the highest bond strength, even though it did not result in the lowest drying shrinkage. In other words, both a low drying shrinkage and a high adhesion ability contribute to providing a high bond strength.

Table 4. Compressive strength.

	Compressive strength (MPa) 0 vol.% fibers	0.35 vol.% fibers
Plain	36±1	/
With M	35±2	34±2
With M + SF	43±1	41±2
With latex	39±1	38±1

Note: M = methylcellulose; SF = silica fume.

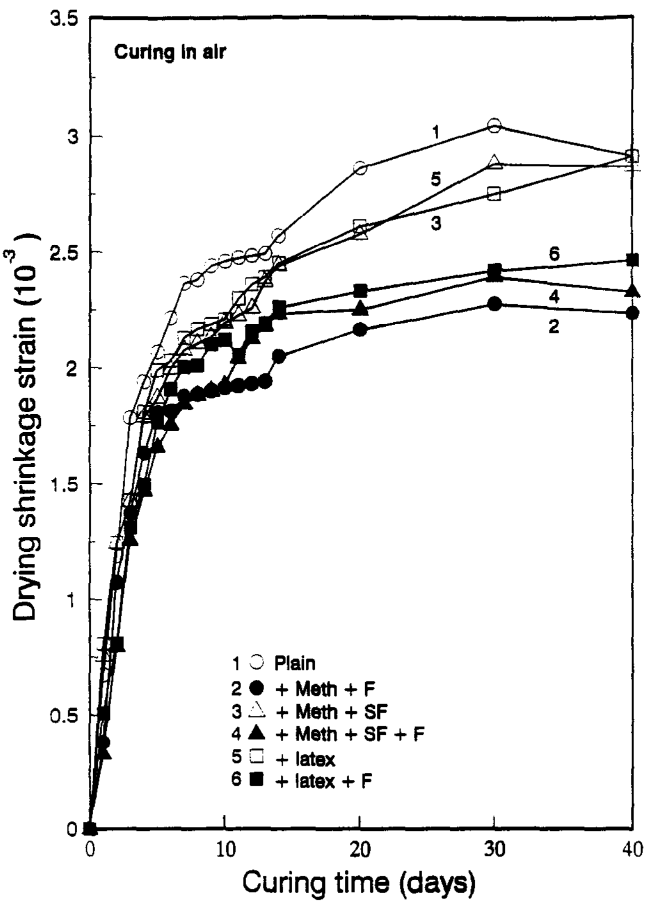

Fig. 2 Drying shrinkage strain vs. curing time.
Meth = methylcellulose; SF = silica fume; F = fibers.

V. Conclusion

The addition of short carbon fibers (0.35 vol.%) resulted in mortars that could bond more strongly to old mortars. The increase in shear bond strength was up to 89%. The fibers were particularly effective when they were used with latex. The use of methylcellulose + silica fume + fibers gave slightly less bond strength than the use of latex + fibers, but gave higher compressive strength and was less expensive (due to the small amount of methylcellulose and the large amount of latex used). The increased bond strength provided by the carbon fiber addition is attributed to the lowering of the drying shrinkage by the fiber addition. Both a low drying shrinkage and good adhesion ability contribute to achieving a high quality mortar-mortar interface, thus making the use of latex + fibers give the highest bond strength.

Acknowledgement

The authors thank Zheng-Qiang Shi of SUNY/Buffalo for technical assistance.

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