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DECREASE OF THE BOND STRENGTH BETWEEN STEEL REBAR AND CONCRETE WITH INCREASING CURING AGE

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ABSTRACT

The effect of curing age on the bond between concrete and steel rebar was studied by measuring both bond strength and contact electrical resistivity. The bond strength decreased with increasing curing age from 7 to 28 days, while the contact resistivity increased. Both effects are due to an increase in interfacial void content, which in turn is due to the drying shrinkage of the concrete. *© 1998 Elsevier Science Ltd*

Introduction

Due the hydration reaction of cement, the strength of concrete increases with the curing age. Because of this well-known trend, it has been commonly assumed that the bond strength between concrete and steel rebar also increases with the curing age. However, it has been recently reported that the bond strength between cement paste and stainless steel fiber decreases with increasing curing age from 1 to 28 days (particularly from 1 to 14 days), due to the increase in interfacial void content, as indicated by the increase in contact electrical resistivity (1,2). The increase in interfacial void content is due to the increase in drying shrinkage of the cement paste as curing progresses. This surprising result is confirmed in this paper, which extends our previous work (1,2) from stainless steel fiber to mild steel rebar and from cement paste to concrete, because the combination of mild steel rebar and concrete is widely encountered in civil structures.

Experimental Methods

The concrete was made with Portland cement (Type I, from Lafarge Corp., Southfield, MI), fine aggregate (natural sand, all of which passed through a #4 U.S. sieve), and coarse aggregate (all of which passed through a 1-inch sieve) in the weight ratio 1:1.5:2.49. The water/cement ratio was 0.45. A water reducing agent (TAMOL SN, Rohm and Haas Co., Philadelphia, PA; sodium salt of a condensed naphthalenesulphonic acid) was used in the

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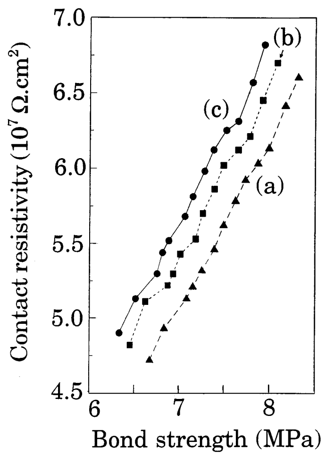

FIG. 1.
Variation of contact electrical resistivity with shear bond strength between steel rebar and concrete of curing age (*a*) 7 days, (*b*) 14 days, and (*c*) 28 days, all cured at 100% relative humidity.

amount of 2% of the cement weight. The concrete was plain concrete (with only cement, aggregates, and water).

All ingredients were mixed in a stone concrete mixer for 15 to 20 min. Then the concrete mix was poured into a 6 × 6 × 6 in (15.2 × 15.2 × 15.2 cm) mold, while a steel rebar was positioned vertically at its center and held in place by protruding into an indentation at the center of the bottom-inside surface of the mold. The mild steel rebar was of size #6, length of 26 cm, and a diameter of 1.9 cm. It had 90° crossed-spiral surface deformations of pitch 2.6 cm and protruded height of 0.1 cm. After the pouring of the concrete mix, an external vibrator was applied on the four vertical sides of the mold. Curing of the concrete was allowed to occur in air at a relative humidity of 100%. Steel pull-out testing was carried out according to ASTM C-234. A hydraulic Material Testing System (MTS 810) was used at a crosshead speed of 1.27 mm/min.

The volume electrical resistivity of concrete was 1.35×10^7, 1.44×10^7 and 1.50×10^7 Ω·cm at 7, 14, and 28 days, respectively, as obtained by the four-probe method. In this procedure, all four probes (silver paint) were around the whole perimeter of the concrete specimen (16 × 4 × 4 cm) in four parallel planes, perpendicular to the longest axis of the specimen.

The contact electrical resistivity between the steel rebar and the concrete was measured using the four-probe method and silver paint as electrical contacts, as illustrated in Figure 1 of Ref. 3. Each of one current contact and one voltage contact was circumferentially on the rebar. The other voltage and current contacts were on the concrete embedding the rebar, such that each of these contacts was around the whole perimeter of the concrete in a plane perpendicular to the rebar; the voltage contact was in a plane about 2 inches (5 cm) from the top surface of the concrete, while the current contact was in a plane about 4 inches (10 cm) from the top surface of the concrete. The resistance between the two voltage probes was measured; it corresponded to the sum of the rebar volume resistance (the resistance down the length of the rebar), the steel-concrete contact resistance (the resistance across the interface), and the concrete volume resistance (the resistance radially outward from the interface to the vertical sides of the concrete). The measured resistance turned out to be dominated by the contact resistance, to the extent that the volume resistance of the rebar can be neglected and that of the concrete cannot. Thus, the volume resistance of the concrete (calculated from the separately measured volume resistivity given above) was subtracted from the measured resistance in order to obtain the contact resistance. The contact resistivity (in $\Omega \cdot cm^2$) was then given by the product of the contact resistance (in Ω) and the contact area (in cm^2). The contact area depended on the embedment length, which was separately measured for each sample.

Steel pull-out testing was conducted on the same samples and at the same time as the contact resistivity was measured. The contact resistivity was taken as the value prior to pull-out testing. The bond strength was taken as the maximum shear stress during pull-out testing. Figure 2 of Ref. 3 is a typical plot of shear stress vs. displacement and of contact resistivity vs. displacement. The contact resistivity abruptly increased when the shear stress reached its maximum, i.e., when the steel-concrete debonding was completed. It did not change before this abrupt increase.

Results and Discussion

Figure 1 shows the correlation of the contact resistivity with the bond strength for different curing ages and curing at 100% relative humidity. The greater the curing age, the lower the bond strength, and the higher the contact resistivity. The decrease in bond strength was substantial when the curing age was increased from 7 to 14 days, and less when the curing age was increased from 14 to 28 days. The same trend was observed for curing at 40% relative humidity, but the bond strength at the same curing age was higher at 100% relative humidity than at 40% relative humidity.

The decrease in bond strength and increase in contact resistivity upon increase in the curing age are both attributed to the increase in the interfacial void content. As curing progressed, drying shrinkage occurred, particularly before 14 days of curing. This shrinkage led to the increase in the interfacial void content.

Conclusion

The bond strength between concrete and steel rebar was found to decrease with increasing curing age from 7 to 28 days, particularly from 7 to 14 days, due to increase in interfacial void content, as indicated by the increase in the contact electrical resistivity. This effect is attributed to the drying shrinkage of the concrete and is consistent with the results previously reported for the bond between cement paste and stainless steel fiber (1,2).

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