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IMPROVING THE BOND STRENGTH BETWEEN STEEL REBAR AND CONCRETE BY OXIDATION TREATMENTS OF THE REBAR

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ABSTRACT

Oxidation treatments of steel rebar by water immersion (2-5 days) and ozone exposure increased the bond strength between steel rebar and concrete by 14% and 22% respectively. The treatments slightly increased the electrical contact resistivity between rebar and concrete. Increase of the water immersion time to 7 or 10 days caused the bond strength to decrease to values still above that of the case without water treatment. The contact resistivity increased monotonically with the water immersion time. *Copyright © 1996 Elsevier Science Ltd*

Introduction

Steel rebars are widely used to reinforce concrete. The effectiveness of the reinforcement depends on the bond strength between rebar and concrete. Surface deformations on the rebar enhance the bond due to mechanical interlocking between rebar and concrete. It had been reported that treatment of steel wires by water (to form rust) enhanced the flexural strength of steel wire reinforced mortar by 20%, though neither flexural strength nor bond strength data were given and the effect of the water immersion time (which relates to the amount of rust) was not reported [1]. As water treatment is simple and inexpensive compared to other treatments (such as those using acetone [1,2] and NaOH [1]), the effectiveness of water treatment in enhancing the bond strength between steel and concrete deserves evaluation. This evaluation constitutes the main objective of this paper. Furthermore, this paper provides a systematic study of the effect of the water immersion time on both the bond strength and the contact electrical resistivity between rebar and concrete. The contact resistivity gives information on the structure of the interface [2-4]. In addition, this paper addresses the effect of ozone exposure of the steel rebar on the bond strength between rebar and concrete, as ozone exposure is a more severe oxidation treatment than water immersion.

Experimental Methods

The concrete was made with Portland cement (Type I, from Lefarge Corp., Southfield, MI), fine aggregate (natural sand, all of which passed through #4 U.S. sieve) and coarse aggregate (all of which passed through 1" 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 amount of 2% of the cement weight. All ingredients were mixed in a stone concrete mixer for 15-20 min. Then the concrete mix was poured into a 6 x 6 x 6 in (15.2 x 15.2 x 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 26 cm, and diameter 1.9 cm, and had 90° crossed spiral surface deformations of pitch 2.6 cm and protruded height 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 33%. Steel pull-out testing was carried out according to ASTM C-234 at 28 days of curing. A hydraulic Material Testing System (MTS 810) was used at a crosshead speed of 1.27 mm/min.

The volume electrical resistivity of the concrete at 28 days was 1.53×10^7 Ω.cm, as obtained by the four-probe method, in which all four probes (silver paint) were around the whole perimeter of the concrete specimen (14 x 4 x 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 at 28 days of curing using the four-probe method and silver paint as electrical contacts, as illustrated in Fig. 1 of Ref. 2. 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 in (5 cm) from the top surface of the concrete, while the current contact was in a plane about 4 in (10 cm) from the top surface of the concrete. The resistance between the two voltage probes was measured; it corresponds 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, such 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 Ω.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. Refer to Fig. 2 of Ref. 2 for typical plots 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.

Water treatment of steel rebars was conducted by totally immersing the rebars in water for 0, 2, 5, 7, or 10 days prior to embedding each rebar in concrete. Ozone treatment of steel rebars was conducted by exposure to O_3 gas (0.3 vol.%, in air) for 20 min at 160°C. Prior to O_3 exposure, the rebars had been dried at 110°C in air for 50 min. Seven samples were tested for each treatment condition.

Results and Discussion

Fig. 1 shows the correlation of the contact resistivity with the bond strength. The contact resistivity increased linearly with increasing bond strength (as in Ref. 2), such that the data for the different water immersion times lie on essentially parallel straight lines. Water immersion

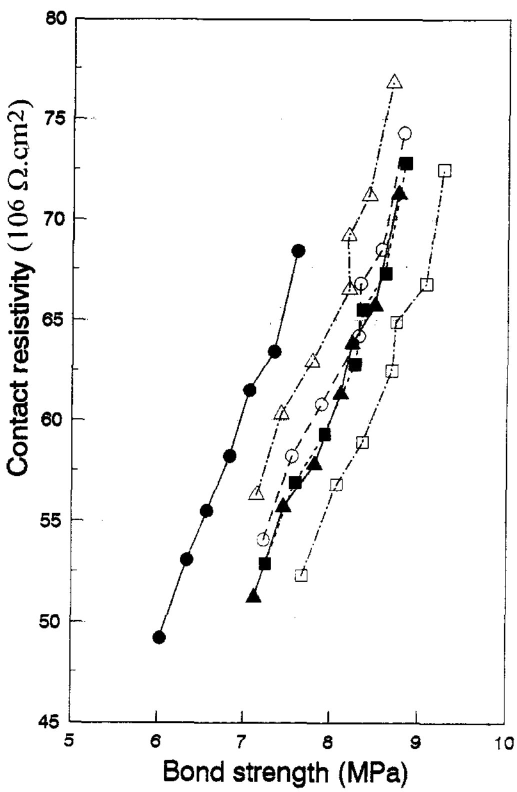

FIG. 1.

Variation of contact electrical resistivity with bond strength at 28 days. Solid circles: as-received steel rebar. Solid triangles: steel rebar immersed in water for 2 days. Solid squares: steel rebar immersed in water for 5 days. Open circles: steel rebar immersed in water for 7 days. Open triangles: steel rebar immersed in water for 10 days. Open squares: O_3 treated steel rebar.

for 2-5 days increased the bond strength by 14% and slightly increased the contact resistivity. Increase of the water immersion time beyond 5 days caused the bond strength to decrease and the contact resistivity to increase further. However, even for a water immersion time of 10 days, the bond strength was still higher than that for the as-received rebar. Thus, a water immersion time of 2 days is recommended. Fig. 1 shows that ozone treatment enhanced the bond strength more than any of the water treatments. The contact resistivity was also increased by the ozone treatment, but not as much as in the case of water treatment for 7 or 10 days.

It is reasonable to assume that the contact resistivity is related to the amount of oxidation product at the rebar-concrete interface, as the oxidation product is a poor electrical conductor. Hence, the differences in contact resistivity (Fig. 1) suggest that the amount of oxidation product is comparable between O_3 treatment and 2-5 day water treatments, but is larger for 7-10 day water treatments. The phase of the oxidation product differs between O_3 and water treatments, as indicated by the black color of the oxidation product of the water treatments and the dark grey color of the oxidation product of the O_3 treatment. This phase difference is believed to be partly responsible for the difference in the extent of bond strength enhancement.

The contact resistivity increases with increasing bond strength among the data for each water immersion time. The origin of this dependence in associated with interfacial phase(s) of volume resistivity higher than that of concrete, as pointed out in Ref. 2. The interfacial phase enhances the bonding. It may be a metal oxide or a metal hydroxide (rust). Water treatment increases both bond strength and contact resistivity because the treatment forms a black phase that may be akin to rust on the rebar; the phase enhances the bonding but increases the contact resistivity. The longer the water immersion time, the more the black phase and the higher the contact resistivity. However, an excessive amount of the black phase (as obtained after 7 or 10 days of water immersion) weakens the bond.

At the same bond strength, the water treated rebar exhibits a lower contact resistivity than the as-received rebar (Fig. 1). As the amount of black phase increases with increasing contact resistivity, this implies that the black phase formed by the water treatment is more effective than the rust or rust-like phase(s) formed without the water treatment in enhancing the bond strength. The greater effectiveness of the former is probably partly because of the more uniform distribution of the black phase and partly because of the possible difference in phase between the black phase and the rust or rust-like phase formed without the water treatment.

Conclusion

The bond strength between steel rebar and concrete was increased by 16% by immersion of the rebar in water for 2-5 days and by 22% by O_3 exposure. The treatments formed coatings (black for water treatment and dark grey for O_3 treatment), which enhanced the bonding, but slightly increased the electrical contact resistivity between rebar and concrete. Water immersion for more than 5 days weakened the bond to strengths still above the case of no water immersion. The contact resistivity increased monotonically with increasing water immersion time. The phase formed by the water treatment was more effective than the rust or rust-like phase(s) formed without the water treatment in enhancing the bond strength.

Acknowledgement

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