Pergamon

PII S0008-8846(98)00026-X

EFFECT OF RUST ON THE WETTABILITY OF STEEL BY WATER

W. Lu and D.D.L. Chung[1]
Composite Materials Research Laboratory, State University of New York at Buffalo,
Buffalo, NY 14260-4400, USA

ABSTRACT

Rust, as formed on steel by immersion of low-carbon steel in water, was found to improve the wettability of steel by water. The advancing contact angle decreased from 87° to 32°, and the receding contact angle decreased from 81° to 29°. Cleansing of steel by acetone also helped improve the wettability, but the advancing angle only decreased from 87° to 73°, and the receding angle only decreased from 81° to 41°. *© 1998 Elsevier Science Ltd*

Introduction

The bond between steel and concrete is critical to the performance of steel-reinforced concrete. An intimate contact between steel and concrete, as brought about by good wettability of the steel by the cement paste in the concrete, is expected to enhance the bond strength. Although this notion is intuitively obvious, little effort has been previously made in improve this wettability (1). On the other hand, it has been reported that rust which is well-adhered to the underlying steel helps the bond between steel rebar and concrete (2,3). It has also been reported that treatment of steel with water prior to incorporation of steel in concrete increases the bond strength between steel and concrete (4,5). In order to help understand why rust helps the bond, this paper addresses the effect of rust on the wettability of steel by water. Water is relevant because the concrete mix contains water.

Experimental Methods

Steel fiber, rather than steel rebar, was used. This is because dynamic contact angle measurement for assessing the wettability involves measuring the wetting force, and a steel rebar is heavy compared to a steel fiber. It is also because the surface deformations (ribs) on a rebar interfere with the dynamic measurement.

The fiber used was low-carbon, cold-drawn Xorex™ steel fiber manufactured by Novocon International Inc. (Mt. Prospect, IL). The average diameter was 0.889 mm. The actual diameter of each fiber tested was separately measured. The length was 51 mm. The cross

---

Communicated by D.M. Roy.
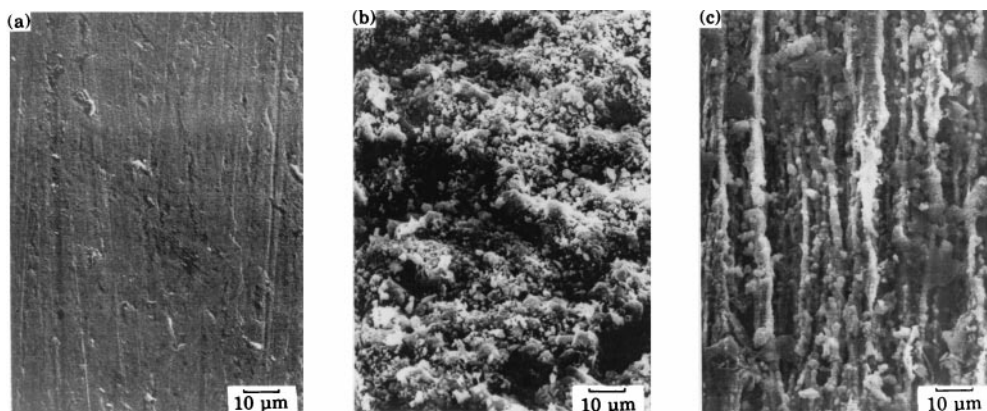[1]To whom correspondence should be addressed.

FIG. 1.
SEM photographs of the surface of steel fiber after treatment by (*a*) acetone, (*b*) acetone, followed by water, and (*c*) acetone, followed by acid solution.

section was circular and uniform (without surface deformation). The fiber conforms to ASTM A820 (specification for steel fibers for reinforced concrete).

The steel fiber was surface treated by the following methods: (i) washing with acetone (immersion in acetone for 1 h and then drying in air), (ii) washing with water (immersion in water for 24 h and then drying in air), (iii) washing with acetone, as in (i), followed by washing with water, as in (ii), and (iv) washing in acetone, as in (i), followed by washing with 5% hydrochloric acid in water (immersion in acid solution for 24 h and then drying in air).

The dynamic contact angle between fiber and doubly deionized water was measured using the Sigma 70 tensiometer of KSV Instruments (Monroe, CT). The tensiometric method (micro-Wilhemy technique) was used. The immersion depth was up to 5 mm and the stage with a beaker of water was moved up (advancing) and down (receding) at a constant speed of 5 mm/min. About ten samples of each type were tested.

Results

Visual observation showed that treatments (ii), (iii), and (iv), which all involved water, resulted in yellow rust (a rough, non-uniform porous layer which appeared to not strongly adhere to the underlying steel) on the steel fiber. In contrast, treatment (i), which did not involve water, resulted in no rust and no change of the surface morphology of the steel fiber. Figure 1 shows scanning electron microscope (SEM) photographs of the surface after treatments (i), (iii), and (iv). The roughness after treatments (iii) and (iv) is due to rust. The striations parallel to the fiber axis (vertical direction) in Figure 1c are related to those in Figure 1a, as the acid treatment etched the steel and revealed the striations more clearly.

Weight measurements before and after a treatment showed that treatment (i) gave a weight loss of 0.09%, treatment (iii) gave a weight loss of 0.23% and treatment (iv) gave a weight loss of 1.13%. Although rusting may cause weight gain or weight loss, depending on the adherence of the rust, the small value of the fractional weight loss, after treatment (iii) in particular, shows that the rusting is limited to the surface region of the steel fiber.

TABLE 1
Contact angle (degrees, ± 2) between steel fiber
and water.

Fiber treatment		Advancing	Receding
None	1st cycle	89.9	83.3
	2nd cycle	88.2	81.9
	3rd cycle	83.5	79.0
	Average	87.2	81.4
(i)	1st cycle	75.0	41.7
Acetone	2nd cycle	73.6	40.2
	3rd cycle	71.6	39.9
	Average	73.4	40.6
(ii)	1st cycle	33.3	29.2
Water	2nd cycle	31.9	28.4
	3rd cycle	31.7	28.2
	Average	32.3	28.6
(iii)	1st cycle	32.8	30.7
Acetone, water	2nd cycle	31.5	29.4
	3rd cycle	31.4	29.0
	Average	31.9	29.7
(iv)	1st cycle	31.5	29.1
Acetone, HCl	2nd cycle	30.2	27.7
	3rd cycle	30.1	28.1
	Average	30.6	28.3

The advancing and receding contact angles for the first three cycles of advancing (increasing immersion depth) and receding (decreasing immersion depth) are shown in Table 1 for each of the as-received and treated fibers. Both advancing and receding angles were decreased by any of the treatments. The advancing angle, which is more relevant to concrete mixing than the receding angle, was decreased greatly by either water or acid, but less significantly by acetone. Acetone (treatment (i)), which presumably cleansed the surface by degreasing, decreased the receding angle more than the advancing angle, but it was not as effective as any of the other treatments in decreasing either advancing or receding angle. Treatments (ii), (iii) and (iv) all gave similarly large decreases in either angle. The decreases are attributed to the rust present after these treatments. The effect of rust overshadowed the effect of degreasing.

Conclusion

Rust, as formed on steel by immersion of steel in water, was found to improve the wettability of steel by water, as shown by large decreases in both advancing and receding contact angles. Acetone washing did not result in rust, and the resulting decreases in advancing and receding contact angles were less than those resulting from rust.

References

1. M. Mantel and J.P. Wightman, Surface & Interface Analysis 21, 595 (1994).
2. F.G. Murphy, CIRIA Report 71, London, 1977.
3. M. Maslehuddin, I.M. Allam, G.J. Al-Sulaimani, A.I. Al-Mana, and S.N. Abduljauwad, ACI Mater. J. 87, 496–502 (1990).
4. B. Mayfield and B. Zelly, Concrete, March, 35–37. (1973).
5. X. Fu and D.D.L. Chung, Cem. Concr. Res. 26, 1499 (1996).