

# How clean must rebar be?

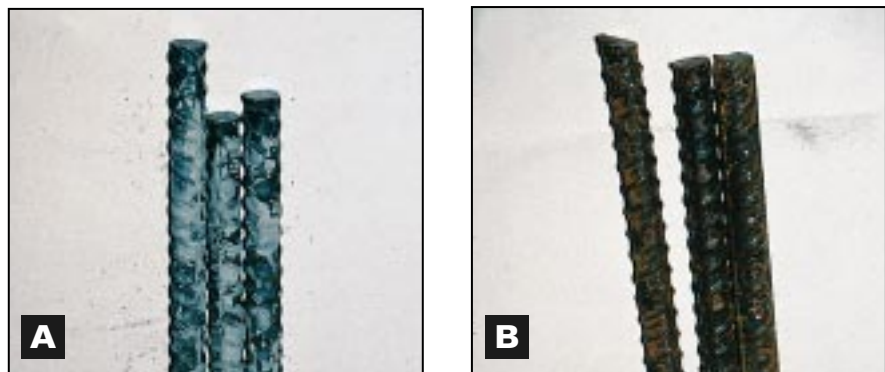
**Most specifications require reinforcement to be free of deleterious materials. But do common construction contaminants have a harmful effect on bond?**

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**F**orm-release agents, bond breakers and cement splatter sometimes contaminate reinforcing steel before concrete is placed. However, ACI 301-96, *Standard Specifications for Structural Concrete* (Ref. 1), says “When concrete is placed, all reinforcement shall be free of materials deleterious to bond.” Inspectors often cite this sentence when requiring contractors to remove form-release or bond-



**Figure 1.** Form-release agent was sprayed on the rebar, covering 100% of the surface.



**Figure 2.** Amount of cement splatter (a) and rust (b) on the rebar tested.

breaker overspray and cement splatter from contaminated rebar. But is this work really necessary?

The Aberdeen Group ran a series of bond pull-out tests to assess the effect of contaminants on bond strength. Pull-out tests measure the bond force acting parallel to the bar on the interface between the bar and concrete (Ref. 2). We tested clean, black Grade-60 steel bars and bars with form-release agents, curing compound/bond breakers, cement splatter, motor oil and rust on their surfaces. The results may surprise most inspectors.

## **Requirements for clean rebar**

Besides ACI 301’s general statement requiring all reinforcement to be free of deleterious materials, the specification also specifically mentions form-release agents: “Do not allow formwork release agent to

contact reinforcing steel or hardened concrete against which fresh concrete is to be placed.” *ACI Manual of Concrete Inspection* (Ref. 3) states that “reinforcement should be clean, and oil or nonadherent mortar which has been spilled on it should be cleaned off.”

In contrast to the requirement for removing oil and mortar, ACI 301 provides different criteria for rust: “Reinforcement with rust, mill scale, or a combination of both will be considered satisfactory provided the minimum nominal dimensions, nominal weight, and the minimum average height of deformations of a hand-wire-brushed test specimen are not less than the applicable ASTM specification requirements.” This recommendation is based on tests performed by Johnston and Cox in 1940 (Ref. 4). These investigators performed about 420 bond pull-out tests on deformed bar specimens

with 78 different degrees of rust.

We couldn't find similar studies showing the effect of common construction contaminants on rebar bond. Without such data, most specifiers and inspectors take a conservative approach by requiring removal of such materials from rebar. But removing contaminants is time-consuming and costly, and if construction contaminants aren't detrimental to rebar bond, their removal may not be necessary. Because of the lack of data, The Aberdeen Group initiated a limited test program.

### Common contaminants

Common construction contaminants were applied to clean rebar, and clean black-steel and rusted rebar were included as reference standards. The bar contaminants and how we applied them are described in the table on page 521.

Grade-60, #4 deformed rebar were used. The form release and curing compound/bond breaker were sprayed on 100% of the rebar surface (Fig. 1) to duplicate the worst case of contaminant coverage possible during construction. The used motor oil was applied to the entire bar length with a rag. A cement paste was mixed and applied to various areas of the rebar (Fig. 2a). To produce rusted rebar, three bars were dipped in hydrochloric acid then stored in a moist curing room. Figure 2b shows the amount of rust on the bars.

### Specimen construction

We constructed bond pull-out specimens with a 6-inch embedment depth by using the bottom halves of 6x12-inch plastic cylinder molds with a  $\frac{3}{8}$ -inch-diameter hole drilled through the bottom of each (Fig. 3). The molds, 27 in all, were placed on 2x6-inch boards that had been predrilled with  $\frac{3}{8}$ -inch-diameter,  $\frac{1}{2}$ -inch-deep holes. We inserted #4, Grade-60 deformed rebar at least 24 inches long in a vertical position, with  $\frac{1}{2}$  inch of the rebar protruding from the bottom of the cylinder mold into the hole in the 2x6. This



**Figure 3.** Pull-out specimens were cast in 6-inch-diameter, 6-inch-tall cylinder molds with a #4 rebar at least 24 inches long inserted at the center.

setup helped keep the bar vertical during concrete placement and provided enough protruding rebar length for the test-machine grips.

Ready-mixed concrete with a 3½-inch slump and 1.3% air content was delivered to the testing lab. The concrete compressive strength at the time of pull-out testing was 5490 psi.

The concrete was cast so it would settle in the direction of the applied load, eliminating any effect bleeding might have on the measured bond. We placed the concrete in two layers, rodded each layer 25 times and lightly hand-tapped the cylinder sides after each layer was rodded. The top surface was floated and then covered with a cylinder lid with a  $\frac{3}{8}$ -inch-diameter hole drilled through the center. The lid provided initial curing and maintained the bars in a vertical position. After 24 hours in lab air at about 70°F, the cylinder lids and molds were removed, and the test specimens were placed in a moist curing room on top of the 2x6 bottom supports. The specimens remained in the moist curing room 15 days and were tested at that age. After removal from the moist curing

room, the loaded ends of the concrete specimens were capped with a high-strength gypsum-based cementitious material.

The test-specimen size, embedded rebar length, concrete placement di-



**Figure 4.** With the test specimen placed on a spherical bearing block on top of the testing machine, a tensile load was applied with serrated grips. An electronic digital indicator measured slip at the free end of the rebar.

rection and curing conditions were the same as those used by Johnston and Cox to determine the effect of rust on rebar bond.

### Test procedure

Figure 4 shows a typical setup for a pull-out test. Test specimens were placed on a spherical bearing block on top of the testing machine. serrated grips were then connected to the rebar to allow the machine to load the bar in tension. A 60,000 pound Tinius-Olsen universal tension/compression frame was used to apply the load to the rebar at about 200 pounds per second. Technicians measured slip of the free end of the rebar with a Fowler 1/10,000 electronic digital indicator.

As the load was applied to each specimen, one person read the dial indicator while another person monitored the load at each slip reading. A third person recorded data and ob-

served specimen failure modes.

### Contaminants had little effect on bond strength

Instead of pulling out of the concrete specimen, which would be expected if the contaminants completely destroyed bond, the rebar broke in eight of the nine sets of three tests. The concrete specimens broke in the remaining test. The table shows the average slip at yield and ultimate load, the average stress at ultimate load, and the failure mode for the two reference bars and seven bars with contaminants. The ultimate stress achieved by the bars was not affected by any of the contaminants.

We broke open the concrete specimens to examine the failure surface of the rebar. A shiny surface on the rebar, indicating where the contaminant had been sprayed, was apparent between the deformations. At

the deformations, however, no shiny surface was visible, indicating that concrete bearing against the rebar deformations during loading removed the contaminant by friction. We believe the greater initial slip of rebar covered with the contaminants was due to loss of adhesion along the smooth part of the bar between the deformations. As shown in Figure 5, after the initial slip, the load was resisted by bearing of the deformations on the concrete and the shear strength of the concrete between the deformations (Ref. 5).

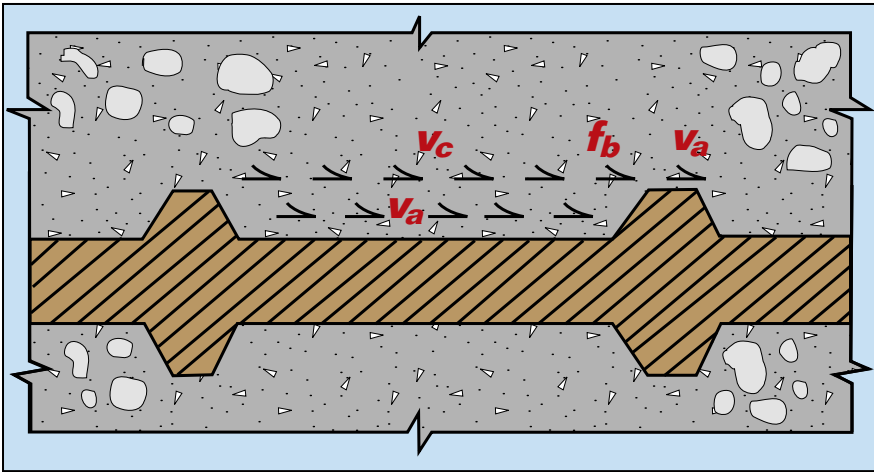
An excessive amount of slip before the yield stress of the bar is reached will increase deflection of reinforced-concrete members. While the slip is greater for bars with contaminants, the increase in slip is similar to that of rusted bars when compared with unrusted bars (Ref. 4).

The data and conclusions are based on only 27 tests of bars with nine different surface conditions.

### Bond pull-out test results (average of three tests)

Description	Slip at yield, in.	Slip at ultimate, in.	Ultimate stress, psi	Failure mode
Plain rebar—in place before concreting	<0.0001	±0.0005	101,125	Bars broke
Rusted rebar—in place before concreting	±0.0002	0.0026	101,083	Bars broke
Cement splatter—applied 24 hrs before concreting	<0.0001	±0.001	101,083	Bars broke
Form release <sup>1</sup> —applied 24 hrs before concreting	±0.0005	0.0032	101,083	Bars broke
Form release <sup>1</sup> —applied 15 mins before concreting	±0.0008	0.0049	100,500	Bars broke
Curing/bond breaker <sup>2</sup> —applied 24 hrs before concreting	±0.0008	0.0034	97,167	Concrete broke
Curing/bond breaker <sup>3</sup> —applied 24 hrs before, then cleaned <sup>4</sup> 15 mins before concreting	±0.0002	0.0024	101,000	Bars broke
Form release <sup>5</sup> —applied 24 hrs before concreting	±0.0002	0.0023	101,083	Bars broke
Used motor oil—applied 24 hrs before concreting	±0.0004	0.0031	101,417	Bars broke

1. A petroleum-based, chemically reactive concrete form-release agent.
2. A solvent-based, chemically reactive curing compound and bond breaker.
3. A water-based, chemically reactive curing compound and bond breaker.
4. A VOC-compliant concrete stripper and degreaser.
5. A petroleum-based, chemically-neutral form-release agent.



**Figure 5.** Applied tensile forces in the rebar are resisted by adhesion ( $v_a$ ) along the bar surface, bearing ( $f_b$ ) against the deformation face and shear in the concrete ( $v_c$ ) between adjacent deformations. For rebar coated with contaminants, adhesion was reduced, but the bar still broke because of resistance provided by bearing and concrete shear strength.

They represent one bar size, steel grade and concrete strength level. When Johnston and Cox tested rusted and nonrusted rebar, however, they noted similar effects for different bar sizes, rust levels, and steel and concrete strengths. Since The Aberdeen Group tests were made with 100% contaminant coverage of the reinforcing steel, they represent the worst possible case. Under these severe conditions, the contaminants didn't adversely affect bond. 🏠

#### **Acknowledgment**

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#### **References**

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