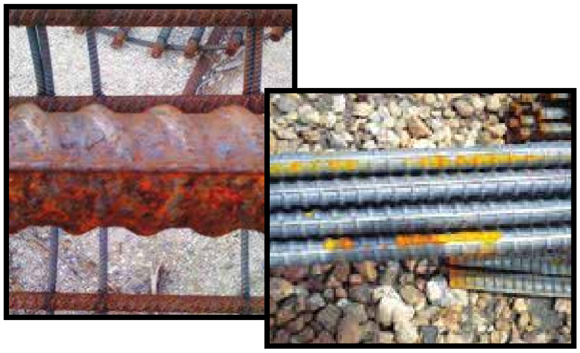
Busting The RUST Myth

Surface rust on reinforcing steel is a common occurrence on the construction jobsite; ferrous materials will corrode. Although every effort is made to reduce the buildup of rust on our concrete reinforcing products, environmental conditions make corrosion unavoidable.

However, studies by the Concrete Reinforcing Steel Institute (CRSI) have found that a moderate amount of rust does not affect the properties of the metal. In fact, tightly adhered rust on the reinforcing steel is not detrimental to bond, but rather can be beneficial. The following summary is from the CRSI study on rust.



According to the CRSI, most specifications in the United States (ACI 301, ACI 318) contain conservative language concerning rust on reinforcing steel, essentially mandating cleaning the reinforcing steel; this is not supported by experimental evidence. Consequently, most engineers and inspectors take a conservative or unwarranted approach by requiring the removal of rust from the reinforcement.

More advanced rust formation producing flaky or laminar rust should be removed; removal is usually facilitated through normal handling or lightly striking the bar with a hammer. Any steel cleaning at a construction site is time-consuming and a costly process. In extreme situations, over polishing by wire brush or flapper wheel may be detrimental to the bond.

Even though developments in reinforcing steel processing technology have considerably modified the surface characteristics of the finished reinforcing steel over the past century, the laboratory results give positive assurance that the various, moderate contaminants will have little, if any, detrimental effect on bond.

Therefore, in reference to typical construction scenarios, CRSI does not endorse any mandatory specifications to require excessive cleaning measures for rust or other contaminants.

For more information, ask your Tree Island Steel sales representative or refer to the following report from the CRSI.

Source: CRSI Technical Note, "Rust, Mill Scale, and Other Surface Contaminants on Steel Reinforcing Bars"

ENGINEERING
ETN-M-5-14

Technical Note

Concrete Reinforcing Steel Institute

Rust, Mill Scale, and Other Surface Contaminants on Steel Reinforcing Bars

Introduction

In reinforced concrete construction, bond between the concrete and reinforcing steel plays a critical role. Bond, either through adhesion/cohesion or mechanical interlock, provides for the transfer of stresses from concrete to steel, producing composite action with materials that have markedly different mechanical properties. There can be contaminants on the reinforcing bar surface, which are commonly assumed to impede the bond. If the bond becomes compromised, the ultimate behavior and serviceability characteristics of reinforced concrete structure can be altered.

Generally accepted construction quality control measures require the removal of deleterious contaminants due to the concern for a reduction in bond capacity. Figure 1 illustrates a common example of rust on the reinforcing bars in a fabricated column cage. The corresponding construction activity required to clean the reinforcing bar has significant time and expense implications. This *Technical Note* explores, in-depth, a common issue of rust and mill scale on steel reinforcing bars at the time of concrete placement, and how much rust is tolerable before it becomes detrimental to the proper performance of the bar when embedded in concrete. A *Note* giving more succinct and practical field guidance on the topic is presented in the CRSI Construction Technical Note, *Field Guide for Rust on Reinforcing Bars: CTN-M-2-11* (CRSI 2011). This *Note* provides the technical backup for the recommendations in the aforementioned technical note.

Uncoated or plain black bars will likely exhibit some light brown corrosion on the bar surface due to exposure to weathering. Surface-rusted bars could arrive on a jobsite from the Fabricator, who cut and bent them to the proper shape. Alternatively, the surface-rusted bars may arrive on the jobsite from the producing steel mill, if the bars were non-fabricated straight bars.

In another scenario, the reinforcing steel may be placed on a project with minimal surface rust. Subsequently, the project is delayed for some reason (work stoppage, project financing, natural disaster, phased construction, etc.). The tied mats or cages of reinforcement will be exposed to the weather, and consequently the plain black bars will likely corrode due to atmospheric exposure. Is bond compromised by the build-up of corrosion? Will the bars tend to corrode at a faster rate once there is surface rust? These and similar relevant questions are answered herein.

Rust on reinforcing bars is a common question asked by both design and construction professionals, and fielded by the regional and technical staff of the Concrete Reinforcing Steel Institute (CRSI). The questions usually focus on bond and development length concerns, and whether the corrosion mechanism will continue once the reinforcing bars are embedded in the concrete. In addition to rust, other common concerns are the presence of mill scale or other surface contaminants on the bars before the concrete is placed. Typical surface contaminants usually include form oils, fuel spills, dirt sticking to wet bars, etc.

Epoxy coatings, used in the protection of reinforcing steel against corrosion, can be viewed as a material that reduces bond. Epoxy coatings are referenced in the ACI 318 Building Code, Sections 3.5.3.8 and 3.5.3.9 (ACI 2011), and their impact is accounted for by specific modification factors in the formulation for tension development lengths.

This *Technical Note* reviews the past research and the current specifications that relate to the reinforcing bar surface conditions and subsequent bar embedment in concrete. CRSI's review of the available information was prompted by the contrast between the

a) Column cage showing general corrosion of the reinforcement. ***b) Close up view of a longitudinal bar.***

Figure 1 — Example of tightly adhered rust on column reinforcement in the fabrication yard.

intuitive, negative concerns reflected in various specifications and the overall positive experimental research results reported in the literature. The research findings point to a direction of alleviating concerns reflected in current specifications and practice. Departing from the current overly conservative design philosophy could easily translate to significant construction labor and cost savings without impacting the quality and strength of reinforced concrete structures.

Influence of Rust

Ferrous materials (those containing iron) naturally corrode when exposed to moisture and oxygen in the atmosphere. Corrosion rates can accelerate when exposed to a chloride environment, which might occur with unprotected steel bars exposed to salty or brackish, humid air in coastal areas, or direct exposure to deicing chemicals. New, uncoated steel reinforcing bars, commonly termed "black bars," are no exception to the corrosion mechanism when exposed to the atmosphere. The amount of rust on new reinforcing bars can be affected by mill processing techniques, fabrication, storage conditions, shipping, and handling.

A thin layer of tightly-adhering mill scale is commonly found on the surface of all hot-rolled steel products, unless the steel is processed in a protective atmosphere, sandblasted, or descaled (e.g. for galvanizing). Mill scale is the oxide produced on steel surfaces through the hot-rolling process. Mill scale consists primarily of magnetite (Fe_3O_4) that has a characteristic blue-gray, "steely" color. Often, an extremely thin outer film of hematite (Fe_2O_3), is formed and invisible to the naked eye. The inner portion of the magnetite contains fine metal grains and sometimes, residual black ferrous oxide (FeO), which contributes to the roughness of descaled metal. The higher the temperature and the longer the cooling time, the thicker the scale layer. Although the magnetite is stable at temperatures above 1,800°F, it begins to break down at atmospheric temperature and forms more Fe_2O_3. This, together with atmospheric moisture, leads to the formation of the light brown rust.

The formation of heavy rust is a very slow process; it may take years of usual jobsite exposure to lose a few percent of the reinforcing bar weight. Typically, if the reinforcing steel is stored under cover, the mill scale will help "preserve" the steel. In contrast, with normal sorting, handling, and placing operations with the bars, coupled with weather exposure, mill scale can become detached and "loose," causing corrosion to occur where the mill scale is lost. Under hot and humid climatic conditions, "black" rust may form on bundled bars. When unbundled and exposed to dry conditions, the corrosion products will dry and convert to red rust, which is powdery and will tend to readily fall off the bar.

One potential issue associated with rust on the reinforcement occurs by rain washing loose rust particles onto the formwork, resulting in unwanted staining of exposed concrete surfaces, such as facades or floor soffits. Aesthetically-critical applications may warrant a thorough cleaning of the uncoated reinforcing bars, or using a more corrosion resistant reinforcement for these exposed surfaces.

The specified minimum concrete cover requirements of the ACI 318 Building Code typically provide sufficient protection against moisture intrusion. The pH level, specifically the high alkaline environment of the encapsulating cement paste, mitigates the mechanism of corrosion on reinforcing bars placed in concrete with the usual degree of surface rust. Corrosion that continues unimpeded after the placement of concrete can lead to excessive cracking and spalling due to the large volumetric expansion of rust as it forms. It is therefore important to address honeycombing, inadequate concrete cover, or cracking issues in new concrete to mitigate any future corrosion potential.

Exposure to a salt water environment may result in more significant problems. The presence of chloride ions in salt water promotes corrosion in steel. Reinforcing steel that has been severely corroded due to salt water or brackish humidity exposure should not be placed in concrete without approval of the Licensed Design Professional (Engineer of Record); the concern is that the chloride in the rust by-products may not diffuse sufficiently when placed in the wet, uncured concrete. Because there is this uncertainty, cleaning is recommended through either low-pressure water washing with a conventional garden hose or power washing at low to medium water pressure. High pressure water blasting should be used with caution; the bars will get very clean through this process, but the salt residue could be driven into any remaining corrosion product. Steel reinforcing bars that have been extensively corroded and pitted should only be used if the various ASTM requirements for deformation and cross-section area are still being met upon cleaning.

Effects of Rust on Bond & Mechanical Properties

Early Research

Rust on reinforcing steel is an issue that has raised concerns since the early 1900s, when reinforced concrete found increasing use as a construction material. In one of the first significant studies of bond, Withey (1909) examined the bond strength of rusted, plain round bars compared to unrusted bars. From the seven beams tested, Withey observed "that the bond between concrete and a bar covered with a firm, hard rust and subjected to either a static or repeated loading is considerably greater than that obtained from a plain round, unrusted rod under the same conditions." Abrams (1913) reported that bars having a heavy coat of firm rust also gave a higher bond resistance than bars having ordinary mill surfaces.

Shank (1934) examined bar surface conditions, which was provided in a brief study report. The reported findings showed both "ground rusted" and "red, weather rusted" bar surfaces had higher bond strengths than clean, uncoated bars. Ground rusted bars were buried 1 ft. in soil for 10 months, while the weather rusted bars were weather exposed for 10 months. The degree and thickness of rust varied on the two exposure types, but both exposures produced the "firm rust" observed in previous studies, which enhanced bond.

To study the effect of exposure time on the degree or level of rust development, Gilkey, Chamberlin, and Beal (1939) at Iowa State College exposed $^5/_8$ in. diameter, plain round bars to the weather for 0, 1, 2, 3, 4, 6, 7, and 8 months. This study found the light, powdery coating of red rust formed in the early exposure stages (0 to 1 month) was insignificant in its effect on bond and can be safely disregarded. For exposures in the 3 to 4 month range, the bars had a heavy coat of firm rust, yet the bond resistance remained unaffected or it increased. Only when thick coatings of rust developed, characterized by the 7 to 8 month exposure, the bond resistance showed a slight decrease. However, removing the loose, flaky or laminar rust on these bars produced bond resistances slightly higher than unrusted bars. Although the heavy rust on these bars looked excessive and unsightly, rust is much lighter and bulkier than the parent steel bar. The actual reduction in cross-section was found to be inconsequential, as determined through micrometer measurements and mechanical tensile testing.

When dealing with rust, a natural inclination may be to remove the rust to achieve a "bright metal" condition; this may not necessarily be a prudent recommendation. In limited tests, Menzel (1939) showed ground and polished plain round bars developed low bond stresses. When the same bars were sandblasted to achieve a surface profile and roughness, the steel stress achieved was about four times (4x) that of the original, polished bar. This suggests that having surface roughness on the bar will enhance bond.

An extensive investigation into the effect of rust was conducted in a CRSI-sponsored study at Lehigh University by Johnston and Cox (1940). In this test program, Johnston and Cox performed about 420 bond pull-out tests on deformed bar specimens having 78 different sizes or degrees of rust. They established that while there was a mild initial slippage increase with contamination, as long as minimum nominal cross section dimensions, weight, and deformations were maintained, reinforcement with moderate rust and mill scale would be expected to perform well. Moreover, they found the ultimate pullout strength of the deformed reinforcing bars tested was not greatly influenced by the condition of the rust.

Research in the 60s and 70s

In the 1960s, the issue of adhered rust and/or mill scale on steel reinforcing bars received additional attention. No criteria or data were available at that time to determine what constitutes "excessive" rust or mill scale. Without a standard to evaluate the degree of rusting or mill scale, the deciding factors were engineering judgment, opinion, or loosely worded specification provisions. These latter factors may have often led to unnecessary rejections of "rusty" or corroded bars on jobsites.

The Committee of Reinforcing Bar Producers of AISI[1] sponsored a test program at West Virginia University (WVU) that resulted in a seminal paper on the subject, "Effect of Rust and Scale on the Bond Characteristics of Deformed Reinforcement," published in the *ACI Journal* (Kemp, Brezny, and Unterspan 1968). The following are highlights of the conclusions:

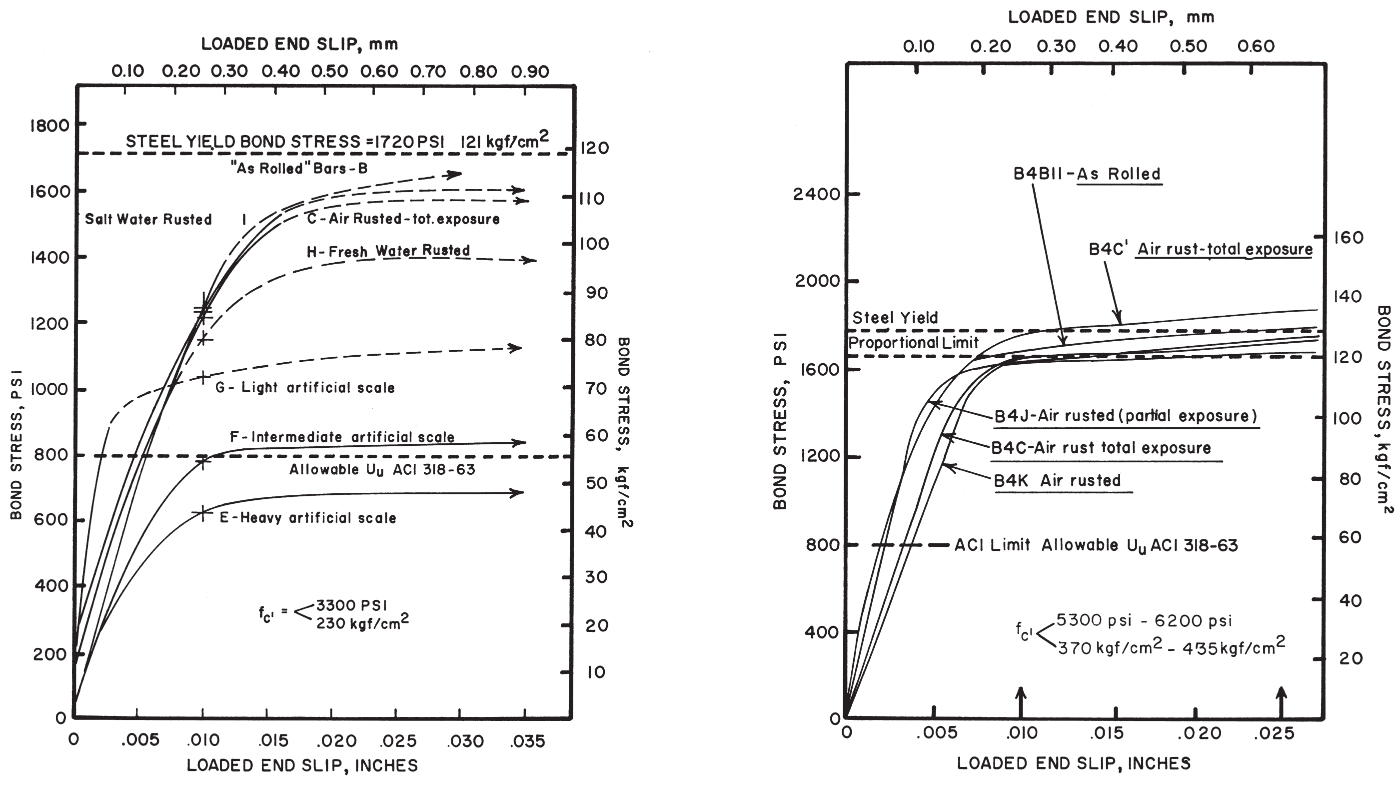
- Tests showed the average ultimate bond stress was affected little by any form of a rusty surface condition, ranging from light air rust to very heavy saltwater rust.
- Bond characteristics of deformed reinforcing bars meeting ASTM specifications are not adversely affected by varying degrees or types of either surface rust or mill scale, provided a virgin, wire-brushed sample meets both minimum weight and deformation height requirements.
- It is not necessary to clean or wipe reinforcing bars having the above conditions before using them in concrete construction. Normal handling practices will usually remove most loose rust and scale that would be detrimental to bond between concrete and reinforcement.
- The research showed that a normal amount of "light air" rust slightly increased the bond. More heavily rusted bars, without the construction handling to remove the loose rust, exhibited only a very slight decrease in relative bond resistance.
- Concrete strength and the reinforcing bar surface deformations control the bond behavior, particularly slip, to a greater extent than does the surface condition of the bar.

Figures 2 and 3 illustrate the bond stress – end slip relationships for the #4 and #9 bars, respectively, tested in this West Virginia study. The four plots show light to intermediate rust or scale had little effect on the bond strength. These bars had bond stresses comparable to the "as-rolled" control bars, which exceeded the ultimate bond stress of the ACI 318-63 Code (1963). Only when the rust or scale was classed as "heavy" did a reduction in bond stress occur, as exhibited in the plots of Figures 2 and 3.

The results of this study and joint proposals of AISI and CRSI for reference tests to establish the critical rust amount based on reduction of cross-section have formed the basis of many practice recommendations, code requirements, and specifications in the United States and other countries.

In a British study, Murphy (1977) studied a total of 70 plain round and deformed bar samples with various degrees of rust. The bars were tested in bond with the bond stress and slip relationship recorded for each test. After extensive study of the data, the conclusions reached were consistent with other work in the United States. Rust on plain bars improved the bond characteristics, while the bond stress for deformed bars decreased with increasing amounts of

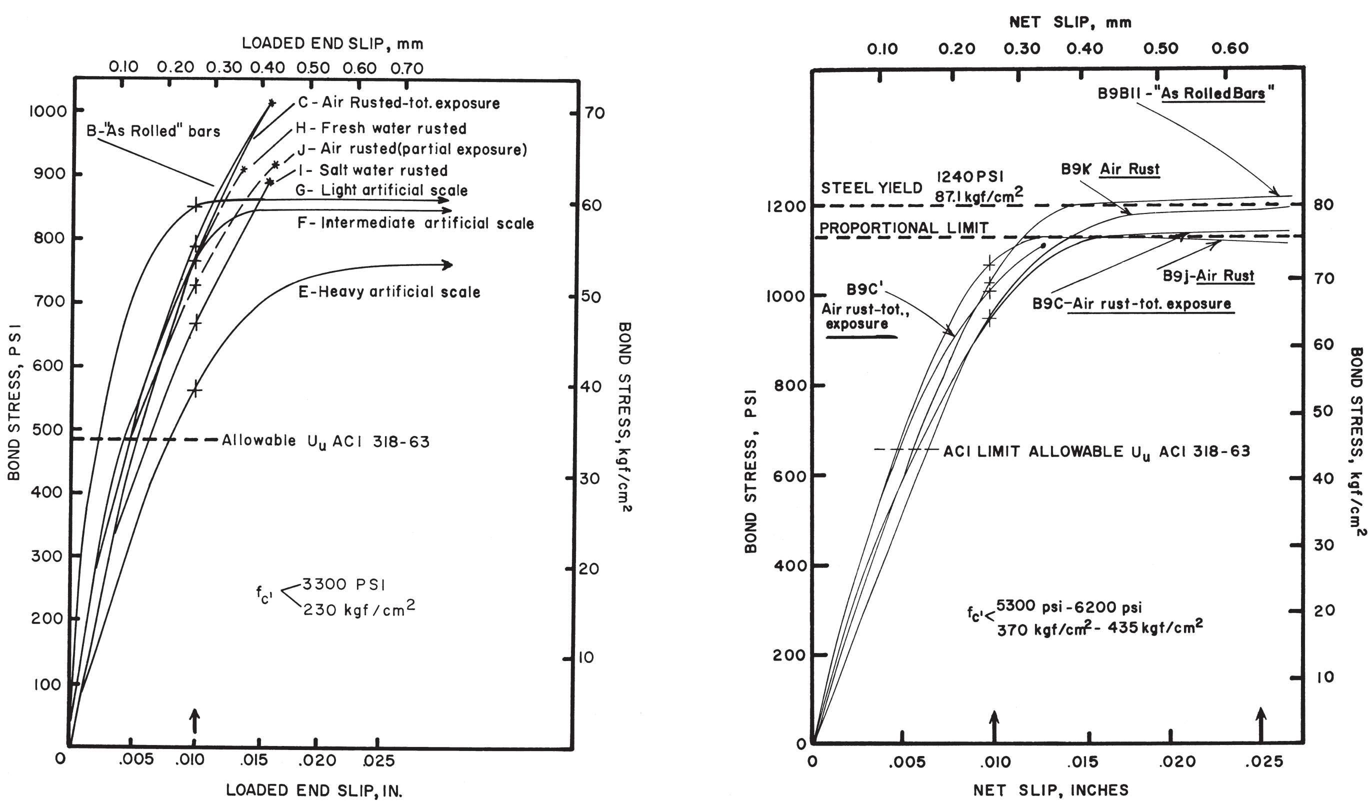
1 AISI's Committee of Concrete Reinforcing Bar Producers was succeeded by a group within CRSI in 1976.



a) First series.

b) Second series.

Figure 2 – Bond stress versus bar end slip for the #4 bars in the West Virginia study (from Kemp, Brezny, and Unterspan 1968).



a) First series.

b) Second series.

Figure 3 – Bond stress versus bar end slip for the #9 bars in the West Virginia study (from Kemp, Brezny, and Unterspan 1968).

rust; for the latter condition, the rust build-up was extensive enough that the deformations filled with rust and shadowed the projected ribs.

This study provided the following recommended criterion regarding the acceptable level of rust on a bar:

"For all rusty bars which can be regarded as still having their original cross-section, the criterion for the acceptable quantity of rust would appear to be the rust remaining when the bar has been subjected to a sudden impact (dropping it onto a hard surface from about 1 m or hammering the end of the bar). In addition, any mechanical handling involved in fixing the reinforcement in question is very likely to remove sufficient loose rust."

Consistent with the previous work of Menzel (1939), this work found excessive cleaning of a bar was detrimental to the bond characteristics. Murphy stated:

"Results of fourteen tests to compare the bond characteristics of rusted and wire-brush-cleaned mild steel bars indicate that wire brushing is, at best, of no benefit and, at worst, detrimental to the bond characteristics because of the polishing action involved in this method of cleaning."

In his landmark work on bond between steel and concrete, Rehm (1968) reported on work in Germany where the effect of surface roughness of the bar was evaluated. Rust on reinforcing bar causes pitting and he noted that the bond behavior was affected by the proportions of coarse, medium, and small pitting on the overall bar roughness. Pitting or a greater bar surface roughness was found to enhance bond.

The United States Bureau of Reclamation, *Concrete Manual* (1981), reported that they previously required reinforcing steel be cleaned to a bright metal condition. Because this was a notably expensive process, the Bureau conducted internal laboratory tests to determine the effect of rust on bond in reinforced concrete specimens. Reinforcing bars with four different conditions of rust were used in this study - untreated, burlap-rubbed, wire-brushed, and sandblasted. Results of this study corroborated the findings of previous investigations; that is, some rust is not detrimental to bond. The following conclusions are noted in the *Concrete Manual:*

1. *"Some rust is not harmful to the bond between concrete and steel, and no benefit appears to be gained by removing all the rust. However, any rust and mill scale which is not firmly attached should be removed to assure the development of good bond."*
2. *"Bond is determined by the size and number of deformations."*
3. *"Rust increases the normal roughness of the steel surfaces and consequently tends to augment the holding capacity of the bar, but it may reduce the effective cross-sectional area of the bar."*
4. *"Usually, normal handling is sufficient for removal of loose rust and scale prior to embedment of reinforcement steel. However, in some instances it may be necessary to rub with a coarsely woven sack or to use a wire brush."*

Recent Research

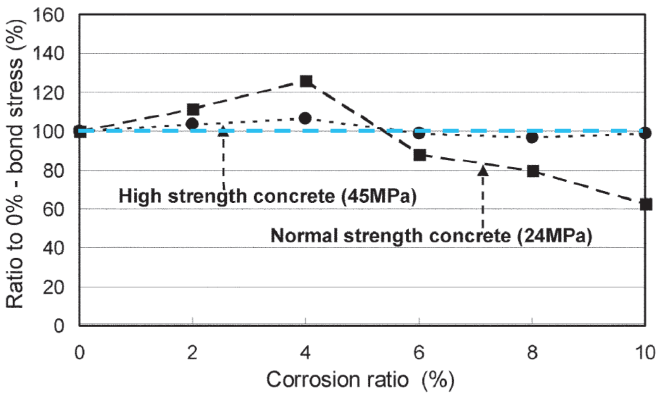
In the last few decades, several studies had been conducted internationally with a common conclusion that the effect of rust and mill scale on the surface is not harmful. In the late 1980s, a team of researchers at the King Fahd University of Petroleum and Minerals, Saudi Arabia undertook a project similar to the AISI investigation in the United States. Maslehuddin, et al. (1990) reported that there was an insignificant effect on the yield and ultimate tensile strength, elongations, and bond on specimens after 16 months of exposure in a corrosive environment. The test results showed that for a variety of bar diameters and atmospheric exposure periods, the bond between concrete and deformed reinforcing bars is due primarily to mechanical interlocking rather than chemical adhesion or friction.

A recent Korean study tried to quantify bond strength against the percentage of rust on a bar, up to 10 percent; the specified amounts of corrosion in this study were 2, 4, 6, 8, and 10 percent, each of which was the ratio of weight loss to original deformed bar weight. In this study, Lee, et al. (2004) found the effects of the rust quantity on the bond stress-slip relationship showed little difference for different nominal diameters of deformed bars. For a D16 (16 mm diameter) deformed bar embedded in both normal and high strength concrete, ultimate bond stresses of the 2 and 4 percent corroded deformed bars were greater than the uncorroded, deformed control bar (0 percent corrosion). For D19 (19 mm) deformed bar, the ultimate bond stress of the 2 percent corroded deformed bar was greater than the control bar irrespective of concrete strength. For the larger diameter D25 (25 mm) deformed bar embedded in high strength concrete, the ultimate bond stress of the 2, 4, 6, 8, and 10 percent corroded deformed bars were all higher than the control bar. The results of this study are shown in the plots of Figures 4(a), (b), and (c) for the three bar sizes tested.

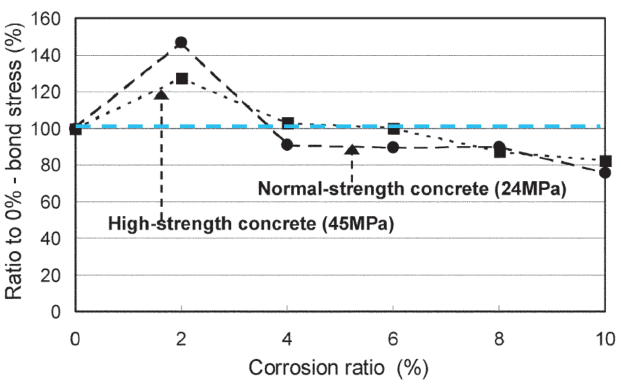
Lee, et al. concluded that a so-called "proper" amount of rust may increase the bond stress by increasing roughness of the bar surface. However, a large build-up of rust may actually decrease the bond stress due to the loose nature of the rust. For this study, a large rust build-up occurred at a 6 percent corroded condition for the D16 and D19 bars. For the larger diameter D25 bars, a large rust build-up causing a decrease in bond strength occurred in the 6 to 10 percent corroded condition. A rust amount equal to or less than 4 percent was selected as a lower-bound rust quantity that seemed to play a role in increasing roughness, and hence resulted in an increase of bond stress.

Pre-Rusted Bars and Further Corrosion

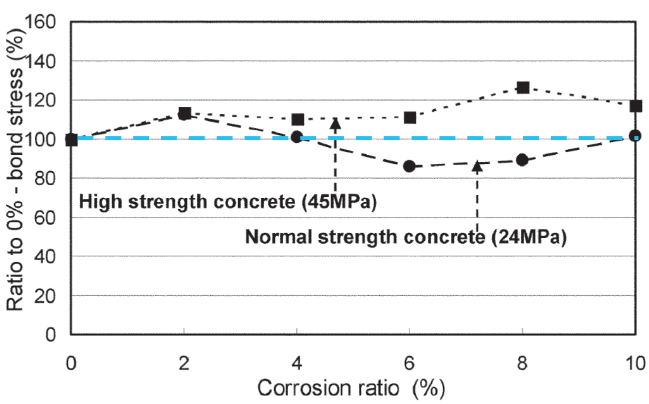
Most published work concerning rust effects on reinforcing bars have focused on the bar mechanical properties and the bond strength in concrete. Mehmood, et al. (1998) studied the corrosion behavior of pre-rusted reinforcing



a) Results for the D16 (~#5) deformed bar.



b) Results for the D19 (~#6) deformed bar.



c) Results for the D25 (~#8) deformed bar.

Figure 4 – Ratio of bond stresses (corroded / control) versus the percentage of bar corrosion from the Korean study (Lee, Kim, Yu, and Ahn 2004).

bars embedded in concrete. They tested different levels of rusting on reinforcing bars produced through different manufacturing processes; these processes were hot rolling and air cooling, and hot rolling and rapid water cooling, known as quenching.

The concrete samples containing these rusted bars were cast, and exposed to normal water and brackish sea water. Based on their test matrix, the researchers found the presence of firm rust on the reinforcing bars had an inhibiting effect on the onset of chloride-induced corrosion in the concrete. The thickness of the rust layer determined the initiation period or threshold required for the corrosion process to start. Nam, Hartt, and Kim (2005) also found the time-to-corrosion initiation was accelerated for wire-brushed reinforcing bars compared to as-received, corroded bars.

With respect to the manufacturing process, Mehmood, et al. found no difference in the corrosion behavior of either of the bars embedded in concrete with respect to manufacturing process. There was, however, a slight difference in initial corrosion development when the bars were exposed "in-air" as they were being preconditioned for embedment in the concrete samples; the quenched bars rusted faster and the rust product was more uniform over the bar surface. This was attributed to a thinner layer of mill scale on the quenched bars compared to the conventionally rolled and cooled bars. For the conventional bars, mill scale development is thicker and provides an initial protection against rusting. Eventually the mill scale breaks down in localized regions and corrosion initiates at these locations. After four (4) months, all bar types had an almost equal rust pack on the bar surface; the quenched bar surface had a smooth looking rust, as opposed to the flaky, granular rust of the conventional rolled products.

Rust in National Standards

Section 7.4.2 of ACI 318 states that *"...steel reinforcement with rust, mill scale, or a combination of both shall be considered satisfactory, provided the minimum dimensions (including height of deformations) and weight of a hand-wire-brushed test specimen comply with applicable ASTM specifications..."* The Commentary of the current ACI 318 Building Code offers a succinct discussion of the rust issue in Section R7.4 as follows: *"Specific limits on rust are based on tests, (Reference 7.4) plus a review of earlier tests and recommendations. Reference 7.4*[2] *provides guidance with regard to the effects of rust and mill scale on bond characteristics of deformed reinforcing bars. Research has shown that a normal amount of rust increases bond. Normal rough handling generally removes rust that is loose enough to injure the bond between the concrete and reinforcement."*

AASHTO (2011) requirements for handling, storage, and the surface condition of the reinforcement are similar to ACI, yet a little more descriptive. Section 9.5 from the Construction Specifications state:

> *"Steel reinforcement shall be stored above the surface of the ground on platforms, skids, or other supports and shall be protected from mechanical injury and surface deterioration caused by exposure to conditions producing rust. When placed in the work, reinforcement shall be free from dirt, loose rust or scale, mortar, paint, grease, oil, or other nonmetallic coatings that reduce bond. Epoxy coatings of reinforcing steel in accord with standards in this article shall be permitted. Reinforcement shall be free from injurious*

2 Reference 7.4 in the ACI 318 Code is the Kemp, et al. (1968) study at West Virginia University.

defects such as cracks and laminations. Bonded rust, surface seams, surface irregularities, or mill scale will not be cause for rejection, provided the minimum dimensions, cross-sectional area, and tensile properties of a hand wire brushed specimen meet the physical requirements for the size and grade of steel specified."

These code prescribed recommendations for rust treatment are not limited to the U.S. experience. The Steel Reinforcement Institute of Australia (SRIA) AS 3600, Clause 19.2.4 states: "At the time concrete is placed, the surface conditions of reinforcement shall be such as not to impair its bond to concrete or its performance in the member. The presence of mill scale or surface rust shall not be a cause for rejection of reinforcement under this Clause." The corresponding Commentary indicates: "Rust and mill scale has little effect on bond. Moderate rusting has been shown to improve bond."

Other Bar Surface Contaminants

In addition to surface rust, usual construction procedures can contaminate the reinforcing steel surface. Construction Inspectors often raise concerns about oversprayed bond-breakers, form-release agents, curing agents, mud, and cement-paste splatter. They often cite ACI 301, *Standard Specifications for Structural Concrete* that requires: "when concrete is placed, all reinforcement shall be free of materials deleterious to bond." A similar statement can be found in ACI 311.1, *Manual of Concrete Inspection*, which states that "reinforcement should be clean, and oil or non-adherent mortar which has been spilled on it should be cleaned off."

Unlike surface rust, the detrimental effect of these contaminants on bond has not been extensively studied. Suprenant and Malisch (1998) reported on a series of 27 bond pull-out tests to address the effect of nine different surface contaminants. They compared the bond pull-out performance of clean, "black bar" and rusted reinforcing steel that had 100 percent of the surface sprayed with bond breaker, curing compound, used motor oil, or cement paste; these conditions were viewed to represent worst case scenarios. The researchers found that even under severe surface contamination, the bond performance was not adversely impacted. Examining data and the test specimen failure surfaces, they concluded that bar deformations played a dominant role in contributing to the bond strength; this bond mechanism is not diminished by the presence of contaminants. The various contaminants influenced the initial and ultimate slip characteristics of the reinforcing bar to varying degrees; however, the ultimate bond behavior was not affected.

Another more recent study at the University of Missouri - Rolla (Taber, et al. 2002) also corroborated the previous findings through both pull-out and flexural beam tests. The only exception found by the researchers was the case of smaller diameter epoxy-coated bars in lower strength concrete. They found the bars were more susceptible to a loss of bond when subjected to bond breakers or form oil, but the effect of concrete splatter contamination was insignificant.

Both of these research studies led the American Society of Concrete Contractors (ASCC) to adopt a position statement (ASCC 2003) on coatings and their effect on reinforcement. Essentially, ASCC does not believe reinforcing bar cleaning provides any structural performance benefit to the Owner.

Summary

Most specifications in the United States (ACI 301, ACI 318) contain very conservative language concerning rust on reinforcing bars, essentially mandating fully cleaning the reinforcing steel; this is not supported by experimental evidence. Consequently, most Engineers and Inspectors take a conservative or unwarranted approach by requiring the removal of rust and other contaminants from the reinforcement.

Surface rust present on "black" reinforcing bars is a common occurrence on the construction jobsite; ferrous materials will corrode. Tightly adhered rust on the reinforcing bar is not detrimental to bond, but rather can be beneficial. An example of minor red or brown rust on reinforcing bars is shown in Figure 5.

Figure 6 illustrates a heavier build-up of rust, yet would not compromise the bar bond behavior. More advanced rust formation producing flaky or laminar rust should be removed; removal is usually facilitated through normal handling or lightly striking the bar with a hammer. Exposing reinforcing bars to exterior conditions for 18 to 24 months produces corrosion, yet the corrosion is normally not extensive enough to cause section loss that will affect the reinforcing bar mechanical properties.

Any bar cleaning at a construction site is time-consuming and a costly process. In extreme situations, over polishing

a) Example of rust on small diameter hoops.

b) Example of rust on straight bars.

Figure 5 – Initial red or brown rust on newly fabricated reinforcing steel is acceptable.

Figure 6 – The tight rust on these bars has not impaired the deformations and would not be detrimental to bond.

by wire brush or flapper wheel may be detrimental to the bond. Even though developments in reinforcing steel processing technology have considerably modified the surface characteristics of the finished reinforcing bars over the past century, as discussed herein, the laboratory results give positive assurance that the various, moderate contaminants will have little, if any, detrimental effect on bond.

Therefore, in reference to typical construction scenarios, CRSI does not endorse any mandatory specifications to require excessive cleaning measures for rust or other contaminants.

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