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SURFACE CONDITION OF STEEL REINFORCEMENT

The strength and performance of reinforced concrete depends on the reinforcement being adequately bonded into the concrete. While the issue of acceptable corrosion of the bar surface is an area that we receive many technical enquiries about, the contamination of the surface by grease, oil, dirt and formwork release agents is also an area that many Engineers are unclear about.

Clause 17.2.4 of AS 3600¹ states: *“At the time concrete is placed, the surface condition of reinforcement shall be such as not to impair its bond to the concrete or its performance in the member. The presence of millscale or surface rust shall not be cause for rejection of reinforcement under this clause.”* Clause C17.2.3.4 of the AS 3600 Commentary² also states: *“Rust and millscale has little effect on bond^{3,4}. Moderate rusting has been shown to improve bond⁵”.*

The bond and anchorage properties of bars and mesh are therefore not detrimentally affected by a light coating of rust which has formed on the steel surface after normal exposure to the atmosphere **Figure 1**. In fact, the light rust on the surface of the bars in **Figure 1** caused by normal exposure to the environment, and which is characterised by a red, orange, or light brown colour, if tightly adhering to the bar, will actually enhance the bond characteristics of the bar^{6,7}.



Figure 1 Examples of acceptable surface condition of reinforcement

Normal Surface Conditions

Hot-rolled bars, as delivered from the mill, have a layer of tightly adhering millscale on the surface. Millscale consists of iron oxides that form on the steel surface during the hot rolling of billets into reinforcing bars **Figure 2**. Research has shown that the sorting and normal processing, handling and placing of bars removes the loose scale and any remaining corrosion and bonded scale is not detrimental to the bond between the bar and the concrete.

Under some climatic conditions, where the atmosphere is hot and humid, 'black' rust may form on bundled bars. When unbundled and exposed to dry conditions, the corrosion products will dry and convert to red rust (iron oxide) which is powdery and will also tend to readily fall off the bar.

As the supply of reinforcement is a just-in-time process to reduce congestion on site, it is usually not exposed to the weather for any significant period prior to the concrete being cast. The typical condition of reinforcement on site is shown in **Figure 3**, with only some minor areas of surface corrosion evident. It normally takes years of exposure for corrosion of the surface to reach the extent where loose and flaking rust is present.

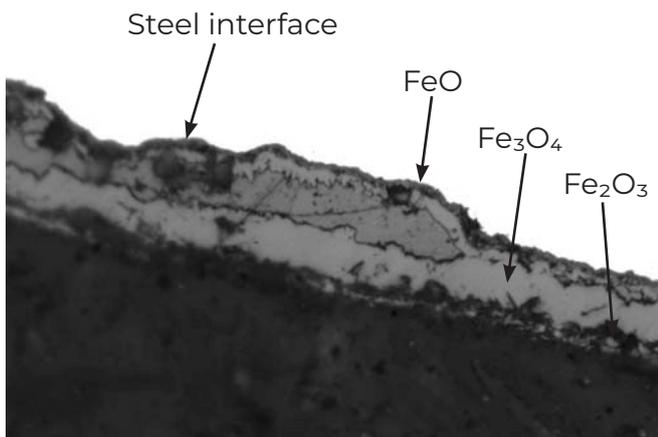


Figure 2 Millscale on surface of reinforcing bar (x1000 etched 2% HCl)



Figure 3 Typical surface condition of reinforcement on site

Potential Problems With Surface Rust

If reinforcement has been exposed to the weather for long periods (usually years), the surface may be corroded to the point where loose or flaking rust is evident on the surface **Figure 4**. This is the point at which the surface condition of the reinforcement should no longer be regarded as acceptable, as the loose and flaking rust indicates a loss of steel material that can affect the design capacity, and it will also significantly affect the bond between the steel and concrete, by potentially reducing the effectiveness of the ribs in anchoring the bar into the concrete. Typically, the bars should be replaced. However, if cleaning of the surface is proposed to remove the loose and flaking rust and the bars reused after cleaning, then the mass of the steel bar after cleaning should be checked

by calculating the mass per metre in accordance with Clause C3.3.3 of AS/NZS 4671⁸ and ensuring that the value is no more than 4.5% less than the mass per metre values given in Table 7.5(A) of AS/NZS 4671⁸ for the particular bar size. If the remaining mass is less than the limit allowed, then the bars should be replaced.



(a) Corroded mesh



(b) Corroded column starter bars



(c) N20 bar



(d) SL72 bar in mesh

Figure 4 Examples of corroded bars that should be replaced or cleaned and weighed to check mass

Where reinforcing steel is exposed to salt water, more significant problems may occur. Corrosion of reinforcement in concrete is promoted by the presence of chloride ions which are present in salt water⁹. Reinforcing steel which has been subjected to salt water exposure and has been severely corroded and pitted should not be placed in concrete without some prior treatment such as high-pressure washing to remove the loose corrosion products and salt¹⁰. Severely corroded and pitted steel (**Figure 4**), which is showing signs of loose and flaking rust on the bar surface, should typically be discarded and not allowed to be cast into the concrete.

Another potential problem with surface corrosion on reinforcement is staining of the concrete surface caused by discolouration of the formwork by the corrosion, particularly the soffits of slabs if corroded reinforcement has been laid or stored on the formwork. This problem can be avoided by ensuring that all loose and extraneous material is removed from the reinforcement prior to fixing in place and concrete placement is not delayed. If corrosion is cleaned from reinforcement in place, all loose material should be immediately cleaned off the formwork surface to avoid staining of the formwork, and hence discolouration of the off-form concrete surface. The mass of the reinforcing bars should also be checked for compliance with the minimum mass requirements. In some critical situations, galvanised reinforcement could be used to eliminate potential staining problems.

Surface Contamination Of Reinforcement

A common issue is cement-paste splatter on the surface of reinforcing bars from previously placed concrete. This should not be regarded as a problem provided the mortar is adhering firmly to the bars. If the cement-paste splatter cannot be removed, it should be left.

Another common issue that is the subject of much debate is the presence of surface contaminants such as form release agents or bond breakers and oils on the surface of reinforcing bars. Suprenant and Malisch¹¹ report on a limited test program that the Aberdeen Group undertook to determine the influence that these contaminants have on the bond strength. A number of Grade 420 (minimum yield stress of 420 MPa), 12 mm diameter bars had 100% of the surface coated with form release and curing compound/bond breaker, with others having the entire length coated with motor oil with a rag. The ends of the bars were cast into 300 mm deep by 150 mm diameter cylinders and subjected to pull out testing and comparison to uncontaminated bars. The results showed that the ultimate stress achieved by the bars was not affected by any of the contaminants. In terms of slip, this was greater for bars with contaminants due to the early loss of adhesion along the smooth part of the bars between the deformations or ribs. However, 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 or ribs. In summary, it was concluded that based on this limited test program involving 27 tests of 12 mm diameter bars with nine different surface conditions, the contaminants did not adversely affect bond, at least for the one bar grade, size and concrete strength tested.

The Concrete Reinforcing Steel Institute (CRSI)⁷ list another more recent study conducted at the University of Missouri-Rolla¹² that provided similar results. These two studies have formed the basis for the American Society of Concrete Contractors (ASCC) releasing Position Statement #3¹³ which states that, *“The test results of both studies indicate that form-release agents (3 different types including water- and petroleum-based products), bond breakers (3 different types including water- and solvent-based products), and cement splatter (same mix proportions as the concrete) did not affect the bond for concrete strengths of 4000 and 5000 psi (28 and 34 MPa). Based on these test results, and the statements in ACI 318¹⁴ and ACI 301¹⁵, removing these materials from reinforcing bars isn’t required because the materials don’t decrease bond.”* They add that, *“ASCC concrete contractors believe that the removal of form-release agents, bond breakers and cement splatter, provides no structural performance benefit to the owner.”* While contaminants such as dirt and mud should always be removed from reinforcement, based on the available research, Engineers and Certifiers should not be too concerned about some localised areas of surface contamination of the reinforcement from products such as form release agents, bond breakers and oils.

The final decision as to what is acceptable regarding surface corrosion/rust and surface contamination is usually left up to the experience of the Engineer or Certifier, however, the information provided in this Technical Note is intended to provide guidance as to what should be considered as acceptable.

References

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