Evaluation of Degree of Rusting on Prestressed Concrete Strand

Presents a procedure for classifying the degree of rust on a piece of prestressing strand and discusses the reasons for acceptance or rejection of each classification. Visual standards are developed by which inspectors can identify the degree of corrosion at which pitting occurs.

Augusto S. Sason, P.E.
Manager, Technical Services
Florida Wire and Cable Company
Jacksonville, Florida
Current Chairman
PCI Committee on Prestressing Steel

The presence of rust on prestressing steel strand has been a source of controversy between the user and supplier of strands. This is due, at least in part, to a lack of a clear understanding of how much rust can exist on the strand surface without any detriment to the performance of the strand. This paper is an attempt to clarify this problem and to provide reliable guidance to inspectors in deciding when to accept or reject a particular strand.

Bright strand refers to the surface quality of uncoated strand with no signs of rusting. This type of surface finish is obtained by the conventional dry drawing process, followed by stranding and the stress relieving operation.[1] Photo 1 shows a typical strand surface before cleaning.

Rust is a brownish-red substance which forms on the surface of iron or steel when it is exposed to damp air. The term rust, when used alone, means iron rust. Note that iron rust consists mainly of hydrated iron oxide. Rust is formed by the reaction of oxygen with iron by the chemical process known as oxidation. Moisture is an essential agent in producing rust.

When prestressing strand is exposed to a humid atmosphere, the original bright surface condition of the strand will not last very long. Weathering, which is the initial stage of oxidation, starts to take place. It is difficult to determine the degree of weathering until visible rust begins to appear on the strand surface. Rusting will inevitably take place when the weathered surface is continuously exposed to dampness or a humid atmosphere.

The material standard specification for seven-wire prestressed concrete strand, ASTM A 416, states in Section 8.4 that "Slight rusting, provided it is not sufficient to cause pits visible to the unaided eye, shall not be cause for rejection."[2] The *Manual for Quality Control for Plants and Production of Precast and Prestressed Concrete Products* published by PCI,[3] under Section 2.2.2, does not necessarily consider the presence of light rust on strand a problem because it has proven not to be detrimental to the bond. In the last paragraph of that section, it says that "If no pitting has developed on the strand surface, then no effective loss of strand area has occurred."[3] This document will be referred to as the PCI Manual in the succeeding text.

Another industry reference which allows slight rusting in prestressing steel is the FIP document[4] entitled, *Recommendations for Acceptance of Post Tensioning Systems*. Section 4.1 of the May 17, 1991, version of this document states that "Slight and uniformly distributed corrosion (with no pitting) is not always entirely avoidable and has no detrimental effects on the mechanical properties and durability of prestressing steel."[4]

All the preceding documents dislike the presence of pits on prestressing strand and recommend that pitted strand be cause for rejection. However, only the PCI Manual has a recommended procedure which can assist field inspectors to accept or reject strands with rust. The PCI Manual recommends the use of a pencil eraser to expose the pits.[3] Nevertheless, this method is not practical because the pencil eraser

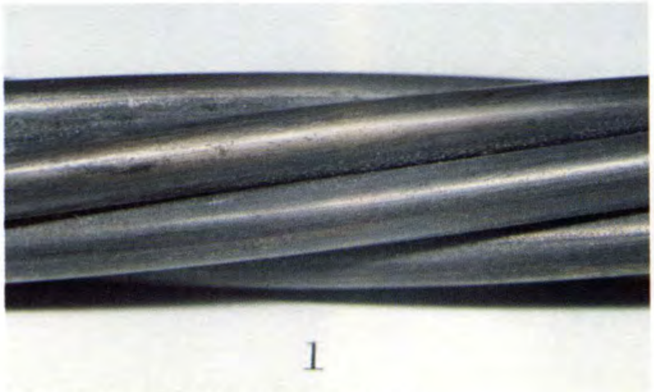


Photo 1. Strand surface before cleaning.

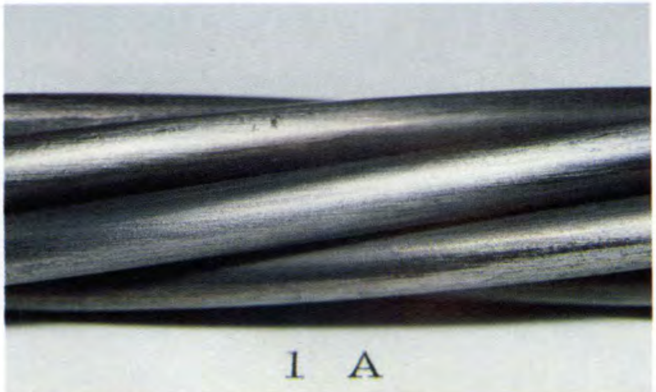


Photo 1A. Strand surface after cleaning.

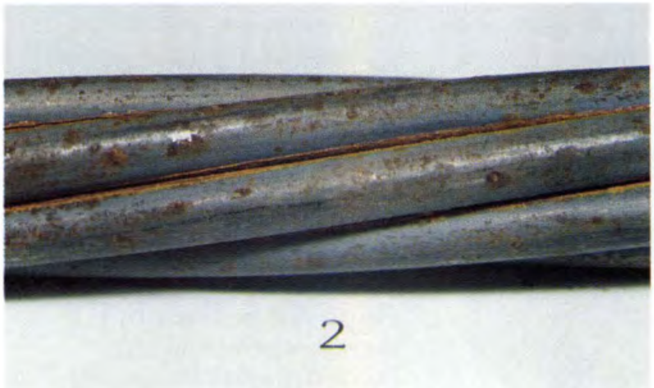


Photo 2. Strand surface before cleaning.

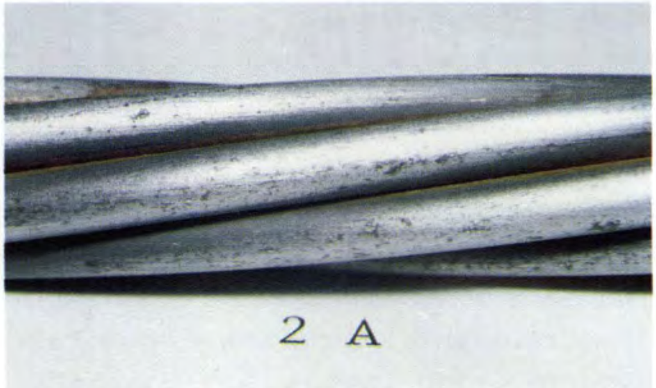


Photo 2A. Strand surface after cleaning.

Photo 3. Strand surface before cleaning.

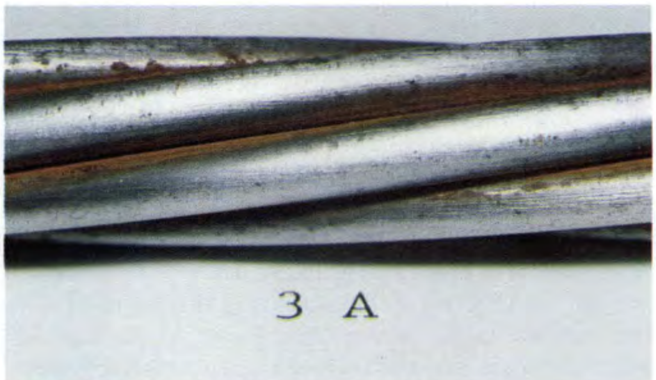


Photo 3A. Strand surface after cleaning.

Photo 4. Strand surface before cleaning.

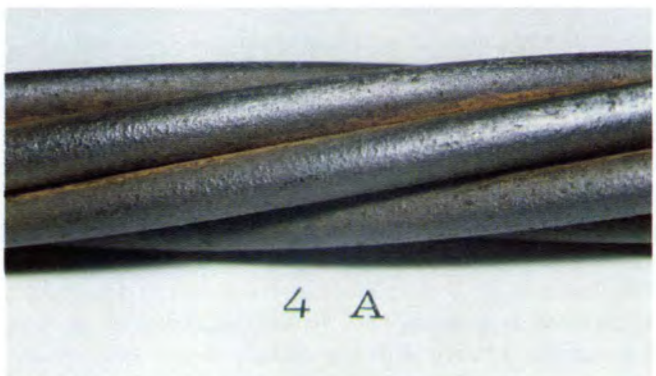


Photo 4A. Strand surface after cleaning.

Photo 5. Strand surface before cleaning.

Photo 5A. Strand surface after cleaning.

Photo 6. Strand surface before cleaning.

Photo 6A. Strand surface after cleaning.

Photo 7. Strand surface before cleaning.

Photo 7A. Strand surface after cleaning.

Photo 8. Strand surface before cleaning.

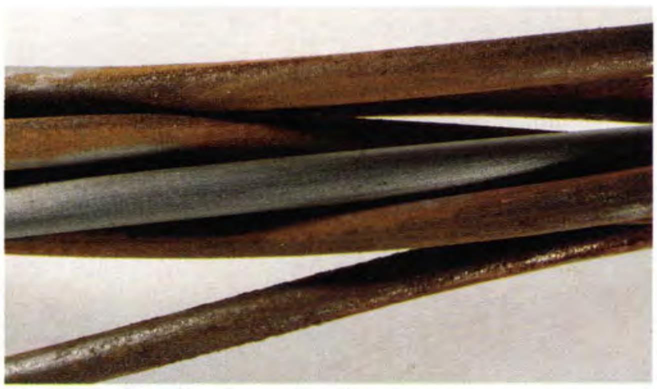


Photo 8A. Strand surface after cleaning.

Photo 9. Scotch Brite Cleaning Pad.

can expose only a very small area of the strand, and it will take a long time to clean a wider area for better observation. Thus, in this paper, the use of a Scotch™ pad for cleaning the strand is recommended to remove the corrosion products and expose the pits.

This paper describes a method to establish visual standards which identify the degree of corrosion in a strand at which pitting occurs. This guide will help field inspectors make proper judgments on the suitability of strand.

Visual standards are established by photographing samples of strand with varying degrees of rust as illustrated in Photos 1 through 6. For publication purposes, the pictures are scaled down. However, the actual examination will be done by inspectors using the unaided eye.

Photo 1 represents a new strand with no rust and has a bright surface. Photos 2 through 6 illustrate various amounts of corrosion on strand samples that were exposed to a corrosive environment for different lengths of time and include some pits that are to be considered cause for rejection.

What is cause for rejection and why?

Light rust does not harm any of the properties of the strand and it actually enhances bond. Rust alone is not a cause for rejection.

A pit visible to the unaided eye, when examined as described herein, is cause for rejection. A pit of this magnitude is a stress raiser and greatly reduces the capacity of the strand to withstand repeated or fatigue loading. In many cases, a heavily rusted strand with relatively large pits will still test to an ultimate strength greater than specification requirements. However, it will not meet the fatigue test requirements.

In order to evaluate the extent of pitting, the superficial rust has to be removed. In the samples described herein, care was taken to not abrade the strand surface below the iron oxide or rust layer. This was accomplished by cleaning the surface with Scotch Brite™ cleaning pads in order to expose the pits. Scotch Brite Cleaning Pad No. 96, made by 3M, or its equivalent, is a synthetic material which is nonmetallic. This material is available from cleaning supply retailers or supermarkets for general purpose cleaning. A sample of this material is shown in Photo 9.

Cleaning is accomplished by holding a new pad by hand and rubbing it against the strand surface longitudinally along the strand axis. The amount of pressure exerted on the pad against the strand is equivalent to that when cleaning pots and pans.

After the samples were cleaned, additional photographs were taken and these are marked as Photos 1A through 6A. All pictures with the suffix "A" were taken after cleaning and are placed next to those taken prior to cleaning for ease in making the comparison.

These pictures can be used as visual standards from which the user and supplier may agree on the surface quality that is acceptable. Following the above-mentioned procedure, the strand in question may be accepted or rejected by comparing the cleaned surface with the picture that was previously agreed upon as the standard.

It is the opinion of the writer that Picture Sets 1 through 3 are acceptable. Picture Set 4 is borderline and is subject to discussion, agreement or compromise. Some engineers may find this level of rusting objectionable for critical applications. Picture Sets 5 and 6 are pitted and unacceptable.

The corrosion and pitting in the center wire were examined. A rusty strand sample shown in Photo 7 has corroded the outer wires with the same degree of pitting as in Picture Set 5. After cleaning with a Scotch Brite pad, the pitted surface is revealed as shown in Photo 7A.

Photo 10. Samples after testing for mechanical properties.

Table 1. Mechanical properties of strand.

Sample No.*	Breaking strength, lb	Load at 1 percent extension, lb	Ultimate elongation, percent
1	43,800	40,000	5.00
2	43,700	39,800	4.95
3	43,500	39,700	5.73
4	43,300	39,600	5.21
5	42,800	38,900	5.73
6	42,400	38,800	5.21

* Designation corresponds to the surface conditions shown in Photos 1 through 6.
Note: 1 lb = 4.448 N.

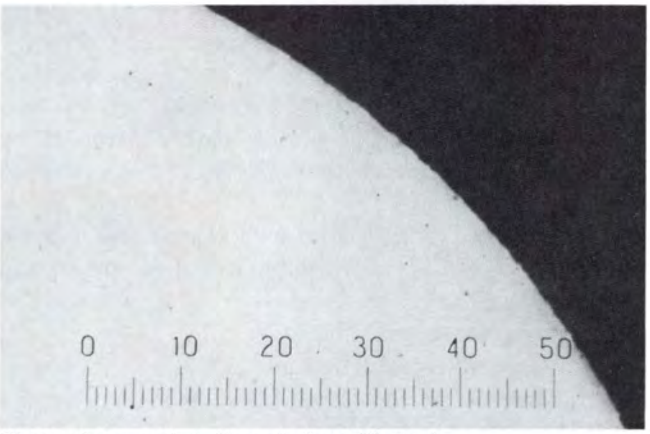
Table 2. Results of bend test on strand.

Sample No.	Number of 90-deg. bends
1	15
2	15
3	14
4	9
5	7
6	5

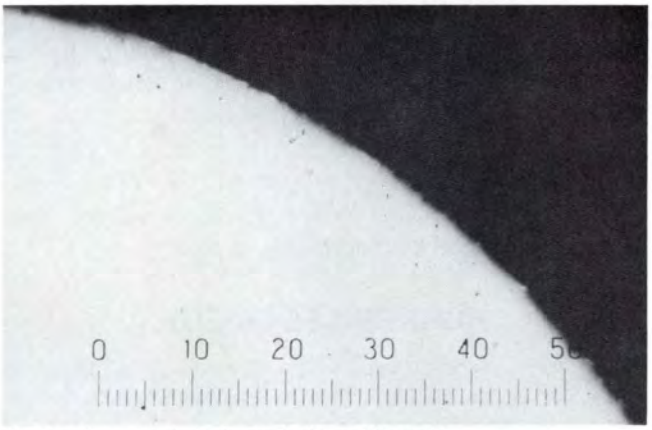
Table 3. Depth of pits on strand. [Note: 1 in. = 25.4 mm.]

Photomicrograph No.	Depth, in.
1	*
2	*
3	*
4	0.0008
5	0.0031
6	0.0077

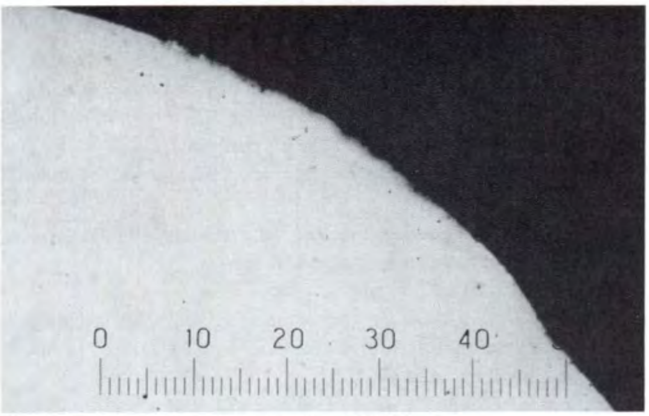
* Not measurable.



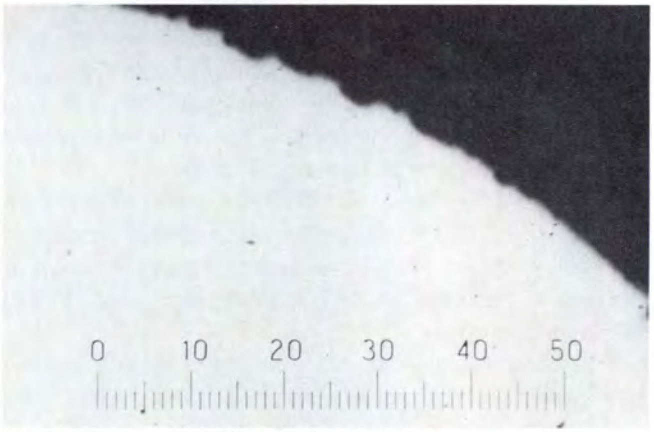
Photomicrograph 1. Sample from Photo 1.



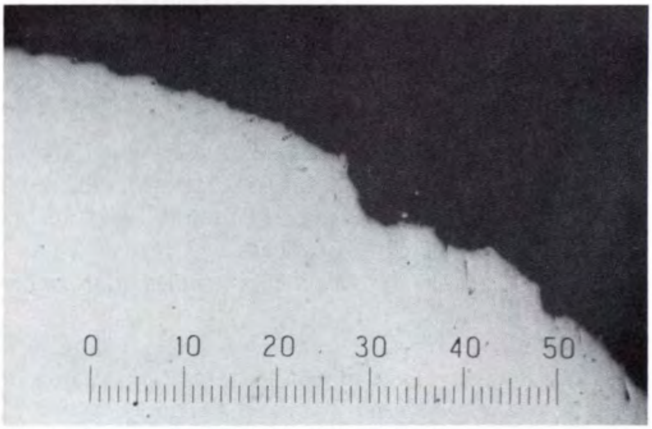
Photomicrograph 2. Sample from Photo 2.



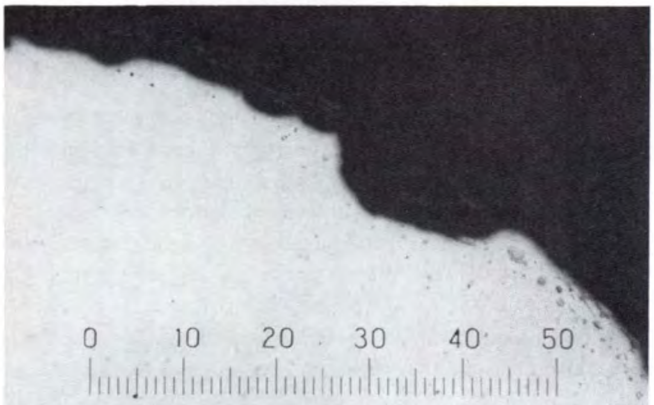
Photomicrograph 3. Sample from Photo 3.



Photomicrograph 4. Sample from Photo 4.



Photomicrograph 5. Sample from Photo 5.



Photomicrograph 6. Sample from Photo 6.

When the strand was opened by unstranding the outer wires, the center wire showed that it was not pitted. A closeup picture of the center wire after unstranding is shown in Photo 8. The center wire did not show any pitting, as shown in Photo 8A, after cleaning with the Scotch Brite pad.

These two pictures indicate that pitting due to corrosion takes place at the outer wires, which are exposed to a humid atmosphere, while the center wire is protected. A similar condition exists on portions of strand located inside the reel, which are protected by the outer layers. The outer layers get full exposure to the atmosphere and have a heavier degree of rusting compared to the inner layers.

The specimens shown in the photographs were not tested for mechanical properties. Another set of six samples of $^1/_2$ in. (13 mm) diameter, 270K low-relaxation strand was prepared and exposed in a similar environment as the specimens that were photographed. All samples were cut from the same reel and were exposed uncovered in an industrial outdoor atmosphere in Jacksonville, Florida.

Samples were removed at different exposure times, such that the second set of samples has a comparable amount of rusting as shown in Photos 2 through 6. It took 19 months of exposure time to get the surface condition similar to that shown in Photo 6.

The second set of samples was tested for mechanical properties and the results are shown in Table 1. The minimum requirements for mechanical properties according to ASTM A 416 are:

Breaking strength .... 41,300 lbf (184 kN)
Load at 1 percent extension .... 37,170 lbf (165 kN)
Ultimate elongation in 24 in. (610 mm) gauge length ....
.... 3.5 percent

Except for Sample 2, which broke with one wire fracture, all samples showed maximum breaking strength with seven wire fractures which occurred away from the grips of the tensile testing machine. This explains why Sample 2 has a slightly lower elongation value. The samples after testing are shown in Photo 10.

The differences in values between Samples 1 through 4 are within the normal variation in the testing procedure and equipment. Samples 5 and 6 showed a significant drop in breaking strength compared to Sample 1 because of excessive pitting, as shown in Photos 5 and 6 and also in Photomicrographs 5 and 6. However, the breaking strengths are high enough to meet the minimum requirement of ASTM A 416 because the loading was axial and the decrease in cross-sectional area was very small.

The effect of the degree of pitting is shown in the following tests for ductility, which are the reverse bend test and the micro-examination of the wires. One sample was picked at random from the six outer wires of each strand for these two tests.

The reverse bend test is conducted using a bend test machine. One end of the wire is clamped in the jaws, which are rounded to a radius of 0.312 in. (7.92 mm). The wire is then bent back and forth at a uniform rate through a total of 180 deg. Each 90-deg. movement in either direction is counted as one bend, and the bending operation is continued until the outer fibers fail. A guide is placed on the lever so that the wire bends on a plane at right angles to the jaws of the vise. The speed of bending is such as to avoid appreciable heating of the specimen.

This test is sometimes used as a measure of ductility or toughness of the wire, but it does not lend itself to accurate duplication of values and its use is not recommended for general application.[5] The results of the reverse bend test are shown in Table 2.

The micro-examination was done by cutting a transverse section of the outer wire. The cut specimen was then mounted and polished using standard metallographic techniques for specimen preparation. The polished section was examined under a metallographic optical microscope at a magnification of 75X, but scaled down for publication.

Photomicrographs 1 through 6 show a section of the wire circumference from samples corresponding to Photos 1 through 6. Measurable depths of pits are observed in Photomicrographs 4, 5 and 6, and the corresponding measurements are shown in Table 3. One small division of the scale imprinted on the photomicrographs is equivalent to 0.00077 in. (0.02 mm).

Based on these examinations, it can be deduced that the sample with the deepest pits will fail first when subjected to cyclic loading. The pits are stress raisers which will serve as initiation sites for fatigue failure.

The foregoing presentation and discussion show that strands which are pitted when observed by the unaided eye should be rejected. The observation must be conducted after removing the rust or the superficial iron oxide layer on the strand surface.

Several disputes in the field regarding the acceptance or rejection of prestressing strand have been settled using this method. Its adoption can eliminate much of the controversy over the acceptability of lightly rusted strand.

The contents of this paper may be reduced to a simple manual as a guide for comparing degree of rusting in prestressing strands. In order to be effective, the pictures must be reproduced clearly and accurately in color.

ACKNOWLEDGMENT

The author wishes to express his appreciation and thanks to James Barker, Ronald Dull, Michael Muckenfuss, Don Pellow and Don Pfeifer for their constructive comments; and to H. Kent Preston for his valuable comments in editing this paper.

REFERENCES

1. ASM, *Metals Handbook*, 9th Edition, S. V., "Bright Wire Finish," American Society for Metals, Metals Park, OH, 1978.
2. ASTM, *ASTM Designation: A 416-90a, Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete*, V. 1.04, American Society for Testing and Materials, Philadelphia, PA, 1991.
3. PCI, *Manual for Quality Control for Plants and Production of Precast and Prestressed Concrete Products*, Precast/Prestressed Concrete Institute, Chicago, IL, 1985.
4. FIP, *Recommendations for Acceptance of Post-Tensioning Systems*, Fédération Internationale de la Précontrainte, London, United Kingdom, May 17, 1991.
5. AISI, *Steel Products Manual, Wire and Rods, Carbon Steel*, American Iron and Steel Institute, Washington, D.C., 1984.