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BOND STRENGTH OF RUSTED DEFORMED BARS

This paper presents the results of an investigation to determine the effect of rust upon the bond strength of deformed reinforcing bars. The acceptability of rusted reinforcing bars presents a question frequently perplexing to the inspector in the field. Three different approaches were made to this question - all approaches were similar but various techniques were employed. Three hundred and seventy-two pullout specimens were tested. The pullouts varying in size of bar and degree of rust.

The acceptability of reinforcing bars used for concrete construction work is usually up to the engineer or inspector in charge of the job. Specifications often contain nothing regarding the surface condition of the bars. THE BUILDING REGULATIONS FOR REINFORCED CONCRETE as adopted by the American Concrete Institute contain this clause:

> "Metal reinforcement, at the time the concrete is placed, shall be free from rust scale or other coatings that will destroy or reduce the bond."

One may look at this sentence in two ways. First, assume that the interpreter understands it to mean that all rust must be removed. The removal of rust increases cost and it is questionable whether the bond is actually improved by brushing. Secondly, assume that the inspector takes another view of this question, and interprets it to mean that rust shall be removed if it is detrimental to the bond. While scattered data are available concerning the effect of rust on the bond value of reinforcing bars, the results are not widely known so that it is questionable whether the inspector is likely to possess much sound information on which to base a decision. Supplementing the information gathered in this series of tests, the following references will prove valuable.

In 1909 M. O. Withey, Professor of Mechanics at the University of Wisconsin, made a report* on the effect of rust on bond strength, stating that rust caused a decided increase in the bond developed, in the following statement:

> "The values of the bond developed in the beams containing rusted round rods was decidedly higher than those obtained from beams reinforced with plain round rods (ordinary mill surface)/ It is evident from the tests 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 rod under the same conditions. In these tests the static bond between concrete and the 1/2-in. rusted round rods averages 83 per cent greater than the similar value from tests where 5/8-in. plain round rods (ordinary mill surface) were employed."

*University of Wisconsin Bulletin No. 321, TESTS ON BOND BETWEEN CONCRETE AND STEEL IN REINFORCED CONCRETE BEAMS

Later in a University of Illinois Bulletin° Professor Duff A. Abrams, at that time Associate in Theoretical and Applied Mechanics, reported:

° Bulletin No.71, 1913, TESTS OF BOND BETWEEN CONCRETE AND STEEL

"The tests on rusted bars gave a bond resistance higher than that developed with bars having ordinary mill surfaces. End slip began at 302 p.s.i.; 13 per cent higher than for round bars with ordinary mill scale surfaces. The maximum bond resistance of the rusted bars was 440 p.s.i., or 16 per cent higher than for ordinary rounds. This result is a natural consequence of the rougher surface, which is responsible for the higher bond resistance developed by the rusted bars."

Research Professor J. R. Shank of Ohio State University, in a bulletin published June 1934 - Engineering Experiment Station News - reporting that red weather-rusted bars, ground rusted and sand blasted bars give approximately 60, 85, and 93 per cent greater bond value, respectively, than the clean uncoated bars.

The results of the investigation at Fritz Engineering Laboratory at Lehigh University is divided into three parts outlined below.

PART I - (5/8-in. Ø deformed bars only)

In this part of the investigation four degrees of rusted surface were tested for their bond value. The concrete had an average compressive strength close to 4000 p.s.i. at 28 days. All the bars were 5/8-in. round with bamboo deformations. The bars were taken from a reinforcing bar fabricator's stock pile, carebeing taken to select bars for each of the groups tested having equal degrees of rust and also having the same physical appearance.

It was early realized that deciding the character of the surface is a field problem where elaborate equipment is seldom available for determining the degree and condition of rust on such surfaces. Several different methods which might be adopted were tried in this investigation. In one method small pieces were cut for photomicrographs, but the sections looked so much alike regardless of the rust coat that this method was abandoned.

In another method ten-inch specimens were cut and weighed to the nearest tenth of a gram. The rust was removed with a buffer and the specimens again weighed. The results can be seen in columns (4), (5) and (6) of Table I. The differences are not very consistent and are too small and irregular to be of practical value.

It would seem, therefore, that one must be guided largely by the eye and by the feeling of the surface of the bar in reaching a conclusion as to the degree and character of rust present.

Fig. I and II show the condition of the bars tested. Descriptions of the bars are as follows:

Group A - The bars in this group are those which have a mill scale surface and sometimes have occasional yellow-brown rust spots of small size. The bar is fairly smooth to touch and has the ordinary mill scale appearance. The mill scale will not flake off easily.

Group B - The bars in this group have lost the mill scale color and are covered with a layer of firm rust. The color of the rust is dark brown and feels slightly rough to the touch. Rubbing with the hand will not remove the rust.

Group C - The bars in this group have lost all mill scale appearance they originally had; they are pitted and covered with a firm hard rust of dark brown color. These bars feel rough to the touch and occasionally granular pieces of rust can be rubbed off in pieces approximately 1/64-in. in diameter. Pits cover the entire surface but do not extend very deeply below the surface.

Group D - The bars of this group appear to be in better condition than the bars of Groups B and C. Their rust is yellow and gives the hands a yellow-brown stain. There are many places where the mill scale has remained intact. The rust is loose but not heavy. This rust was soft and crushed readily under small pressure.

In order to determine the relative order of bond value for the bars, 6 by 6-in. pullout specimens were made and the end slip measured with an Ames dial reading to 1/10,000 of an inch. Fig. III shows a typical set-up for a pullout test.

One group of twenty specimens was made with the bars as they were received in the laboratory, that is, in the unbrushed state. A second group of sicreen was carefully brushed in the laboratory by hand before they were incorporated in the bond specimens. The compressive strength of the concrete as obtained on 3 by 6-in. control specimens averaged about 4000 p.s.i. The proportioning of the concrete was done by weight. All aggregates were dry at the time of weighing. The mix used was as follows: cement 20.8 lb; water 15.4 lb; sand 58.5 lb; 3/8-in. coarse aggregage 35.5 lb; and 3/4-in. coarse aggregate weighing 53.0 lb. Twenty-four hours after being made the specimens were placed in the moist room where they were cured for 27 days at 70°F. The testing was done on a 50,000-lb. Riehle testing machine with a speed of 0.05 of an inch per minute. The set-up is that shown in Fig. III and IV.

In addition to the pullout tests, tensile tests were made for each degree of rusted bars, Huggenberger extensometer readings were made on two specimens and "drop of beam" readings made on three other specimens for each degree of rust. The results of these tests are shown in Table I and Fig. V. It is evident from the table that there were bars selected from at least three different heats.

CONCLUSIONS DRAWN FROM PART I

There are two significant points brought out by this part of the investigation. First, the effect of rust is not as important as the size and shape of the deformations on the bars. Curves showing bond stress plotted against end slip, (Fig. VI and VII) seem to indicate that certain types of rust were detrimental to a small degree. If the reader will examine the photographs of the bars in Fig. I and II he will notice that some bars have sharper - more pronounced - deformations than other bars. Rating these bars on the order of their appearance regarding these deformations will place them in the order as they fall on the bond-slip curves, Fig. VI and VII. The second point to note is that with the bars which were brushed the average bond-slip value at 0.001-in. slip was raised five to ten per cent and at 0.005-in. slip was raised ten to fifteen per cent by the brushing. The unrusted group as we would naturally expect remained practically unchanged. This seems to indicate that brushing would benefit bars, but the question arises does it make them better than an unrusted, unbrushed bar?

PART II (Several sizes with various exposures)

The results in Part I did not bring out the effect which rust might have on a bar exposed for a period of time. Part II of this program was designed to find what effect rust might have on a reinforcing bar if it were subjected to various periods of exposure; and giving, therefore, several different degrees of rusted surface.

Six 20-ft. bars of each of the following sizes; 3/8-in.∅ deformed, 1/2-in.∅ deformed, 3/4-in.∅ deformed, 1-in. square deformed, and 1-1/4 in. square deformed were cut into two-foot lengths. The properties of these bare are shown in Table II. One specimen from each bar was used as a specimen to represent the unrusted state. One hundred and fifty specimen, or five specimens from each bar were wired into racks and placed on the north side of Fritz Engineering Laboratory as shown in Fig. VIII. The remaining bars were placed in the moist room at 70°F as shown in Fig. IX. The exposure started on December 15, 1937. Every three months thirty bars would be taken from each of these two exposures (six specimens for every size of bar) to be made into a pullout specimens.

The bars were imbedded in concrete designed to have an average compressive strength of 2500 p.s.i. at 28 days.

The concrete was proportioned by weight; the materials being dry at the time of weighing. The mix used is as follows:

cement - 13,400 gm.

water - 12,600 gm.

sand - 92 lb.

3/8-in. aggregate - 61 lb.

3/4-in. aggregate - 122 lb.

The average concrete strength for each period of exposure is given in Table III. The depth of imbedment was established at eight times the normal diameter. Pilot tests indicated that with this depth of embedment the bar would not reach its yield point before being pulled from the concrete block. This would mean that the actual frictional resistance could be measured before there was any necking down. Two diameters of specimens were used, namely, 6 and 10 in. The 6-in. diameter was used for the 3/8-in.Ø and 1/2-in.Ø bars while the 10-in. diameter was used for the 3/4-in.Ø, 1-in. square, and 1-1/4 in. square bars. These sizes were used to eliminate splitting of the specimen before sufficient slip had taken place. Fig. X shows a group of typical pullout specimens made for this part of the program.

The specimens were rodded as they were made until the concrete was sufficiently compact and free of voids. Three test cylinders were made by the standard procedure. At the age of one day the specimens and the cylinders were placed in the moist room.

At the age of 28 days pullout specimens were taken from the moist room and tested in the same manner as the specimens in Part I. Results of these tests are shown in Fig. XI to XXX inclusive. These curves show hoe the bars compared at 0.0010-in. and 0.0055-in. slip at various lengths and kinds of exposure. Fig. 31 shows the condition of the bars at nine months exposure.

In regard to the surface condition of the bars in this series of tests; it could plainly be seen that a wide variety of rust conditions were encountered. The 0 month exposed bars were of course, free of rust; they were embedded as they were received at the laboratory. The three months group had rust very similar to Group D in Part I. The outside rusted bars always had a great deal more rust than those placed in the moist room. The small sized bars were quite thoroughly rusted while the large sized bars were hardly rusted at all. The rust of the bars in the moist room was a little more yellow in color, and apparently because of the moisture was more crumbly.

The six months group had more rust than the three months group. The large sizes were beginning to rust and had reached a condition almost as bad as the small sizes had at three months. Again the outside rusted bars showed more rust than the moist room exposed bars.

The nine months bars, shown in Fig. 31, had a very heavy coat of rust; the rust had become loose and flaky, especially the outside exposed bars. Rust would crumble off under very small pressures. The bars at this stage had a very poor appearance. By the end of the twelve months period the bars had become even more rusted than before and were in far worse than the condition of the nine months group. After fifteen months the bars had an exceedingly heavy, loose coat of rust. The writer has never seen building materials with a rust coat so heavy.

In spite of these heavy coats of rust the bars, in general, showed better bond properties at the end of their exposure than they had in the unrusted state. The six months group does not entirely fall in line with this observation. However, these specimens were not made under the direct supervision of the writer and the falling down cannot be accounted for unless there might have been a difference of materials or technique.

CONCLUSIONS DRAWN FROM PART II

These tests show that rust is not detrimental to the bond but actually beneficial.

The pullout tests in this report indicate that the pullout specimen is an erratic method of measuring bond value, and is very difficult to obtain consistent results.

PART III (Three sizes, vibrated)

Since the drop of the six months exposure group below the three and nine months groups in Part II could not be accounted for, Part III was carried out to duplicate to a certain extent the tests of Part II.

In Part III three sizes of bar were used, namely, 3/8"Ø deformed, 3/4"Ø deformed and 1" square deformed. Three pullout specimens were made of each of the above bar sizes for outside exposures of 0, 1, 3, and 6 months. The exposure starting on November 14, 1938. The 3/8"Ø deformed bar was embedded 3 in. in a 6-in. diameter cylinder, the 3/4"Ø deformed bar was embedded 6 in. in a 10-in. diameter cylinder and the 1-in. square deformed bar was embedded 8 in. in a 10-in. diameter cylinder. These are the same size used in Part II. The concrete mixture also was the same as used in Part II. The physical properties of the concrete and steel are given in Tables and .

The pullout specimens and control cylinders were vibrated for controlled periods of time. The 6-in. diameter pullouts were filled completely and the vibrator, which is shown in Fig. 32, was held in each quadrant of the cross section for five seconds, meaning that these specimens were vibrated for a total of twenty seconds. The 10-in. diameter specimens were made in a similar fashion except that the above procedure was carried out when the mould was half full and again when entirely filled.

The control cylinders, three 3 by 6-in., were made in oiled steel moulds. The moulds were half filled and the vibrator was applied for 20 seconds; each; then the moulds were completely filled and the vibrator applied for another 20 seconds.

The pullouts were tested the same manner as the pullouts in Part I and Part II. Fig. 33 to 38 inclusive show how the load at slips of 0.001 and 0.0055 in. varied with the various periods of exposure. The same erratic appearance of the points is evident as has been noticed before in Part II.

CONCLUSIONS DRAWN FROM PART III

The conclusions are the same as were drawn for Part II, i.e., in general; rust does not appear to be detrimental to the bond of reinforcing bars.

TABLE I

TABLE SHOWING PROPERTIES OF THE RUSTED STEEL TESTED IN BOND

Specimen	Unit Stress at Yield Point	Unit Stress at Ultimate Strength	% Elong. of 8-in. Gage Length	Initial Weight of 10-in. Specimen	Rust and Mill Scale Removed by Buffer Final Weight 10-in. Specimen	Difference (Column 4-Column 5)
A-1	47,000	76,700	23.2	387.50	385.90	1.60
A-2	47,700	76,000	21.3	389.65	388.50	1.15
A-3	46,400	76,600	20.5	388.25	387.55	0.70
A-4	46,300	75,400	22.8	388.35	387.85	0.50
A-5	46,400	76,400	21.3	388.90	388.15	0.75
Average	46,760	76,220	21.8			
B-1	47,200	75,700	22.8	381.45	380.25	1.20
B-2	47,600	76,00	21.2	379.45	377.95	1.50
B-3	47,900	75,700	23.3	379.10	378.10	1.00
B-4	47,200	75,300	23.4	380.50	379.50	1.00
B-5	27,500	75,700	22.6	380.00	379.25	0.75
Average	47,480	75,680	22.7			
C-1	43,500	74,400	31.8	378.90	377.10	1.80
C-2	43,800	74,300	24.0	378.70	377.05	1.65
C-3	43,500	74,500	22.2	377.55	376.55	1.00
C-4	43,800	73,900	21.6	379.35	377.65	1.70
C-5	44,100	74,100	20.4	378.30	377.05	1.25
Average	43,740	74,240	22.0			
D-1	51.700	79.400	23.6	399.35	398.20	1.15
D-2	51,500	78,500	23.6	399.65	398.55	1.10
D-3	50,300	78,200	25.9	399.55	398.20	1.35
D-4	49,000	77,800	24.3	394.05	392.70	1.35
D-5	50,900	79,300	22.5	400.95	399.90	0.15
Average	50,680	78,640	24.0			

TABLE II
PHYSICAL PROPERTIES OF STEEL IN PART II

Size of Bar	Yield Point p.s.i.	Ultimate Stress p.s.i.	Per Cent Elongation at 2 in.	Per Cent Elongation at 8 in.	Per Cent Reduction of Area
3/8"Ø	50,000	75,000	30.5	22.6	55.6
1/2"Ø	52,300	83,285	31.0	20.0	48.0
3/4"Ø	44,200	75,600	37.0	24.25	50.0
1" sq.	41.900	67,513	40.5	27.4	38.5
1-1/4" sq.	40,000	72,100	42.0	28.8	38.8

TABLE V

PHYSICAL PROPERTIES OF STEEL IN PART III

3/8"Ø	49,900	69,400	36.5	25.6	65.4
3/4"Ø	47,800	77,100	34.0	22.1	49.1
1" sq.	47,600	74,560	39.0	26.0	42.2

TABLE III

AVERAGE CYLINDER STRENGTH OF CONCRETE IN PART II

Months	Stress p.s.i.
0	2580
3	2610
6	2370
9	2420
12	2730
15	2980
Average	2615

TABLE IV

AVERAGE CYLINDER STRENGTH OF CONCRETE IN PART III

0	2320
1	2413
3	
6	