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THE BOND STRENGTH OF RUSTED DEFORMED BARS

by Bruce Johnston* and Kenneth C. Cox'

SYNOPSIS

Results of about 420 bond pullout tests on deformed bar specimens of 78 different sizes or degrees of rust are reported herein. Three different series of tests were made in all. In the first series, bars were selected from a stock pile and were classified as to degree of rust. Although these bars were of the same nominal size and type it was found that small differences in the size of lug produced a greater difference in test results than the degree of rust. In the second series, deformed bars of different sizes cut from identical stock were stored both in a moist room and out-of-doors in an exposed position. The time of exposure was a variable and the maximum time for the out-of-door exposed specimens was fifteen months. The third series of tests consisted of bars exposed out-of-doors as a check test on the results of the second series.

FOREWORD AND ACKNOWLEDGMENT

This investigation, sponsored by the Concrete Reinforcing Steel Institute, was started in 1937 under the direction of Inge

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Lyse, formerly Research Professor of Engineering Materials at Lehigh University and now Professor of Reinforced Concrete and Solid Bridges at the Norges Tekniske Hoiskole at Trondheim, Norway. The investigation was a regular research project of the Fritz Engineering Laboratory, which is under the direction of Professor Hale Sutherland, Head of the Department of Civil Engineering. Acknowledgment is due to Mr. Howard Godfrey, Engineer of Tests at the Laboratory, for his assistance in carrying out the work of the investigation.

**INTRODUCTION**

The effect of rust on the bond strength of rusted reinforcing bars is an important practical problem. The "Proposed Building Regulations for Reinforced Concrete" of the American Concrete Institute state in Clause 504 "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." This statement is open to the interpretation that if rust scale is of a type which will not destroy or reduce the bond the reinforcing bars may be considered acceptable.

In 1909 M. O. Withey reported in Bulletin 321 of the University of Wisconsin that a firm hard coating of rust improved the bond strength of plain round reinforcing bars as compared with as-rolled bars free from rust. Similar findings were reported by D. A. Abrams in Bulletin 71 of the University
of Illinois Experiment Station, and more recently J. R. Shank* of Ohio State University has reported that red weather-rusted bars and ground rusted bars both gave considerably higher bond values than clean uncoated bars. A complete bibliography on the subject of bond in general is presented in the paper by H. J. Gilkey, S. J. Chamberlain, and R. E. Beal, "The Bond Between Concrete and Steel", published in the September 1938 Journal of the American Concrete Institute. The recent paper by C. A. Menzel "Some Factors Influencing Results of Pullout Bond Tests" Journal of the American Concrete Institute, June 1939, should also be mentioned in introducing the subject of bond tests.

TEST PROGRAM AND RESULTS - PART I

(5/8-in.Ø deformed bars only)

In this part of the investigation four different degrees of rusted surface were tested for their bond value. As noted in the synopsis, the results of the tests in this part of the investigation were influenced more by variation in the size of lugs than by variations in rust coat. These results are included, however, as a matter of record. All the bars were 5/8-in. round with transverse lugs. The bars were taken from a reinforcing bar fabricator's stock pile, care being taken to select bars for each of the groups tested having equal degrees of rust.

* "Effect of Bar Surface Conditions in Reinforced Concrete"
Ohio State Engineering Experiment Station News, June 1934, p.9
Judging the character of the rusted surface will usually be a field problem where elaborate equipment is seldom available. Attempts to develop a laboratory test to evaluate the degree of rust proved somewhat unsatisfactory. Photomicrographs of the rusted surface yielded little information. In another approach to the problem, 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 differences were not very consistent and were too small and irregular to be of practical value. As a result of these preliminary experiments it was decided that the best method of judging the degree and character of the rust was by means of a visual examination, comparable to what might be easily carried out by a field inspector.

Fig. 1 shows the condition of the bars tested in this first group of tests. Descriptions of the bars are as follows:

Group A - The bars in this group had most of the original mill scale surface except for occasional yellow-brown rust spots of small size. The bars were fairly smooth to the touch and the mill scale did not flake off easily.

Group B - The bars in this group had lost the mill scale color and were covered with a layer of firm rust. The color of the rust was dark brown and was slightly rough in texture. Rubbing with the hand did not remove the rust.

Group C - The bars in this group had lost all of the original mill scale surface and were pitted and covered by a firm
hard rust of dark brown color. These bars were rough to the touch and occasionally granular pieces of rust could be rubbed off in pieces approximately 1/64-in. in diameter. The pits covered the entire surface but were not very deep.

Group D - The bars of this group appeared to be in better condition than the bars of Groups B or C. The rust was yellow and gave the hands a yellow-brown stain. There were many places where the mill scale had remained intact. The rust was loose, soft, and crushed readily under small pressure.

The bond pullout test specimens made in this series of tests were made with the reinforcing bars in a vertical position and with the concrete settling against the direction of pull. The specimens were six inches in diameter and the bars were embedded in six inches of concrete.

Slip at the free end was measured by means of an Ames dial reading to 1/10,000 of an inch. Fig. 2 shows a typical setup for a pullout test. A 50,000-lb. Riehle Testing Machine was used in making the tests, and the reinforcing bar was pulled at a rate of 0.05 inches per minute.

One group of twenty specimens was made with the bars as received, and in the second group the sixteen specimens were given a thorough brushing by hand. The concrete was designed to give a 28-day compressive strength of 4000 p.s.i. and the average obtained on eighteen 3 by 6-in. control specimens was
3930 p.s.i. The proportioning of the concrete was made by means of trial mixes. The mix selected was as follows: cement 20.8 lb.; water 15.4 lb. (including absorption allowance); sand 58.5 lb.; 3/8-in. coarse aggregate 35.5 lb.; and 3/4-in. coarse aggregate weighing 53.0 lb. Twenty-four hours after molding, the specimens were placed in the moist room where they were cured for 27 days at 70°F.

Tensile tests were made for each group of bars with Huggenberger extensometer readings taken on two specimens and "drop of beam" yield point observed on the three other specimens. The results of these tests are shown in Table I, below:

TABLE I
TENSILE PROPERTIES OF STEEL USED IN SERIES I

<table>
<thead>
<tr>
<th>Group</th>
<th>Unit Stress at Yield Point</th>
<th>Ultimate Elongation in 8 in.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p.s.i.</td>
<td>p.s.i.</td>
</tr>
<tr>
<td>A</td>
<td>46,760</td>
<td>76,220</td>
</tr>
<tr>
<td>B</td>
<td>47,480</td>
<td>75,680</td>
</tr>
<tr>
<td>C</td>
<td>43,740</td>
<td>74,240</td>
</tr>
<tr>
<td>D</td>
<td>50,680</td>
<td>78,640</td>
</tr>
</tbody>
</table>
The test results of Part I of the investigation are tabulated in Table II, below. The total pull on the bar for end slips of 0.00005, 0.0001, 0.0005, and 0.001-in. is recorded in the table for both the brushed and unbrushed specimens. Each figure in the table represents an average of five tests in the case of the unbrushed specimens and four tests in the case of the brushed specimens. Reference should be made to pages 4 and 5 for a description of the comparative rusted condition of the groups A, B, C, D.

**TABLE II**

**TEST RESULTS OF PULLOUTS IN PART I**

<table>
<thead>
<tr>
<th>Rust Classification</th>
<th>End Slip at Free End</th>
<th>Total Load (Average)</th>
<th>Ratio: Brushed / Unbrushed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unbrushed</td>
<td>Brushed</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0.00005</td>
<td>5,066</td>
<td>5,130</td>
</tr>
<tr>
<td></td>
<td>0.0001</td>
<td>6,414</td>
<td>6,106</td>
</tr>
<tr>
<td></td>
<td>0.0005</td>
<td>9,370</td>
<td>8,876</td>
</tr>
<tr>
<td></td>
<td>0.001</td>
<td>10,362</td>
<td>9,670</td>
</tr>
<tr>
<td></td>
<td>Ult.</td>
<td>13,386</td>
<td>14,127</td>
</tr>
<tr>
<td>B</td>
<td>0.00005</td>
<td>4,730</td>
<td>5,145</td>
</tr>
<tr>
<td></td>
<td>0.0001</td>
<td>6,086</td>
<td>6,106</td>
</tr>
<tr>
<td></td>
<td>0.0005</td>
<td>9,386</td>
<td>10,146</td>
</tr>
<tr>
<td></td>
<td>0.001</td>
<td>10,386</td>
<td>11,933</td>
</tr>
<tr>
<td></td>
<td>Ult.</td>
<td>13,266</td>
<td>15,055</td>
</tr>
<tr>
<td>C</td>
<td>0.00005</td>
<td>5,626</td>
<td>5,510</td>
</tr>
<tr>
<td></td>
<td>0.0001</td>
<td>7,686</td>
<td>7,285</td>
</tr>
<tr>
<td></td>
<td>0.0005</td>
<td>12,654</td>
<td>12,652</td>
</tr>
<tr>
<td></td>
<td>0.001</td>
<td>13,572</td>
<td>13,935</td>
</tr>
<tr>
<td></td>
<td>Ult.</td>
<td>16,672</td>
<td>20,052</td>
</tr>
<tr>
<td>D</td>
<td>0.00005</td>
<td>4,040</td>
<td>4,833</td>
</tr>
<tr>
<td></td>
<td>0.0001</td>
<td>5,206</td>
<td>5,708</td>
</tr>
<tr>
<td></td>
<td>0.0005</td>
<td>7,627</td>
<td>7,878</td>
</tr>
<tr>
<td></td>
<td>0.001</td>
<td>7,983</td>
<td>8,555</td>
</tr>
<tr>
<td></td>
<td>Ult.</td>
<td>12,706</td>
<td>13,578</td>
</tr>
</tbody>
</table>
Not much consideration should be given to the differences between the bond strength of the various groups, A, B, C, and D. The differences are influenced not only by the rust differences but also by small variations in the height of the transverse lugs, which may be noted in Fig. 1. Such differences in the size of lugs may be developed by reason of differential wear in rolls, in the same nominal size and type of bar.

The tests in Part I afford a comparison between the bond strength of brushed and unbrushed specimens, as affected by different degrees and classifications of rust. Brushing had no well defined effect upon the bond strength of the bars in classifications A and C. The bars in Group C were deeply pitted by rusting. The bond strengths of the bars in Groups B and D were raised an average of between ten and fifteen per cent by brushing, for low values of slip. The bars in Groups B and D were not as heavily rusted as those in Group C (see pp. 4 and 5 and Fig.1).

The results of these tests are inconclusive. The bond strength of bars with certain types of rust seemed to be benefited but slightly by brushing, but there is no reason to believe that the unrusted bars of the same type would have higher bond strength than the same bars in the rusted but unbrushed condition.

**TEST PROGRAM AND RESULTS - PART II**

The results of Part I were inconclusive with respect to the net effect of varying degrees of rust upon the bond strength of rusted deformed bars.
In Part II of the investigation it was decided to expose bars for varying lengths of time and thus provide different degrees of rust on identical specimens.

Six 20-ft. bars of each of the following sizes; 3/8-in.Ø deformed, 1/2-in.Ø deformed, 3/4-in.Ø deformed, 1-in. square deformed, and 1-1/4 in. square deformed were cut into two-foot lengths. The tensile properties of these bars are given in Table III, which also gives the properties of similar bars tested in Part III.

TABLE III
TENSILE PROPERTIES OF STEEL USED IN PARTS II AND III

<table>
<thead>
<tr>
<th>Size of Bar</th>
<th>Unit Stress, P.s.i.</th>
<th>Per Cent Elongation in 2 in.</th>
<th>Per Cent Elongation in 8 in.</th>
<th>Reduction in Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield Point</td>
<td>Ultimate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Part II</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/8 in.Ø</td>
<td>50,000</td>
<td>75,000</td>
<td>30.5</td>
<td>22.6</td>
</tr>
<tr>
<td>1/2 in.Ø</td>
<td>52,300</td>
<td>83,280</td>
<td>31.0</td>
<td>20.0</td>
</tr>
<tr>
<td>3/4 in.Ø</td>
<td>44,200</td>
<td>75,600</td>
<td>37.0</td>
<td>24.5</td>
</tr>
<tr>
<td>1 in. sq</td>
<td>41,900</td>
<td>67,510</td>
<td>40.5</td>
<td>27.4</td>
</tr>
<tr>
<td>1-1/4 in. sq</td>
<td>40,000</td>
<td>72,100</td>
<td>42.0</td>
<td>28.8</td>
</tr>
<tr>
<td>Part III</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/8 in.Ø</td>
<td>49,900</td>
<td>69,400</td>
<td>36.5</td>
<td>25.6</td>
</tr>
<tr>
<td>3/4 in.Ø</td>
<td>47,800</td>
<td>77,100</td>
<td>34.0</td>
<td>22.1</td>
</tr>
<tr>
<td>1 in. sq</td>
<td>47,600</td>
<td>74,560</td>
<td>39.0</td>
<td>26.0</td>
</tr>
</tbody>
</table>

Note - Each figure is an average of three tests.
One specimen from each bar was used as a specimen to represent the unrusted state. One hundred and fifty specimens, or five specimens from each bar, were wired into racks and placed on the north side of the Fritz Engineering Laboratory as shown in Fig. 3. The remaining bars were placed in the moist room at 70°F as shown in Fig. 4. The exposure started on December 15, 1937.

After periods of exposure of 3, 6, 9, 12, and 15 months the bond pullout test specimens were made. The concrete was designed to have an average compressive strength of 2500 p.s.i. at 28 days, with proportions as follows: cement 29.6 lb., water 27.8 lb., sand 92 lb., 3/8-in. aggregate 61 lb., 3/4-in. aggregate 122 lb. Sand and aggregate were weighed dry and weight of water included allowance for absorption. The average concrete strengths were 2580, 2610, 2370, 2402, 2720, and 2908 p.s.i. for 0, 3, 6, 9, 12, and 15 months exposure tests respectively.

The depth of embedment was established at eight times the diameter of round specimens and eight times the minimum thickness of square specimens. Pilot tests indicated that with this depth of embedment the bars would not reach their yield point before being pulled from the concrete block. The concrete was placed so as to settle against the transverse lugs of the reinforcing bars, which were all held in a vertical position while the concrete was placed. 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. 5 shows a typical group of pullout specimens made for this part of the program.

Six bond pullout tests in duplicate were made for each size and degree of exposure. Six 3 by 6-in. test cylinders were made to check the strength of each concrete mix. The concrete was rodded into place until sufficiently compact and free of voids. At the age of one day the pullout specimens and the cylinders were placed in the moist room, to be tested at the age of 28 days.

The rusted surface condition of the bars in this series of tests varied widely during the progress of the work. The zero month exposed bars were practically free of rust and were embedded in this condition.

The three months group had rust similar to that described for Group D, Part I, (see p.5). The bars exposed outside had a great deal more rust than those placed in the moist room. The small sized bars were quite thoroughly rusted over their entire area while the large sized bars had large areas relatively free of rust. The rust of the bars in the moist room was a little more yellow in color and somewhat more crumbly than those exposed outside.
The six months group showed more rust than the three months group. The large sizes were not generally rusted 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 rusted bars, shown in Fig. 6, had a very heavy coat of rust; the rust had become loose and flaky, especially on the bars exposed out-of-doors. Rust would crumble off under very small pressures and in general the bars at this stage had a very poor appearance. By the end of the twelve and fifteen months periods the bars had become progressively more rusted and were in far worse condition than the nine months group. The coat at fifteen months was exceedingly loose and heavy.

The total load on the embedded bars at various stages of slip and at ultimate load are shown in Fig. 7 to 16 inclusive. The bond strength is progressively higher for the 9, 12, and 15 months, rusted bars as compared with the unrusted ones. These correspond to the more advanced stages of loose, flaky, rust. In the twelve and fifteen months groups part of the superiority may be attributed to the fact that the compressive strength of the concrete was somewhat above the average of all of the tests; but the total increase is greater than that which could be accounted for in this way. Three and six months of exposure seemed to have little effect upon the bond strength, particularly at slips of
0.00005 and 0.0001 in. For larger values of slip the six months tests were in some cases lower in bond strength than the unrust-ced bars. The general conclusion from these tests is, however, that advanced degrees of rust (provided there is no appreciable loss in net area) increases the pullout strength in bond of de-formed reinforcing bars.

TEST PROGRAM AND RESULTS - PART III

The tests in Part III represent a series which supplement and serve as a check on the results of Part II. The concrete in this series was vibrated into place whereas the concrete in Part II was placed by hand-rodling. Three sizes of bar were used, namely, 3/8-in.Ø deformed, 3/4-in.Ø deformed and 1-in. square deformed. Three pullout specimens were made of each of the above bar sizes for outside exposures of 0, 1, 3, 6, and 12 months. The exposure started on November 14, 1938. The concrete mix was the same as that used in Part II but 6 by 12-in. control cylinders were used with concrete vibrated into place. The average compressive strengths were 2320, 2410, 2300, 2390, and 2130 p.s.i. for the 6, 1, 3, 6, and 12-month groups with an average of 2310 p.s.i. This average is 300 p.s.i. lower than the average of the rodded 3 by 6-in. cylinders used in Part II. The physical properties of the steel were given in Table III.
The 6-in. diameter pullouts were filled completely and the vibrator, which is shown in Fig. 17, 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. Three 6 by 12-in. control cylinders were made for each mix in oiled steel moulds. The moulds were half filled and the vibrator was applied for twenty seconds; then the moulds were completely filled and the vibrator applied for another twenty seconds.

The appearance of the rusted bars in this series was quite similar to that of the bars in Part II at similar stages. The bars at twelve months were coated with a heavy rust coat which appeared to be somewhat more solid and not quite as flaky as the same stage of rust in Part II. The pullout tests were carried out in exactly the same manner as the similar tests in Part II and the loads at various stages of slip are shown in Fig. 18 to 20 inclusive.

In Part III the load on the bars for the six and twelve months tests were higher than the load at zero months exposure for the various slips between 0.00005 and 0.001 in. for all sizes of bars but the load at ultimate failure showed a decrease. The ultimate strength of the concrete used in the twelve months series was slightly below average. This is reflected in the results
of the pullout tests but the same general conclusions made for Part II apply as well to Part III. In Part III the six months results are better than the zero, one, or three months results for all stages of slip except ultimate load.

SUMMARY AND CONCLUSIONS

1. Bond pullout tests of deformed bars of the type tested usually showed higher strength at low values of slip than corresponding tests in the unrusted condition.

2. The ultimate pullout strength of the deformed bars was not greatly affected by their condition of rust.

3. The effect upon bond pullout strength produced by brushing rusted reinforcing bars was erratic, producing increased strength at low values of slip in some cases and but little effect in other cases.
Fig. 1 - Rusted Bars Used in Part I
Left to Right: A, B, C, D
Fig. 2 - Test Set-Up For Measuring End Slip
Fig. 3 - Bars Exposed Out-Of-Doors

Fig. 4 - Bars Exposed In Moist Room
Fig. 5 - Group Of Pull-Out Specimens

For Part II
Fig. 6 - Bars After Nine Months Exposure

Above - Outdoor Exposure

Below - Exposure In Moist Room
Fig. 7 Effect of Prior Exposure in Moist Room on 28 Day Bond Strength of 3/8" φ Deformed Bars

Embedded Length of Bar 3 Inches
Each Point is Average of 6 Tests

Load in Pounds

Time of Exposure in Months

Ultimate

0.001" Slip

0.0005" Slip

0.0001" Slip

0.00005" Slip
Fig. 8  Effect of Prior Exposure Out of Doors on 28 Day Bond Strength of $\frac{3}{8}$" Deformed Bars
Embedded Length of Bar
4 Inches ~ Each Point is
Average of 6 Tests

Time of Exposure in Months

Load in Pounds

0.001" Slip
0.0005" Slip
0.0001" Slip
0.00005" Slip

Fig. 9 Effect of Prior Exposure in Moist Room on 28 Day Bond Strength of ½" φ Deformed Bars
Fig. 10 Effect of Prior Exposure Out of Doors on 28 Day Bond Strength of \( \frac{1}{2}'' \) Deformed Bars
Fig. 11 Effect of Prior Exposure in Moist Room on 28 Day Bond Strength of $\frac{3}{4}''$ φ Deformed Bars
Fig. 12 Effect of Prior Exposure Out of Doors on 28 Day Bond Strength of 3/4" Deformed Bars
Fig. 13 Effect of Prior Exposure in Moist Room on 28 Day Bond Strength of 1" □ Deformed Bars
Fig. 14  Effect of Prior Exposure in Out of Doors on 28 Day Bond Strength of 1" Deformed Bars
Fig 15 Effect of Prior Exposure in Moist Room on 28 Day Bond Strength of $\frac{1}{4}''$ Deformed Bars
Fig. 16. Effect of Prior Exposure Out of Doors on 28 Day Bond Strength of $\frac{1}{4}$" Deformed Bars
Fig. 17 - Vibrator Used in Part III
Fig. 18 Effect of Prior Exposure Out of Doors on 28 Day Bond Strength of 3/8" φ Deformed Bars
Fig. 19 Effect of Prior Exposure Out of Doors on 28 Day Bond Strength of 3/4\" \( \phi \) Deformed Bars
Embedded Length of Bar 8 Inches
Each Point is Average of 3 Tests

Fig. 20 Effect of Prior Exposure Out of Doors on 28 Day Bond Strength of 1" □ Deformed Bars