# Effect of the Existing Rust on Bond Strength of Concrete and Reinforcement

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ABSTRACT

An experimental investigation on the relationship between corrosion of reinforcement and bond strength in pull-out test specimen has been conducted to establish the allowable limit of rust of reinforcement in the construction field. The reinforcing bars used in this study were rusted before embedded in pull-out test specimen. The first component of this experiment is to make reinforcing bar rust electrically based on Faraday's theory to be 2, 4, 6, 8 and 10% of reinforcing bar weight. For estimation of the amount of rust by weight, Clarke's solution and shot blasting were adopted and compared. Parameters also include 24 and 45MPa of concrete compressive strengths and diameter of reinforcing bar (16, 19 and 25mm). Pull-out tests were carried out according to KS F 2441 and ASTM C 234. Results show that up to 2% of rust increases the bond strength regardless of concrete strength and diameter of reinforcing bar. As expected, the bond strength increases as compressive strength of concrete increases and the diameter of bar decreases.

## 1. Introduction

Most of reinforcing bar stored at construction field is likely to corrode due to the direct exposure to outdoors. However, the current specification is based on bond characteristics of clean reinforcing bar and previous researches have been also carried out often embed in clean reinforcing bars. Therefore, it has been in conflict between contractor and inspector to use corroded reinforcing bar in construction sites.

According to previous research results about corrosion of the reinforcing bar(Al-Sulaimani et al., 1990 ; Malvar, L. J, 1995), when the corrosion level of reinforcing bar is not much, the bond strength between the reinforcing bar and surrounding concrete increases with an increase of corrosion.

The main purpose of this investigation is to suggest the allowable corrosion level of reinforcing bar by test without decrease of bond strength between reinforcing bar and surrounding concrete. The reinforcing bars used in this study are rusted by artificial accelerated potentiometric corrosion method based on Faraday's law in order to induce exact amount of the rust and to reduce the time of rust production. The calculation of degree of rust is conducted by weight loss method in accordance with the ASTM G1-81 Clarke's solution method and the Shot blasting method.

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2. Experimental Program

The test parameters and mix proportionings used in this study are summarized in Table 1 and Table 2, respectively.

Table 1. Test parameters for corrosion measurement and bond strength

| Parameters | Variable for corrosion test | Bond strength test |
|---|---|---|
| Diameter of deformed bar | D16, D19, D25 | D16, D19, D25 |
| Level of corrosion (%) | 2, 4, 6, 8, 10 % | 0, 2, 4, 6, 8, 10 |
| Removal methods of rust | Claker's solution Shot blasting | - |
| Concrete compressive strength (MPa) | - | 24, 45 |

Table 2. Mix proportion of concrete

| Target strength (MPa) | Gmax (mm) | Slump (cm) | W/C (%) | S/A (%) | Unit mix content ($kg/m^3$) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Water | Cement | Fine aggregate | Coarse aggregate |
| 24 | 25 | 13.2 | 41 | 43 | 167 | 406 | 761 | 1095 |
| 45 | 25 | 16.3 | 36 | 43 | 167 | 463 | 741 | 1066 |

Schematic diagram of deformed bar for corrosion and bond tests are illustrated in Fig. 1 and Fig 2, respectively.

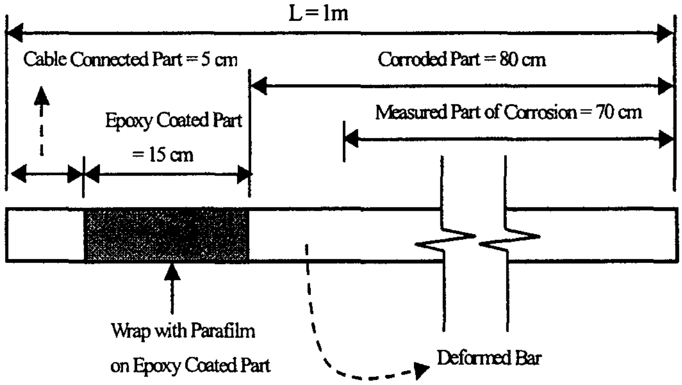



Fig. 1. Schematic diagram of deformed bar for corrosion testing

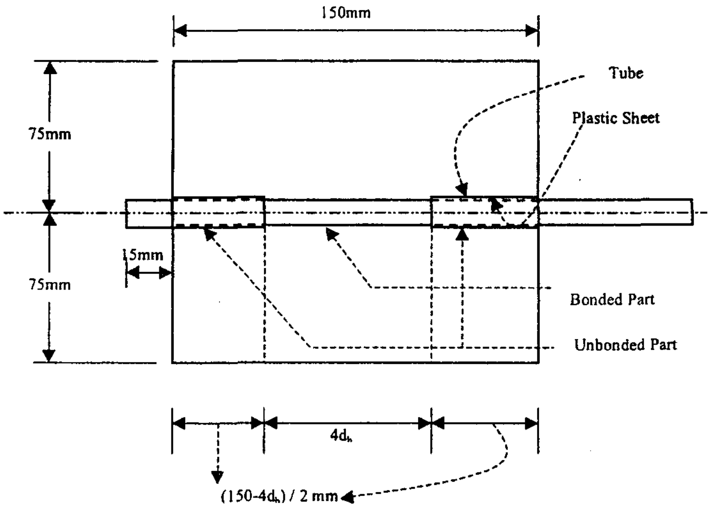


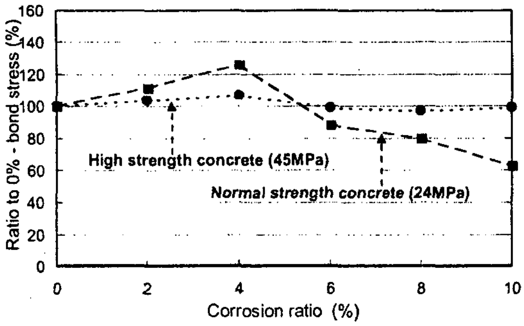

Fig. 2. Schematic drawing of the specimen for bond strength

3. Test Results and Discussions

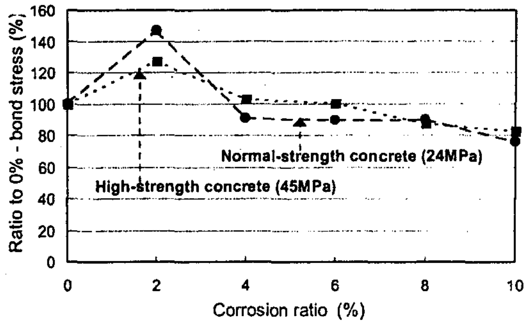
The ratios of ultimate bond stress of the deformed reinforcing bars with various amount of rust to that with 0% corrosion are shown in Figs. 3(a)~(c).

Ultimate bond stress of 2% corroded deformed bars is greater than that of 0% corroded deformed bars irrespective of nominal diameters of deformed bar and concrete strength. For D-19 deformed bar embedded normal strength concrete, ultimate bond stress of 4% corroded deformed bars is lower than that of 0% corroded deformed bars. Although, ultimate bond stress of bars with corrosion more than 6% is sometimes greater than that of 0% corroded deformed bars, it is general tendency that bond strength of bars with corrosion more than 6% is lower than that of 0% corroded deformed bars. For D-25 deformed bar embedded in high strength concrete, ultimate bond stress of 2, 4, 6, 8, 10% corroded deformed bars become higher than that of 0% corroded deformed bars. It might resulted from the mechanical interaction between deformations and surrounding concrete in high strength concrete which is different with that in normal strength concrete.

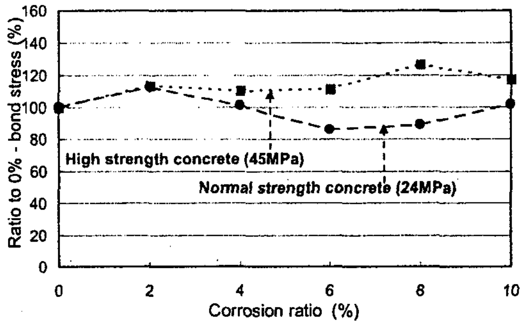
For the effects of concrete strength on bond strength, the rate of change in bond stress with the amount of rust in high strength concrete is lower than that in normal strength concrete irrespective of nominal diameter of reinforcing bar. It might be concluded from the results that there is no reduction in bond stress of the bars with less than 2% corrosion irrespective of nominal diameters and concrete strength. However, with further corrosion, the bond stress declines consistently until it becomes negligible for about 4, 6, 8, 10% corrosion. It is similar to previous research results(Al-Sulaimani et al., 1990). This can be explained on the basis of increased surface roughness of reinforcing bar with the growth of firm rust, which tends to enhance the holding capacity of the reinforcing bar.




(a) For D-16 deformed bar




(b) For D-19 deformed bar




(c) For D-25 deformed bar

Fig. 3. Relative ultimate bond stress to that of 0% corrosion

## 4. Conclusions

The effects of the amount of rust on bond stress-slip relationship show a little difference for different nominal diameters of deformed bars. For D-16 deformed bar embedded in both high strength and normal strength, ultimate bond stresses of 2% and 4% corroded deformed bar are greater than that of 0% corroded deformed bar. For D-19 deformed bar, ultimate bond stress of 2% corroded deformed bar is greater than that of 0% corroded deformed bar irrespective of concrete strength. For D-25 deformed bar embedded in high strength concrete, ultimate bond stress of 2, 4, 6, 8, 10% corroded deformed bars become higher than that of 0% corroded deformed bars. A proper amount of rust may increase the bond stress by increasing roughness of the bar surface while a large amount of rust may decrease the bond stress due to loose rust. The amount of rust less than 4% seem to play a role in increasing roughness rather than loosening which resulted in increase of bond stress.

## References

1. Al-Sulaimani, G. J., Kaleemullah, M., Basunbul, I.A., and Rasheeduzzafa. (1990) Influence of Corrosion and Cracking on Bond Behavior and Strength of Reinforced Concrete Members, ACI Structural Journal, Technical Paper, pp. 220-231.