Pullout Test on Bond Splitting Property of Corroded Reinforced Concrete Member

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ABSTRACT: This paper aims to present the fundamental properties of bond splitting failures between corroded reinforcing bar and concrete in order to accumulate experimental data for proposing practical evaluating method. In this study, focusing on the relatively long bond region under the condition without confinement, concrete slab specimens, each of which have one reinforcing bar, were subjected to the pullout-loading test in order to determine the global bond performance between reinforcing bar and concrete. After the pullout test, specimens after failure were cut at a particular cross section in order to investigate damage and cracks due to corrosion or loading. From the test results, relationships between bond strength and relative mass loss of reinforcing bar up to 0.25 can be recognized. It is clarified that maximum bond stress will reduce as the corrosion proceeds, and its reduction rate will become larger when the thickness of cover concrete is large.

1. INTRODUCTION

It is important to confirm the safety performance of existing reinforced concrete structures, especially when they are damaged by corrosion. It is considered that the structural performance of reinforced concrete members decreases due to corrosion of reinforcing bars.

Until now, many researches have been carried out for evaluating structural performance of non-corroded reinforced concrete members, especially focused on the bond behaviour between reinforcing bar and concrete. According to the previous study[1], bond behaviour for confined deformed bars has been reported, showing that medium level (around 4%) of corrosion had no substantial influence on the bond strength, but substantial reduction in bond took place when corrosion increased thereafter to a higher level of around 6%, On the other hand according to the previous study by authors[2], bond behaviour for the local area has been reported using test results of the specimen with a bond length of four times of the diameter of reinforcement, showing that the internal cracks of surrounding concrete occur by corrosion of reinforcement, and the relationship between bond strength and weight reduction ratio of reinforcement up to 7% can be recognized.

However, no practical evaluating method has been proposed for corroded reinforced concrete members because of lack of experimental data and related information. In order to evaluate the bond splitting properties of corroded reinforced concrete member, a fundamental theory for bonding mechanisms based on the practical test results should be established. This paper aims to present the fundamental properties of global bond splitting failures between corroded reinforcing bar and concrete, focusing on the relatively long bond region under the condition without confinement, in order to propose a fundamental theory for bond mechanisms.

2. Test outline

2.1 Specimen

In this paper, authors have made an assumption that the bond splitting strength can be estimated by the summation of the strength carried by concrete splitting and confinement. It can be assumed that the former strength, carried by concrete splitting, would be effected by concrete damage due to corrosion. In order to confirm this assumption, pullout test with investigation of concrete damage due to corrosion has been planned.

Table 1 shows the properties of the specimens, and Figure 1 shows details of the specimen. Concrete slabs, each of which have one deformed bar in its center, were adopted as test specimens. The bond length as the testing region was set to 480mm, which is thirty times of the diameter of the reinforcing bar ($\phi = 16$ mm). Twenty-four mm (24=1.5 ϕ) region of each reinforcing bar at its loading and

free end is covered by plastic tubes in order to free from bond between reinforcing bar and concrete. In Table 1, specimens A and B were planned for the pullout test. On the other hand, specimens A2 and B2, were fabricated and subjected to the investigation on the concrete damage due to corrosion. (Investigation results and consideration using specimens A2 and B2 would be reported in the next opportunity.) Specimens A and A2, and also specimens B and B2, were subjected to the same electrolytic corrosion process, with the same accumulated corrosion current. Therefore, the internal corrosion situation and concrete damage of the specimen for pullout test (specimens A and B) can be estimated by the specimen for damage investigation (specimens A2 and B2).

2.2 Materials

The deformed high strength steel bars with specific diameter of 15mm (D16) were used for test reinforcement. The yield strength and elastic modulus of the reinforcing bar is 530MPa and 710MPa respectively. Normal concrete with the target compressive strength of 21MPa was utilized for the electrolytic corroded specimen. The compressive strength and elastic modulus of the concrete measured by compressive test results of cylindrical test pieces (diameter =100mm, height =200mm) at the age of pullout tests show 24.8 MPa and 26.7GPa respectively, and the tensile splitting strength measured by the same test pieces show 2.94MPa.

Table 1 Properties of test specimen

Specimen Name	Thickness of cover C (mm)	Relative mass loss	Accumulated corrosion current (A*hr)
D16CF15-0		0	0
D16CF15-A (A2)	24 (C/ ϕ =1.5)	0.132	73.3
D16CF15-B (B2)		0.249	146.6
D16CF25-0	40 (C/ ϕ =2.5)	0	0
D16CF25-A (A2)		0.144	73.3
D16CF25-B (B2)	(0,7 -10)	0.190	146.6
D16CF35-0	56 (<i>C/ø</i> =3.5)	0	0
D16CF35-A (A2)		0.099	73.3
D16CF35-B (B2)		0.157	146.6

 C/ϕ = quotient when dividing thickness of cover concrete by diameter of reinforcing bar



Figure 1 Details of the specimen



Figure 2 Electrolytic corrosion process

2.3 Electrolytic corrosion process

The accelerated corrosion process of specimens took place as a simulation of the corrosion of existing structures. Twelve specimens A and B shown in Table 1 were subjected to the electrolytic accelerated corrosion process. In table 1, the relative mass loss is determined by the mass loss divided by the original measured mass before corrosion. The relative mass loss of corrosion was targeted to 0.075 or 0.15 to make it a testing parameter.

Figure 2 shows the experimental set-up of the electrolytic corrosion process. After a minimum period of 28 days after casting, each specimen was subjected to electrolytic corrosion. A 3% NaCl solution by the weight of water was used as the electrolyte in a tank. The corrosion process shown in Figure 2 is intended for the entire testing region to corrode equally. U-shaped tanks were used in order to prevent corrosion of the reinforcing bar exposed at the loading end and free end. The corrosion extent was adjusted by controlling corrosion duration (accumulation of the electrolytic current). The corrosion current was set to 0.27A, and accumulation of the current was planned as shown in Table 1 referring to past experimental results.

2.4 Loading and measurement

Figure 3 shows the test set-ups. The specimens after electrolytic accelerated corrosion process were provided to pullout test. The specimen was set on the Teflon sheet, and the loading bed plate on which the hole with the same diameter corresponding to concrete cover not to restrict the lateral deformation of concrete. The reinforcing bar was subjected to monotonic pullout loading.



Figure 3 Loading and measurement





(D16CF15-B)

(D16CF35-B)



(ex. of rust-removed reinforcing bars)

Figure 4 Examples of corrosion situation

The measurement items are pullout load, lateral deformation and slippage of reinforcing bar at the loading end and free end. The slippage of reinforcing bar at the loading end was measured by a displacement transducer pointing at a target attached on the loading end of the reinforcing bar. The lateral deformations were measured by two displacement transducers attached on each north and south side surface.

3. Test results

3.1 Electrolytic corrosion process

Figure 4 shows examples of the corrosion situation after the electrolytic corrosion process. Corrosion rust from each (north and south) side surface was observed position by position in the electrolytic corrosion process. Also corrosion cracks took place along the reinforcing bar longitudinally. It is conceivable that thickness of cover concrete can have much effect on the corrosion extent, however, it cannot be recognized any relationship between the thickness of cover concrete and the corrosion extent.

The relative mass loss is determined by the weight measurement. After pullout test, reinforcing bars were retrieved from each specimen to determine their mass loss. Mass loss was measured by weighing rust-removed reinforcing bars after soaking in the solution of the diammonium hydrogen citrate, in accordance with the Japanese test code of JCI-SC1. Examples of rust-removed reinforcing bars are shown in Figure 4. The measured relative mass losses are summarized in Table 1. It is generally recognized that relative mass loss becomes larger as the accumulated corrosion current increases.

The distribution of crack width was summarized in Figure 5. Crack widths on the concrete surface were measured by crack-scale at the intervals of 50mm. According to this figure, significant opening of crack due to corrosion is located at the particular area (limited at x=100 or 450) even in case of severe corrosion. The reason can be assumed that severe corrosion will be produced only at the concentrated area, not at everywhere.



Figure 5 Distribution of crack width

Specimen name	At the time of max. load					
	Load (kN)	Bond stress (MPa)	Slippage at loading end (mm)	Relative mass loss		
D16CF15-0	50.66	2.10	-	-		
D16CF15-A	38.18	1.58	0.65	0.132		
D16CF15-B	31.83	1.32	0.99	0.249		
D16CF25-0	89.27	3.70	-	-		
D16CF25-A	63.80	2.64	0.88	0.144		
D16CF25-B	49.94	2.07	0.97	0.190		
D16CF35-0	123.29	5.11	-	-		
D16CF35-A	79.90	3.31	0.99	0.099		
D16CF35-B	58.90	2.44	0.89	0.157		
- : not measured						

з

2

0

D16CF15-A

D16CF15-B D16CF25-A D16CF25-B D16CF25-B D16CF35-A

D16CF35

2

Table 2 Test result

Figure 6 Relationship between modified slippage and average bond stress

3.2 Pullout test

All specimens failed by bond splitting between reinforcing bar and concrete. Test results of pullout tests are shown in Table 2. There were two patterns of fracture processes, in one case a specimen failed by newly generated splitting crack in spite of existing longitudinal crack due to corrosion. In another case a specimen failed by widening of existing longitudinal crack due to corrosion. In both case bond splitting cracks were generated or widened continuously from the loading end to the free end.

The relationships between the average bond stress and modified slippage at loading end are shown in Figure 6. The average bond stress is determined to the maximum pullout load divided by the perimeter length and the bond length of the reinforcing bar. The modified slippage at loading end is determined to the measured slippage at the loading end minus the elongation of the reinforcing bar at the region other than the testing (bond) region. It is clarified that maximum bond stress will reduce as the corrosion proceeds. When focusing on the average bond stress at the same modified slippage, the average bond stress decreases as the relative mass loss increases, and also the average bond stress decreases as the thickness of the cover concrete decreases.

The relationship between the average bond stress and the lateral displacement is shown in Figure 7. According to this figure, the difference of lateral displacements between south and north side surface can be clearly observed, and as is true with the all specimens. It can be considered that the reason of this difference is due to the difference of corrosion extent between south and north side surface, as stated in Figure 4.



Figure 7 Relationship between lateral displacement and average bond stress



Figure 8 Relationship between standardized bond strength and relative mass loss

4. Evaluation of bond strength

Figure 8 shows the relationship between the standardized bond strength and relative mass loss. The standardized bond strength is determined to the maximum bond stress divided by that of specimen without corrosion. (For example, the standardized bond stress of D16CF15-A is its maximum bond stress divided by that of D16CF15-0.) In this figure, the regression line by means of least square fit assigned for the results with the same C/ ϕ (cover / diameter) was shown together. According to this figure, the relative mass loss. From the regression analysis, the formula shown in this figure can be obtained, and relationships between the standardized bond strength and relative mass loss of reinforcing bar up to 0.25 can be recognized. The reduction rate of the standardized bond strength in reference to the relative mass loss will become larger when the thickness of cover concrete is large.

The situations of splitting surface of the specimens after failure are shown in Figure 9. Corrosion rust can be observed at the splitting surface, and its amount increases as the relative mass loss increases. Severe corrosion rust can be observed at one particular side (D16CF35-A= North side, D16CF35-B= South side) of cover



Figure 9 Situation of splitting surface after failure



Figure 10 Examples of the cross section of the specimens

concrete, and it can be easily assumed that the tensile resistant at that side is sufficiently small. On the other hand, corrosion rust at the other side (D16CF35-A= South side, D16CF35-B= North side) of cover concrete is relatively small, and it is presumable that the tensile strength at this splitting surface between front-back both sides is still remain to some extent.

After the pullout test, specimens after failure were cut at a cross section shown in Figure 10 by a dashed–dotted line, in order to investigate damage and cracks due to corrosion or loading. Note that this investigation method cannot distinguish corrosion cracks from loading cracks, therefore, in order to investigate the exact cracks due to corrosion, investigation results and consideration using specimens A2 and B2 should be studied.

Examples of the cross section of the specimens are shown in Figure 10. There is no crack other than a few significant cracks. It can be recognized that a particular splitting crack due to corrosion proceeded by pullout loading, and widening of the corrosion crack caused the ultimate failure.

5. CONCLUSION

In this paper, in order to present the fundamental properties of global bond splitting failures between corroded reinforcing bar and concrete, concrete slab specimens, each of which have one reinforcing bar, were subjected to the pullout-loading test, focusing on the relatively long bond region under the condition without confinement. It can be assumed that the bond strength carried by concrete splitting is effected by concrete damage due to corrosion, and in order to confirm this assumption, investigation of concrete damage due to corrosion after the pullout test has been planned.

From the test results, relationships between the bond strength and the relative mass loss of reinforcing bar up to 0.25 can be recognized. It is clarified that the maximum bond stress will reduce as the corrosion proceeds, and its reduction rate will become larger when the thickness of cover concrete is large. It is considered that the internal cracks due to corrosion make the bond strength lower in case of splitting failure of concrete. In order to discuss the effect of internal cracks due to corrosion, investigation results and considerations using specimens A2 and B2 should be discussed, and further researches and discussion should be made.

6. ACKNOWLEDGMENT

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7. REFERENCES

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