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# Corrosion in tensile reinforcement and its influence on shear performance of RC members

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## ABSTRACT

The corrosion in tensile reinforcement has significant effects on structural performances of reinforced concrete (RC) members because bond deterioration occurs between the reinforcing bar and concrete as the corrosion progresses. This study presents a shear test of RC members with corroded tensile reinforcement, where the anchorage detail and corrosion rate of tensile reinforcing bars were set as the key test variables. The experimental results showed that the shear strength decreased with increasing corrosion rate when the tensile reinforcing bars were simply anchored, and that the shear strength of corroded specimen increased compared to the reference specimen without corrosion damage when full anchorage condition was provided.

## 1. INTRODUCTION

In reinforced concrete (RC) structures, combined deterioration of concrete occurs over time due to many factors, such as concrete carbonation, chloride attack, sulfate attack, and freezing and thawing cycle, as shown in Fig. 1 (Han 2019). Among them, the concrete carbonation and chloride ion penetration induces steel corrosion (Azad et al. 2007; Azam 2010), by which reinforcing bars cause expansion pressure to the surrounding concrete because of corrosion products whose volume is 1.6 to 6.9 times the original steel volume (Liu and Weyers 1998; Han 2020). When the tensile stress of concrete induced by the expansion pressure reaches the tensile strength of concrete ($f_t$), radial cracks occur, thereby reducing bond performance between reinforcing bars and concrete (Lachemi et al. 2014). As a result, flexural and shear performances of RC

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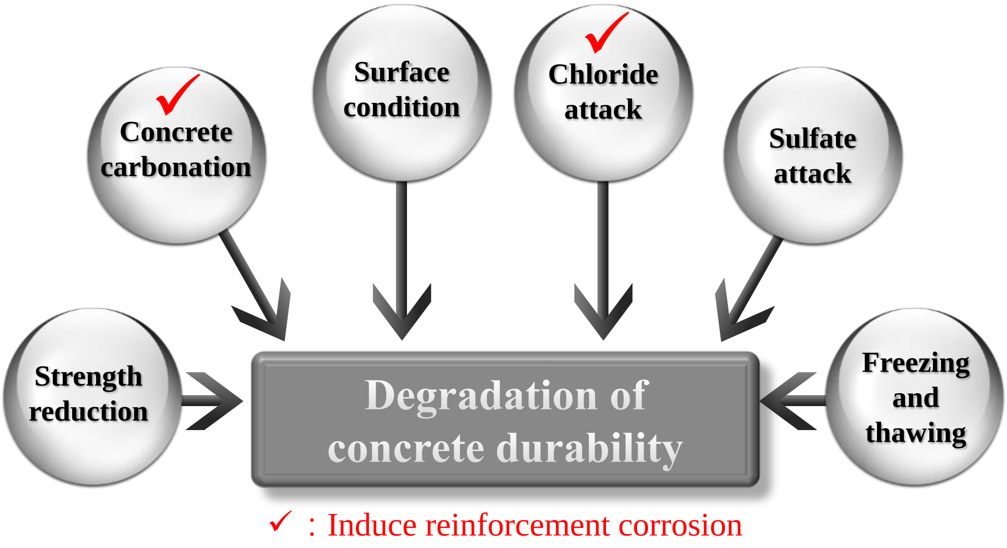


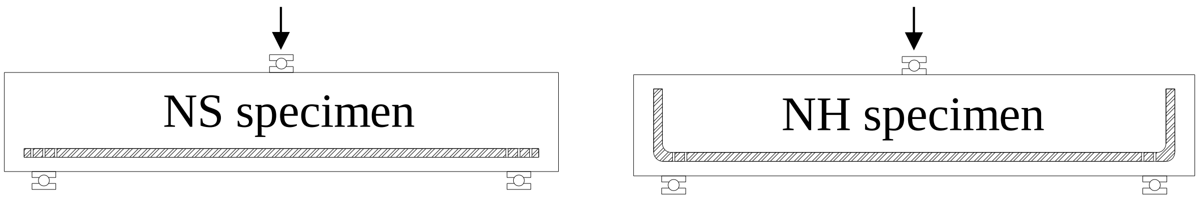

Fig. 1 Combined deterioration factors affecting on durability of concrete

members can be significantly degraded as corrosion progresses.

In this study, a shear test was performed to investigate the shear performance of RC beams with corroded tensile reinforcement. To this end, a total of eight RC beams were designed and fabricated, where the anchorage detail of tensile reinforcement and corrosion rate were set as the key test variables.

## 2. EXPERIMENTAL PROGRAM

Fig. 2 and Table 1 show the details and material properties of test specimens. In the NS specimen series, the tensile reinforcing bars were simply placed without any anchorage detail, whereas in the NS specimen series, the reinforcing bars with end hooks were used to achieve full anchorage condition. After the specimens were fabricated, they were immersed in 5% sodium chloride (NaCl) solution, and a direct current was applied to the tensile reinforcing bars to accelerate corrosion. Note that the period of accelerated corrosion test was determined via Faraday's law (Han 2019). After accelerating corrosion, all the specimens were simply supported and loaded with a shear span-to depth ratio ($a/d_s$) of approximately 3.0.




(a) NS specimen series (b) NH specimen series

Fig. 2 Details of test specimens

Table 1 Details and material properties of test specimens

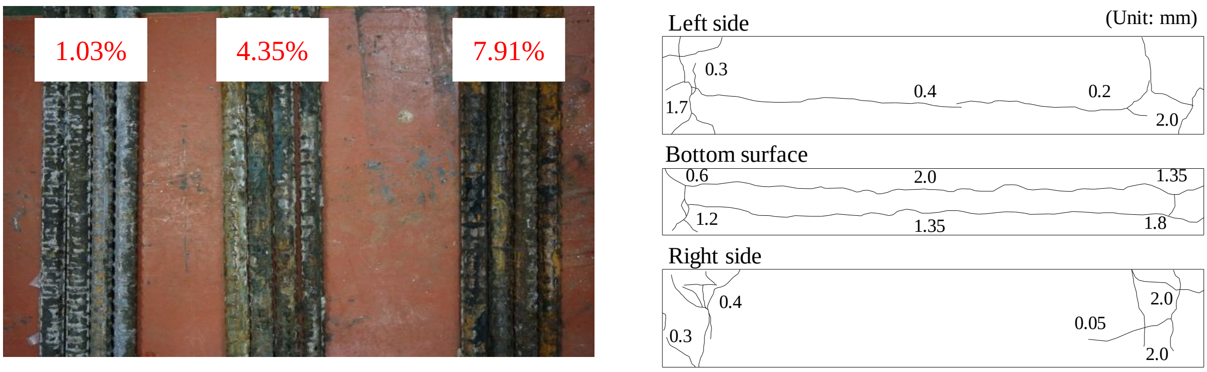
| Specimen | | $b_w$ (mm) | $h$ (mm) | $d_s$ (mm) | $A_s$ (mm$^2$) | $C_x$ (mm) | $f_c'$ (MPa) | $f_y$ (MPa) | $a/d_s$ | $\omega_{corr}$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| NS series | NS-0 | 170 | 250 | 203 | 774 | 30 | 39.2 | 400 | 2.96 | - |
| | NS-1 | 170 | 250 | 203 | 774 | 30 | 39.2 | 400 | 2.96 | 1.03 |
| | NS-4 | 170 | 250 | 203 | 774 | 30 | 39.2 | 400 | 2.96 | 4.35 |
| | NS-8 | 170 | 250 | 203 | 774 | 30 | 39.2 | 400 | 2.96 | 7.91 |
| NH series | NH-0 | 170 | 250 | 203 | 774 | 30 | 39.2 | 400 | 2.96 | - |
| | NH-1 | 170 | 250 | 203 | 774 | 30 | 39.2 | 400 | 2.96 | 1.38 |
| | NH-4 | 170 | 250 | 203 | 774 | 30 | 39.2 | 400 | 2.96 | 3.88 |
| | NH-7 | 170 | 250 | 203 | 774 | 30 | 39.2 | 400 | 2.96 | 6.71 |

Note: $b_w$: web width, $h$: height of member, $d_s$: depth of tensile reinforcement, $A_s$: amount of tensile reinforcement, $C_x$: clear cover thickness of concrete, $f_c'$: compressive strength of concrete, $f_y$: yield strength of tensile reinforcement, $a/d_s$: shear span-to-depth ratio, $\omega_{corr}$: corrosion rate of tensile reinforcement

## 3. EXPERIMENTAL RESULTS

### *3.1 Accelerated corrosion test result*

After the shear test, all the tensile reinforcing bars were extracted from the corroded specimens, subsequently the corrosion products formed on the reinforcing bar surface were removed by using Clark solution (Han 2020). The corrosion rates were determined by dividing the difference in weights measured before and after accelerated corrosion test by the original weight of tensile reinforcement, and the corrosion rate of each specimen was presented in Table 1. In addition, as shown in Fig. 3, splitting cracks occurred along the tensile reinforcing bar layers due to corrosion. At a low corrosion rate (i.e., $\omega_{corr} \cong 1.0\%$), the crack width was very small, while at a high corrosion rate of greater than 7.0%, a very large crack width of 2.0 mm was observed.



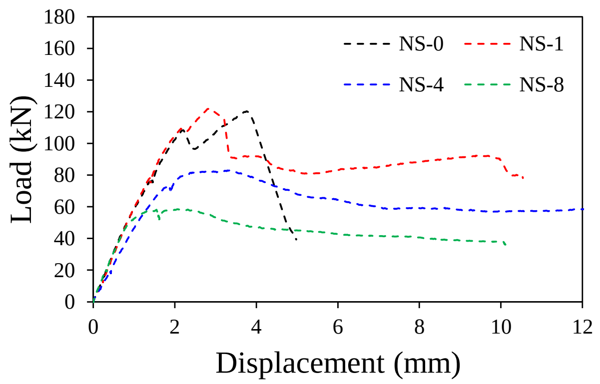

(a) Corroded tensile reinforcements

(b) Cracks due to corrosion (NS-8 specimen)

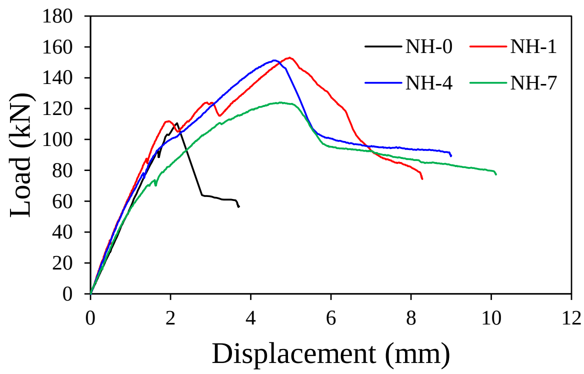
Fig. 3 Accelerated corrosion test results

### *3.2 Shear test result*

Fig. 4 shows the comparison of shear behaviors of test specimens, and the shear strength and failure mode of each specimen are summarized in Table 2. As shown in Fig. 4(a), when the tensile reinforcing bars had no proper anchorage detail, the stiffness and shear strength decreased as the corrosion rate increased. By contrast, when the tensile reinforcing bars were fully anchored in the anchorage zone, as shown in Fig. 2(b), the shear strength of corroded RC specimen was larger than that of the reference specimen NH-0. Even in the case of NH-7 specimen with a high corrosion rate of 6.71%, the strength increased compared to the NH-0 specimen. It is estimated that, when the tensile reinforcement is properly anchored in RC member, the main shear transfer mechanism of the member changes from the beam action to the tied-arch action as the corrosion rate of tensile reinforcement increases, resulting in increase in shear strength.




(a) NS specimen series




(b) NH specimen series

Fig. 4 Comparison of shear behavior according to corrosion rate

Table 2 Details and material properties of test specimens

| Specimen | | $\omega_{corr}$ (%) | $P_n$ (kN) | $V_n$ (kN) | $\Delta$ (mm) | Failure mode | Strength ratio |
|---|---|---|---|---|---|---|---|
| NS series | NS-0 | - | 120.2 | 60.1 | 3.76 | Shear | 1.00 |
| | NS-1 | 1.03 | 122.2 | 61.1 | 2.86 | Shear | 1.02 |
| | NS-4 | 4.35 | 83.0 | 41.5 | 3.36 | Shear + bond | 0.69 |
| | NS-8 | 7.91 | 58.5 | 29.3 | 2.06 | Shear + bond | 0.49 |
| NH series | NH-0 | - | 110.5 | 55.3 | 2.54 | Shear | 1.00 |
| | NH-1 | 1.38 | 153.1 | 76.6 | 4.97 | Shear | 1.39 |
| | NH-4 | 3.88 | 151.2 | 75.6 | 4.62 | Shear | 1.37 |
| | NH-7 | 6.71 | 124.0 | 62.0 | 4.76 | Bond | 1.12 |

## 4. CONCLUSIONS

The following conclusions can be drawn through this research.

1. When the tensile reinforcing bars were simply anchored without any specific anchorage details, the shear strength of corroded RC specimen decreased with increasing corrosion rate. This is because the bond performance between tensile reinforcement and concrete was deteriorated as the corrosion rate increased.
2. It was clearly shown in the shear test that, when the tensile reinforcing bars were fully anchored in the anchorage zone, the shear strength of corroded RC specimen increased compared with the non-corroded specimen even when the tensile reinforcement was severely corroded. It is estimated that this phenomenon was due to the change in shear transfer mechanism from the beam action to the arch action.

## ACKNOWLEDGMENT

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