■Ngày nhận bài: 13/5/2024 ■Ngày sửa bài: 20/6/2024 ■Ngày chấp nhận đăng: 17/7/2024

Influence of artificial accelerated cyclic corrosion on tensile behavior of reinforcement in concrete

Ảnh hưởng của ăn mòn cưỡng bức đến ứng xử kéo của cốt thép bị ăn mòn

> NGUYEN THANH HUNG[1], PHD DUY KIEN DAO[1*], DOAN DINH THIEN VUONG[1]
[1]Department of Civil Engineering, Ho Chi Minh City University of Technology and Education
nthung@hcmute.edu.vn, 1980839@student.hcmute.edu.vn, kiendd@hcmute.edu.vn
[*]Corresponding author, E-mail: kiendd@hcmute.edu.vn

ABSTRACT

This study focuses on analyzing the tensile behavior of accelerated corrosion of rebar in reinforced concrete structures. The test specimens were created to accurately reflect the actual working conditions of reinforced concrete structures subjected to corrosion. Three types of test specimens corresponding to three types of rebar diameters of 12mm, 16mm, 20mm, concrete grades B25, B35 and B45, were immersed in a tank of 3.5% NaCl solution for certain periods of time. The steel specimens after the corrosion test were put into the tensile test. The results indicated that, the maximum load - slipping displacement reduce from D20, D16 and D12. There are no difference between specimens but in D16 and D20 ones, we can see this thing clearly. Based on this, the smaller diameter of rebar the more effectively connect between rebar and concrete. The bearing capacity decreased up to 40%, the deformation decreased up to 35%.

Keywords: Local corrosion; accelerated cyclic corrosion test; tensile behavior; Faraday principle.

TÓM TẮT

Nghiên cứu này tập trung vào việc phân tích ứng xử kéo của cốt thép trong các kết cấu bê tông cốt thép chịu ăn mòn cưỡng bức. Mẫu thí nghiệm được tạo ra nhằm phản ánh chính xác điều kiện làm việc thực tế của kết cấu bê tông cốt thép chịu ăn mòn. Ba loại mẫu thí nghiệm tương ứng với ba loại đường kính cốt thép là 12mm, 16mm, 20mm, mác bê tông B25, B35 và B45, được ngâm trong bể chứa dung dịch NaCl 3,5% trong các khoảng thời gian nhất định. Các mẫu thép sau khi thử ăn mòn được đưa vào phân thích bằng thí nghiệm kéo. Kết quả cho thấy, tải trọng - chuyển vị cực đại giảm từ D20, D16 và D12. Không có sự khác biệt giữa các mẫu nhưng ở mẫu D16 và D20, chúng ta có thể thấy rõ điều này. Dựa trên điều này, đường kính cốt thép càng nhỏ thì sự kết nối giữa cốt thép và bê tông càng hiệu quả. Khả năng chịu lực giảm tới 40%, biến dạng giảm tới 35%.

Từ khóa: Ăn mòn cục bộ; thí nghiệm ăn mòn cưỡng bức; ứng xử kéo; định luật Faraday.

1. INTRODUCTION

Reinforced concrete structures work together over time under the influence of working conditions such as load, climate, erosion, chemicals, and especially corrosion, which will lead to a gradual loss of working capacity, even destruction [1].

The steel itself is designed to always work under ideal conditions, but the reality is not the same as the design. Many factors cannot be quantified and standardized into standards, and in the design stage, it can only be estimated. Corrosion is one of those factors, and to date, the establishment of standards for the design of corrosion-resistant structures has not yet had official results. However, corrosion is an obvious phenomenon when reinforced concrete structures work [2-4].

Concrete has the effect of protecting the rebar, but the steel itself will automatically corrode inside the concrete. The corrosion process forms and develops rapidly in conditions where the concrete structure is cracked, when the corrosive agent will come into direct contact with the steel. Then, under the effect of the load, the steel itself will have initial small cracks called initial cracks. Corrosion will develop very quickly in these areas [5-6].

The cross-sectional area of corroded steel will decrease, leading to a rapid decrease in the bearing capacity of the steel structure due to the problem of concentrated stress on the corrosion holes. The formation and development of corrosion of steel in concrete is completely random and difficult to predict. Therefore, periodic maintenance and warranty work must be continuously carried out, causing heavy economic losses [7-9].

Many authors in the world have conducted research on corrosion of reinforced concrete structures by experiment, simulation, and finite element analysis [10-12]. Gu et al. [13] experimentally studied the non-uniform distribution of cross-sectional area and mechanical properties of corroded steel bars in chloride environment by exposing 19 pre-loaded steel plates to chloride environment to achieve rapid corrosion. Using 3D simulation to generate geometric model of corroded steel bars and cross-sectional area of corroded steel bars, the probability distribution model of spatial variation coefficient R, was developed through signal processing and statistical analysis methods. The coefficient R is the ratio of the average cross-sectional area to the minimum area and is applied to analyze the mechanical behavior of bars against non-uniform corrosion under tensile load.

This study focuses on performing electrochemical corrosion experiments of reinforced concrete structures in 3.5% salt water solution. The study was conducted to change the concrete strength, steel diameter, current intensity, and exposure to corrosive environment for different periods of time. The corroded samples after the experiment were analyzed for corrosion characteristics, then performed tensile tests to determine the tensile behavior of corroded steel over time. Corrosion formation and development led to serious destruction with complex random nature. The knowledge gained from this study will supplement the design of corrosion-resistant steel structures.

2. PROCESS TO OBTAIN THE CORRODED SPECIMENS BY ELECTROCHEMICAL CORROSION METHOD

2.1 Test specimens

CB400-V steel is used to create the specimen

The diameter of the steel bars is selected as 12mm, 16mm, 20mm respectively

The concrete strength is investigated through 3 durability levels B25, B35 and B45

The geometry model of specimen is shown in Figure 1

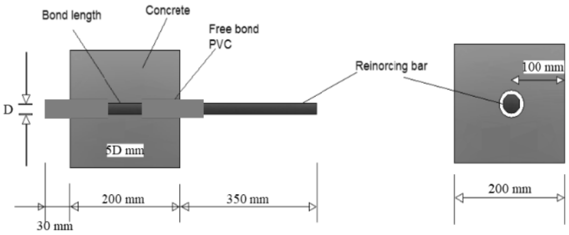

Figure 1. Dimension and geometry of specimens

2.2 Accelerated cyclic corrosion test

- The amount of water and the concentration of NaCl 3.5%
- The sample was immersed in the solution tank for 7 days
- After 7 days, the sample was connected to the power source to perform forced corrosion

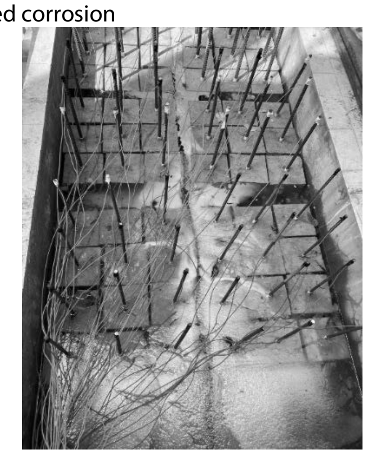

Figure 2. Test Samples when corrosive with salt electrolyses $NaCl$ 3,5%

Table 1: List of specimens were used to carry out the corrosion test

Type of specimens	Dimension of steel bar (mm)	Bond length (mm)	Compressive strength of Concrete (MPa)	Corrosion solution % NaCl	c_c (%)	M_{th} (g)	T ($hours$)	Number of specimens
M_{11}	12	60	25	0	0	0	0	3
M_{12}	12	60	35	0	0	0	0	3
M_{13}	12	60	45	0	0	0	0	3
M_{21}	16	80	25	0	0	0	0	3
M_{22}	16	80	35	0	0	0	0	3
M_{23}	16	80	45	0	0	0	0	3
M_{31}	20	100	25	0	0	0	0	3
M_{32}	20	100	35	0	0	0	0	3
M_{33}	20	100	45	0	0	0	0	3
$S1_1$-1	12	60	25	3.5	5	2,664	51,14	3
$S1_1$-2	12	60	25	3.5	15	7,992	153,47	3
$S1_1$-3	12	60	25	3.5	25	13,325	255,78	3
$S1_2$-1	12	60	35	3.5	5	2,664	51,14	3
$S1_2$-2	12	60	35	3.5	15	7,992	153,47	3
$S1_2$-3	12	60	35	3.5	25	13,325	255,78	3
$S1_3$-1	12	60	45	3.5	5	2,664	51,14	3
$S1_3$-2	12	60	45	3.5	15	7,992	153,47	3
$S1_3$-3	12	60	45	3.5	25	13,325	255,78	3
S_{21}-1	16	80	25	3.5	5	6,32	121,32	3

S_{21}-2	16	80	25	3.5	15	18,96	363,95	3
S_{21}-3	16	80	25	3.5	25	31,60	606,58	3
S_{22}-1	16	80	35	3.5	5	6,32	121,32	3
S_{22}-2	16	80	35	3.5	15	18,96	363,95	3
S_{22}-3	16	80	35	3.5	25	31,60	606,58	3
S_{23}-1	16	80	45	3.5	5	6,32	121,32	3
S_{23}-2	16	80	45	3.5	15	18,96	363,95	3
S_{23}-3	16	80	45	3.5	25	31,60	606,58	3
S_{31}-1	20	100	25	3.5	5	12,35	237,07	3
S_{31}-2	20	100	25	3.5	15	37,05	711,20	3
S_{31}-3	20	100	25	3.5	25	61,75	1185,3	3
S_{32}-1	20	100	35	3.5	5	12,35	237,07	3
S_{32}-2	20	100	35	3.5	15	37,05	711,20	3
S_{32}-3	20	100	35	3.5	25	61,75	1185,3	3
S_{33}-1	20	100	45	3.5	5	12,35	237,07	3
S_{33}-2	20	100	45	3.5	15	37,05	711,20	3
S_{33}-3	20	100	45	3.5	25	61,75	1185,3	3

Table 2. Tensile tests results when steel bars corroded

D12			D16			D20		
Specimens	Load (kN)	Displacement (mm)	Specimens	Load (kN)	Displacement (mm)	Specimens	Load (kN)	Displacement (mm)
M_1	72,1	69,09	M_2	124,55	76,12	M_3	200	85,588
S_{11}-1	70,09	67,16	S_{21}-1	112,49	68,75	S_{31}-1	151,64	64,89
S_{11}-2	68,31	65,46	S_{21}-2	101,07	61,77	S_{31}-2	132,21	56,58
S_{11}-3	62,04	59,46	S_{21}-3	85,70	52,38	S_{31}-3	123,45	52,83
S_{12}-1	70,89	67,93	S_{22}-1	117,76	71,97	S_{32}-1	176,97	75,73
S_{12}-2	68,86	65,99	S_{22}-2	115,54	70,61	S_{32}-2	157,82	67,54
S_{12}-3	67,65	64,83	S_{22}-3	110,75	67,69	S_{32}-3	149,16	63,83
S_{13}-1	70,45	67,51	S_{23}-1	122,58	74,92	S_{33}-1	184,925	79,14
S_{13}-2	69,79	66,88	S_{23}-2	121,26	74,11	S_{33}-2	173,73	74,35
S_{13}-3	67,84	65,01	S_{23}-3	117,4	71,75	S_{33}-3	165,91	71,00


Figure 3. Tensile test of corroded reinforcing bar

2.3 Bearing capacity of reinforcement when corrosive

- The test sample after corrosion is cleaned
- Measurement of corrosion parameters such as corrosion hole diameter, corrosion depth, remaining mass
- Classification and testing for tensile test
- The experiment is determined according to ASTM Standard E8/E8M-18

3. RESULTS AND DISCUSSION

The experimental results are summarized in Table 2, in which the values obtained from the load and displacement of each type of sample are presented in detail.

On the above figures, the maximum load - slipping displacement reduce from D20, D16 and D12. In the D12 figure; there are no difference between specimens but in D16 and D20 ones, we can see this thing clearly. Base on this, the smaller diameter of rebar the more effectively connector between rebar and concrete.

In another hand; since the corrosion has appeared, the delamination will develop fastest from D20 and reducing to D16 and D12.

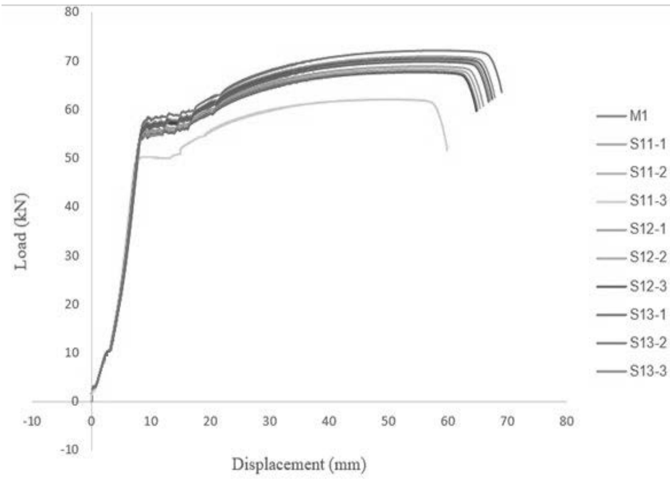

Figure 4. Relation of load - sliping displacement with reinforcement D12

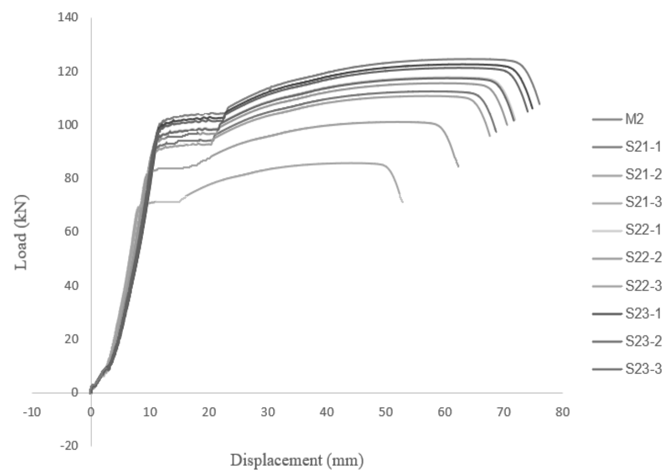

Figure 5. Relation of load - sliping displacement with reinforcement D16

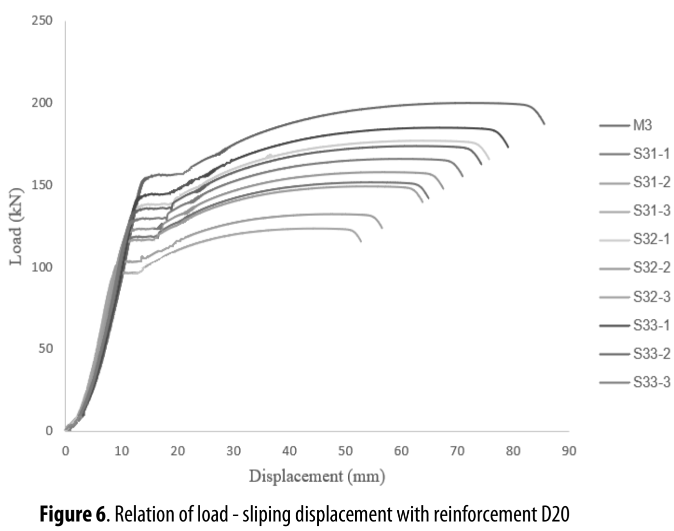

Figure 6. Relation of load - sliping displacement with reinforcement D20

4. CONCLUSION

After accelerated corrosion test, 12 corroded steel samples were analyzed for the effect of corrosion on the tensile behavior of rebar working with concrete as follows:

- Higher strength concrete will protect the steel from corrosion better, the corrosive agent will have difficulty penetrating into the gap between concrete and steel, so the corrosion process will occur more slowly.
- Under the influence of corrosion, the tensile strength of steel decreases by up to 40%
- Displacement and deformation decrease by up to 35%

REFERENCES

[1] A. Kivell, A. Palermo and A. Scott, "Effects of Bond Deterioration due to Corrosion in Reinforced Concrete," Proceedings of the Ninth Pacific Conference on Earthquake Engineering, Auckland, New Zealand, 14-16 April, 2011.

[2] S. Lim, M. Akiyama and D. M. Frangopol, "Assessment of the structural performance of corrosion-affected RC," *Engineering Structures,* vol. 127, pp. 189-205, 2016.

[3] M. Blomfors, "Engineering bond model for corroded reinforcement," *Engineering Structures,* vol. 156, pp. 394-410, 2018.

[4] A. K. Rafiq and M. Imran, "Performance assessment of corroding RC beams using response surface," *Engineering Structures,* vol. 49, pp. 671-685, 2013.

[5] Z. H. Wang, L. Li, Y. X. Zhang and W. T. Wang, "Bond-slip model considering freeze-thaw damage effect of concrete and its," *Engineering Structures,* vol. 201, p. 109831, 2019.

[6] W. Zhu, R. François, D. Coronelli and D. Cleland, "Effect of corrosion of reinforcement on the mechanical behaviour of," *Engineering Structures,* vol. 56, pp. 544-554, 2013.

[7] W. Zhu and R. François, "Experimental investigation of the relationships between residual cross-section shapes and the ductility of corroded bars," *Construction and Building Materials,* vol. 69, pp. 335-345, 2014.

[8] D. M. Ahmed, E. Hafez, M. A. Hussei and A. M. Hazem, "Bond behavior and assessment of design ultimate bond stress of normal and high strength concrete," *Alexandria Engineering Journal,* vol. 53, pp. 355-371, 2014.

[9] D. A. Moran and C. P. Pantelides, "Stress-strain model for fiber-reinforced polymer-confined concrete," *Journal of Composites for Construction,* vol. 6, no. 4, pp. 233-240, 2002.

[10] K. A. Soudki and F. G. Mark, "Freeze-thaw response of CFRP wrapped concrete," *Concrete International,* vol. 19, no. 8, pp. 64-67, 1997.

[11] B. S. Pantazopoulou, "Repair of corrosion damaged columns with FRP Wraps," *Journal of Composites for Construction,* vol. 2, pp. 3-11, 2001.

[12] A. Debaiky, F. Mark and B. Hope, "Carbon fiber-reinforced polymer wraps or corrosion control and rehabilitation of reinforced concrete columns," *Journal Materials,* vol. 2, pp. 129-137, 2002.

[13] X. Gu, H. Guo, B. Zhou, W. Zhang and C. Jiang, "Corrosion non-uniformity of steel bars and reliability of corroded RC beams," *Engineering Structures,* vol. 167, pp. 188-202, 2018.