Corrosion Rate of Reinforced Bar under Different Strains

Xun WU[1,a,*], Zhi-Chao ZHANG[2,b], Jian-Jun YUE[3,c]

[1,2,3]Department of Bridge Engineering, Tongji University, Shanghai, China

[a]wuxuns@126.com, [b]15801822589@163.com,[c]jianjun1234588@126.com,

*Corresponding author

Keywords: Reinforced Bar, Corrosion Rate, Strain, Salt-spray Corrosion.

Abstract. Steel bar corrosion is a major cause of the durability failure of concrete structures. Researches of corrosion were basically done in steel bars without stress by domestic and foreign scholars. Therefore, it is significant to study the relationship between rebar strain and corrosion rate by testing. In the test, reinforced bar groups were imposed with different levels of strain and the strains were kept by reaction frame. Then, these groups were put into the salt spray device for accelerated corrosion in four time periods. Finally, mass loss rates of these reinforced bars were measured and calculated. By data fitting, the result shows a relation between mass loss rate and strain level of reinforced bars.

Introduction

Among all the factors causing the durability failure and destruction of concrete structures, steel bar corrosion has been a major one. The damages of steel bar corrosion for concrete structures mainly reflect in three aspects: reduce the carrying capacity and safety margin of structures or members; decrease the stiffness of structures, increase the deformation and influence the serviceability; weaken the ductility and change the failure mode, resulting in deaths and injuries [1].

In order to make the durability design and evaluation of concrete structures, it is necessary to study the factors affecting the steel bar corrosion. A lot of steel bar corrosion tests and theoretical analysis [2, 3, 4] have been done by domestic and foreign scholars and many useful results have been achieved. However, those studies are generally carried out in the unstressed state of steel bars, and even the research for steel bars obtained from the actual structure also ignored the influence of the stress on results. Obviously, the steel bars in actual structures are always under some strain state, so it has an important practical significance to study the impact of strain levels on steel bars.

Test Method

Imposing Stress on the Reinforced Bar

The reinforced bar called HRB400 in Chinese specifications was chosen to do the test. The diameter of each specimen is 16cm. Four strain values (0, 0.5×10^{-3}, 0.75×10^{-3}, and 1.0×10^{-3}) ware imposed on four reinforced bar groups. Each group contains 24 reinforced bars. The initial strains of reinforced bars were balanced by reaction frames. Each reaction frame consists of two steel plates and four screws. Both ends of the steel specimen were processed into threads and anchored through nuts. By turning the nuts on the screws, tensile stress was induced in the reinforced bar. Initial strain values were controlled by strain gauges on reinforced bars and pressure sensors under nuts. Strain conditions of bars were monitored during the experiment process.

Accelerated Corrosion Method

According to “Artificial atmosphere corrosion test, salt spray test (GB/T10125) [5]”, test time was respectively set for 4 days, 10 days, 20 days, and 30 days. Namely, every 6 reinforced bar in each group suffered a period of time. Corrosion of reinforced bars in natural environment is essentially electrochemical reaction process. There are two factors leading to the damage of steel passivation

© 2014. The authors - Published by Atlantis Press

film and making the steel bars rust. One is the neutralization of concrete (mainly in the form of carbide), resulting in the decrease of pH value around steel bars. The other is the concentration of free chloride ion to steel surface, penetrating the passivation film. In this test, the main purpose is to study the effects of strain level on steel corrosion. Therefore, other factors were excluded and the strain level was set as a separate variable. The corrosion of reinforced bars was accelerated by chloride salt. First, different specimen groups were put into a salt spray chamber. Then, the salt fog is formed using sodium chloride salt solution 5%. Finally, different test time groups were accelerated corrosion and removed respectively.

Determination of Corrosion Rate

For each specimen taken from the salt spray chamber, fifty centimeters long was cut from the middle. According to the method prescribed in "Ordinary concrete long-term performance and durability test method standards (GBT50082) [6]", the specimens cut were all washed, weighed and measured. The quality corrosion rate of each one was calculated, based on the Eq.1.

$$\text{mass corrosion rate}=\frac{M_0 / L_0 - M_1 / L_1}{M_0 / L_0}\times 100\%. \quad (1)$$

In the Eq.1, M0 and M1 are respectively the quality of reinforced specimens before and after the test. L0 and L1 are respectively the length of reinforced bars as well.

Analysis of Steel Corrosion Rate under Different Strains

After the accelerated corrosion test, the average test data are shown as Table.1.

Tab. 1 the Average Corrosion Rate Value of Each Group Specimen

	Test time[day]	4d	10d	20d	30d
Strain level	0×10^{-3}	0.93%	1.91%	3.05%	3.86%
	0.5×10^{-3}	1.02%	2.05%	3.29%	4.21%
	0.75×10^{-3}	1.06%	2.20%	3.51%	4.43%
	1.0×10^{-3}	1.13%	2.34%	3.75%	4.71%

Table 1 shows that the corrosion rate increases with time. Besides, corrosion rate and the stress level are closely related. At some condition and test time, corrosion rate expands with the increase of strain level, which can be clear understood from Fig.1.

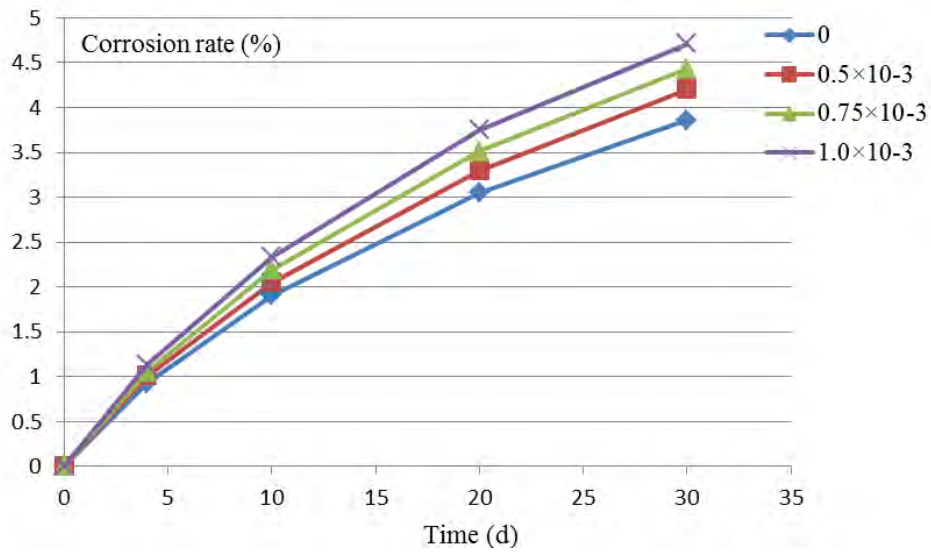

Fig. 1 Corrosion Rate Curves under Four Different Strain Levels

As the Fig.1 shows, the strain level has a non-ignorable influence on reinforced bar corrosion rate. Therefore, it is improper to take no account of the strain of steel bar in practical and experimental

research projects. In order to study the influence law and degree of strain on the corrosion rate, statistical methods will be used. Before the data analysis, some symbols need to be defined to make a clear description. The strain corresponding to the standard value of rebar tensile strength (400MPa) is denoted by εsk. Strain value of some strain level is denoted by εa. Corrosion rate for strain 0 under some condition and time is denoted by η0. At the some condition and time, corrosion rate for strain εa is denoted by ηa. Then, the relationship between η0 and ηa will be established. Statistical regression curves of weigh corrosion rate and strain values under different test time are drawn as Fig.2, Fig.3, Fig.4 and Fig.5.

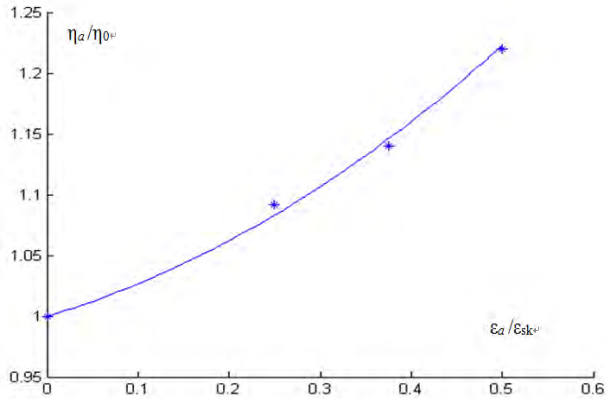

Fig. 2 Relationship between Strain and Corrosion Rate (4 days)

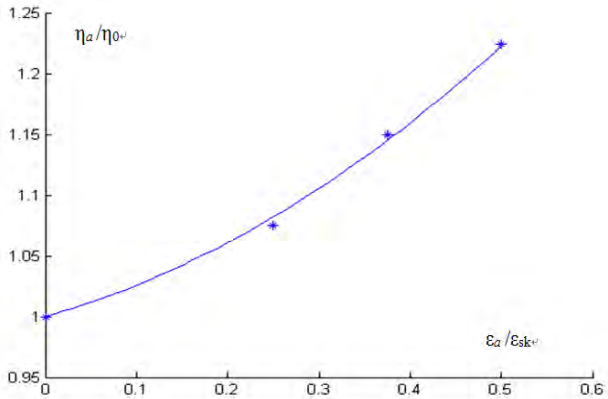

Fig. 3 Relationship between Strain and Corrosion Rate (10 days)

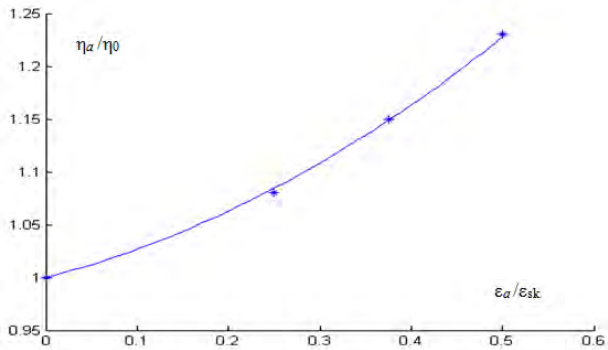

Fig. 4 Relationship between Strain and Corrosion Rate (20 days)

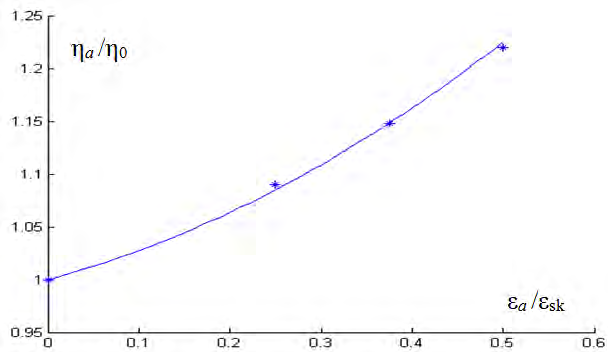

Fig. 5 Relationship between Strain and Corrosion Rate (30 days)

The regression curve in Fig.2 is fitted by quadratic function and its mathematical relationship can be expressed as Eq.2.

$$\eta_a=\eta_0[1+0.22\left(\frac{\varepsilon_a}{\varepsilon_{sk}}\right)+0.45\left(\frac{\varepsilon_a}{\varepsilon_{sk}}\right)^2] \tag{2}$$

The regression curve in Fig.3 is fitted by quadratic function and its mathematical relationship can be expressed as Eq.3.

$$\eta_a=\eta_0[1+0.21\left(\frac{\varepsilon_a}{\varepsilon_{sk}}\right)+0.47\left(\frac{\varepsilon_a}{\varepsilon_{sk}}\right)^2] \tag{3}$$

The regression curve in Fig.4 is fitted by quadratic function and its mathematical relationship can be expressed as Eq.4.

$$\eta_a=\eta_0[1+0.22\left(\frac{\varepsilon_a}{\varepsilon_{sk}}\right)+0.47\left(\frac{\varepsilon_a}{\varepsilon_{sk}}\right)^2] \tag{4}$$

The regression curve in Fig.5 is fitted by quadratic function and its mathematical relationship can be expressed as Eq.5

$$\eta_a=\eta_0[1+0.23\left(\frac{\varepsilon_a}{\varepsilon_{sk}}\right)+0.44\left(\frac{\varepsilon_a}{\varepsilon_{sk}}\right)^2] \tag{5}$$

From Eq.2 to Eq.5, we can see there is a similar relationship between weigh corrosion rate and strain level under different corrosion test time. Considering the test and calculation errors, it can be thought that the relationship between weigh corrosion rate and strain level don't change with time. Therefore, a unified equation can be gotten as Eq.6

$$\eta_a=\eta_0[1+0.22\left(\frac{\varepsilon_a}{\varepsilon_{sk}}\right)+0.455\left(\frac{\varepsilon_a}{\varepsilon_{sk}}\right)^2] \tag{6}$$

Summary

By the accelerated corrosion test, we can draw two main conclusions

1. Corrosion rate and the stress level are closely related. At some condition and test time, corrosion rate expands with the increase of strain level.
2. The Eq.6 elaborates a relationship between weigh corrosion rate of reinforced bar with strain εa and strain 0 under the same other conditions. Thus, if we know the weigh corrosion rate of reinforced bar with strain 0 under a certain condition, then we can calculate the weigh corrosion rate of the reinforced bar with any strain value at the same condition, using Eq.6.

Acknowledgement

This research was financially supported by China National 973 Plan No. 2013CB036303.

References

[1]Mu Lu, Puxin Wang, Research Status of steel corrosion in concrete, Concrete. 2(2000) 37-41. (In Chinese)

[2]Vu KAT, Stewart M G, Structural reliability of concrete bridges including improved chloride-induced corrosion models, Structural safety. 22(2000) 313-333.

[3]Liu T, Weyers R W, Modeling the dynamic corrosion process in chloride contaminated concrete structures, Cement and Concrete Research. 28(1998) 365-379.

[4]Weiping Zhang, Dengfeng Shang, Xianglin Gu, Stress-Strain Relationship of Corroded Steel Bars, Journal of Tongji University(Natural Science).34(2006) 586-592.(In Chinese)

[5]State Quality and Technical Supervision, Artificial atmosphere corrosion test, salt spray test (GB/T10125), Beijing, 1997. (In Chinese)

[6]Ministry of Housing and Urban-Rural Development of the People's Republic of China, Ordinary concrete long-term performance and durability test method standards (GBT50082), Beijing, 2010. (In Chinese)