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Effect of strain level on corrosion of stainless steel bar

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HIGHLIGHTS

- The degree of corrosion of stainless steel bar increased with increase of strain level.
- The mechanical properties of stainless steel bar had an obvious degradation with increase of degree of corrosion.
- The strain level ($\leq 1.0 \times 10^{-3}$) had no significant effect on mechanical properties of stainless steel bar within 15% corrosion degree.

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ABSTRACT

This paper presents an experimental investigation into the corrosion of stainless steel bar in the stressed state. By performing an electrochemical accelerated corrosion test on S11203 stainless steel bar under different strain levels and a tensile test on corroded stainless steel bar, effect of strain level on corrosion of stainless steel bar was investigated. The experimental results indicated that strain level affected the degree of corrosion of stainless steel bar. The higher the strain, the higher the degree of corrosion. The degree of corrosion of stainless steel bar under a strain of 1.0×10^{-3} was 9 percent higher than that of under zero strain. With increase of the degree of corrosion, the yield strength, ultimate strength and elongation of stainless steel bar gradually degenerated, and especially significant for the degradation of elongation. It was also found that the influence of strain level ($\leq 1.0 \times 10^{-3}$) on corrosion morphology and mechanical properties of stainless steel bar within 15% corrosion degree was not significant.

1. Introduction

The electrochemical corrosion of reinforcement caused by chloride ion erosion is the main reason for the decrease in durability of concrete structures [1–4]. Concrete structures such as port structures, marine structures, and highway bridges using deicing salt are exposed in severe chloride environment for long periods [5–7]. The invasion of chloride ion will make the passive film on the surface of reinforcement ruptured, causing reinforcement corrosion. Corrosion can bring a degradation of tensile strength of the reinforcement and a decrease of the cohesive force between the concrete and reinforcement [8], resulting in the decrease of carrying capacity, reliability and durability of the structure. For some important concrete structures in severe chloride environment, some higher requirements on their service life and durability may be put forward by the owner. Since the use of ordinary reinforcement is unable to meet these requirements, the stainless steel bar with excellent corrosion resistance is suggested to be used in concrete to ensure the durability of structures [5,9–11]. It is generally believed that the use of stainless steel bar will increase the investment, and there is a risk of corrosion due to the electric coupling between stainless steel bar and carbon steel bar [5]. However, large quantities of engineering practices indicate that the use of stainless steel bar may increase the early investment, but can effectively reduce post-project maintenance and repair expense. Instead, life cycle cost is lower [12–14]. Experimental studies also have shown that the combined use of stainless steel bar and carbon steel bar in concrete doesn't increase the risk of corrosion [15]. Therefore, instead of using carbon steel bar, stainless steel bar is used in the surface or the weakest parts of concrete structures [5]. In recent years, stainless steel bar has been applied to many bridge projects of China, such as Hong Kong Stonecutters Island Bridge, Shenzhen West Passage Bridge and HK-Zhuhai-Macao Bridge [16,17].

With the gradual application of stainless steel bar in the structures, it is a very significant topic to study the corrosion of stainless steel bar. It is well-known that the corrosion resistance of reinforcement is mainly derived from the passive film on the surface

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of reinforcement. The stainless steel bar has more excellent corrosion resistance because much denser passive films can be formed on its surface [16]. The salt-spray corrosion comparative tests of 2205 and 2304 stainless steel bar and ordinary reinforcement indicate that, the corrosion amount of ordinary reinforcement is greater than stainless steel bar at the same corrosion condition, corrosion leads to the degradation of strengths and ductility of ordinary reinforcement but without affecting mechanical properties of stainless steel bar [18]. The study of Xu et al. [19] indicates that uniform pitting corrosion is main corrosion morphology of stainless steel bar in the coupling environment of chloride ion and current. In addition to the external environmental factors, the composition, manufacturing processes and surface appearance of stainless steel bar can also affect the corrosion behavior of stainless steel bar [20–23].

Most of these studies are based on the corrosion of stainless steel bar in zero-stress state, but stainless steel bar in concrete structures under service load is usually in a stressed state. The corrosion process of stainless steel bar may be different under these two state. The impact of stress on corrosion has been considered in the study of high strength stainless steel wire [24]. In Sanchez's work [24], the resistance to pitting corrosion of 304 high strength stainless steel wire subjected to zero load and 70% of the tensile strength was studied in the chloride ion environment. It was concluded that when the chloride ion concentration reached 0.5 mol/L, pitting corrosion didn't appear under zero load, but pitting corrosion occurred under 70% of the tensile strength. Besides, the effect of load on pitting corrosion increased with chloride ion concentration increasing. Although Sanchez has studied the corrosion of stainless steel wire in a stressed state, there is only one non-zero strain applied and the mechanical properties of corroded stainless steel wire are not studied. Therefore, it is necessary to study the effect of different strain levels on corrosion and mechanical properties of stainless steel bar in the chloride ion environment. Since the corrosion rate of stainless steel bar in natural corrosion condition is relatively slow [25], it is difficult to obtain the expected corrosion degree in a short term. It is suggested that electrochemical accelerated corrosion technique can be adopted to accelerate the corrosion process of stainless steel bar in the experiment [25–27], achieving a significant amount of corrosion in a relatively short time for analyzing the effect of corrosion on mechanical properties of corroded stainless steel bar. The external current way is widely used in the electrochemical accelerated corrosion test to simulate corrosion damage of reinforcement at a certain time. In the electrochemical corrosion test, the corrosion process of reinforcement is accelerated under the promotion of the external power. It should be noted that there is no standard procedure for the electrochemical corrosion test [28].

The purpose of this paper is to study the effect of different strain levels on corrosion of stainless steel bar. Test specimens were made of ferrite stainless steel bar, which was due to the fact that the price of ferrite stainless steel bar was much cheaper than other stainless steel bars, and the ferrite stainless steel bar with high strength, low thermal expansion and high temperature resistance was widely applied in concrete structures. In this paper, an electrochemical accelerated corrosion test under different strain levels and a uniaxial tensile test of corroded stainless steel bar were designed to study the impact of strain on corrosion and mechanical properties of stainless steel bar.

2. Experimental study

2.1. Materials and specimen preparation

The specimens were made of S11203 ferrite stainless steel bar. The requirements of chemical component contents and mechanical properties of S11203 ferrite stainless steel bar are listed in Table 1. Each specimen had a nominal diameter of 16 mm and a length of 120 cm. The structure and dimensions of the specimen are shown in Fig. 1.

Since stainless steel bar is often used as outer steel bar or stirrup in practical engineering, the stress of stainless steel bar is generally less than 200 MPa. Besides, specification (YB/T 4362-2014, China) also specifies the stress of stainless steel bar for fatigue performance test doesn't exceed 200 MPa. Therefore, it is reasonable to choose 200 MPa as the maximum initial stress of the specimen, and the corresponding strain level is 1.0×10^{-3}. This strain value is far less than yield strain value of the specimen (0.2%), which indicates that the specimen is in elastic deformation phase. Three strain levels (0, 0.5×10^{-3} and 1.0×10^{-3}) were chosen as constant strain of the specimen to study the impact of strain on corrosion of stainless steel bar. The electrochemical accelerated corrosion test was conducted by external current way. The amount of corrosion can be calculated using Eq. (1) based on Faraday's Law.

$$\Delta m = \frac{MIt}{ZF} \tag{1}$$

where Δm is mass of steel bar consumed (g); M is atomic weight of iron (56 g/mol); I is the current (A); t is time (s); Z is ionic charge (assumed 2 for $Fe \rightarrow Fe^{2+} + 2e^-$); and F is Faraday's constant (96,320 A/s).

The theoretical corrosion degree of rebar can be expressed as Eq. (2).

$$\eta = \frac{\Delta m}{m} = \frac{MIt}{mZF} = \frac{MIt}{\pi r^2 \rho l Z F} \tag{2}$$

Table 1
The chemical components and mechanical properties for the stainless steel bar.

Chemical component(%)							Mechanical performance		
C	Si	Mn	P	S	Ni	Cr	Tension strength (MPa)	Yield strength (MPa)	Elongation at break (%)
0.03	1.00	1.00	0.040	0.030	0.60	12.25	875.8	800.2	22.0

Note: The elongation in the paper refers to the elongation at break.

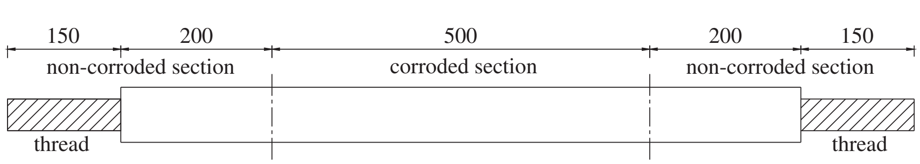

Fig. 1. The structure and dimensions of the specimen (unit: mm).