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Study on the degradation of mechanical properties of corroded steel plates based on surface topography

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ABSTRACT

Degradation laws of mechanical properties of corroded steel plates were studied by experimental method and numerical simulation method based on surface topography in this paper. First, Q235 steel plate was subject to accelerated corrosion with artificial salt spray, and the characteristics of the surface of corroded steel plate were measured by three-dimensional morphology observation instrument to obtain the values related to corrosion damage parameters, and the relationship between the surface characteristic parameters and the corrosion rate was established. Then the stress-strain curves and mechanical properties of the corroded steel plates were obtained by monotonic tensile test. Finally, the mechanical properties of steel plates with real corroded surfaces were studied by numerical simulation method with reverse engineering software Geomagic Studio and finite element software ANSYS, and the stress concentration phenomenon caused by corrosion pit was discussed. The results showed that: (a) the corrosion rate is within 15%, the stress-strain curves have obvious yield plateaus; (b) and with the increase of corrosion rate, yield plateaus, yield strength, ultimate strength, and fracture strength of corroded steel plates does not decrease much, but ductility significantly decreases; (c) when the corrosion rate is over 15%, all the mechanical property index significantly decreases; (d) the constitutive model was established, and the law of the variations of the parameters of the model was summarized; (e) the numerical simulation method is feasible compared with the experimental results.

1. Introduction

Steel structure has the phenomenon of corrosion damage if being exposed in the corrosive environment such as soil, air, acid rain, marine climate etc. for a long time [1]. In order to study the corrosion of the steel structures and the related theoretical problems in the real circumstances, the accelerated corrosion method is normally adopted [2], and the research has shown that the correlation between accelerated corrosion method and long-term natural exposure test is good [3].

The corroded surface of the material is rough and irregular [4–6], and the features of the corroded surface can be obtained by using the contacting and non-contacting surface topography [7,8]. Corrosion usually occurs on the surface of the material and the fracture normally follows the gradual expansion of the surface cracks, [9–11]. Therefore, the degradation of the mechanical properties of the corroded material is greatly connected to the surface features of the material. However, there is little research on the quantitative relationship between the statistical characteristics of the steel surface and the degradation of the mechanical properties, and few researches involve the constitutive model [12–17] of corroded steel.

Wei-long Hu et al. [12] suggested two new constitutive models for regression of various experimental stress–strain relations to improve the accuracy of numerical analysis. M.E. Rodriguez et al. [13] conducted monotonic and cyclic tests on deformed steel bars. Based on test results of several specimens, they proposed equations to the locate onset of buckling during monotonic and cyclic loadings. Silvia Caprili et al. [14] presented stress-strain model of tensile tests on corroded bars in terms of mechanical properties (yield strength, Young modulus and breaking strength) under different mass loss. Rajesh Prasad Dhakal et al. [15] presented uniaxial stress–strain relationships considering tension envelop diagram. The tension envelope diagram consists of four parts: elastic branch, yield plateau, strain-hardening zone and post-ultimate descending branch. Although a closer look inside the yield plateau is reported to reveal small stress undulations, it is represented here as a straight line with the stress equal to the yield strength for simplicity. M.R. Khedmati et al. [16] and Y. Wang et al. [17] found that mechanical properties of materials will lead to the irreversible degradation due to corrosion. Many scholars who studied the deterioration of mechanical properties of corrosion steel, had found out that not only the cross-section of corrosion steel reduced, and surface features changed, but also yield strength, ultimate strength and ductility

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reduced, and among them the reduction of the ductility performance was more obvious.

In this paper, the damage parameters of the corrosion steel and their effects on the macro mechanical properties of the steel were studied from the angle of the surface feature, and the constitutive model of corrosion steel was established and the variation of parameters was analyzed.

In addition to the experimental method, the numerical simulation analysis based on real surface topography is necessary. Because of the huge amount of *3D* data points, it is very complicated and difficult to exchange data with ANSYS and import the data into ANSYS directly. Therefore, in order to use computer technology to reflect effectively the degradation of the mechanical properties of the corroded steel plate based on real surface topography, the Geomagic Studio [18–20] and ANSYS [21] were used to simulate mechanical properties of the corroded steel under the monotonic tension in this paper.

2. Experimental introduction

2.1. Accelerated corrosion

There were nine sets of specimens named A0*i*–A8*i* (280 mm × 50 mm × 8 mm) [22]. A0*i* to represent different degrees of corrosion, with A0i not corroded and A8*i* corroded the most. Among them, A01–A81 were used for surface analysis, A02-A82 and A03-A83were used for monotonic tension analysis.

Neutral salt spray accelerated corrosion test was conducted to obtain the corroded specimens, based on the standard of GB/T 10125–2012 [23] and GB/T 24517–2009 [24]. Where, the NaCl solution concentration was 50 mg/L, the PH value was 6.2–7.2, the diameter of the nozzle and the rate of mist spray of the spraying equipment were 0.5 mm–1.5 mm and 0.5–1.5 L/(min m^2), respectively. The specimens were divided into 8 groups for corrosion, each group containing three standard specimens A group of corrosion-free specimens were also used as a control for tensile properties studies. All specimens for corrosion were placed individually on an exposure test fixture which parallel at an angle of 45° with regards to the vertical direction, as showed in Fig. 1. They were sprayed for 30 min with NaCl solution 4 times a day and rotated every day to provide uniform exposure to the salt spray. After exposed for several months, respectively, the specimens were retrieved and cleared away the corrosion products with dilute hydrochloric acid and distilled water, and then kept in CaO desiccator until the scanning test and tensile test. In order to achieve the mass-loss rates of the corroded specimens, they were weighed on an analytical balance before and after the accelerated corrosion test, and expressed in ρ_w (the weight loss rate or corrosion rate). The sampling time were the first group: 30 days, the second group: 110 days, the third group: 150 days, the fourth group: 250 days, the fifth group: 310 days, the sixth group: 370 days, the seventh group: 440 days, and the total experiment period was 440 days.

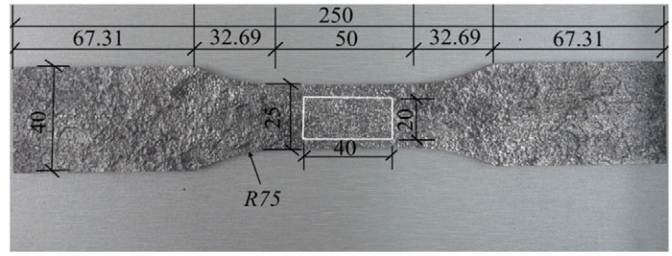

Fig. 2. Dimensional drawing of experimental components.

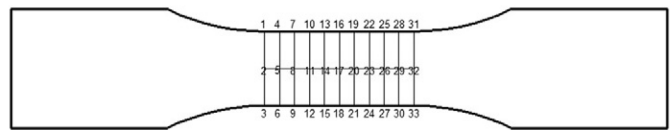

Fig. 3. Measurement of residual thickness.

2.2. Surface testing and monotonic tensile

The corroded specimens were subject to rust removal, and processed into the test pieces shown in Fig. 2.

As showed in Fig. 3, drawled a vertical line every 5 mm along the length direction, selected three points on each vertical line and measured residual thickness of the steel by vernier caliper (see Table 2).

The middle areas of both sides were measured by three-dimensional non-contacting surface topography (PS50 see Fig. 4), and the size of the areas was 40 mm × 20 mm (40 mm along the length, and step size was 50 μm; 200 mm along the width, and step size was 50 μm), and *a* and *b* were used to name different sides. 3D data of each measurement area were obtained by professional 3D software, then the void volume ratio V_w, the average corrosion depth D_{mean}, the maximum corrosion depth D_{max} and the related evaluation parameters S_a, S_q etc. were obtained.

Fig. 1. Condition of accelerated corrosion experiment.

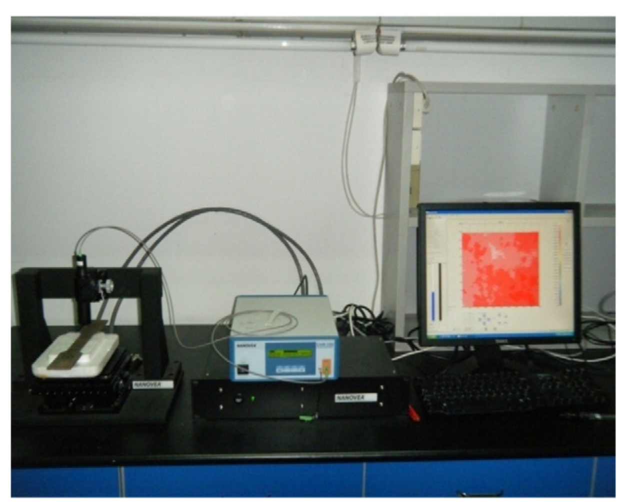

Fig. 4. PS50.