

Corrosion accelerating effect of temperature on common steel contacted by carbon fiber

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1. Introduction

Nowadays, Carbon Fiber-reinforced Plastics (CFRP) has proven to be a reliable structural reinforcement material in engineering applications. However, as the electrode potential of carbon fiber is more negative than iron, the combination of the two phases will form a corrosive galvanic cell which make iron is corroded preferentially. Therefore, it is necessary to investigate the accelerating effect of carbon fiber (CF) on steel corrosion. As a preliminary study, this article discusses the temperature accelerating effect on the galvanic corrosion between CF and common steel.

2. Experimental method

The electrode material used in this experiment is JIS G3106 SM490A. The shape of the electrode is a cuboid with a bottom area of 100 mm². The bottom surface of specimen were grinded with 240, 400, 600, 800, 1000 and 2000 grade SiC paper and polish successively. Before electrochemical experiment, the specimen was ultrasonically cleaned using deionized water and absolute ethanol for 5 min, respectively. There are two types of specimens: Type 1 was promptly sealed and reserve the bottom surface as test area of 100 mm² which used for potentiodynamic polarization curves test. Compared with Type 1, Type 2 is covered with a layer of CF tow (fiber count of 12,000, bundle width 40mm, exposed length 10 mm) on the test surface. Type 2 will be used for potentiostatic test. The carbon fiber tow used in this study are the PAN-based continuous fiber provided by Mitsubishi Chemical Corporation.

The electrochemical performance of the prepared samples was investigated by versa STAT 4 electrochemical workstation. All electrochemical measurements were carried out at constant temperature bath in a three-electrode system with 3.5wt.% NaCl aqueous solution as electrolyte, and fix the working electrode 15 mm below the solution surface (Fig.1). The temperature of the water bath were 25°C, 32°C, and 40°C (±0.1°C). A Pt wire and saturated Ag/AgCl was served as counter electrode and reference electrode, respectively. The voltage range of the polarization curve is -0.5V to +0.5V versus E_{OCP} , and the scan rate is 0.1667 mV/s. Before the polarization curve, the specimen was immersed in 3.5 wt.% NaCl aqueous solution and measure the open circuit potential for 2 hours to obtain a stable state. The polarization potential of potentiostatic test is 0.78V (vs. Ag/AgCl) [1].

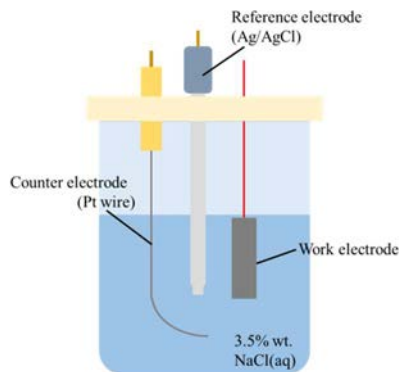


Fig. 1 Three-electrode system used in the experiment

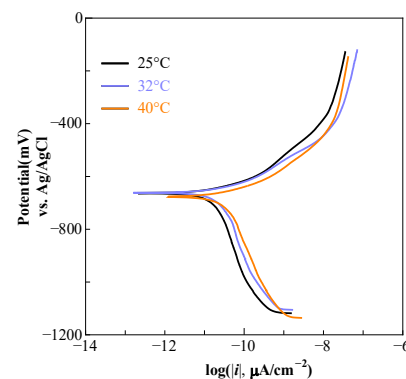


Fig. 2 The potentiodynamic polarization curves of steel electrode at different temperatures

3. Results and discussion

Use the original data to draw the potentiodynamic polarization curves of electrode at different temperatures, as shown in Fig 2. In addition, using Zview software to calculate the corrosion potential (E_{corr}), corrosion current density (i_{corr}), Tafel slope at different temperatures and average annual corrosion depth at current density, as shown in Table 1.

Table. 1 Corrosion parameters calculated from Tafel plot.

Temperature T (°C)	E_{corr} (mV)	i_{corr} ($\mu\text{A}\cdot\text{cm}^{-2}$)	β_a (mV)	β_c (mV)	Corrosion rate ($\text{mm}\cdot\text{a}^{-1}$)
25	-664	19.1	77.6	480	0.222
32	-662	22.6	73.6	349	0.262
40	-677	41.0	79.9	524	0.477

It can be seen from the data that the self-corrosion potential of the material at 40 °C is more negative than 25 °C and 20 °C, which means the material is more likely to be corroded at high temperatures. In terms of i_{corr} , $i_{corr40} > i_{corr32} > i_{corr25}$, we could find that as the temperature increases, the self-corrosion current density also increases. Through the Tafel slope values of the anode and cathode at different temperatures, we could figure out that the corrosion of this system is mainly controlled by the cathodic reaction.

Fig.3 shows the polarization curve of a composite electrode system of steel electrode and CF at the anti-corrosion potential - 0.78V (vs. Ag/AgCl). The abscissa is the time of potentiostatic test, and the ordinate is the current density. We selected the stable current density of 5,000 to 10,000 sec. after the start of the test. We calculated the average current density at 25°C, 32°C, 40°C and found that when temperature increases the corrosion current density also increases. The result is consistent with the above result.

Fig. 4 compared the corrosion current density of potentiodynamic polarization test and potentiostatic test under different temperature. The results show that after CF joining, the corrosion rate of the steel itself will increase, the higher the temperature, the more obvious the acceleration.

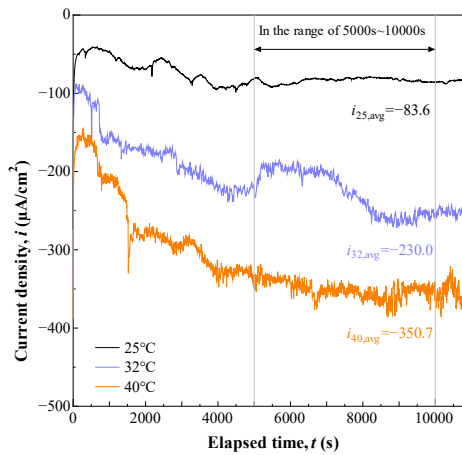


Fig. 3 Potentiostatic test of steel electrode at different temperatures

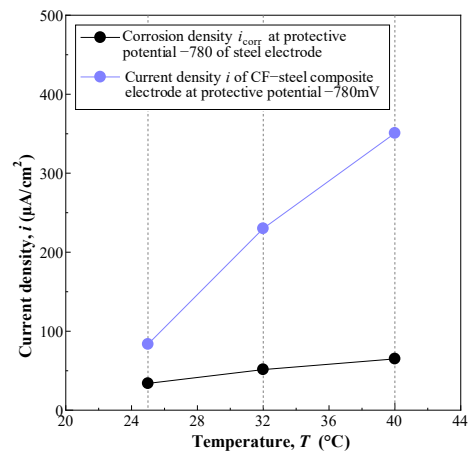


Fig. 4 The relationship between SM490A self-corrosion current density and temperature with or without CF

Normally, it's linearly dependent between reaction temperature and reaction activation energy. And Arrhenius equation (1) is a useful method to calculate the activation energy, that relates the rate constant of a reaction with the temperature (energy) of the system.

$$k = Ae^{-\frac{E_a}{RT}} \tag{1}$$

where k is the rate constant, A is a constant related to the geometry needed, E_a (activation energy) is the energy level that the reactant molecules must overcome before a reaction can occur, R is the gas constant ($8.314 \text{ J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$), T is the temperature in Kelvin.

Here we define the corrosion current density ($i / \text{A}\cdot\text{m}^{-2}$) as k in the formula (1). After taking the natural logarithm of the above formula, we can get formula (2)

$$\ln i = -\frac{E_a}{RT} + \ln A \tag{2}$$

Because in a certain reaction, the activation energy E_a is a constant value and the parameter A and the gas constant R are also constant, Equation (2) should be a linear function of $\ln i$ and T^{-1} . This should also correspond to the curve after fitting the two sets of points in Fig. 4. Therefore, by using formula (2) we can calculate E_a in both cases of steel electrode and composite electrode system of steel electrode and CF, the calculation result of is listed in Table. 2.

Table. 2 Arrhenius equation in both cases

Electrode type	E_a (kJ)	Formula
Type 1	76.0	$\ln i = -9.14 \times 10^3 T^{-1} + 35.1$ (3)
Type 2	37.3	$\ln i = -4.48 \times 10^3 T^{-1} + 18.5$ (4)

If we define $25 \text{ }^\circ\text{C}$ as T_0 , and use the corrosion rate at this temperature as a reference value, we can find the prediction formula for the corrosion rate under the effect of temperature promotion. We define the reaction rate under the reference temperature T_0 condition as k_0 , and define the temperature acceleration factor as $r(T)$.

$$r(T) = \frac{k}{k_0} = \exp\left\{\frac{E_a}{R}\left(\frac{1}{T_0} - \frac{1}{T}\right)\right\} \tag{5}$$

For steel electrode: $r(T) = \exp\left\{9.137 \times \left(\frac{1}{298.15} - \frac{1}{T}\right)\right\}$ (6)

For composite electrode system: $r(T) = \exp\left\{4.482 \times \left(\frac{1}{298.15} - \frac{1}{T}\right)\right\}$ (7)

Summary and findings

- (1) The relationship between the corrosion current density and the ambient temperature under the corrosion potential of steel and CF-steel composite system were calculated. The corrosion promotion effect of temperature on steel will be significantly enhanced in the presence of carbon fiber.
- (2) Based on the corrosion rate at 25°C , this article summarizes the empirical formula for corrosion rate under steel and CF-steel contacted system.

References

[1] T. Iwamoto, Y. Suzuki and M. Yatomi: Environmental dependence of anticorrosion method using electrodeposition coating. Zairyo-to-Kankyo Vol.65, No.1, pp.450-453, 2016.