Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)

Corrosion behavior and protection mechanism of carbon steel coated with ethylene chlorotrifluoroethylene (ECTFE)

Peihu SHEN[1], Jun WEN[1], Biqin DONG[2], Hedong LI[1], Minjia WANG[1,3]*

1.School of Civil Engineering and Architecture, Zhejiang Sci-Tech University, Hangzhou 310018, China

2. College of Civil and Transportation Engineering, Shenzhen University, Shenzhen 518061, China

3. Zhejiang Research Institute of Chemical Industry Co. Ltd, Hangzhou 310023, China

Key words:

Coating; Fluorine resin; Edge corrosion; Corrosive behavior; Electrochemical performance

Cite this as: Peihu SHEN, Jun WEN, Biqin DONG, Hedong LI, Minjia WANG, 2024. Corrosion behavior and protection mechanism of carbon steel coated with ethylene chlorotrifluoroethylene (ECTFE). *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 25(6):502-515. https://doi.org/10.1631/jzus.A2300157

Introduction

In this study, an ECTFE coating was prepared on the surface of carbon steel by electrostatic spraying and low-temperature heat treatment, followed by soaking in 3.5 wt.% NaCl solution. The corrosion behavior and protection mechanism of the coated steel were studied in-depth. It is evident that corrosion initiates from the periphery due to the thinness of the coating edge. Even so, the ECTFE coating still exhibits corrosion protection performance. The main objective of this study is to provide an empirical and theoretical foundation for protection against edge corrosion in fluororesin coatings and thereby advance durability technology for steel structures and for the development of anti-corrosion coating materials.

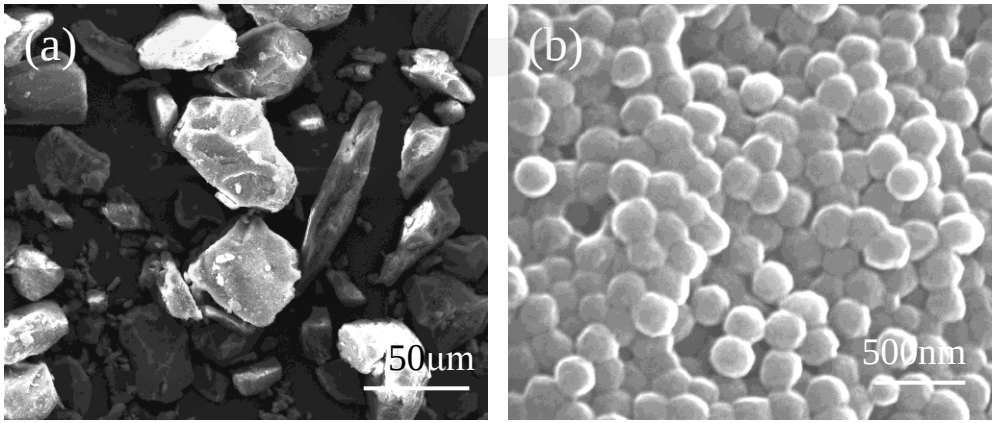


Figure 1 SEM images of ECTFE powder

Experimental Procedure

(1) Raw materials and coating preparation

ECTFE coating was prepared on the surface of carbon steel by electrostatic spraying and heat treatment at 260 ℃

(2) Morphological and structural characterization

The micromorphology of ECTFE coating was characterized by TG-DSC, FTIR, XRD, SEM and EDS.

(3) Anti-corrosion and associated performance evaluation

The hydrophilic/hydrophobicity, adhesion, electrochemical performance and salt spray test of ECTFE coating were tested.

JZUSA

Results and discussion

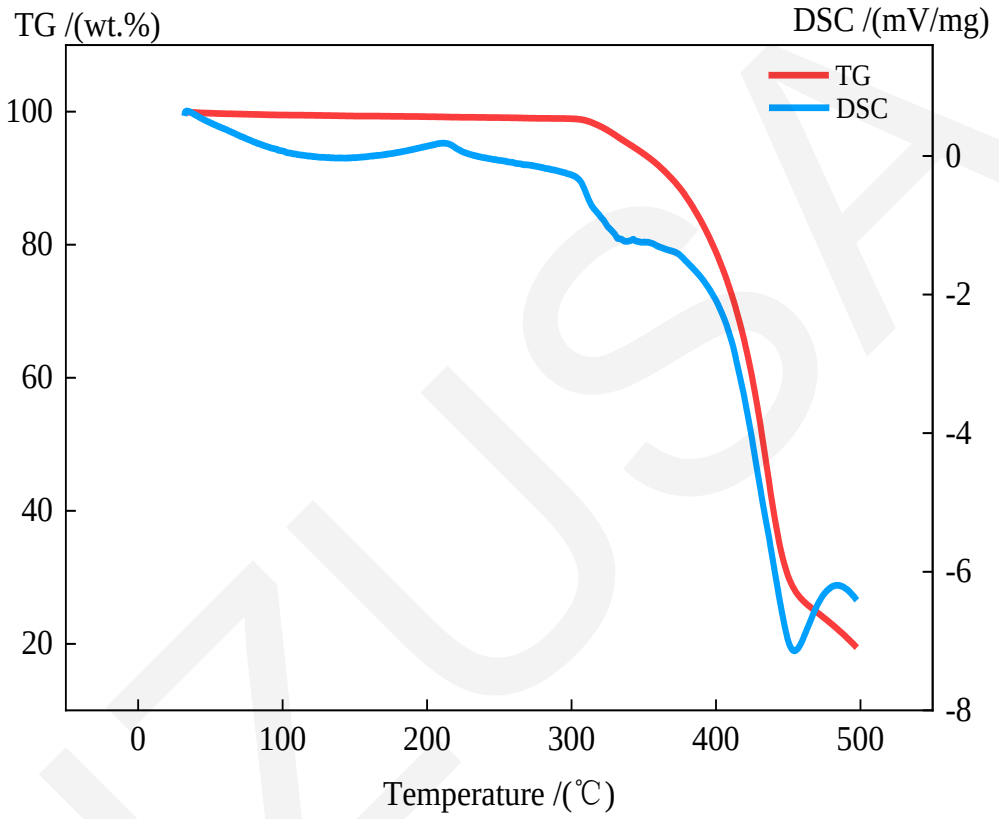


Figure 2 TG-DSC spectra of ECTFE powder

- **The endothermic peaks at 215 ℃ and 300 ℃ in the DSC curve indicate the melting of powder and breaking of some chemical bonds, respectively.**
- **A heat treatment temperature of 260 ℃ was therefore chosen as the intermediate temperature**

Results and discussion

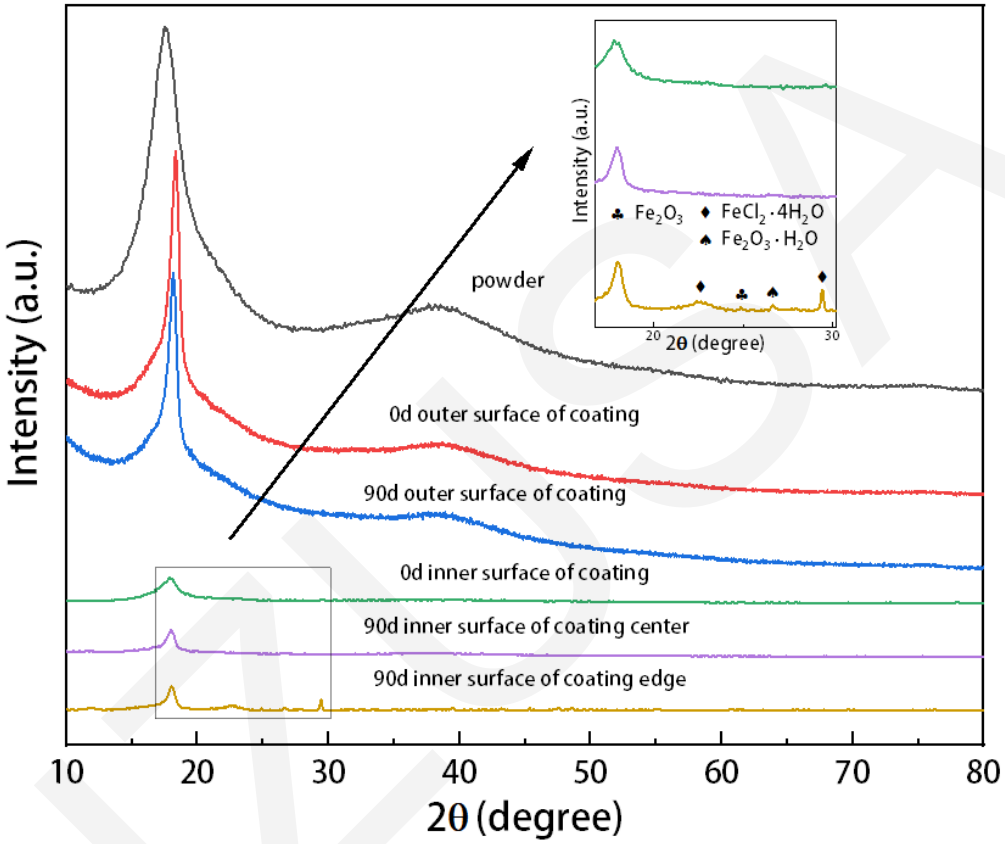


Figure 3 XRD patterns of ECTFE powder and coating at different periods and parts

- **There exist impurity phases on the inner surface of the coating edge, which are $FeCl_2 \cdot 4H_2O$, $Fe_2O_3 \cdot H_2O$ and Fe_2O_3, respectively. They indicate that corrosion has occurred on the inner surface of the coating edge and has resulted in the formation of crystalline water-containing corrosion products.**

Results and discussion

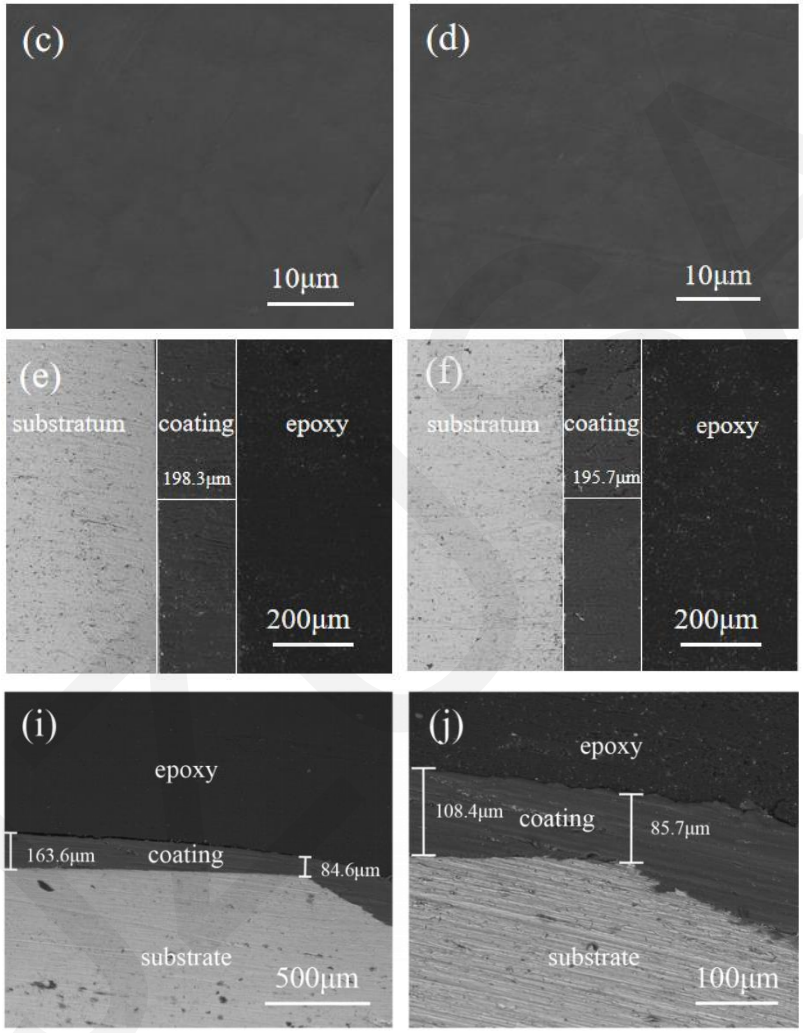


Figure 4 SEM images of ECTFE coating. (c) & (d) the outer surface of coating before and after soaking, (e) & (g) cross-sectional morphology of the coating center before soaking, (f) & (h) cross-sectional morphology of the coating center after soaking, (i) & (j) cross-sectional morphology of the coating edge before and after soaking

Results and discussion

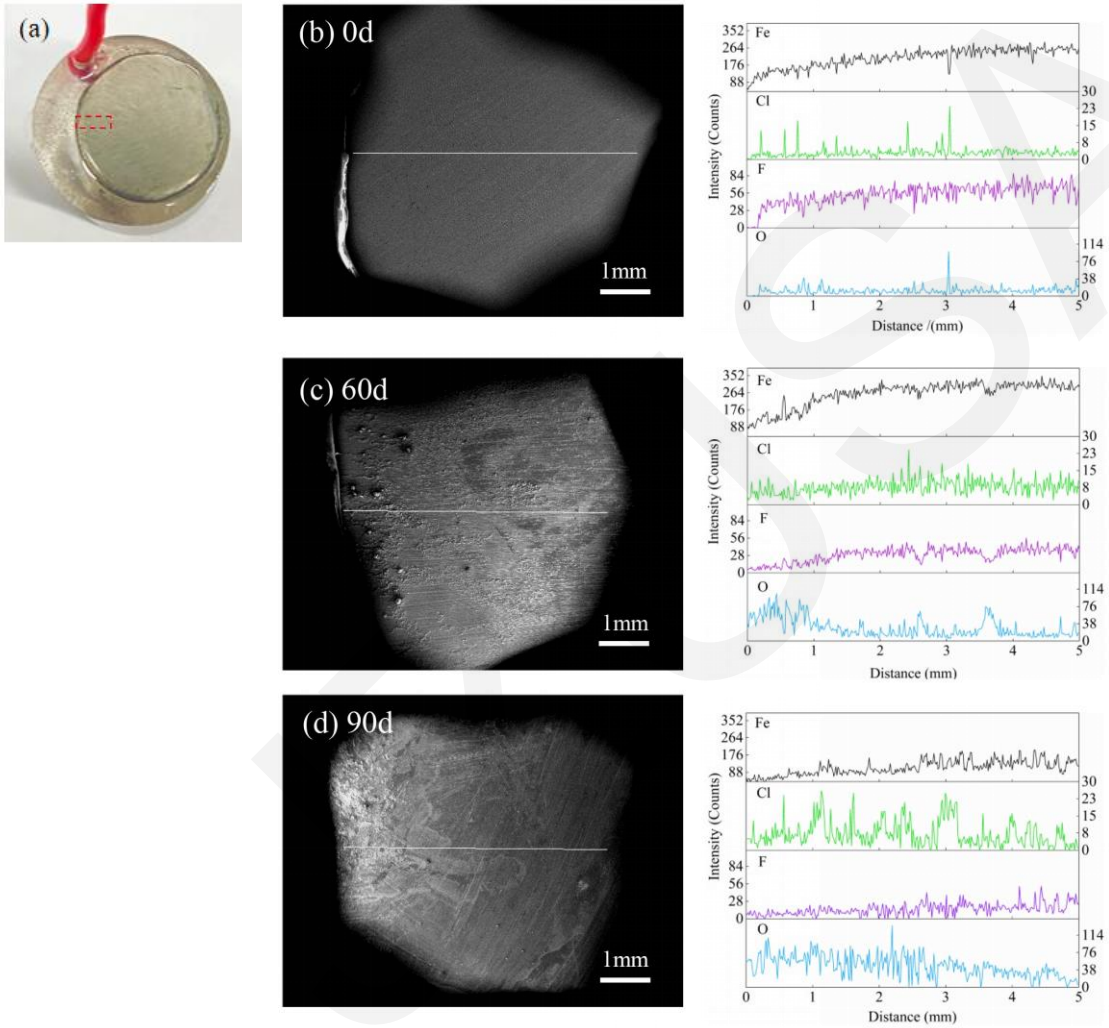


Figure 5 Elemental line scan at the steel surface after removing coatings of the coated steel soaking at different periods

Results and discussion

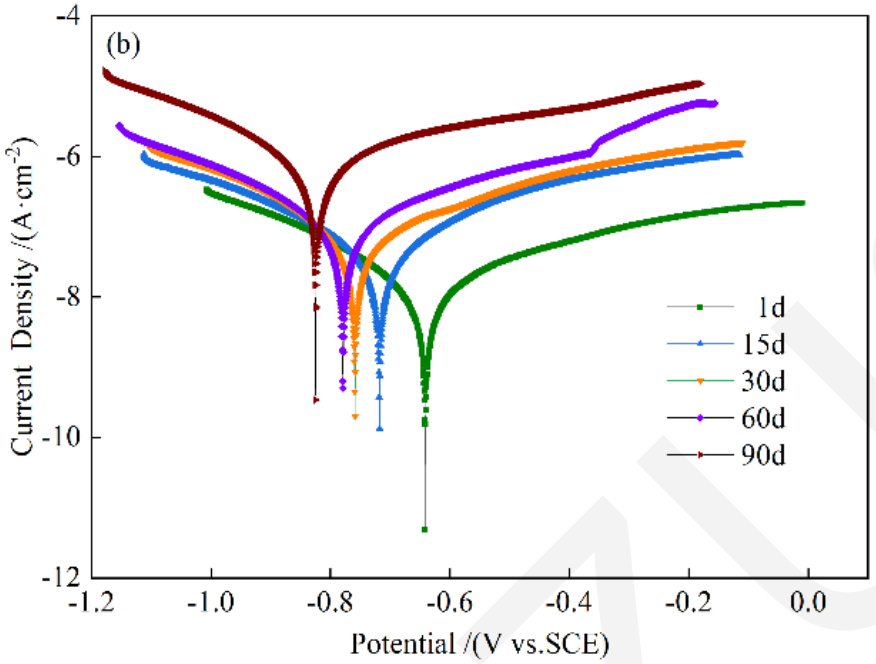


Figure 6 The polarization curves of the coated steel soaking in 3.5 wt% NaCl solution in different periods

Time (d)	bare steel		coated steel	
	E_{corr} (V vs. SCE)	i_{corr} (A·cm^{-2})	E_{corr} (V vs. SCE)	i_{corr} (A·cm^{-2})
1	-0.78	5.32×10^{-5}	-0.64	2.19×10^{-8}
15	-0.86	4.32×10^{-5}	-0.71	6.35×10^{-8}
30	-0.87	4.96×10^{-5}	-0.75	8.70×10^{-8}
60	-0.88	4.44×10^{-5}	-0.77	1.72×10^{-7}
90	-0.97	1.61×10^{-4}	-0.82	1.13×10^{-6}

Table 1 The electrochemical fitting parameters of the bare steel and coated steel

- **The self-corrosion current density of the coated steel is 2-3 orders of magnitude lower than that of bare steel in the whole soaking period, indicating a slow rate of corrosion.**
- **The high level of protection from the coating indicates that it still maintains its protective capabilities even in the presence of edge corrosion.**

Results and discussion



Figure 7 Salt spray tests results after exposing the scratched coatings to salt spray for 720 h

- **For the scratch area where the macroscopic corrosion phenomenon predominantly occurs, longitudinal direction is the primary mode of corrosion while lateral development is somewhat inhibited.**
- **The initial adhesion between coating and steel substrate and the semicrystalline structure confer a significant capability of corrosion protection upon the coating, thereby affording longterm effective protection to the substrate.**

Conclusions

In this study, ECTFE coating approximately 200 μm thick was prepared on the surface of carbon steel by electrostatic spraying and heat treatment at 260 ℃. The edge corrosion behavior of ECTFE coated steel and its mechanism were thoroughly investigated, leading to the following conclusions.

- The outer surface structure of the ECTFE coating remains essentially unaltered before and after soaking in 3.5 wt.% NaCl solution for 90 days.
- F ions can diffuse into the steel substrate, which enhances the bonding between the coating and steel substrate but weakens the crystalline structure.
- Due to the edge thickness of the coating, corrosive media can easily penetrate from the edges and cause corrosion.
- Despite edge corrosion, the coated steel exhibits great corrosive protection performance, due to its dense and stable structure with excellent barrier properties.

JZUSA