Improvements of CFRP strip with peel-ply surface pretreatment on electrochemical behavior in marine environment

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1. Introduction A considerable interest has been raised to use carbon fiber reinforced polymer (CFRP) composites to strengthen existing structures or to be employed as a key component of fiber metal laminate [1]. The advantages of CFRP composites can be normally summarized as: a) superior mechanical properties, such as high strength-to-weight and stiffness-to-weight ratios; b) well abilities in the corrosion- and the fatigue-resistance; and c) in case of construction, it can shorten construction period and is easy to assemble by adhesive bonding, which effectively avoids the stress concentration or thermal stress caused by mechanical fastening systems. However, recently many scholars like Vina [2] obtained a significant decrease in mechanical properties during a period of the first 8-year outdoor exposure tests, due to the loss of surface resin and fiber/matrix interface ageing. Currently, more attention has been paid to the surface pre-treatment of CFRP plate, primarily because its surface property is not only related to the adhesive bonding, but also plays a major role in its own environmental durability and the action of galvanic coupling with metallic materials. Therefore, this study aims to explore the effects of CFRP plate with three kinds of surface pretreatments on its durability in a sodium chloride solution, through the fundamental electrochemical tests.

2. Sample preparation Three different surface pre-treatments for the CFRP plate (Thickness: 2 mm, Type: GM520, Mitsubishi Chemical Infratec Co.,Ltd), are shown in **Fig. 1**. The carbon fiber covered by a thick epoxy resin and exposed directly without any epoxy resin covering, are regarded as Case #1 and #2, respectively. while a peel-ply layer on the surface can protect the surface during transport and after peeling off this fabric layer, its corresponding CFRP surface refers to Case #3, can thus have a chemical-active surface with a required roughness.

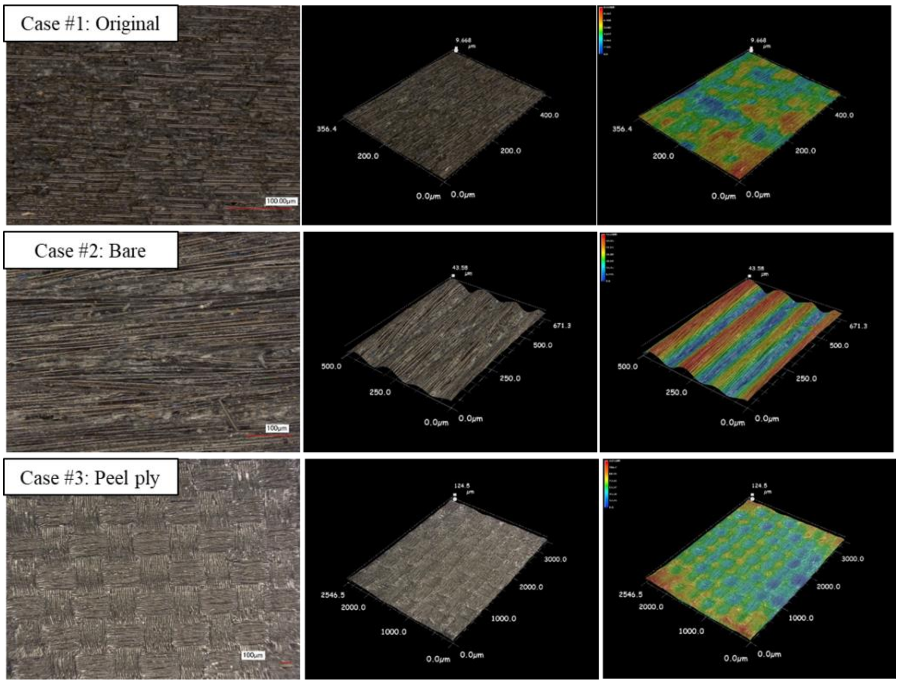

Fig. 1 Observation of surface pretreatment of CFRP

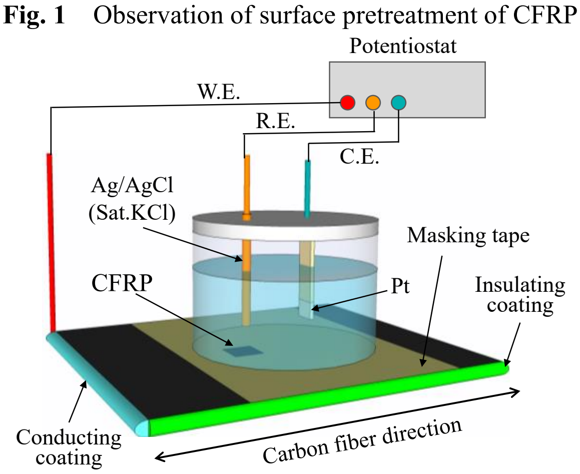

Fig. 2 Diagram of test setup

Keywords: CFRP, surface pretreatment, electrochemical test, galvanic corrosion
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3. Methodology The open circuit potential (OCP) and polarization curves were measured successively in the 3.5 wt% NaCl aq electrolyte at room temperature (25.4°C), through a Versa STAT 4 electrochemical station. The masking tape was used to mask the surfaces of the steel or CFRP plate, only leaving an exposure area of around 0.785 cm^2 as the target region. A traditional three-electrode cell was employed, with a counter electrode of Pt and a reference electrode of Ag/AgCl (Sat. KCl), and with a working electrode of CFRP plate or steel plate. The detailed test setup is shown in Fig.3. During testing, the OCP measurement was lasting for 120 min, and the polarization behavior of CFRP plate was measured from -1.5 to 0.3V (vs. Ag/AgCl) at a scan rate of 10mV/min. Also, the steel plate was taken into consideration to compare and check the tendency of galvanic corrosion when it is coupled with CFRP plate, based on the mixed-potential theory.

4. Test results and discussion Fig. 4 shows the OCP curves of steel and CFRP plates with time changing in 120 min. As can be seen, CFRP plates start from a positive OCP and increase gradually during the initial immersion period, regardless of the surface pre-treatment. After that, OCP value become stable for Case #2 and #1 at around +179 mV and +160mV, respectively, which are slightly higher than Case #3 (+120 mV). But the time required for Case #2 to reach the steady value of OCP is obviously longer than that of the other two cases. In addition, they are all significantly nobler than the OCP of steel plate with blasting, and in detail the potential difference between the CFRP plate and the steel is in the range of +860 to +919 mV. Hence, the galvanic corrosion should be paid more attention, because this potential difference is greatly higher than the tolerance value of 50 mV of the galvanic corrosion as reported.

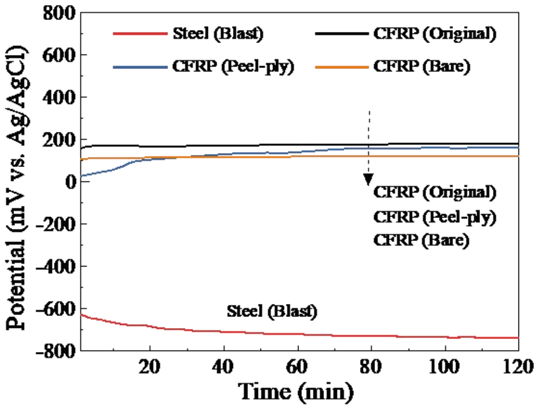

Fig. 4 OCP curves

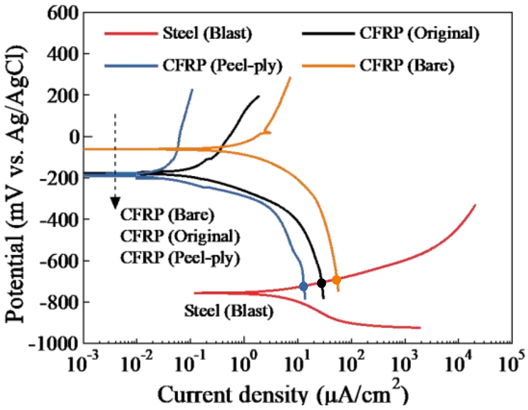

Fig. 5 Polarization curves

Table 1 Comparison of corrosion parameters for the steel and CFRP plate

Individual material		i_{corr} (μA/cm^2)	E_{corr} (mV)	Galvanic coupling	i_g (μA/cm^2)	E_g (mV)
Steel	Blast	+3.13	-757	—	—	—
	Original	+0.17	-178	Steel / CFRP(Original)	+25.65	-706
CFRP	Peel-ply	+0.036	-188	Steel / CFRP(Peel-ply)	+14.47	-719
	Bare	+1.47	-62	Steel / CFRP(Bare)	+58.02	-687

Note: i_{corr}, E_{corr} are the free corrosion current density and its potential; while i_g, E_g are the galvanic corrosion current density and its potential, respectively.

The polarization curves of the steel and CFRP plate are plotted as shown in Fig. 5, where the intersections of the cathode polarization plots for the CFRP and the anodic polarization plot for the steel are also marked by three solid circles. The anodic reaction of CFRP is the oxidation of carbon fibers which causes the composite degradation, while that of the mild steel is the metal corrosion as known; in the case of the cathodic reaction, both materials are the reduction of oxygen leading to the hydroxide ion occurred on their surface. Moreover, Table 1 indicates a brief comparison between the free corrosion system and the galvanic coupling system based on the mixed potential theory. It can be observed that there is an obvious influence regarding i_{corr} for Case #1, Case #2 and Case #3, corresponding to 0.17 μA/cm^2, 0.036 μA/cm^2 and 1.47 μA/cm^2, respectively. On the other hand, i_{corr} of the steel is about 3.13 μA/cm^2 and however, this corrosion rate would be accelerated significantly ranging from 4.62 times to 18.5 times when it is coupled with CFRP plate in three cases. That means that the galvanic corrosion could possibly occur, even though an epoxy resin covering seem to separate the carbon fiber and the steel. In comparison with the other two cases, Case #2 shows better anti-corrosion ability, and effectively slow down the galvanic corrosion rate as coupling with the steel.

4. Summary 1) The potential difference between the steel and CFRP plate is over 860 mV in 3.5wt% NaCl aq, greatly higher than 50 mV, resulting in a strong driving force to accelerate corrosion, which is irrelevant to which kind of CFRP surface pretreatment employed. 2) Compared to the other two cases, CFRP plate with the peel-ply surface pretreatment shows better anticorrosion ability, and effectively slow down the galvanic corrosion rate as coupling with the steel.

Reference 1) T. Sinmazçelik, E. Avcu, M.Ö. Bora, O. Çoban. A review: fibre metal laminates, background, bonding types and applied test methods, Materials & Design, Vol. 32, pp.3671–3685, 2011. 2) J. Vi˜na, J. Bonhomme b, V. Moll´on, I. Vi˜na b, A. Argüelles b. Mechanical properties of fibreglass and carbon-fibre reinforced polyetherimide after twenty years of outdoor environmental aging in the city of Gij´on (Spain), Composites Communications, Vol. 22, pp. 100522, 2020.