Effect of hydrothermal aging on resin-impregnated carbon fiber fabric

Kyushu University Student Member ○Jiajing XIE
Kyushu University Regular Member Muye YANG
Kyushu University Fellow Member Shigenobu KAIN KAINUMA

1. Introduction In recent years, CFRP has been widely used for steel structure reinforcement. The epoxy resin-impregnated carbon fiber fabrics with one major drawback when it comes to using CFRP composites for strengthening and repairing steel structures is the need for more knowledge relating to the long-term performance and durability properties of CFRP/Steel bonded joints. A review of the literature reveals that moisture is the most problematic substance when it comes to the durability of adhesive joints with FRP and metallic adherents[1,2]. In the case of epoxy resin-impregnated carbon fiber fabrics, the resin is not only the binder but also part of its material composition, so the deterioration effect of moisture is more pronounced. In this paper, the effect of moisture on its mechanical and material properties is discussed experimentally.

2. Test method The epoxy resin specimens were made with a two-component epoxy called XL-800, which comes from Mitsubishi Chemical Infratec Co., Ltd. The main agent and epoxy hardener were mixed at a weight ratio of 4:1. All the test specimens were cured at 35℃ for 5 days. Water absorption test and tensile test were conducted to discuss the effect of moisture on the properties of resin materials. In the water absorption test, epoxy resin sheets were made with a size of 60×60×2 mm. The main purpose of the water absorption test was to investigate the impression of different environments on the water absorption rate of epoxy resin. Therefore, three test environments were set up: 1) 25℃ Distilled water, 2) 25℃ 3.5 wt% NaCl aq, 3) 25℃ 95% RH. The test was conducted for 120 days, and the test conditions were referred to according to JIS-7092. Before the test, all the specimens were cured in an oven under 35℃ and 10% RH for 24 hrs to dry. Specimens were weighed using a scale with an accuracy of 0.01 mg to obtain their dry stage weight (w_0) as the reference value. Then the specimens were immediately exposed to the experimental environments. To measure the weight changing according to time, specimens were removed from the experimental environment after a fixed exposure period (t), wiped using a dry cloth, and weighed immediately (w_t). The specimens were then returned to the experimental environment for continuing exposure. The moisture uptake (M_t) for each specimen was calculated using Eq.(1).

$$M_t = \left(\frac{w_t - w_0}{w_0}\right) \times 100 \tag{1}$$

The dog bone tensile test was specifically designed to investigate the moisture effect on the mechanical properties of epoxy resin. The size of dog bone specimens is shown in Fig.1. Fifteen test bodies were prepared and divided into three groups of 5 test bodies each. The first group was a control test group that did not absorb any water, and the remaining two groups were immersed in a 25℃ 3.5 wt% NaCl aq environment for water absorption, the second group was immersed for 20 days, and the third group was immersed for 120 days. The tensile test was performed using a tensile testing machine (Tokyo Koki Tester MSC-10/500-2) at a tensile speed of 0.5 mm/min. Each group was tested five times, and the average value was taken. Furthermore, Poisson's ratio of the test body was also measured. Two uniaxial strain gauges were attached to both measurements of the test body, and the two strain gauges were perpendicular to each other, as shown in Fig.1. To investigate the effect of moisture absorption at the chemical level, FT-IR and DSC analyses were also performed. Among them, FT-IR was carried out for a wavenumber (cm^{-1}) between 400 cm^{-1} and 4,000 cm^{-1}, and DSC analysis was performed at measurement temperatures between 0 °C and 200 °C with a heating rate of 10 °C/min.

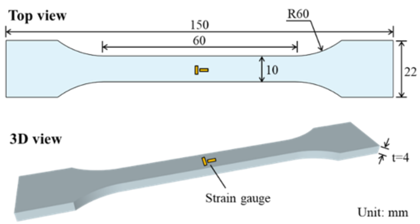


Fig.1 Size of dog bone specimen

3. Test results The mean value of each group's moisture uptake (Mt) was calculated, as shown in Fig.2. From the results, it can be seen that at the beginning of the water absorption test, the water absorption rate of the test body in distilled water and 3.5 wt% NaCl aq is roughly the same, greater than the test bodies in a humid environment. 20 days later, gradual slowdown in the rate of increase of water absorption rate of the test bodies in 3.5 wt% NaCl aq. From the tensile test result in Fig.3, with the increase in moisture uptake the tensile strength of the resin gradually decreases, and Poisson's ratio increases. It is predicted that when the moisture uptake reaches saturation, the tensile strength decreases to the lowest value, and the Poisson's ratio reaches the maximum value. The increase in Poisson's ratio indicates that the ductility of the resin gradually increases with the intrusion of moisture, which is accompanied by a decrease in tensile strength and may lead to the deformation of the reinforced part of the structure. FT-IR results as shown in Fig.4, significantly show that with the water uptake increases, the OH group, C-H group, C-OH, and C≡C group all increased, indicating that the resin not only absorbed a large amount of water but also underwent hydrolysis reactions. This is also one of the reasons for the decrease in the mechanical properties of the resin. Comparing the FT-IR waveforms of the three exposure environments, no significant difference was found. The characteristic peaks of the C-OH group, C≡C group, and C-H group showed a significant increase from 12 days of exposure for all three

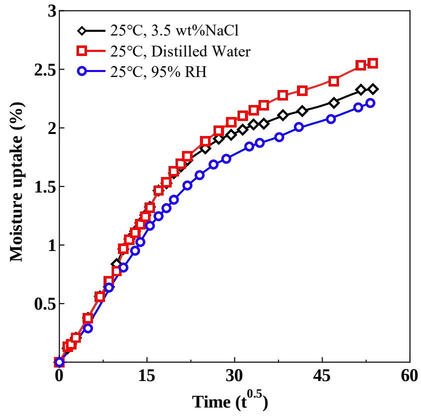
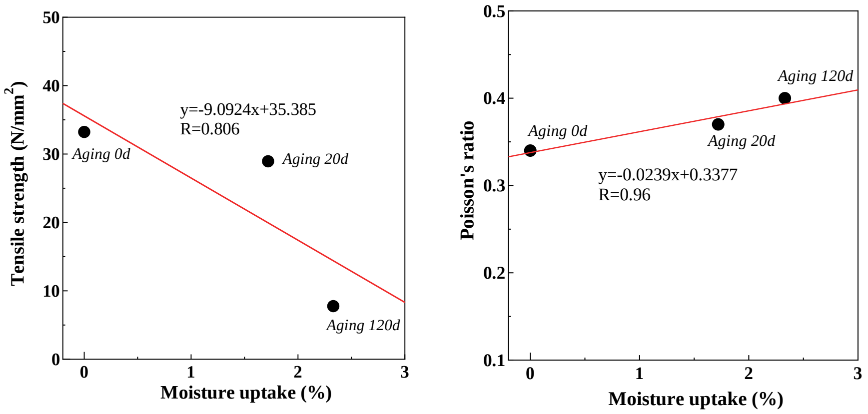
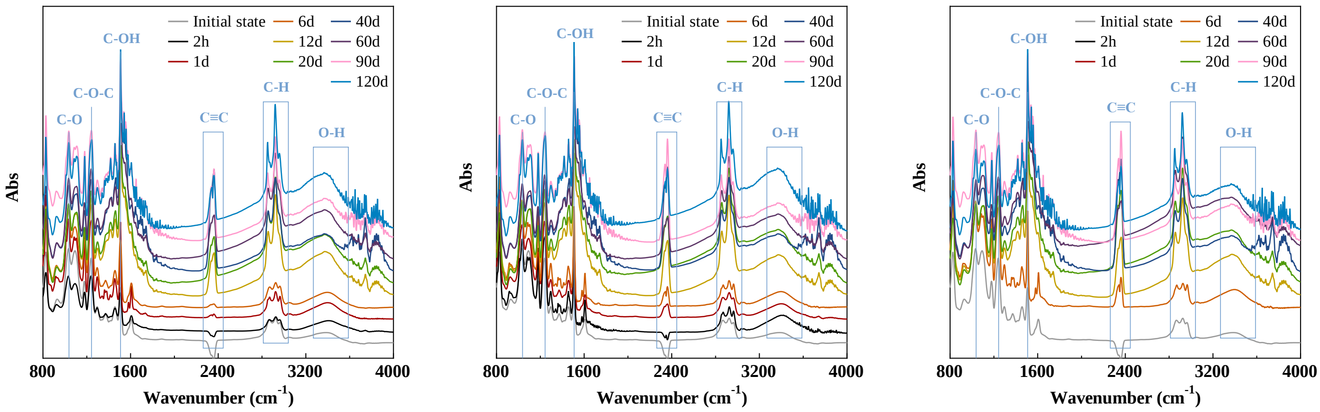


Fig.2 Water absorption curve



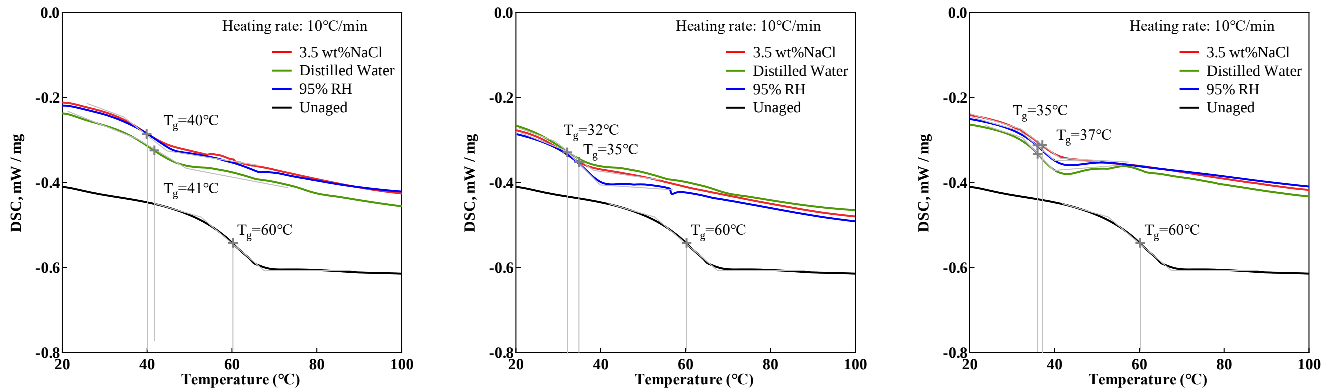
(a) Tensile strength- Moisture uptake (b) Poisson's ratio- Moisture uptake

Fig.3 Effect of water absorption on mechanical properties



(a) 3.5 wt% NaCl (b) Distilled water (c) 95% RH

Fig.4 FT-IR result of epoxy in different aging environments



(a) 20 Days aging (b) 60 Days aging (c) 120 Days

Fig.5 The glass transition temperature of epoxy resin after aging

environments, which indicates that the polymer chains of the resin were broken at this time due to hydrolysis and changed from one long chain to several short chains, resulting in the increase of the content of these groups. In Fig.5, the results of the DSC analysis showed a trend, the glass transition temperature (T_g) of the epoxy resin decreased with the increase of moisture absorption. At the same time, the T_g in the immersion environment decreased slightly more than that in the high-humidity environment, and the T_g of the test bodies in NaCl aq and distilled water decreased by basically the same amount, indicating that the chloride ions in the NaCl solution did not play a role in promoting the decrease of T_g.

4. Conclusion 1) At the same temperature, the immersion environment will lead to more moisture intrusion. 2) Moisture can change the mechanical properties of the resin, leading tensile strength to decrease and Poisson's ratio increases. 3) The chloride ion does not promote a decrease in glass transition temperature.

References

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