Fundamental study on the reversible effects of water absorption in epoxy adhesive used in CFRP/steel joints

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1. Introduction Recent years, CFRP was usually used to reinforce the steel structures. One major drawback when it comes to using CFRP composites for strengthening and repairing steel structures is the lack of knowledge relating to the long-term performance and durability properties of CFRP/steel bonded joints. Particularly, adhesive degradation is the most widely concerned problem. Adhesive bonding has distinct advantages compared with mechanical fastening techniques, such as easier assembly, cost efficiency, and more uniform stress distribution. However, a number of environmental parameters such as moisture and UV radiation, are known to affect the durability and deterioration characteristics of the CFRP strengthened steel structures. 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]. Epoxy resin (ER) as a most common type of polymer adhesive, is susceptible to the ambient humidity, and moisture diffusion can alter their thermo-physical, mechanical, and chemical characteristics [2,3]. The modulus and strength of adhesives are also known to deteriorate as a consequence of moisture ingression.

2. Specimens and test method In this test, all the specimens were made by epoxy adhesive (Araldite® 420), the dimension of specimens were 50×50×1 mm, made by steel mold base. The specimens were immersion in five environments: 1) Atmosphere of 50℃ and 50% RH; 2) Immersed in 23℃ distilled water; 3) Immersed in 23℃ 3.5 mass% NaCl solution; 4) Immersed in 50℃ distilled water; 5) Immersion in 50℃ 3.5 mass% NaCl solution. The test conditions were referred to according to JIS-7092. There were three same samples tested in each kind of test environment. Before the test, all the specimens were cured in a thermo-hygrostat under 60℃ and 30% RH for 12 hrs to dry. All 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 test environments. To measure the weight changing according to time, specimens were removed from the test environment after a decided exposure period (t) about 2, 4, 8, 12, 24, 48 and 72hrs, wiped using a dry cloth and weighed immediately (W_t). The specimens were then returned to the test environment for continuing exposure. The moisture uptake (M_t) for each specimen was calculated using Eq. (1):

$$M_t=\left(\frac{W_t-W_0}{W_0}\right)\times 100 \tag{1}$$

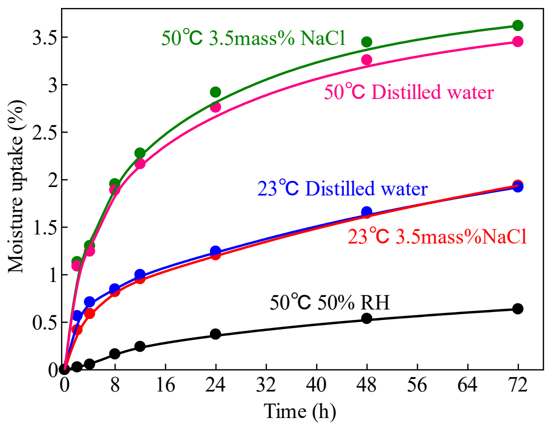
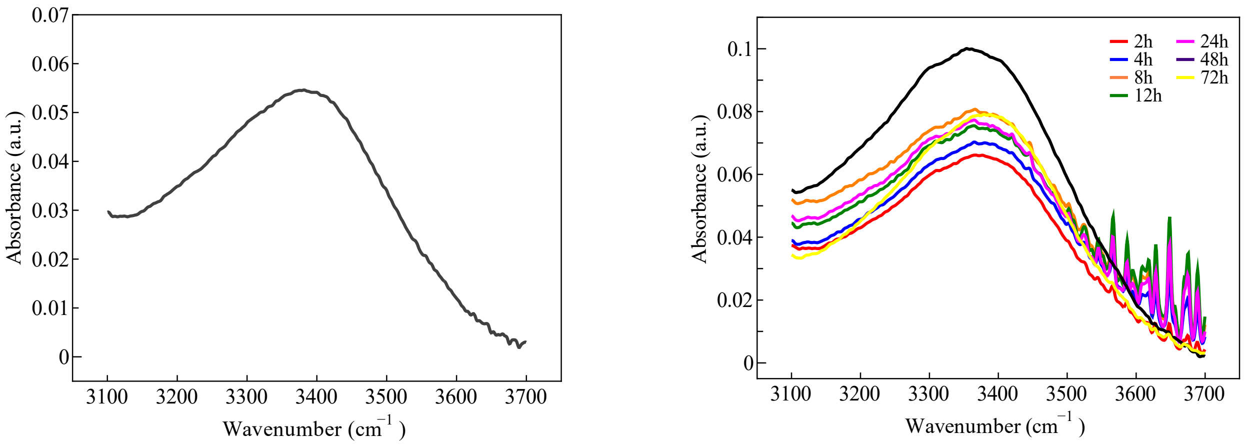
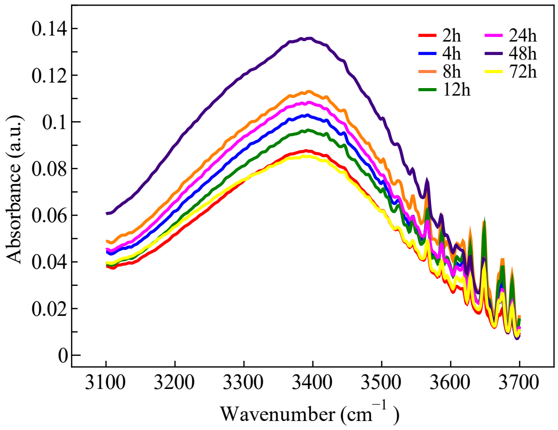


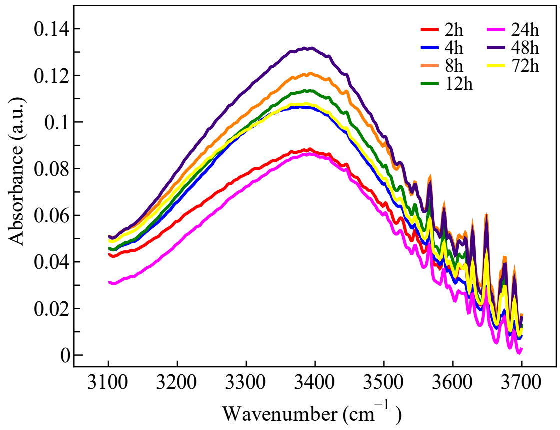
Fig.1 Moisture uptake



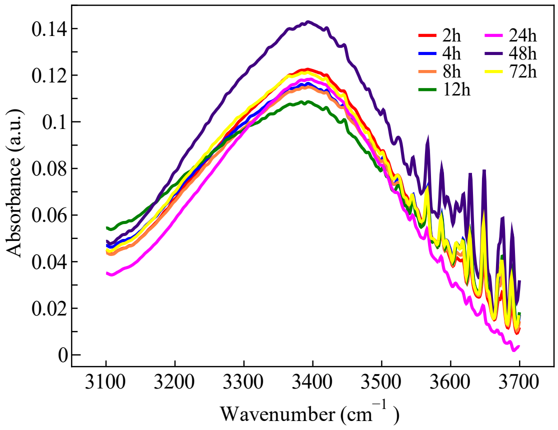
(a) Dried specimen (0 hr)　　　　　(b) Atmosphere (50℃, 50%RH)



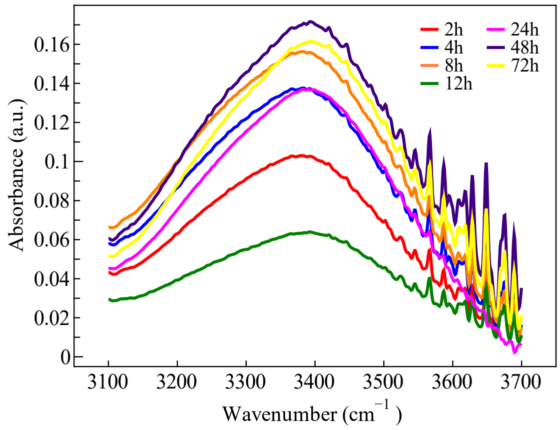
(c) Immersion in Distilled water (23°C)



(d) Immersion in 3.5 mass% NaCl aq (23°C)



(e) Immersion in Distilled water (50°C)



(f) Immersion in 3.5 mass% NaCl aq (50°C)

Fig.2 Test results of FTIR-ATR

To analyze the content of free water. This study used Fourier transform infrared spectroscopy – attenuated total reflectance (FTIR-ATR) to analyze the effect of water absorption for 2, 4, 8, 12, 24, 48 and 72hrs. The test was carried out for a wavenumber (cm^{-1}) between 3100 and 3700 (cm^{-1}), which corresponds to O-H groups. The analysis performed under atmospheric conditions. Inside the specimens, there were two kinds of water called free water and sorbed water. After FTIR analysis, the specimens were immediately returned to the test environment for continuing exposure.

3. Test results The mean value of the moisture uptake (M_t) of each group was calculated as shown in Fig.1. From the obtained M_t of the specimens according to time, atmosphere and immersion environments showed considerable difference to the water absorption, that the water absorption in the atmospheric environment is about one-seventh of that in solution environment after 72 hrs. For the immersed specimens, their water absorption rates were all rapidly increased from 0~12 hrs, whereas after 12 hours, their water absorption rate gradually slowed down and the inner free water tended to be saturated. Moreover, for the cases of different electrolytes (distilled water; 3.5 mass% NaCl aq) performed under the same temperature, various electrolyte concentrations almost would not affect the water absorption of the adhesive. The difference in concentration has no effect on water absorption rate and capacity. However, for the cases under different temperatures, even the same electrolyte would lead to multiple differences in water absorption. It was indicated that the accumulated water environment and temperature are the main control factor of EP water absorption, and the higher temperature significantly accelerated water absorption speed.

The content of free O-H groups has an increasing tendency with the increase of immersion time as shown in Fig.2. In the 48th hour, the amount of O-H groups reached the peak. In the period of 8 to 12 hrs, the peak value of O-H groups were all decreased as shown in Fig.2(b) to Fig.2(f). It may be that a part of the free O-H groups had combined with the molecules of the adhesive material so that a part of free water became sorbed water. This change may have a series of effects on the mechanical properties and electrical resistance of the material, this will be verified in subsequent experiments.

4. Conclusion 1) The water absorption behavior of epoxy resin shows different behavior in the atmospheric and immersion environment, while the temperature would largely affect the moisture uptake in adhesive plate. 2) During the dipping process, a part of the free water combined with the molecules inside the adhesive material to become sorbed water.

References

1) P. Galvez, J. Abenojar, M.A. Martinez, Effect of moisture and temperature on the thermal and mechanical properties of a ductile epoxy adhesive for use in steel structures reinforced with CFRP, Composites Part B: Engineering 176 (2019) 107194. 2) J. Zhou, J.P. Lucas, Hygrothermal effects of epoxy resin. Part I: The nature of water in epoxy, Polymer 40 (1999) 5505–5512. 3) M. Heshmati, R. Haghani, M. Al-Emrani, Effects of moisture on the long-term performance of adhesively bonded FRP/steel joints used in bridges, Composites Part B: Engineering 92 (2016) 447–462.