

# A COMPARATIVE STUDY OF MOISTURE ABSORPTION AND DESORPTION OF COMPOSITE MATERIALS

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**SUMMARY:** In the present investigation, the moisture absorption and desorption of two types of composite materials have been studied. The two types of composite materials are T1: unidirectional glass fiber-reinforced DGEBA type epoxy resin composite (filament winding unidirectional flat plate) and T2: chopped glass fiber-reinforced hydroxymethylated nylon-modified phenol resin composite (mould pressing plate). The absorption test was carried out in deionized water and in artificial seawater at room temperature. The desorption test was conducted in a dessicator also at room temperature. The water absorption and desorption curves were determined. The experiment indicated that on a time basis, T1's moisture absorption rate and saturation moisture content in deionized water were significantly greater than in artificial seawater. In contrast to T1, T2's moisture absorption rate in artificial seawater was slightly higher than in deionized water. For both T1 and T2, the immersive media almost had no influence on after-immersed desorption curves.

**KEYWORDS:** moisture absorption, moisture desorption, swelling, artificial seawater, leaching

## INTRODUCTION

Moisture absorption and desorption tests can be used to see if irrevesible changes in the specimens have taken place.[1] In this study, we carried out two comparisons: 1) the moisture absorption and desorption of two types of composite materials; 2) the two types of composite materials being immersed in two immersive media: deionized water and artificial seawater.

The water gain and water loss were measured as a function of time. The apparent diffusion coefficients were evaluated from a simple theoretical model and experimental data.

## EXPERIMENTAL

Two materials were chosen for the tests. The first (T1) was unidirectional glass fiber-reinforced DGEBA type epoxy resin composite (filament winding unidirectional flat plate). The formulation of resin matrix is the following :

epoxy resin (diglycidyl ether of bisphenol-A)	90 parts
reactive diluent (butyl glycidylether)	10
curing agent (70 anhydride: mixture of tetrahydrophthalic anhydride isomer)	80
promoter (benzyl dimethylamine)	1

The reinforcement is S-2 glass fiber (made in China).

The samples were step cured at 100° for 2 hrs, followed by 150° for 2 hrs, and by 180° for

2 hrs. After cooling, the samples were removed from the mold, any flashing was removed, and the rough ends on the samples were cut off.

The fiber volume fraction and the void content in T1 are approximately 53.2% and 5.9% respectively. Specimen dimension is 50×50×1.2mm (side was not sealed). 5 specimens were tested as one group.

The second (T2) was chopped S-2 glass fiber-reinforced hydroxymethylated nylon-modified phenol resin composite (mould pressing plate).

Molding pressure was 45MPa, mould temperature was 170°. Keep such temperature and pressure for 15 minutes. The weight rate of hydroxymethylated nylon-modified phenol resin and chopped S-2 glass fiber was 25:75.

Specimen dimension is Ø50×2mm. 5 specimens were tested as one group.

The absorption test was carried out in deionized water and in artificial seawater at room temperature. Water uptakes were monitored by repeated weighing of the samples using an analytical balance with an accuracy of 0.1 mg, following immersion in water kept at room temperature. The specimens were removed from the water, blotted, weighed, and then replaced in the water bath.

The desorption test was carried out in a dessicator also at room temperature.

## EXPERIMENTAL RESULTS

Figures 1-2 show the moisture absorption curves and desorption curves respectively.

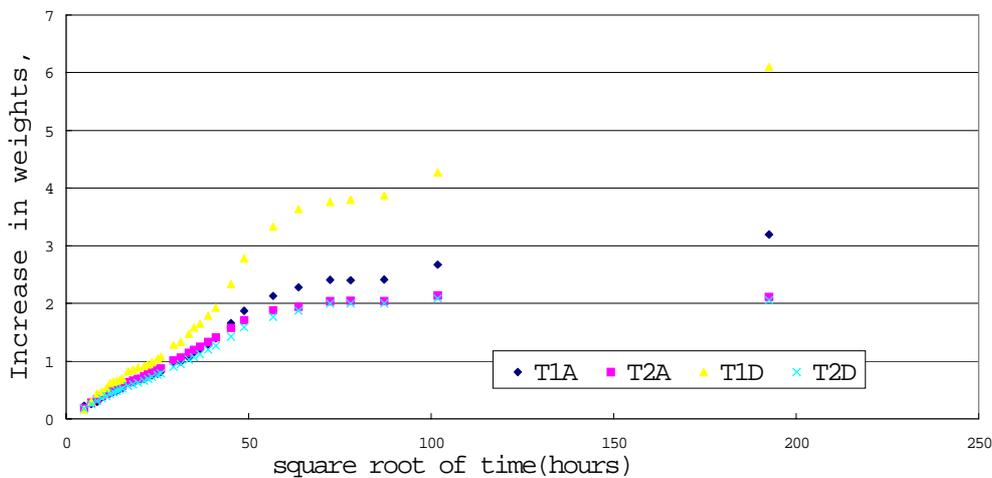


Figure 1. Moisture absorption curves of T1A, T2A, T1D and T2D

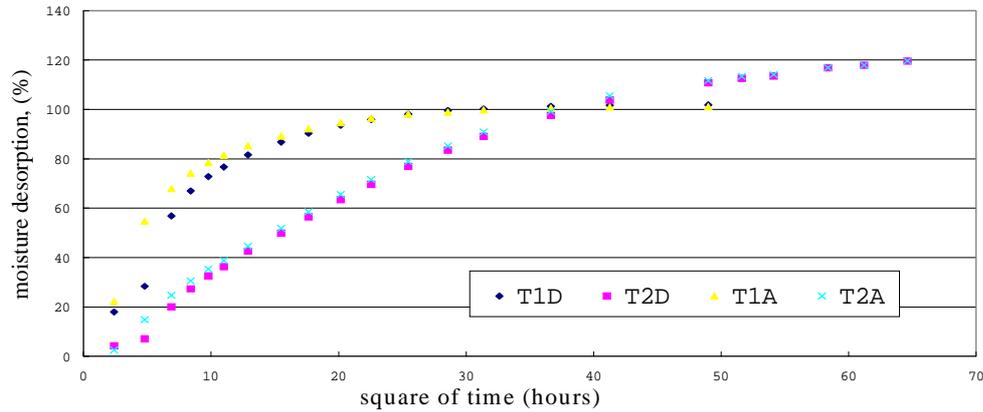


Figure 2. Moisture desorption curves of T1D, T2D, T1A and T2A, as a percentage of maximum moisture content

In Fig.1 and Fig.2, T1D and T2D expresses T1 and T2 immersed in deionized water; T1A and T2A expresses T1 and T2 immersed in artificial seawater. Each data point in the plots represents an average value of five specimens.

From the nature of the curves in Fig.1 it can be seen that T2 specimens immersed in both immersive media exhibit a Fickian diffusion pattern. On the other hand, T1 specimens immersed in both immersive media exhibit a non-Fickian diffusion behaviour.

The diffusion coefficient can be easily evaluated from the Eqn 1:[2]

$$D = (\pi h^2) / (16 M_{\infty}^2) \cdot (M_2 - M_1)^2 / (\sqrt{t_2} - \sqrt{t_1})^2 \quad (1)$$

where  $M_1$  and  $M_2$  are the uptakes of water in percent of the initial weight after times  $t_1$  and  $t_2$  respectively and are taken from the linear portion of the  $M$  vs  $\sqrt{t}$  plot. The diffusion coefficients and assumed saturation moisture content are given in Table 1.

Table 1: Diffusion coefficients and assumed saturation moisture contents

Materials	Diffusion coefficients*, D(mm <sup>2</sup> /S)(10 <sup>-8</sup> )	Assumed saturation moisture contente (%)
T1D (assumed saturation time: 316 days; )	1.31	3.877
T1A (assumed saturation time: 316 days;)	1.92	2.418
T1D (assumed saturation time: 1545 days; )	0.528	6.098
T1A (assumed saturation time: 1545 days;)	1.10	3.195
T2D (assumed saturation time: 316 days; )	5.05	2.004
T2A (assumed saturation time: 316 days)	5.99	2.047

\*Moisture contents at the assumed saturation time are used as saturation moisture contents.

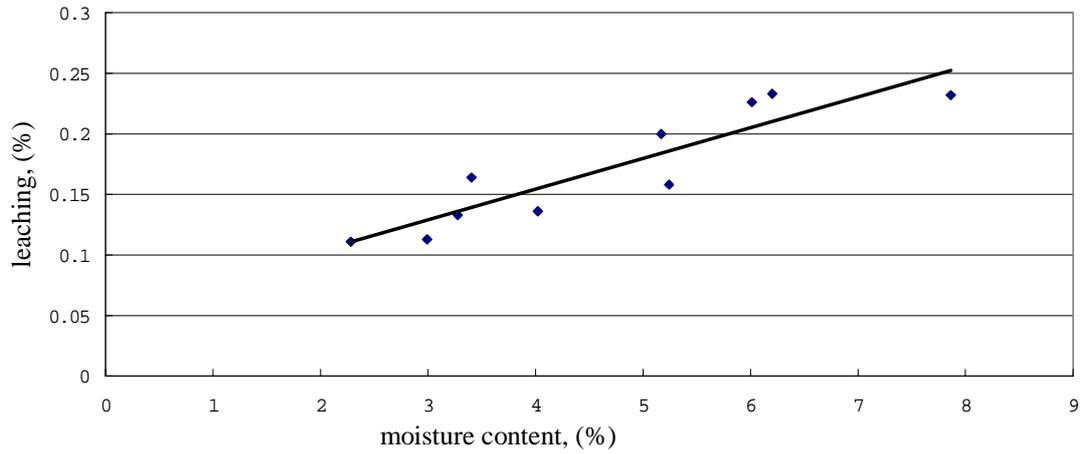
T1 and T2's desorption tests were carried out (in a dessicator at room temperature) 2400 and 4175 hours respectively. Then their specimens were placed in an air oven at 50°, until they reached constant weights. The leaching results and moisture contents (1545 days) are given in Table 2. In Table 2, each value is for individual specimen.

Basing on Table 2, we obtained Fig.3 and Fig.4.

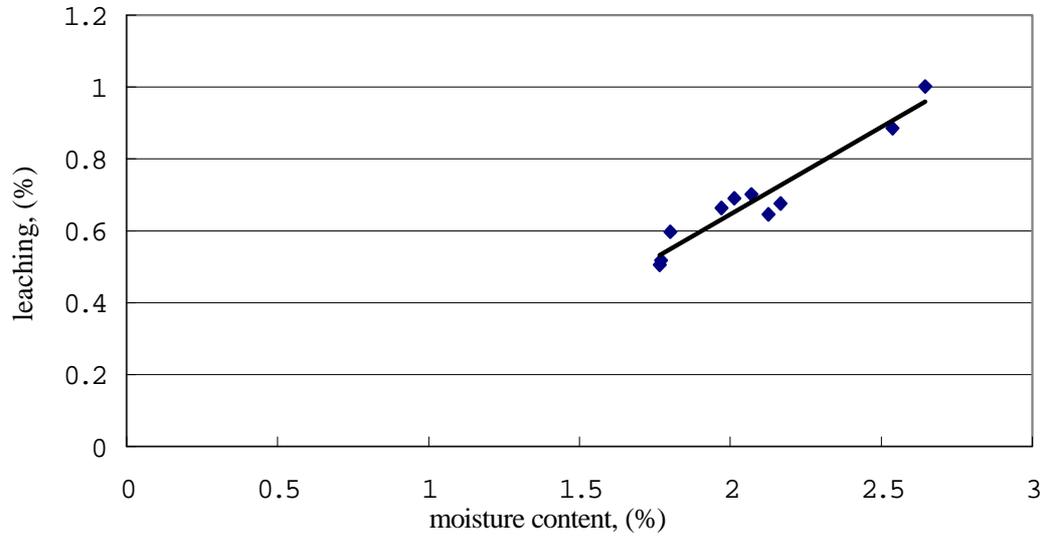
Table 2: The leaching and moisture content (1545 days) results in percent of the initial weight

Specimens	Moisture content (%)	Leaching(%)	Specimens	Moisture content (%)	Leaching(%)
T1D-1	6.203	0.233	T2D-1	2.166	0.675
T1D-2	6.013	0.226	T2D-2	1.770	0.517
T1D-3	5.168	0.200	T2D-3	2.537	0.885
T1D-4	5.242	0.158	T2D-4	2.013	0.690

T1D-5	7.863	0.232	T2D-5	1.801	0.597
T1A-1	2.992	0.113	T2A-1	2.126	0.646
T1A-2	2.282	0.111	T2A-2	1.971	0.664
T1A-3	4.022	0.136	T2A-3	2.070	0.702
T1A-4	3.404	0.164	T2A-4	1.766	0.506
T1A-5	3.276	0.133	T2A-5	2.645	1.001



*Fig.3 The T1's leaching roughly as a linear function of moisture content*



*Fig.4 The T2's leaching roughly as a linear function of moisture content*

## DISCUSSIONS

a) From Fig.1, it is obvious that on a time basis, T1's moisture absorption rate and moisture content in deionized water were significantly greater than in artificial seawater. The difference observed in the absorption rate and moisture content may be ascribed to the presence of the massive ionic species in artificial seawater, since the ability of a chemical species to enter into a polymeric material is inversely proportional to its size and/or atomic weight.[3] In contrast to T1, T2's moisture absorption rate and moisture content in artificial seawater were slightly higher than in deionized water. So we may conclude that the influence of the massive ionic species in artificial seawater on the absorption behaviour is different for different composites.

b) If the absorption experiment is discontinued at the first plateau level about 316 days, as is the case for most data reported to date, a rather good fit with Fick's law can be obtained. If the fitting is done under the assumption that the moisture content about 1545 days represents saturation then the T1's fit is not as good. So we should be careful when we decide to discontinue the absorption experiments.

The following question maybe should be studied further: when we can reasonably discontinue the absorption experiments?

c) After prolonged periods of moisture absorption (about 432 days), T1's specimens immersed in both media began to warp.

This may be due to the resin's swell which cause a change in the residual stresses of the composite.

The change of the residual stresses due to moisture absorption may cause warping and microcracking. These microcracks in turn provide fast diffusion paths and thus alter the moisture absorption.

One problem which often arises with the winding flat plate specimens is that unequal tension in the fibers will cause the plates to warp. Our experimental results further suggest that the warping of the winding flat plate may lead to non-Fickian absorption behaviour.

However, this phenomena need to be studied further.

d) From Fig.2, it can easily be seen that for both T1 and T2, the immersive media (deionized water and artificial seawater) almost have no influence on after-immersed desorption curves. One possible explanation was that water molecule's interaction with the polymer matrix maybe the same for both media: the resin is the same and so are the sorption sites.[4]

e) Almeida investigated the effect of saline solutions on the short beam shear strength of aramid/epoxy composites and showed the decrease in strength as a function of moisture content.[4] Our experimental results (see Fig.3 and Fig.4) suggest that T1 and T2's leaching was roughly as a linear function of moisture content.

## CONCLUSIONS

On a time basis, T1's moisture absorption rate and saturation moisture content in deionized water was significantly greater than in artificial seawater. In contrast to T1, T2's moisture absorption rate in artificial seawater was slightly higher than in deionized water. So we may conclude that the influence of the massive ionic species in artificial seawater was different for different composites.

For T1 and T2, the immersive media (deionized water and artificial seawater) almost have no influence on after-immersed desorption curves. One possible explanation was that

water molecule's interaction with the polymer matrix maybe the same for both media: the resin is the same and so are the sorption sites.

T1 and T2's leaching was roughly as a linear function of moisture content.

### **ACKNOWLEDGES**

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