Factors Affecting Moisture Absorption in Polymer Composites Part II: Influence of External Factors

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(Received March 1, 1984)

ABSTRACT

The influence of external factors like relative humidity (Ø) and ambient temperature (T) on the moisture absorption behaviour of permeable (Jute-Epoxy) and impermeable (Glass-Epoxy and Graphite-Epoxy) types of composites were reported. The respective equilibrium moisture contents (M_m' and M_m) increased exponentially with relative humidity. The diffusion coefficients of both type of composites (D_c' and D_c) increased with ambient temperature and could be represented by an Arrhenius relationship.

The permeable composite showed a higher exponential power on the relative humidity term than the impermeable composite (2.64 for Jute composite as compared to 2.0 reported by Shen and Springer for a graphite composite) and a lower activation energy for diffusion (0.9×10^3 cal. mole^{-1} for the jute composite as compared to 4.429×10^3 cal. mole^{-1} obtained for a glass composite). These trends were attributed to the fibre permeability leading to different diffusion barriers in such composites.

INTRODUCTION

MOISTURE ABSORPTION IN POLYMER COMPOSITES IS INFLUENCED BY internal (fibre fraction and its orientation) and external (relative humidity and ambient temperature) factors.

Investigators like Shen and Springer [1] reported on the influence of these factors on the moisture absorption in graphite-epoxy composites representing the impermeable type composites. Rao [2] for the first time investigated the influence of both the factors on the absorption behaviour of a jute-epoxy composite denoting the permeable type composite. Rao et al [3] subsequently reported that, the disparities in the moisture absorption behaviours of both

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0731-6844/84/03/0246-08 $04.50/0

class of composites under the influence of the internal factors stemmed out of the very fibre nature.

In this paper, the authors report the influence of external factors on the moisture absorption characteristics (equilibrium absorption and diffusion coefficient), of permeable and impermeable composites by considering respectively the jute-epoxy and the glass and graphite-epoxy composites.

THEORY

Effect of Ambient Temperature (T)—The Arrhenius Relationship

Any activated process can be conveniently characterised by an Arrhenius relationship. For the composites under consideration, the temperature dependence of respective composite diffusion coefficients can be represented as,

$$D_c = D_o \exp^{-E_d/RT} \qquad \text{impermeable composite} \qquad (1)$$

$$D_c' = D_o' \exp^{-E_d'/RT} \qquad \text{permeable composite} \qquad (2)$$

Where the respective diffusion coefficients can be calculated using the following expressions,

$$D_c = \pi \left[\left(\frac{h}{4M_m} \right)^2 \quad \left(\frac{M_2 - M_1}{\sqrt{t_2} - \sqrt{t_1}} \right)^2 \right] \qquad (3)$$

$$D_c' = \pi \left[\left(\frac{h}{4M_m'} \right)^2 \quad \left(\frac{M_2 - M_1}{\sqrt{t_2} - \sqrt{t_1}} \right)^2 \right] \qquad (4)$$

A plot between the diffusion coefficient and 1/T, will then be helpful in evaluating the pre-exponential factor *(D_o or D_o')* and the activation energy for diffusion *(E_d or E_d')*. That the composite diffusion coefficients increase with temperature readily indicates that, equilibrium absorption conditions are reached faster, the higher the temperature is, since the saturation times *(t_m or t_m')* are related to respective diffusion coefficients inversely as reported by Shen and Springer [1].

Effect of Relative Humidity ∅

Shen and Springer reported that, the equilibrium moisture content of a composite is related exponentially to the relative humidity term and accordingly, the following two expressions may be written to represent this dependence.

$$M_m = a\, \varnothing^b \qquad \text{impermeable composite} \qquad (5)$$

$$M_m' = A\, \varnothing^B \qquad \text{permeable composite} \qquad (6)$$

The constants (a,b) and (A,B) have to be evaluated experimentally.

EXPERIMENTAL PROCEDURE

Commercial grade jute-fibres of 1mm diameter and 8 end E-glass rovings were used with a laminating grade epoxy system (LY 556 resin and HT 972 hardener, supplied by Ciba Giegy), to prepare unidirectional composite laminates of 2mm thickness. Details of laminate fabrication and specimen preparation were reported elsewhere [3].

Moisture absorption curves were obtained for jute and glass composites by exposing the specimens to various relative humidity conditions (32%, 76%, 92% and 98%) simulated as per the specications of ASTM E-104 using super saturated salt solutions.

To study the temperature effect, specimens were immersed in distilled water at different temperatures (298 °K, 313 °K and 333 °K) and moisture absorption data obtained by weight difference technique as reported earlier [3]. All these data were obtained on specimens with respective volume fractions of 0.7, for both type of composites. Composite diffusion coefficients have been calculated using Equations (3) and (4).

RESULTS AND DISCUSSIONS

Effect of Ambient Temperature (T)

Figure 1 shows the moisture absorption curves for the jute composite at different ambient temperatures. The slopes of the curves increase as the temperature is increased, while the equilibrium absorption levels remain

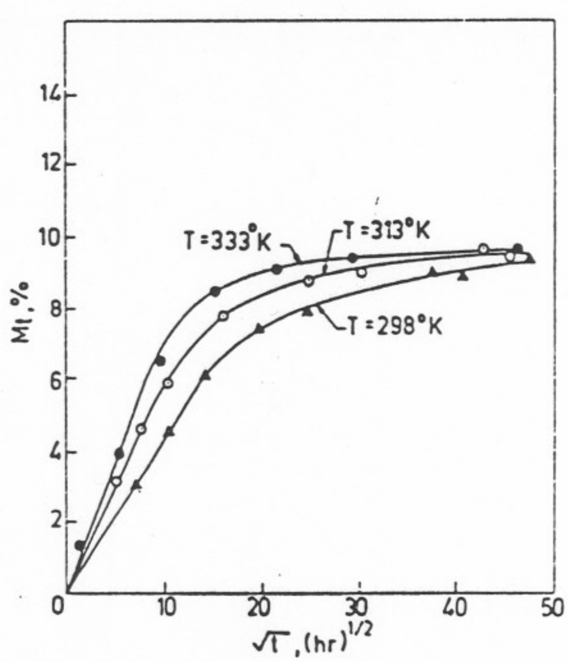

Figure 1. Moisture absorption curves of jute-epoxy composite at different temperatures (V_f' = 0.70).

essentially the same. The Arrhenius plot is shown in Figure 2. The diffusion kinetics parameters as calculated from the figure are as follows,

$$D_o' = 1 \times 10^{-3}\ cm^2\ sec^{-1}$$

$$E_d' = 0.9 \times 10^3\ cal\ mole^{-1}$$

The temperature dependence of the composite diffusion coefficient (D_c') can therefore be written as,

$$D_c' = 1 \times 10^{-3}\ exp^{-0.9} \times 10^3/RT \tag{7}$$

Figure 3 and Figure 4 show the data for the glass-epoxy composite under the influence of different temperatures. The kinetics parameters for this composite are,

$$D_o = 1 \times 10^{-1}\ cm^2\ sec^{-1}$$

$$E_d = 4.429 \times 10^3\ cal.\ mole^{-1}$$

The Arrhenius relationship for the glass composite is therefore,

$$D_c = 1 \times 10^{-1}\ exp^{-4.429} \times 10^3/RT \tag{8}$$

Comparison of Equations (7) and (8) shows that, the jute composite has a lower activation energy than the glass composite, indicating a weaker diffu-

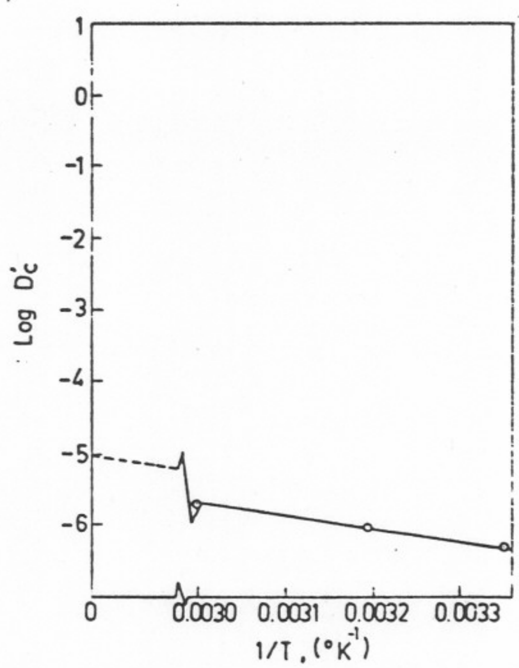

Figure 2. Arrhenius relationship for the jute-epoxy composite ($V_f' = 0.70$).

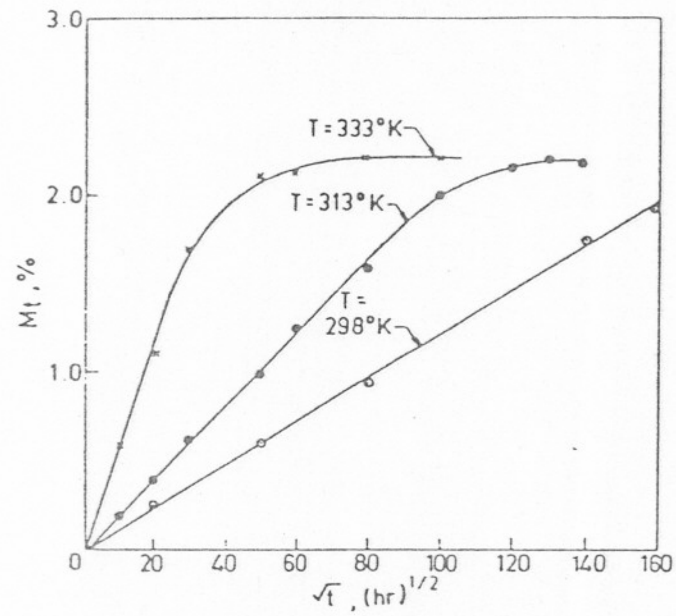

Figure 3. Moisture absorption curves of glass-epoxy composite at different temperatures ($V_f' = 0.70$).

sion barrier in this composite. This largely accounts for the high diffusion coefficient values observed in this composite.

Effect of Relative Humidity Ø

The effect of relative humidity on the moisture absorption of the jute composite is shown in Figure 5 and Figure 6 shows a plot of log (M_m') against log (Ø). The following equation can therefore be obtained from this figure.

$$M_m' = 0.00003\ (\text{Ø})^{2.64} \tag{9}$$

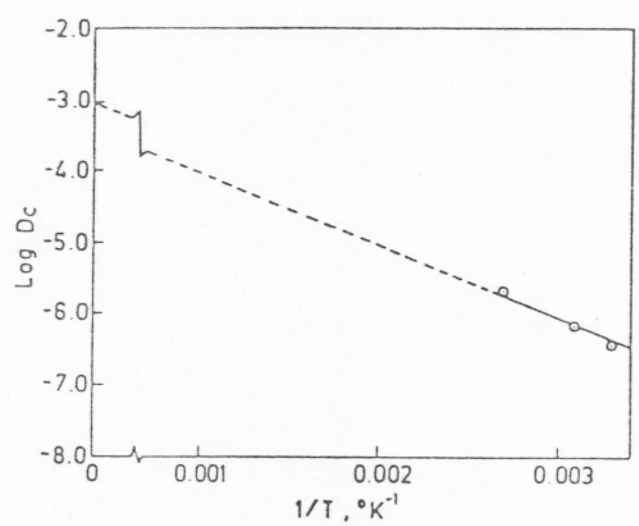

Figure 4. Arrhenius relationship for the glass-epoxy composite ($V_f' = 0.70$).

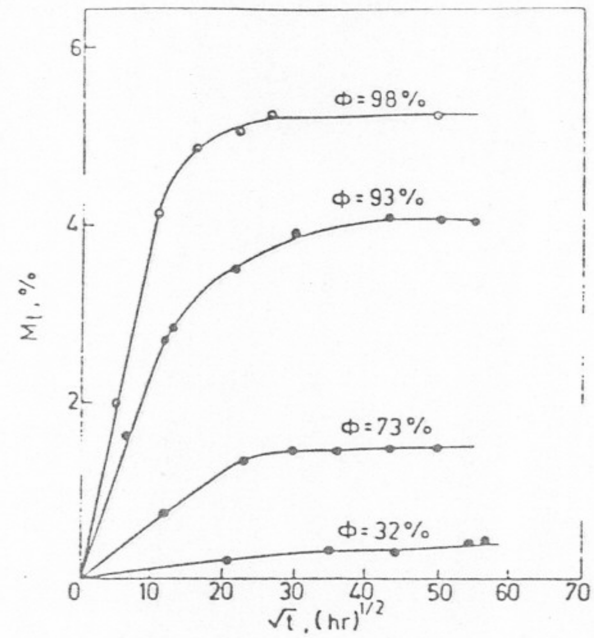

Figure 5. Effect of relative humidity on the moisture absorption characteristics of jute-epoxy composite ($V_f' = 0.70$, $T = 298°K$).

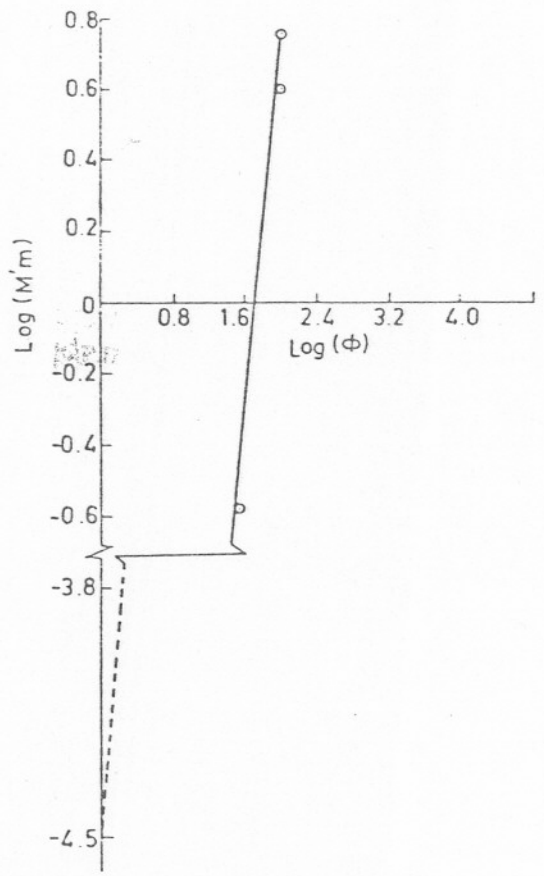

Figure 6. The relationship between log (M_m') and log (Φ) for jute-epoxy composite ($V_f' = 0.70$, $T = 298°K$).

Table 1. Diffusion characteristics of jute-epoxy and glass-epoxy composites—overall comparison.

Diffusion Property	Epoxy Resin	Jute-Epoxy Composite ($V_f' = 0.7$)	Glass-Epoxy Composite ($V_f = 0.7$)
M_m (%)	3.2	8.5	2.0
D_c' or D_c	8.3×10^{-10}	4.4×10^{-9}	9.2×10^{-11}
E_d' or E_d (cal. Mole^{-1})	—	0.9×10^{3}	4.42×10^{3}
D_o' or D_o (Cm^{2}Sec^{-1})	—	1×10^{-3}	1×10^{-1}
Fickian Model	Applicable	Applicable	Applicable

Earlier Shen and Springer [1] gave the following expression for a graphite-epoxy unidirectional composite,

$$M_m = 0.0004\ (\varnothing)^{2.0} \tag{10}$$

Comparison of Equations (9) and (10) indicates that, the permeable fibre (jute) composite is characterised by a higher exponential power on the relative humidity term, which accounts for the high moisture absorption levels in such composites. This is also confirmed by the data on glass-epoxy for which Bonniau and Bunsell [4] obtained the expression,

$$M_m = 0.01\ (\varnothing)^{1} \tag{11}$$

Table 1, shows the important diffusion characteristics of the jute and glass epoxy composites subjected to identical conditions of exposure.

CONCLUSIONS

Temperature dependence of the diffusion coefficients of permeable and impermeable fibre composites can be represented by an Arrhenius relationship.

Equilibrium moisture contents of both type of composites are influenced alike by the changes in relative humidity. The low activation energy of diffusion in the jute composite and a high exponential power on the relative humidity term indicate a weaker diffusion barrier in the permeable composite and largely account for the faster diffusion process in such composite.

ACKNOWLEDGEMENTS

The authors are thankful to Dr. A.K. Singh, Head, Materials Science Division and Dr. S.R. Valluri, Director, National Aeronautical Laboratory for all support they received in the investigations.

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