Moisture Absorption of Polyester-E Glass Composites

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ABSTRACT

Moisture absorption of polyester-E glass composites immersed in liquids and in humid air were investigated. The weights of the composites as a function of exposure time and temperature were measured for three different types of materials. Tests were performed a) with the materials immersed in distilled water, in saturated salt water, in No. 2 diesel fuel, in jet A fuel, in synthetic aviation lubricant, in gasoline, and b) with the materials exposed to humid air. The apparent maximum moisture contents and the apparent diffusivities were deduced from the data.

INTRODUCTION

THE OBJECTIVE OF this program was to determine the moisture absorption characteristics of polyester-E glass composites. Three different types of materials were tested, these being designated as SMC-25, SMC-65, and SMC-30EA. A brief description of each of these materials is given in Table 1.

The weight change of the material as a function of time and temperature was measured with samples of the material immersed in a) humid air, b) distilled water, c) saturated salt water, d) No. 2 diesel fuel, e) jet A fuel, f) synthetic aviation

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Table 1. Description of the Polyester-E Glass Composites Used in This Investigation [1].

SMC-25		
Ingredient	Type	Weight %
Polyester (OCF* E-920-1)	Resin	29.4
Calcium Carbonate	Filler	41.8
Zinc Stearate	Internal Release	1.1
Tertiary Butyl Perbenzoate	Catalyst	0.3
Magnesium Hydroxide	Thickener	1.5
Mapico Black	Pigment	0.8
E-Glass (OCF 951 AB)	2.54 cm Chopped	25

SMC-65		
Ingredient	Type	Weight %
Polyester (PPG**50271)	Rigid Resin	16
Polyester (PPG 50161)	Flexible Resin	16
E-Glass (PPG 518)	2.54 cm Chopped	65
Balance	Thickener, etc.	3

SMC-30EA		
Ingredient	Type	Weight %
Polyester	Resin	19.9
Calcium Carbonate	Filler	41
E-Glass (OCF 956)	2.54 cm Chopped	28
Balance	Thickener, etc.	11.1

lubricant, and g) gasoline (Indolene HO 30).

The experimental procedures are described in the next section.

EXPERIMENTAL

The dimensions of the specimens used in the tests are given in Table 2. Before placing the specimens into the moist environment (liquid or humid air) the specimens were dried in an oven at 66°C until no more weight loss was observed. The dry specimens were then placed in the appropriate environmental chambers and their weights were measured by weighing them periodically on a Mettler Analytical Balance.

During tests where the specimens were immersed in liquids, the specimen temperature was kept constant within ±1°C by placing the liquid container inside a constant temperature chamber. During the tests with humid air the specimens were

Table 2. Nominal Dimensions of the Test Specimens.

Material	Dimension, mm		
	Thickness	Width	Length
SMC-25	3.30	25.4	8.89
SMC-65	2.79	25.4	8.89
SMC-30EA	3.17	25.4	8.89

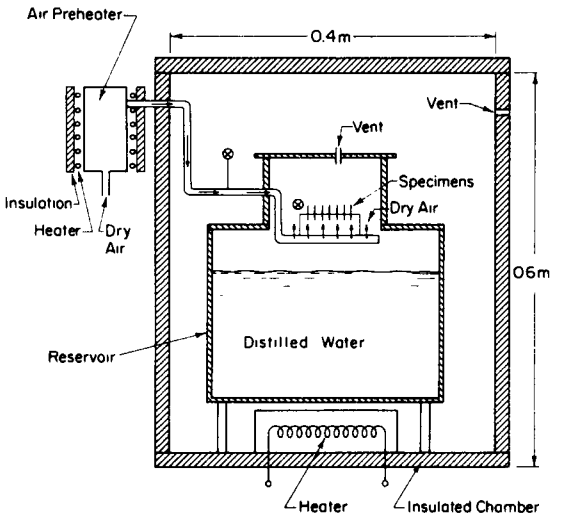

Figure 1. Schematic of apparatus used in tests where the relative humidity of the air was less than 100 percent. Ø: thermocouple locations.

mounted above the surface of a pool of water. The relative humidity of the air was regulated by passing preheated air through the vapor (Figure 1). The relative humidity was measured with an Abbeon Hygrometer. The temperatures of the air, the water and the specimens were controlled by heaters and measured by thermocouples.

RESULTS

Tests were performed with specimens immersed in humid air and in seven different liquids. The test conditions are summarized in Table 3.

The weight changes of the materials are presented in Figures 2–9. The weight change is defined as:

$$M = \frac{\text{Weight of specimen} - \text{Weight of dry specimen}}{\text{Weight of dry specimen}} \times 100 \text{ percent} \qquad (1)$$

Table 3. Conditions Used in the Tests.

	Environment	Temperature °C
1)	Humid air 100% rel. hum.	32
2)	Humid air 100% rel. hum.	50
3)	Humid air 100% rel. hum.	65
4)	Humid air 60% rel. hum.	65
5)	Humid air 40% rel. hum.	65
6)	Distilled water	23
7)	Distilled water	50
8)	Saturated NaCl-water solution	23
9)	Saturated NaCl-water solution	50
10)	Phillips Petroleum Co. jet A fuel	23
11)	Phillips Petroleum Co. jet A fuel	50
12)	Amoco No. 2 diesel fuel	23
13)	Amoco No. 2 diesel fuel	50
14)	Stauffer type 2 synthetic aviation lubricant	23
15)	Stauffer type 2 synthetic aviation lubricant	50
16)	Amoco Indolene HO 30	23

For each material the weight changes are given as a function of time and temperature. Each point in Figures 2–9 is the average of three data points. All three data were generally within ±15 percent.

The results presented in Figures 2–9 show the weight change as a function of exposure time. These results indicate that, in addition to exposure time, the weight change depends on a) the material, b) the temperature and c) the composition of the environment (relative humidity of the air or the type of liquid used). A good assessment of the influences of these parameters on the weight change can be obtained by evaluating an "apparent maximum moisture content" and an "apparent diffusivity" for each set of test conditions. The apparent maximum moisture content (Mm) was taken from Figures 2–9 as the value at which the weight change first seemingly levelled off. The apparent diffusivity was calculated by assuming that the moisture absorption process followed Fick's law. Hence, the apparent diffusivity was calculated from the expression [2]

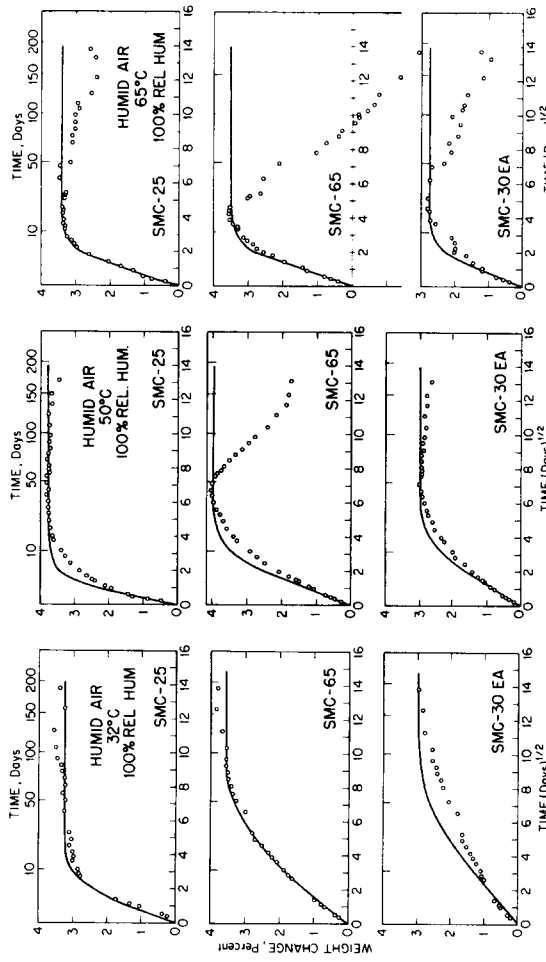

Figure 2. Weight change as a function of time of specimens exposed to air at 100 percent humidity. o : Data; – Fick's law solution (Equation 3).

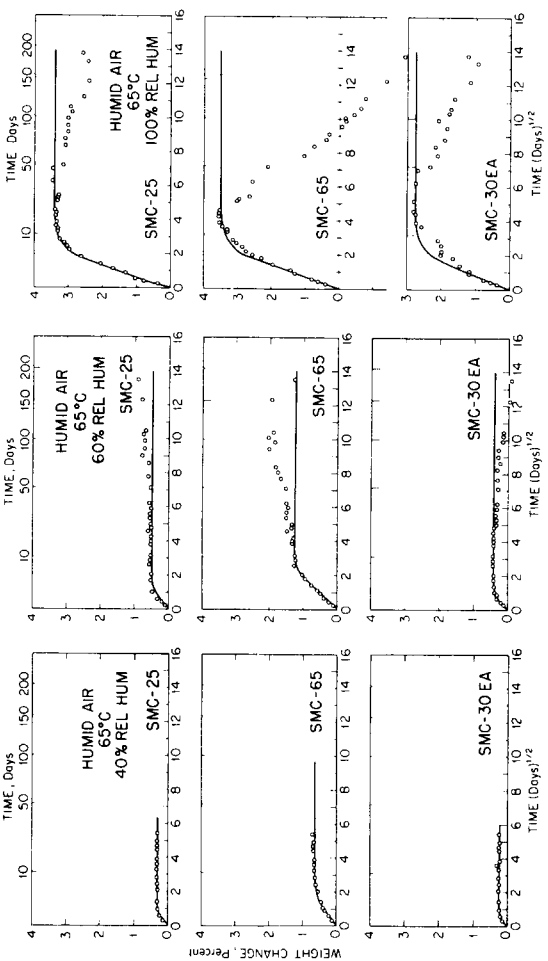

Figure 3. Weight change as a function of time of specimens exposed to air at 40, 60, and 100 percent relative humidities. o: Data; — Fick's law solution (Equation 3).

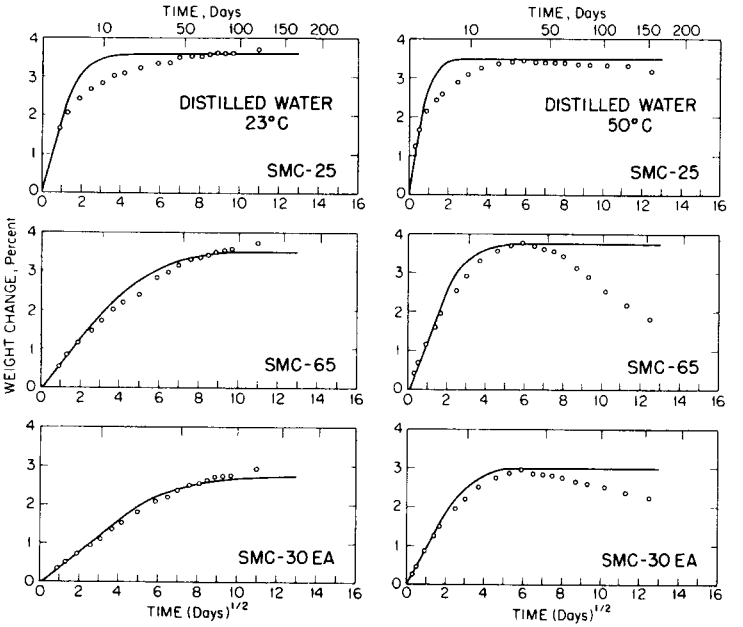

Figure 4. Weight change as a function of time of specimens immersed in distilled water. o: Data; – Fick's law solution (Equation 3).

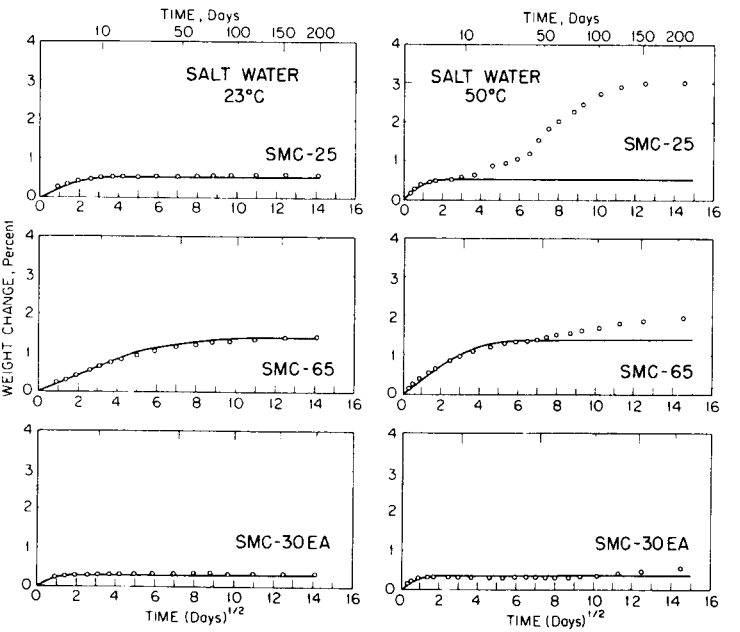

Figure 5. Weight change as a function of time of specimens immersed in saturated salt water (NaCl) solutions. o: Data; – Fick's law solution (Equation 3).

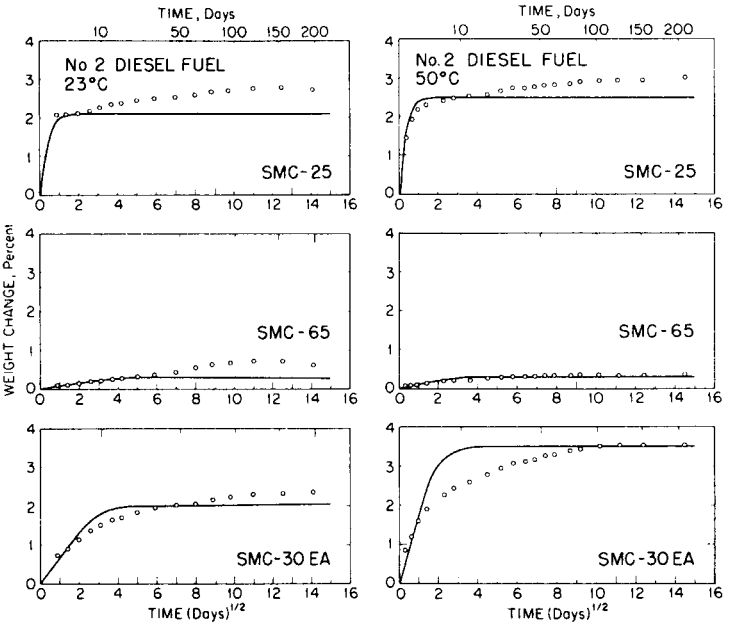

Figure 6. *Weight change as a function of time of specimens immersed in No. 2 diesel fuel. o: Data; – Fick's law solution (Equation 3).*

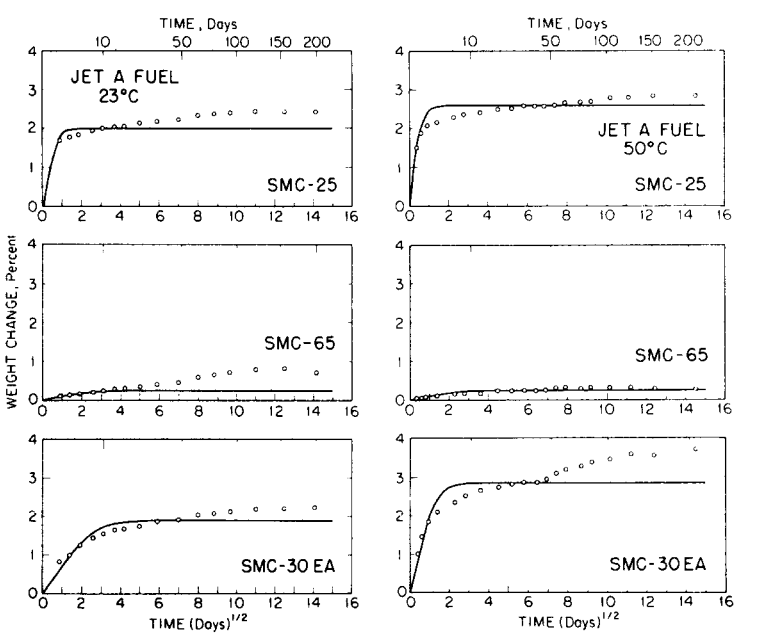

Figure 7. *Weight change as a function of time of specimens immersed in jet A fuel. o: Data; – Fick's law solution (Equation 3).*

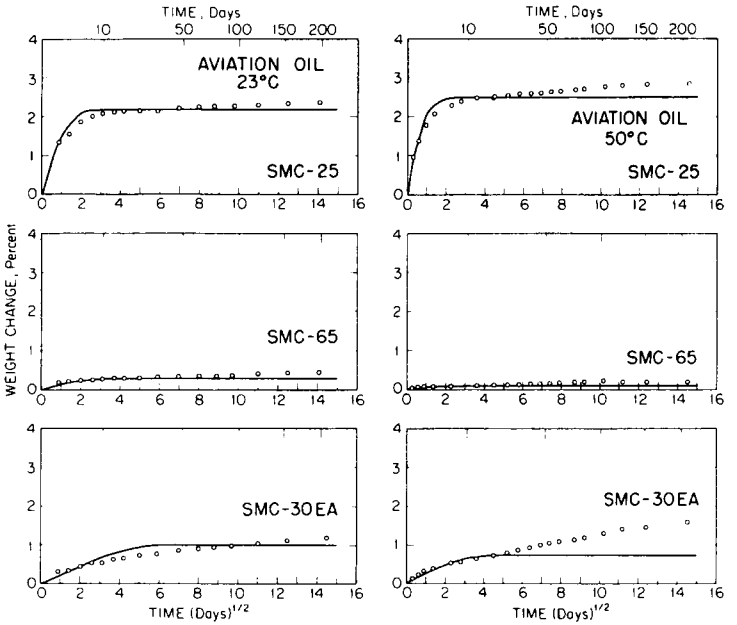

Figure 8. Weight change as a function of time of specimens immersed in synthetic aviation lubricant. o: Data; – Fick's law solution (Equation 3).

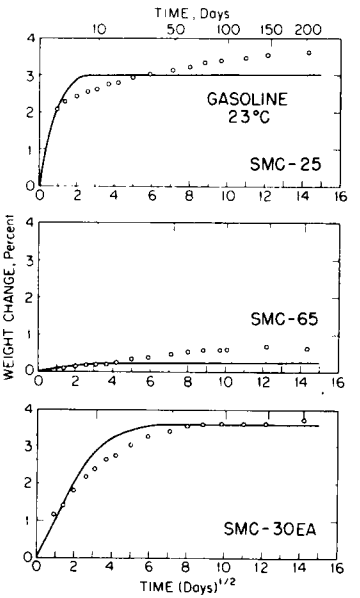

Figure 9. Weight change as a function of time of specimens immersed in gasoline (Indolene HO 30). o: Data; – Fick's law solution (Equation 3).

$$D = \pi\left(\frac{h}{4Mm}\right)^2\left(\frac{M_2 - M_1}{\sqrt{t_2} - \sqrt{t_1}}\right)^2\left(1 + \frac{h}{\ell} + \frac{h}{n}\right)^{-2} \tag{2}$$

where h, ℓ and n are the thickness, the length, and the width of the specimens, respectively. M_1 and M_2 are the moisture contents at times t_1 and t_2, these times being sufficiently low so that the weight change can still be taken to vary linearly with $(\text{time})^{1/2}$.

The results of Mm and D values resulting from these calculations are listed in Table 4. The results in Table 4 show that both the apparent moisture content and the apparent diffusivity depend on the relative humidity (in the case of humid air) or on the type of liquid used. Furthermore, the apparent diffusivity is strongly affected by the temperature, while Mm is relatively insensitive to temperature. These results are consistent with those observed with graphite-epoxy composites [2, 3, 4]. However, for the polyester-E glass composites tested here the apparent diffusivity also depends on the relative humidity, while for graphite-epoxy composites the diffusivity was not affected significantly by the relative humidity. The effect of relative humidity on the weight change of polyester-E glass composites is likely due to the deterioration of the material, a phenomenon which will be discussed subsequently.

It is of interest to determine how the Mm and D values listed in Table 4 predict the weight change of the material over the six month period of the tests. Therefore, for each test condition the weight change as a function of time was calculated using the expression developed for Fickian absorption [2].

$$M = \left\{1 - \frac{8}{\pi^2}\sum_{j=0}^{\infty}\frac{\exp[-(2j+1)^2\,\pi^2\,(Dt/h^2)]}{(2j+1)^2}\right\}(Mm - M_i) + M_i \tag{3}$$

In the present tests the initial moisture content M_i was zero.

The results of these calculations are shown as solid lines in Figure 2–9. In most cases the calculated values and the data agree reasonably well until the apparent maximum weight change is reached. Beyond this point the calculated values generally deviate from the data. The measured weight changes either increased or decreased once the apparent maximum moisture content was reached. This behavior was most pronounced at the higher temperatures and at the higher relative humidities.

Once the data deviated from the calculated values the absorption process was "non-Fickian". The following is a plausible explanation of the observed non-Fickian absorption process. Owing to the moist, high temperature environment, microcracks developed on the surface and inside the material. Moisture rapidly entered the material, causing the increase in weight. As the cracks developed, mate-

Table 4. The Apparent Maximum Moisture Content Mm and the Apparent Diffusivity D of Polyester-E Glass Composites Immersed in Different Substances.

Substance	Temperature	SMC-25		SMC-65		SMC-30 EA	
	C°	Mm %	D x 10^5 mm^2/sec	Mm %	D x 10^5 mm^2/sec	Mm %	D x 10^5 mm^2/sec
Humid air, 100%	32	3.25	8.1	3.60	3.1	3.0	1.0
Humid air, 100%	50	3.75	20	4.00	4.0	3.00	2.9
Humid air, 100%	65	3.40	14	3.50	7.4	2.75	8.3
Humid air, 60%	65	0.50	40	1.25	9.3	0.45	50
Humid air, 40%	65	0.35	82	0.65	15	0.25	160
Distilled water	23	3.60	12	3.50	1.1	2.95	0.85
	50	3.50	40	3.75	4.5	3.00	3.6
Salt water	23	0.55	8.3	1.40	0.8	0.35	21
	50	0.55	33	1.40	2.5	0.35	30
Jet A fuel	23	2.0	80	0.25	5.0	1.90	5.3
	50	2.6	115	0.25	6.5	2.85	20
No. 2 diesel	23	2.1	80	0.30	3.0	2.00	4.9
	50	2.5	125	0.30	4.5	3.50	10
Aviation oil	23	2.2	27	0.25	5.0	1.0	2.0
	50	2.5	51	0.10	5.0	0.75	5.0
Gasoline	23	3.0	30	0.25	5.0	3.60	3.0

rial, most likely in the form of resin particles, was actually lost. In many instances such material loss was observed after a few hours of exposure to the moist environment. As long as the moisture gain was greater than the material loss, the weight of the specimen increased. Once the weight of the lost material exceeded the weight of the absorbed moisture, the weight of the specimen decreased. Of course, when material was lost, the measured weight change no longer corresponded to the moisture content of the material.

It is noted that similar non-Fickian absorption behavior was observed with graphite-epoxy composites immersed in saturated steam at 150°C. The microcracks formed during these tests were readily apparent on photo-micrographs taken of the specimens [5].

SUMMARY

On the basis of the test results obtained, the following general conclusions can be made regarding the moisture absorption characteristics of the SMC-25, SMC-65, and SMC-30EA polyester-E glass composites:

1. Under most conditions Fick's law, together with values of the apparent diffusivity, may be used to approximate the weight change until the apparent maximum moisture content is reached.
2. In the temperature range of the present tests (23°C to 65°C), the apparent maximum moisture content depends strongly upon the type of material, the environment (type of liquid or relative humidity of the air) but is not too sensitive to temperature.
3. The apparent diffusivity, calculated by assuming Fickian diffusion, is strongly affected by the type of material, the environment (type of liquid or relative humidity of air), and the temperature.
4. When the moisture absorption process can no longer be described by Fick's law, actual test data, such as presented here in Figures 2–9, must be used to determine the long-term behavior of the material.

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