Hygrothermal Effects on RT-Cured Glass-Epoxy Composites in Immersion Environments. Part B: Degradation Studies

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ABSTRACT: The degradative effects of artificial seawater and distilled water immersion at 333° K on the mechanical properties (ILSS, compression strength) of BID glass/epoxy composite materials has been studied. Experimental results showed that the composite degradation trends were similar in both the media. It was found that the composite specimens exhibited a higher compressive and ILSS retention when immersed in the artificial seawater than when immersed in distilled water. This is attributed to the moisture absorption levels being higher in specimens immersed in distilled water than those immersed in artificial seawater (Part A). Further, it was found that the measured and predicted mechanical strength retention ratios (compression and ILSS) were in fairly good agreement with each other for both the immersion conditions.

KEY WORDS: glass/epoxy composite, moisture gain, degradation, compression, ILSS, hot wet property.

INTRODUCTION

THE GLASS/EPOXY COMPOSITES are used in a variety of structural components in lighter aircraft due to their good strength, stiffness and significant weight savings. Composite materials are known to exhibit some degree of degradation due to moisture absorption [1–4]. Glass/epoxy composites show significant changes in the matrix dependant mechanical properties (ILSS, compression strength) due to moisture absorption. To expand the application of polymeric composites in application environments, the nature and degree of degradation due to moisture needs to be better understood. Previous studies on com-

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posites in moist environments have concentrated on the kinetics of absorption and the effect of this moisture on mechanical properties. The fibres in the composites are essentially impermeable and do not absorb any moisture. Resins on the other hand, absorb considerable moisture, often as much as 5% by weight [5]. This moisture causes plasticization of the matrix and often some swelling. As the matrix swells, hydrothermal stresses are induced at the fiber/matrix interface which can result in debonding and/or matrix cracking under prolonged periods of exposure. This accumulated moisture may further weaken the interfacial strength of the polymeric composite [6–8]. The plasticization of the matrix by absorbed moisture will cause some reduction in the creep of the matrix modulus as well as toughening of the matrix. A reduction in interfacial strength due to absorbed moisture will significantly reduce short beam shear strength (ILSS) and compression strength, which can be collectively termed as the matrix dominated properties.

The main focus in these studies has been to study the effects of seawater and distilled water on the mechanical properties of a BID glass-reinforced epoxy composite immersed at 333° K. These studies have considered the effects of seawater and distilled water on ILSS compression properties, which are found to compare well with the theoretically calculated wet mechanical properties.

EXPERIMENTAL DETAILS

BID glass/epoxy resin composites were fabricated by a vacuum bagging technique (described in Part A). ILSS specimens (20 mm × 10 mm × 2 mm) and compression specimens (125 mm × 12.5 mm × 2 mm) were cut from these test laminates, edge coated and post cured again as mentioned in Part A. These specimens were immersed in distilled and artificial seawater environments. The specimens were then tested for their mechanical properties (compression, ILSS) using INSTRON (UK-make) testing machine at different stages of moisture gain. The load vs displacement curves for the unexposed and exposed specimens were also plotted for both the environments as shown in Figures 1–4, respectively.

RESULTS AND DISCUSSIONS

The load versus displacement curves for ILSS specimens immersed in both distilled water and artificial seawater are shown in Figure 1 and Figure 2. It is seen that addition of moisture results in reduced maximum (peak) loads. Similarly Figure 3 and Figure 4 show the load versus displacement curves in case of compression specimens immersed in both environments also showing similar trends.

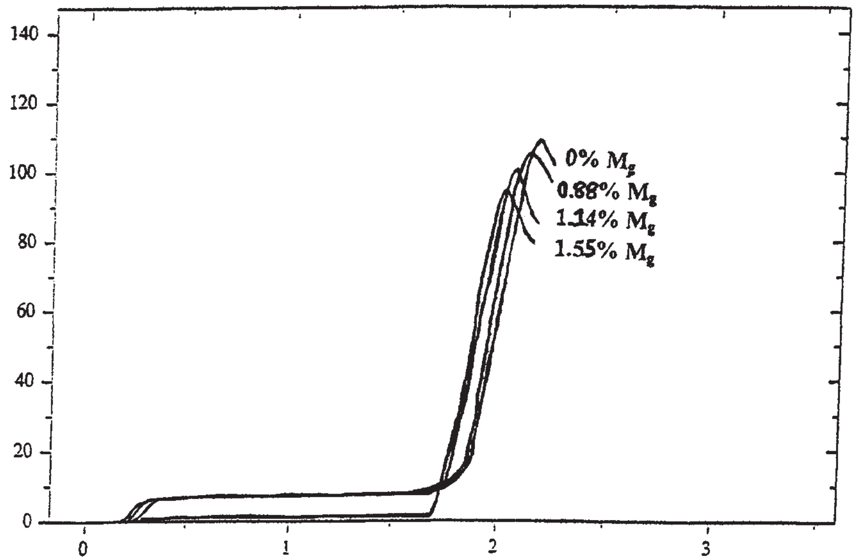

Figure 1. *Load vs displacement curve for ILSS specimens immersed in distilled water at 333° K. x-axis: displacement (mm) and y-axis: load (kgs).*

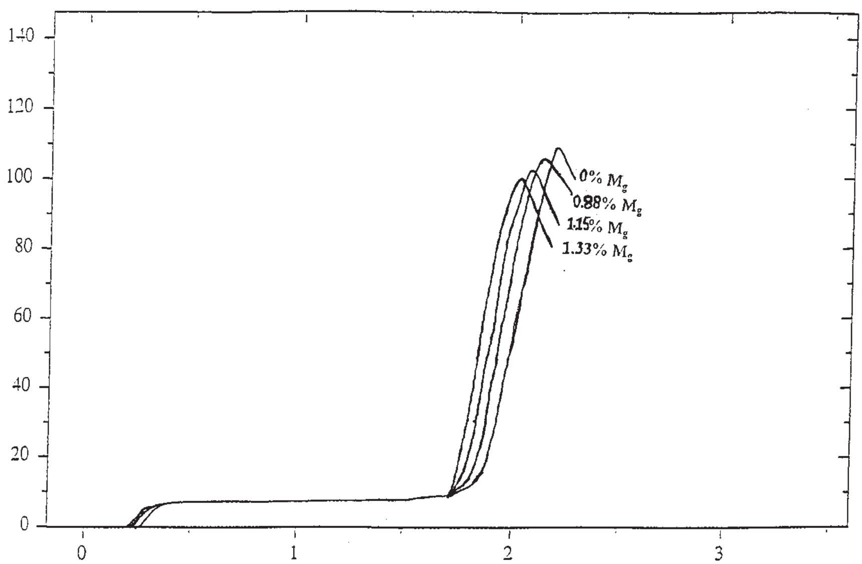

Figure 2. *Load vs displacement curve for ILSS specimens immersed in artificial seawater at 333° K. x-axis: displacement (mm) and y-axis: load (kgs).*

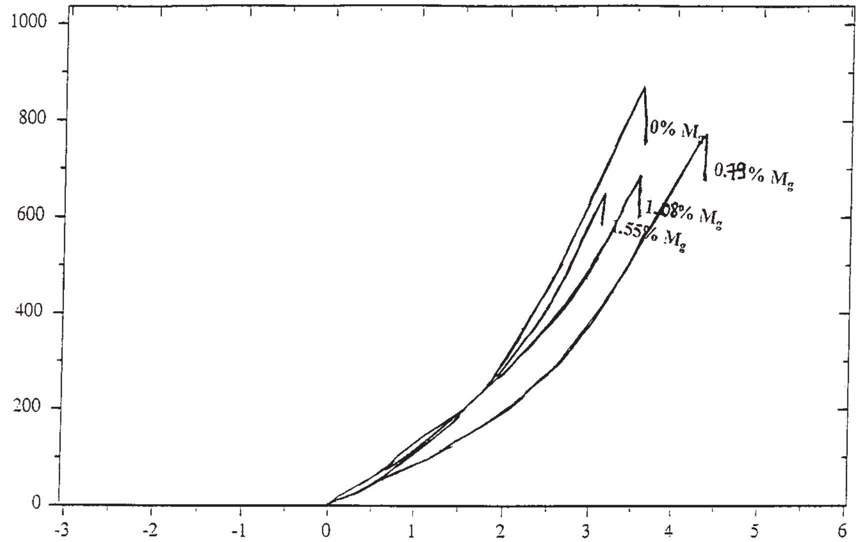

Figure 3. *Load vs displacement curve for compression specimens immersed in distilled water at 333° K. x-axis: displacement (mm) and y-axis: load (kgs).*

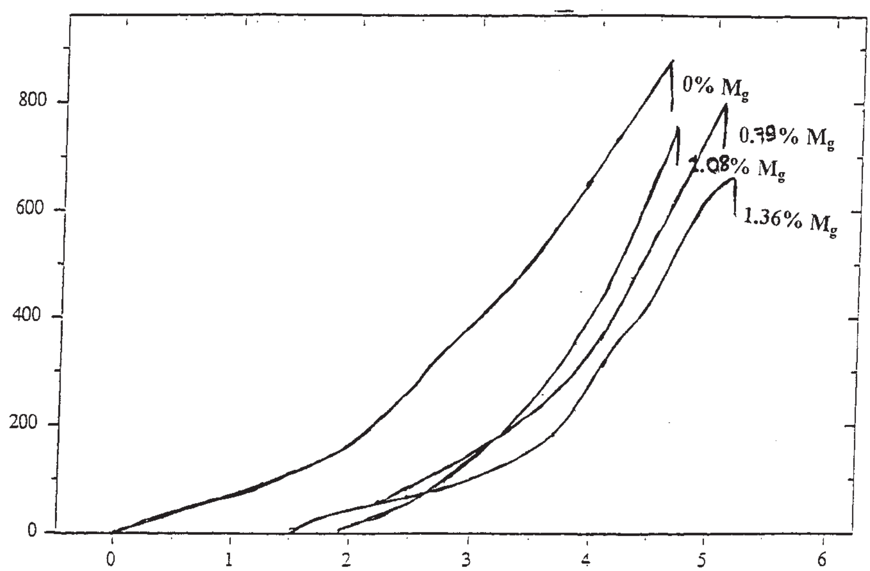

Figure 4. *Load vs displacement curve for compression specimens immersed in artificial seawater at 333° K. x-axis: displacement (mm) and y-axis: load (kgs).*

Verification of an Empirical Relationship for Wet Mechanical Properties

Hygrothermal (hot-wet) environments usually affect the matrix controlled properties. The degraded properties due to hygrothermal affects can be estimated using the following equation [9,10] when the use temperature (T) and moisture pickup (M) are known.

$$\frac{P_{lHT}}{P_{lo}} = \frac{T_{GW} - T}{T_{GD} - T_o}^{1/2**} \quad (1)$$

$$T_{GW} = T_{GD}(0.005M_t^2 - 0.1M_t + 1)^* \quad (2)$$

where P_{lHT} the degraded property. T_{GW} the wet glass transition temperature of the composite, T_{GD} the dry glass transition temperature of the composite. T the use temperature at which P_{lHT} is required, T_o the reference temperature (i.e., room temperature) at which P_{lo} is determined and M_t the moisture in the composite in percent weight.

Using the T_{GW} obtained from Equation (2) for different moisture contents and experimentally obtained dry mechanical property of the composite at room temperature in Equation (1), the wet degraded properties (compression strength and ILSS) were calculated and compared with the experimentally obtained values in both the immersion environments. These predicted and measured degraded values of the composites and wet glass transition temperature (T_{GW}) are shown in the Tables 1–3, respectively. Figure 5 and Figure 6 show respectively the correlation curve for % compressive strength retention versus % moisture gain in distilled water and artificial seawater. Further, they show that the matrix dependent properties of the glass-epoxy composite are more affected by immersion in distilled water than in artificial seawater. The % compressive strength retention was higher

Table 1. Predicted wet glass transition temperature (T_{GW}) of the glass/epoxy composite at different % moisture gain.

Sl. No.	% M_m	Wet T_g(T_{GW})*
1	0.00	115.00
2	0.79	106.36
3	0.88	105.49
4	1.08	103.20
5	1.15	102.00
6	1.34	100.46
7	1.55	98.17

*From Equation (2).

Table 2. Comparison of the measured and predicted wet ILSS and % strength retention of the glass/epoxy composite at different % moisture gain in distilled water and artificial seawater immersion environments.

		ILSS (MPa)			
		Distilled Water		Artificial Seawater	
Sl. No.	% M_m	Measured Strength (% retention)	Predicted Strength (% retention)*	Measured Strength (% retention)	Predicted Strength (% retention)**
1	0	36.78 (100.00)	—	36.78 (100.00)	—
2	0.88	26.36 (71.66)	26.14 (71.01)	27.82 (75.63)	26.39 (71.77)
3	1.15	25.62 (69.65)	25.12 (68.31)	25.78 (70.09)	25.12 (68.31)
4	1.34	23.50 (63.89)	24.63 (66.96)	24.00 (65.25)	24.66 (67.04)
5	1.55	21.84 (59.38)	23.94 (65.1)	—	—

**From Equation (1).

Table 3. Comparison of the measured and predicted wet compression strength and % strength retention of the glass/epoxy composite at different % moisture gain in distilled water and artificial seawater immersion environments.

		Compression Strength (kg/mm^2)			
		Distilled Water		Artificial Seawater	
Sl. No.	% M_m	Measured Strength (% retention)	Predicted Strength (% retention)*	Measured Strength (% retention)	Predicted Strength (% retention)**
1	0	35.11 (100.00)	—	35.11 (100.00)	—
2	0.79	27.65 (78.75)	24.96 (71.09)	28.10 (80.03)	25.19 (71.77)
3	1.08	24.39 (69.46)	24.13 (68.75)	25.52 (72.68)	24.32 (69.28)
4	1.34	23.62 (67.27)	23.51 (66.96)	22.52 (64.14)	23.54 (67.04)
5	1.55	20.63 (58.75)	22.86 (65.12)	—	—

**From Equation (1).

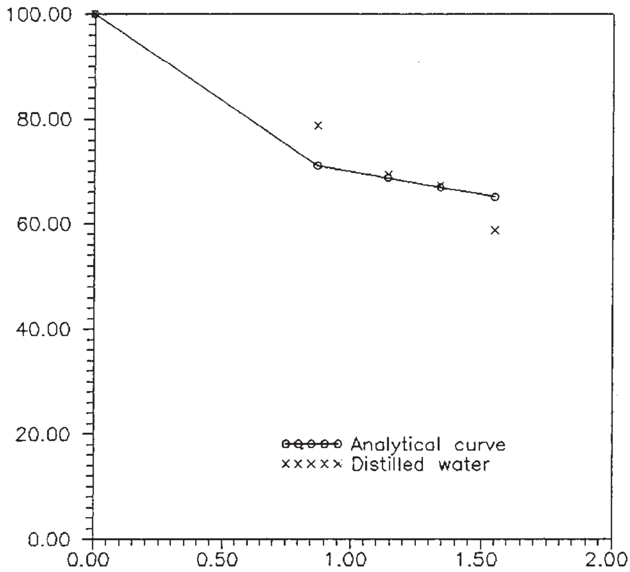

Figure 5. *Comparison of analytical and experimental %compressive strength retention values of glass/epoxy composite specimens at different %moisture gain immersed in distilled water at 333° K. x-axis: % moisture gain and y-axis: % compressive strength retention.*

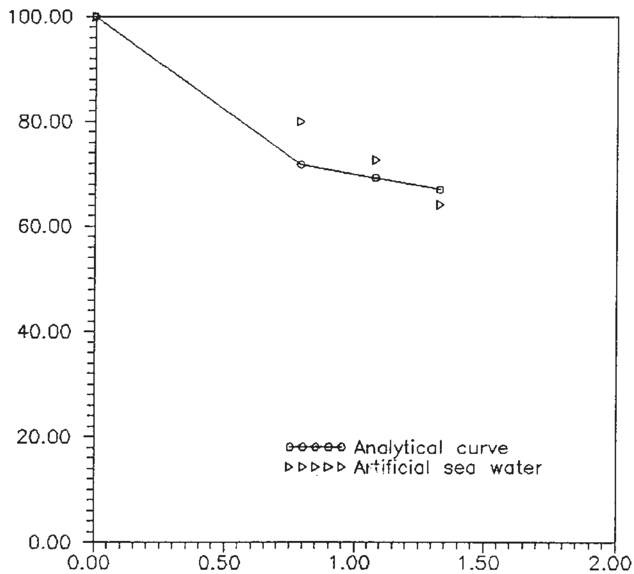

Figure 6. *Comparison of analytical and experimental %compressive strength retention values of glass/epoxy composite specimens at different %moisture gain immersed in artificial seawater at 333° K. x-axis: % moisture gain and y-axis: % compressive strength retention.*

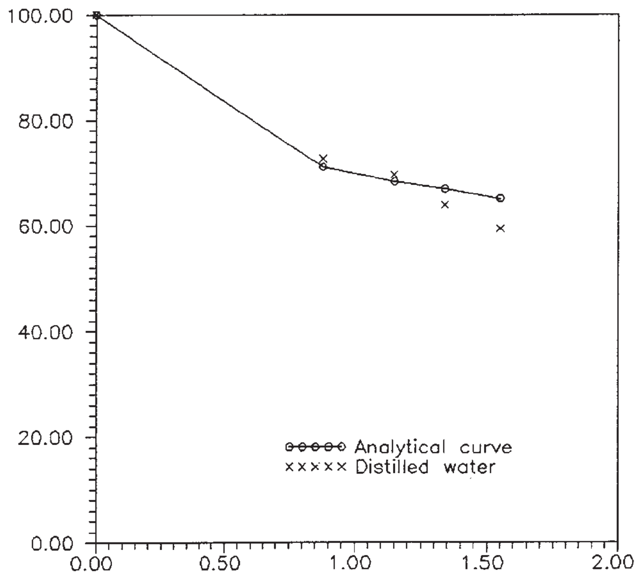

Figure 7. *Comparison of analytical and experimental % ILSS retention values of glass/epoxy composite specimens at different % moisture gain immersed in distilled water at 333° K. x-axis: % moisture gain and y-axis: % ILSS retention.*

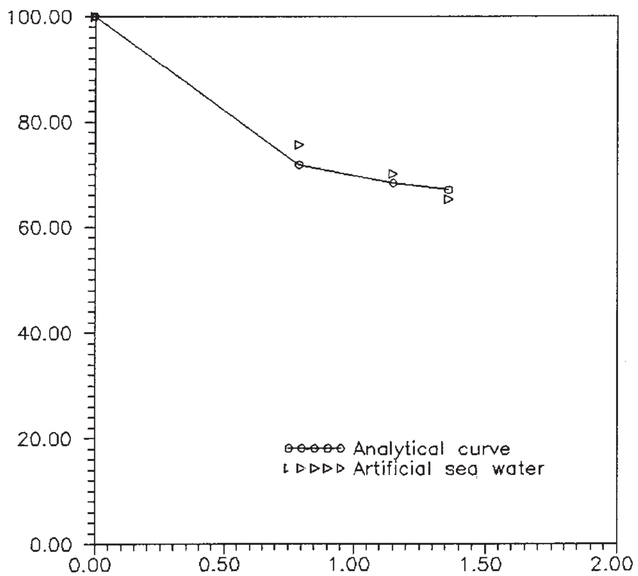

Figure 8. *Comparison of analytical and experimental % ILSS retention values of glass/epoxy composite specimens at different % moisture gain immersed in artificial seawater at 333° K. x-axis: % moisture gain and y-axis: % ILSS retention.*

in artificial seawater than in distilled water immersion. This can be attributed to higher absorption levels in the former environment. Figure 7 and Figure 8 shows the % ILSS retention versus % moisture gain in both immersion environments. Similar trends of strength retention were seen in this case also. But the % ILSS retention in both the environments was higher than the % compressive strength retention.

CONCLUSIONS

The experimental results presented on a RT-cured glass/epoxy composite showed that the degradation trends were similar in both distilled and artificial seawater immersion environments. It was found that addition of moisture results in reduced maximum loads and hence reduced stiffness of the composite in both immersion environments. The compressive strength and ILSS retention of composite specimens were higher in artificial seawater than those immersed in distilled water. The % compressive strength retention was lesser than the % ILSS retention in both the immersion environments.

An empirical relationship was verified for the composite system which relates the wet mechanical strength (compression and ILSS) of the composite to its room temperature dry strength and its wet glass transition temperature. The deviations between the experimentally obtained values are 4–10% higher than the theoretical values in case of compression strength retention and 3–8% in case of ILSS retention in both the immersion environments.

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