Chapter 9

In the present work it was observed that the 1-D analytical model for Fickian diffusion tended to over predict the moisture content in the unidirectional composites, especially in the 'knee' of the curve. This has been observed and addressed by other researchers[9.1-9.3] too. One of the ways to overcome this problem is to use the 2-D form of the diffusion equation. Recalling that the short-term solution of the Fick's law in three-dimensions is given by[9.1],

$$M_t = \frac{4M_m}{h\sqrt{\pi}}\sqrt{t}\left(\sqrt{D_x} + \frac{h}{l}\sqrt{D_y} + \frac{h}{b}\sqrt{D_z}\right) \quad (1)$$

where, M_t, M_m, h, l, b, t, D_x, D_y, and D_z are the moisture content at a given time, saturation moisture content, specimen thickness, length, width, diffusion coefficients through the thickness of the sample, along the fiber and normal to the fibers respectively. Recognizing that for the case of an isotropic plate with h<<l, where 'h' is the thickness, 'l' the length the problem takes a one dimensional through the thickness form. The overall diffusivity, $D = D_x$ can be evaluated experimentally using the following equation,

$$D = \pi\left(\frac{h}{4M_m}\right)^2\left(\frac{dM_t}{d\sqrt{t}}\right)^2 \quad (2)$$

where, M_m is the equilibrium moisture content (%), t is exposure time and $dM_t/d\sqrt{t}$ is the slope of the experimental data collected and plotted as moisture content versus √time curve. Substituting equation (2) into equation (1), the following relation between the overall measured diffusivity and the diffusivities in the other directions is obtained,

$$D = D_x\left(1 + \frac{h}{l}\sqrt{\frac{D_y}{D_x}} + \frac{h}{b}\sqrt{\frac{D_z}{D_x}}\right)^2 \quad (3)$$

where, D is the overall diffusivity of the composite. For a unidirectional composite however, it can be assumed that $D_x = D_z$. This then reduces equation (3) to the following form

$$\sqrt{D} = \sqrt{D_x}\left(1 + \frac{h}{b}\right) + \left(\frac{h}{l}\right)\sqrt{D_y} \quad (4)$$

A plot of $\sqrt{D}$ versus h/l will yield an intercept proportional to $\sqrt{D_x}$ and a slope equal to $\sqrt{D_y}$.

The goal would therefore be to cut specimens to different lengths keeping the breadth and thickness fixed and measuring the overall diffusivities by taking periodic weight measurements. Once the overall diffusivity is calculated using equation (2), a plot similar to the one explained above in equation (4) can be generated to evaluate the magnitude of the diffusion coefficients in the 'x' and 'y' directions. This experiment will permit both the validation of the 1-D Fickian model as well as help evaluate the influence of the interphase and it's contribution to the diffusion process.

About the interphase micro-mechanics, a greater emphasis must be paid on utilizing the idea of the interphase as opposed to the interface. This is necessary, as several researchers have reported the existence of an interphase region with graded chemical structure and mechanical properties in the past[9.4,9.5]. Pagano and Tandon have developed one such analytical model for brittle matrices[9.6]. This model is based on the geometry of a sector that is composed of a cylindrical core surrounded by a number of concentric cylinders. The model therefore has the ability of accepting a positional dependence of mechanical properties. It is therefore imperative that work on characterizing the properties of vinyl ester/sizing interphase continues. The use of the AFM with improved sample preparation techniques in conjunction with the testing of matrix/sizing blends made with varying concentrations of the sizing polymer will allow us to fully characterize the interpahse region. An accurate measurement of both tensile as well as fracture toughness will prove to be very useful for the code.

Concerning Stief's compression micro-mechanics model, an experimental technique to measure the misalignment length is crucial. This can be after the compression test is over via microscopy of polished damage surfaces. Tests such as micro-indentation have proven successful in the past to measure kink band length[9.7]. Caution must however be exerted while doing this, because the kind band is known to change in both inclination and width from the time of inception to final fiber fracture.

Finally, all things being the same, composites made with carbon fiber with different modulli (example AS4 and IM7) should be tested in both shear and compression to check the applicability of the Budiansky model. This will a particularly interesting study because the model relies purely on the initial misalignment angle and composite shear response to predict compression strength and does not have any apparent influence of fiber modulus.