MEASUREMENT OF WATER DIFFUSION COEFFICIENT FOR UPE/PVC BLEND REINFORCED WITH E-GLASS FIBERS

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Abstract
The objective of this work was to study the influence of weight percentage ratios of (Unsaturated Polyester/Poly vinyl chloride) blends and E-glass fibre content on the diffusion coefficients of the blends from the relationship between water weight gain \( M_t \) and diffusivity for water immersed samples. Unreinforced and reinforced (by one or two layers of chopped E-glass fibers) samples were prepared by hand lay up method with the ratios (95\%UPE+5\%PVC, 90\%UPE+10\%PVC and 85\%UPE+15\%PVC), the prepared samples were immersed for 60 days in water to get the absorption curves. The results of laboratory examinations show the absorption curves of water gain \( M_t \) against the square root of the immersion time \( \sqrt{t} \) are gradual increase until saturation then deviate lower due to weight loss of the immersed samples. The diffusion coefficients values have been calculated from the plotted curves, the calculated values reveal diffusion coefficients values increased with the increasing of PVC weight percentage and fibre content.

Introduction
Using polymers depend on their properties, there are many factors can affect the properties of polymer materials. External factors such as temperature, humidity, applied external forces and other factors. Inner factors include samples structures, materials type, regularity, direction and strength of molecular chains which form the polymer materials [1].
Moisture absorption characteristics of polymers comprise an important aspect of moisture/durability studies. Such information can generally be used to obtain some insight into how and why the material is influenced by moisture [2].

The absorption process for all polymer materials when humidity found in atmosphere or when these materials immerse in water or other solutions followed Fick's law in diffusion, i.e. absorption mass from the water or solutions increasing linearly with the square root of time gradually and slowly until saturation state [3].

Water enters the composite by diffusion through the resin and by capillary action along the fiber matrix interface in fibrous composites. The surface damage and cracks produced as a result of weathering further facilitate the entrance of water. The effect of water on the resin which causes swelling and plasticization-hydrolysis is not considered to be an important process under the conditions encountered outdoors [4].

There is two main types of basic moisture conditioning; fixed conditioning, where a test specimen is exposed to a conditioning environment for a specified time, and equilibrium conditioning, where a specimen is exposed until the material reaches equilibrium with the conditioning environmental. The rate of moisture uptake is fairly rapid in early stages of conditioning with the rate of moisture uptake then decreasing with time as shown in (Figure 1).

\[
M = \frac{(W_t - W_o)}{W_o} \times 100\%
\]

Where the weights of the sample after and before immersion are denoted by \(W_t\) and \(W_o\) respectively [4].

At temperatures well below the glass transition \(T_g\) of the conditioned material, water absorption of most polymers correlates well with Fick's laws. The diffusion coefficient \(D\) is independent of moisture concentration, it can be calculated from the initial linear region of Fickian diffusion curve of (Figure 1) using the following equation[4]:

\[
D = \frac{\pi}{16} \left( \frac{h(M_\infty - M_1)}{M_\infty \left( \sqrt{t_2} - \sqrt{t_1} \right)} \right)^2 \quad \text{........... (1)}
\]

Where \(M_\infty\) is the equilibrium moisture content (maximum water content), \(M_1\) is the moisture uptake after time \(t_1\), \(M_2\) is the moisture uptake after time \(t_2\) and \(h\) is the sample thickness.

The term \(\left( \frac{M_2 - M_1}{\sqrt{t_2} - \sqrt{t_1}} \right)\) is the slope of the linear portion of the plot of \(M\) against \(\sqrt{t}\).

**Experimental**

**Material used Preparation**

The material used to prepare the test samples were Unsaturated polyester resin (UPE) type (H-265), with hardener MEKP and accelerator cobalt naphthenate, supplied by IPI Jordan and PVC (polyvinyl chloride), supplied by industrial chemical and resin CO.LTD, kingdom of Saudi Arabia. The reinforcement used was chopped mat E-glass fibres supplied by (Moulding Comp.Ltd., UK.).

The UPE /PVC blends were prepared with different weight percentage ratios for both polymers as matrix system, reinforced by one or two layers of chopped E-glass fibers.

The test specimens were prepared by hand lay-up method with dimensions (20x15x3)mm³. The details of the test samples presented in (Table 1).
Table 1: details of the test samples

<table>
<thead>
<tr>
<th>No.</th>
<th>Blends Ratios</th>
<th>Reinforcing type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>95% UPE + 5% PVC</td>
<td>Unreinforced</td>
</tr>
<tr>
<td>2</td>
<td>90% UPE + 10% PVC</td>
<td>Reinforced with one layer of E- Glass Fiber</td>
</tr>
<tr>
<td>3</td>
<td>85% UPE + 15% PVC</td>
<td>Reinforced with two layers of E- Glass Fiber</td>
</tr>
<tr>
<td>4</td>
<td>95% UPE + 5% PVC</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>90% UPE + 10% PVC</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>80% UPE + 15% PVC</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>95% UPE + 5% PVC</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>90% UPE + 10% PVC</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>85% UPE + 15% PVC</td>
<td></td>
</tr>
</tbody>
</table>

Testing Procedure

The samples were weighted before immersion, then immersed in water free of any admixture or any other wetting agent for 60 days. The test was performed under ambient temperature. The immersed samples were frequently removed from water and weighted and then replaced again to monitor the water uptake by using an analytical balance of accuracy 10⁻⁴g.

Water weight gain (M, %) as percentage of the original dried specimen weight was calculated from the following equation [4].

\[ M, \% = \frac{W_2 - W_1}{W_1} \]

Where

\[ W_0 = \text{weight of the sample before immersion} \]
\[ W_1 = \text{weight of the sample after immersion} \]

The plotted curves of (Figures 2 to 4) of water gain M, against the square root of the immersion time \(\sqrt{t}\) for the test samples show that the water uptake increased linearly with the increasing of the square root of immersion time in early stages until maximum moisture content, this is similar to the prediction of Fickian behavior[5], then the curves show deviation as a “knee” with increasing the period of immersion for all the samples, because the absorbed water diffuse through the material weaken the cross-links of the polymers and dissolve the polymer molecules then the samples suffered from weight loss and bubbles appear on the surface of the samples. The effect of water tends to decrease the hydrogen bonding between polymer chain which is reflected by plastization of resin. As the absorbed water enters the resin and reaches the fibres, it dissolves the surface layer to create an osmotic pressure which will rapidly debond the whole fibres. The effect is usually attributed to hydrogen exchange [6, 7].

\[ \text{Si-O-Na}^+ + \text{H}^+ \rightarrow -\text{Si-O-H} + \text{Na}^+ \]

However when Na⁺ or K⁺ of E-glass fibres released by hydrolysis degradation the PH value of the interface region raises[8].

(Figure 2) of unreinforced samples declare a drastic increase of weight gain (M,) with PVC content, which is attributed to occurrence of voids due to the difference in degree of miscibility at different blends ratios that facilitate diffusion of water molecules [9].

![Figure 2 weight gain M, % versus square root of immersion time for unreinforced blends](image)

On the other hand it was found that most polymer blends are heterogeneous and consist of polymer matrix in which the second polymer is embedded, consequently the effects on permeability are very dependent on the degree of heterogeneity of the system and therefore free volume formation [10].

(Figure 3) and (Figure 4) of the reinforced samples, declare water absorption (M, %) of samples reinforced with two laminates exceed that of specimens reinforced with one laminate.
Diffusion coefficient were calculated from the relationship between weight gain \( M_t \) and diffusivity \( D \) during initial water uptake for Fickian diffusion which is given by the following equation [4]:

\[
\frac{M_t}{M_{\infty}} = \frac{4}{h}\left(\frac{Dt}{\pi}\right)^{1/2}
\]

The calculated values of diffusivity were listed in (Table 2) that reveals the values of diffusion coefficients of the unreinforced blends are much less than that of the reinforced blends. This is possibly attributed to the presence of fibres which introduce fibre/matrix interface that can be considered as channels for water flow [11].

The discrepancy between the values of diffusion coefficients of the reinforced blends is due to the difference in fibre and matrix content.

<table>
<thead>
<tr>
<th>Blends Ratios</th>
<th>Reinforcing type</th>
<th>Diffusion Coefficient (cm²/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>95% UPE + 5% PVC</td>
<td>Unreinforced</td>
<td>2.5x10⁻⁶</td>
</tr>
<tr>
<td>90% UPE +10% PVC</td>
<td>Unreinforced</td>
<td>5.2x10⁻⁶</td>
</tr>
<tr>
<td>85% UPE +15% PVC</td>
<td>Unreinforced</td>
<td>7.7x10⁻⁶</td>
</tr>
<tr>
<td>95% UPE + 5% PVC</td>
<td>Reinforced with one layer of E-Glass Fiber</td>
<td>1.01x10⁻⁵</td>
</tr>
<tr>
<td>90% UPE +10% PVC</td>
<td>Reinforced with one layer of E-Glass Fiber</td>
<td>1.9x10⁻⁵</td>
</tr>
<tr>
<td>85% UPE +15% PVC</td>
<td>Reinforced with two layers of E-Glass Fiber</td>
<td>3x10⁻⁵</td>
</tr>
<tr>
<td>95% UPE + 5% PVC</td>
<td>Reinforced with two layers of E-Glass Fiber</td>
<td>5.7x10⁻⁵</td>
</tr>
<tr>
<td>90% UPE +10% PVC</td>
<td>Reinforced with two layers of E-Glass Fiber</td>
<td>6.1x10⁻⁵</td>
</tr>
<tr>
<td>85% UPE +15% PVC</td>
<td>Reinforced with two layers of E-Glass Fiber</td>
<td>8x10⁻⁵</td>
</tr>
</tbody>
</table>

**Conclusion**

It is concluded that the water gain increases with the increasing of PVC ratios for the unreinforced blends. For the reinforced specimens water gain increases with the increasing of PVC ratios and fibre content, and the samples differ in the saturation state. The diffusion coefficient of the reinforced specimens much higher than that of unreinforced blends.

**References**

2. Lawrence H. Van Vlack, "elements of materials science "An introductory text
for engineering students, Addison-Wesley publishing company, ing. 1964, Second edition.


