CHAPTER 7

Studies on Melamine-Formaldehyde (MF) Loaded Polyvinyl Acetate – Polyester Nonwoven Fabric Composites
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STUDIES ON MELAMINE-FORMALDEHYDE (MF) LOADED POLYVINYL ACETATE -POLYESTER NONWOVEN FABRIC COMPOSITES

This chapter deals the effects of different amount of melamine - formaldehyde (MF) loading into PVAc. This chapter is divided into two parts. Part A deals with the effect of different amount of MF in PVAc on the physico-mechanical properties, water absorption, heat ageing and thermal stability. The effect of salt water soaking at different temperatures on the mechanical properties of composites has been studied. Vertical flammability test was conducted to ascertain the flame resistance of the composites. In order to know the fibre-matrix adhesion, tensile fractured composite specimens were analysed through scanning electron microscope. Part B describes the effect of different amount of MF in PVAc on sorption and diffusion behavior of water into the composites.

PART A – EFFECT OF DIFFERENT AMOUNT OF MF LOADING INTO PVAc

7.1 INTRODUCTION

Interest in poly vinyl acetate (PVAc) based materials having higher bond strength and better film forming properties have grown considerably in the past two decades in the adhesive, paint, paper and the textile industries [1]. It is manufactured by addition polymerization of vinyl acetate monomer and stabilizers with other polymers or co-polymers. However, the mechanical resistance of PVAc adhesive decreases with increasing temperature and it loses its bonding capacity above 70°C [2-3]. Some modification [4] have been carried out to enhance the resistance to moisture and to decrease the creep of PVAc adhesive bonds. One such method is the addition of other types of vinyl monomer during polymerization. A second method is the addition of cross-linking agents, which enhance the rigidity of the polymer. Because of the fact that, PVAc is polymerized with minor amounts of vinyl alcohol, there are free hydroxyl groups on the polymer network [5-
Free hydroxyl groups are also formed during the hydrolysis of the acetate groups. These hydroxyl groups offer sites for crosslinking. Cross-linking agents such as urea-formaldehyde (UF), melamine-formaldehyde (MF) and isocyanates have been used as chemical cross-linkers. Cross-linked PVACs are more rigid, have better moisture and heat resistance, and have greater initial tack.

The mechanical properties, resistance to humidity and adhesion of coating formulations have been improved by the incorporation of MF resin [8]. These MF resins are also well known as flame-retardants. The basic melamine structure consists of an aromatic triazine ring with six substituent sites, two on each terminal nitrogen. The complexity and crosslinking reaction of MF resins was extensively studied by Blank and coworkers [1,9]. Hung et al explained the formation of hydrogen bonds between the hydroxyl groups of the phenolic and the carbonyl groups of the PVAC [10]. Mek Hilef et al [11] and Ma et al [12] reported the effect of hydrogen bond formation on the miscibility of the poly (ethylene vinyl acetate)/phenolic resin blend and aliphatic polyester/phenolic resin blend. The drastic reduction in formaldehyde emission during the cure reactions with PVAC/MF blends was reported by Kim et al [13]. The improvement in thermal stability of PVAC/MF blends by the formation of hydrogen bonds was explained by Garnier et al [14].

The textile based nonwoven fabric has several applications for disposable and durable applications. Among the various types, the needle punched nonwoven fabric has the advantage of low cost and process flexibility. The use of such nonwoven fabric for the fabrication of composites has servaral advantage like high delamination resistance, light in weight and high strength to weight ratio. In addition to this, the highly porous structure of needle punched nonwoven fabrics allow to incorporate high amount of polymer matrix, which helps to fabricate a range of composites from soft to stiff type. Few reports available on the polymer binder/latex used for the fabrication of nonwoven composites [15-20].

Although there are few reports available on the nonwoven fabric reinforced polymer composites [21-23], there is a scarcity in the literature on the studies of MF incorporated PVAC-polyester nonwoven fabric composites. The present chapter deals with the fabrication of composites by impregnating the needle-punched polyester nonwoven fabric in MF loaded PVAC latex. The effect of different amount of MF loading on the performance of the composites has been studied.
7.2 EXPERIMENTAL

7.2.1 Fabrication of composites

Different amount of MF resin was added into PVAc with mechanical stirring. Two parts ammonium chloride (based on 100 part dry weight of MF) was added as a catalyst into the PVAc/MF blend. Polyester nonwoven fabric having 400 g/m² was impregnated in a MF loaded polyvinyl acetate latex. The impregnated fabric is squeezed in a two-roll squeezer to adjust the desired optimized pickup of latex to fabric (3.2:1). After the desired amount of latex was adjusted, the impregnated fabric was dried in hot air oven at 60°C for 8 h and cured at 150°C for 30 min. Composites were fabricated by varying the amount of MF in PVAc latex viz., 100/0, 100/5, 100/10, 100/15 and 100/20 (PVAc/MF) weight-by-weight on dry-to-dry basis.

7.3 RESULTS AND DISCUSSION

7.3.1 Mechanical properties

The obtained physico-mechanical properties such as density, tensile strength, percentage elongation at break, stiffness, tear strength, surface hardness, void content, percentage compressibility and recovery of MF incorporated PVAc-polyester nonwoven fabric composites are given in Table 7.1.

7.3.1.1 Effect of curing time

The effect of curing time on the tensile strength of PVAc-polyester nonwoven fabric composites is shown in Figure 7.1. It is found that, the tensile strength increased with increasing curing time upto 30 min. The incorporation of MF above 10 parts showed a slight improvement. Considering the cost and energy involved for this slight improvement, the optimum curing time may be fixed for 30 min. The unfilled PVAc-polyester nonwoven composite was not subjected to curing because PVAc debonds above 70°C [2-3].

7.3.1.2 Tensile behavior

The stress-strain curves of polyester nonwoven fabric and different amount of MF loaded PVAc-polyester nonwoven fabric composites (cured) is shown in Figure 7.2. Polyester nonwoven fabric exhibited high strain (185%) with low stress (0.9 MPa) indicating poor mechanical strength. Generally, the nonwoven fabric has poor mechanical properties and polymeric binders are required to improve the properties [16, 17, 24-25].
The tensile strength and percentage elongation at break of uncured and 30 min cured PVAc-polyester nonwoven fabric composites as a function of different amount of MF resin in PVAc are shown in Figure 7.3.

### Table 7.1. Mechanical properties of MF loaded PVAc-polyester nonwoven fabric composites

<table>
<thead>
<tr>
<th>PVAc/MF composition</th>
<th>Tensile modulus (MPa)</th>
<th>Taber stiffness (arbitrary units)</th>
<th>Burst strength (MPa)</th>
<th>Stitch tear strength (N)</th>
<th>Hardness (Shore A)</th>
<th>Compressibility (%)</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100/0</td>
<td>33</td>
<td>542</td>
<td>2.8</td>
<td>190</td>
<td>75</td>
<td>10</td>
<td>75</td>
</tr>
<tr>
<td>100/5</td>
<td>58</td>
<td>659</td>
<td>3.2</td>
<td>213</td>
<td>85</td>
<td>9.5</td>
<td>70</td>
</tr>
<tr>
<td>100/10</td>
<td>75</td>
<td>725</td>
<td>3.4</td>
<td>219</td>
<td>89</td>
<td>9.0</td>
<td>66</td>
</tr>
<tr>
<td>100/15</td>
<td>84</td>
<td>730</td>
<td>3.5</td>
<td>220</td>
<td>90</td>
<td>9.0</td>
<td>66</td>
</tr>
<tr>
<td>100/20</td>
<td>87</td>
<td>730</td>
<td>3.5</td>
<td>220</td>
<td>91</td>
<td>9.0</td>
<td>66</td>
</tr>
</tbody>
</table>

From these figures, it can be noted that, the curing has increased the tensile strength and decreased the percentage elongation of the composites. The tensile strength increased with increase in the MF content upto 10 parts and further increase in the MF content showed a marginal improvement. In the present study, a significant increase in the tensile strength was noticed with the impregnated polyester nonwoven fabric-PVAc/MF composites. The composites will fracture under stress, as the fiber-matrix bond is broken due to uneven distribution of stresses due to differential elongation between the fabric and matrix. A systematic increase in stress with increase in strain was noticed for all the composites. This indicates better toughness of the composites. The stress transfer characteristics of the composites fabricated with MF dosage above 10 parts in PVAc is almost same. This revealed that, incorporation of 10part MF into PVAc is the optimized dosage to achieve the maximum performance of the composites.

#### 7.3.1.3 Specific tensile strength

The specific tensile strength of different amount of MF incorporated PVAc-polyester nonwoven fabric composites lie in the range 12-25 N.m/g. As shown in Figure 7.4, the specific strength of the composites is optimized at an MF dosage of 10 parts by weight into PVAc. A further increase in MF content did not enhance the specific tensile strength of the composites.
7.3.1.4 Reinforcement factor

As shown in Figure 7.4, the reinforcement factor followed a mirror image as specific tensile strength. The reinforcement factor of composites lies in the range 8-17 units. As the MF resin undergo a self-limiting polymerization in the presence of liberated hydrochloric acid (from ammonium chloride catalyst) [26] and the subsequent polymerization of the same to the water insoluble C-stage would be the reason for increased specific tensile strength and reinforcement factor of the composites.

7.3.1.5 Stiffness

The taber stiffness of different amount of MF incorporated PVAc-polyester nonwoven fabric composites lie in the range 542-730 units. From Table 7.1, it can be observed that with increase in the MF content in PVAc enhanced the stiffness value. The observed enhancement is not significant above 10 parts by weight of MF dosage.
Figure 7.2. Stress-strain curves of: (a) polyester nonwoven fabric (b) different amount of MF loaded PVAc-polyester nonwoven fabric composites

7.3.1.6 Burst strength

From the Table 7.1, it can be observed that the burst strength values of composites increased with increase in the MF content from 0 to 20 parts by weight. The values of burst strength of composites lie in the range 2.8-3.5 MPa for 0-20 parts by weight of MF content.
Figure 7.3. (a) Tensile strength and (b) percentage elongation at break of cured and uncured composites with respect to different amount of MF content.

Figure 7.4. Effect of MF loading on specific tensile strength and reinforcement factor of PVAc-polyester nonwoven fabric composites.
7.3.1.7 Stitch tear strength

The stitch tear strength of the composite indicates the ability of the composite material to hold the stitches. A sharp increase in the stitch tear strength values of the composites was noticed with increase in the MF content. As shown in Table 6.1, the stitch tear strength values lie in the range 190-220 N for 0-20 parts MF loading.

7.3.1.8 Surface hardness

The surface hardness values of different amount of MF incorporated PVAc – polyester nonwoven fabric composites lie in the range 75-91 Shore A. Like other properties, the surface hardness values of the composites increased with increase in the MF content. This result clearly indicates the improvement in dimensional stability of the composites.

7.3.1.9 Percentage compressibility and recovery

Both percentage compressibility and percentage recovery of composites have been reduced with increase in the MF content in PVAc latex. It can be expected that, with increase in the MF content in the system, the hardness of the composite increases. This result revealed that, dimensional stability increases with increased in the amount of cross linker (MF) due to increased crosslink density. The increased hardness would not allow the composite to compress to the applied force. Hence, the percentage compressibility and recovery reduces with increase in the MF content. From the above discussion, it appears that the physico-mechanical properties of the composites increased with increase in the cross linker MF content in the system. This may be due to increase in crosslink density of PVAc after the incorporation of MF. A schematic representation of crosslinked networks between PVAc and MF resin as shown in Scheme 7.1.

7.3.2 Chemical resistance

The calculated percentage loss in tensile strength of the composites after exposing to different chemical reagents are given in Table 7.2. Compared to the neat PVAc film, the PVAc-polyester nonwoven fabric composites showed improved chemical resistance. This may be due to the synergistic effect of the two components present in the composite. The unfilled composites exhibited excellent chemical resistance in methyl acetate. This may be due to the insoluble nature of PVAc in ester type solvents. The unfilled composites exhibited poor chemical resistance both in acids and alkalis. This may be due to the
hydrolysis of PVAc in presence of both acids and alkalis. The hydrolysis of PVAc occurs by way of removing the atoms from the carbonyl groups of PVAc, as there is no steric protection. From Table 7.2, it can be noticed that, the incorporation of MF into the composites significantly increased the chemical resistance. The inherent resistance of MF to acids and alkalis, the interruption of long sequences of hydrolysable vinyl acetate units by the MF units and steric protection of hydrolysable units from the attack by hydroxide ions could be the reason for increased chemical resistance with increase in the MF content in the composites [27-28].

\[
\begin{align*}
(a) & \quad \text{MF} \\
(b) & \quad \text{PVAc} \\
(c) & \quad \text{Cross linked network of PVAc-MF}
\end{align*}
\]

Scheme 7.1. Chemical structure of; (a) MF, (b) PVAc and (c) cross linked network of PVAc and MF resin

7.3.3 Heat ageing

The variation in tensile strength of unfilled and MF loaded PVAc-polyester nonwoven fabric composites after heat ageing are given in Table 7.3. From the table, it can be observed that the MF loaded composites have better heat ageing resistance at 150°C compared to 200°C. Kim et al [29] noticed a significant weight loss in PVAc/MF blend in their thermogravimetric study. As expected, the unfilled composite shown poor thermal stability and it is generally known that PVAc loose its bonding capacity above 70°C [2-3].
At 150°C, the specimens aged for 48 h showed a much-improved heat ageing resistance compared to 24 h aged sample. This can be attributed to the post curing of MF resin. As the MF content in PVAc is increased, the composites showed improved heat ageing resistance. This study reveals that, the composites with MF resin have better dimensional stability at 150°C.

Table 7.2. Chemical resistance of MF loaded PVAc-polyester nonwoven fabric composites

<table>
<thead>
<tr>
<th>Chemical reagent</th>
<th>% Loss in tensile strength of the composites after exposed into different chemical environment</th>
<th>PVAc-film</th>
<th>PVAc/MF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>100/0</td>
<td>100/5</td>
</tr>
<tr>
<td>15% HCl</td>
<td>65</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>25% CH₃COOH</td>
<td>71</td>
<td>59</td>
<td>28</td>
</tr>
<tr>
<td>5% NaOH</td>
<td>82</td>
<td>70</td>
<td>30</td>
</tr>
<tr>
<td>10% KMnO₄</td>
<td>86</td>
<td>72</td>
<td>30</td>
</tr>
<tr>
<td>Methyl acetate</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Distilled water</td>
<td>45</td>
<td>35</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 7.3. Percentage loss or improvement in tensile strength of MF loaded PVAc-polyester nonwoven fabric after heat ageing at 150 and 200°C for 24 and 48 h

<table>
<thead>
<tr>
<th>PVAc/MF composition (Wt/Wt, %)</th>
<th>% Loss or improvement in tensile strength after heat ageing at different temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>150°C</td>
</tr>
<tr>
<td></td>
<td>24 h</td>
</tr>
<tr>
<td>100/0</td>
<td>-2</td>
</tr>
<tr>
<td>100/5</td>
<td>+18</td>
</tr>
<tr>
<td>100/10</td>
<td>+34</td>
</tr>
<tr>
<td>100/15</td>
<td>+36</td>
</tr>
<tr>
<td>100/20</td>
<td>+36</td>
</tr>
</tbody>
</table>
7.3.4 Water absorption

Water absorption and thickness swelling of unfilled and MF loaded PVAc-polyester nonwoven fabric composites were determined by immersing the individual samples for 24 h in water at room temperature and for 2 h in boiling water. The obtained results for water absorption and thickness swelling are shown in Figures 7.5 and 7.6 respectively. It is evident from these figures that the percentage of water absorption and thickness swelling of unfilled composite is high compared to that of composites crosslinked with MF. The incorporation of MF in the composite reduced the percentage water absorption and thickness swelling of the composites both at room temperature and boiling water. The observed water absorption and thickness swelling is relatively low in boiling water compared to that at room temperature. A significant reduction in water absorption and thickness swelling of the composites was noticed upto 10 part MF incorporated PVAc-polyester nonwoven fabric composite and further increasing the MF content showed a little improvement. The reduction in water absorption and thickness swelling with increasing the MF content could be due to the formation of cross link networks between PVAc and MF. This crosslinking maintains the strength of the composites by reducing the swelling [29-32].

![Figure 7.5. Effect of different amount of MF on percentage change in water absorption and thickness swelling of composites for 24 h at room temperature](image-url)
7.3.5 Cyclic water soaking test

The effect of cyclic water soaking on the percentage thickness of un-crosslinked and crosslinked PVAc/MF-polyester nonwoven fabric composites is shown in Figure 7.7. A significant reduction in percentage thickness swelling was noticed in all the composites containing MF compared to un-crosslinked composite. The reduction in percentage thickness swelling is optimized at 10-part MF dosage. An upward trend was noticed both in oven-dried and wet samples with an increase in the number of cycles. The plasticisation of PVAc by water could be the reason for increased percentage thickness swelling in unfilled composites. The possible chemical reaction between the hydroxyl groups of PVAc (from the presence of polyvinyl alcohol) and methylol groups of MF resin may result in the formation of strong hydrogen bonds and such type of bonding would have resulted in reduced swelling capacity with increase in the MF content in the composites. A similar observation was made by few authors with respect to the hydroxyl groups of cellulose and methylol groups of MF resin [33-34].

Figure 7.6. Effect of different amount of MF on percentage change in water absorption and thickness swelling of composites for 2 h
7.3.6 Effect of salt water

The effect of salt water soaking on the percentage absorption, tensile strength and stitch tear strength of the composites are given in Table 7.4. For this study, the salt-water solution was prepared by adding 30g of sodium chloride (NaCl) to one litre of the distilled water, which gave a molar concentration of 0.1528 M, which is approximately the concentration of NaCl in sea water. All the specimens were soaked for 120 h to ensure that they were completely saturated [35]. From the Table 7.4 it can be observed that, the percentage weight gain increase with soaking temperature in both distilled and salt water. The percentage weight gain of the composites in salt water is much higher compared to distilled water. This could be due to the preferential diffusion of NaCl molecules or the presence of salt creates an additional capacity in the specimen to accommodate more water molecules. All the composites showed reduction in tensile strength and stitch tear strength after soaking both in distilled water and salt water. The reduction in tensile strength is severe in salt water compared to distilled water.
Table 7.4 Effect of salt water soaking and thermal treatment on the mechanical properties of unidirectional and MF PVA/PEM composites

<table>
<thead>
<tr>
<th>Year</th>
<th>Weight Gain (%)</th>
<th>PVAc/PEM Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

Note: The table provides data on weight gain and PVAc/PEM composition for different years. The data is presented in a tabular format with years as the primary variable and weight gain and composition as the dependent variables.
From the table it can be observed that the incorporation of MF minimized the loss in tensile and stitch tear strength. The reduction in properties due to this hygrothermal effect may be because of the diffusion of water and sodium chloride into the composites, which strain or rupture the intermolecular bond in the matrix and at the fibre-matrix interface [35].

7.3.7 Water vapor exclusion

Dry composite specimens were weighed, conditioned at 27°C and 30% relative humidity (RH) and then re-weighed after reaching equilibrium moisture content. Specimens were then subjected to 90% RH at 27°C and weighed after 1, 3, 6, 9, 12, 24, 48, 83, 171 and 222 h. Moisture absorption was calculated as percentage of moisture based on the dry weight of the specimens [36]. The rate at which the composites absorbed the water vapor was shown in Figure 7.8. It was found that the un-crosslinked composites have shown much higher water vapor sorption than MF crosslinked composites. The increase in the MF content has reduced the percentage moisture sorption.

![Figure 7.8. Percentage moisture absorption of PVAc-polyester nonwoven fabric composites containing different amount of MF viz., 0, 5, 10, 15, and 20 part by weight.](image)

Figure 7.8. Percentage moisture absorption of PVAc-polyester nonwoven fabric composites containing different amount of MF viz., 0, 5, 10, 15, and 20 part by weight.
7.3.8 Flammability test

The measured flammability characteristics of unfilled and MF loaded composite are given in Table 7.5. The reduced char length with increasing the MF content indicates the enhancement in flame retardant nature of the composites.

7.3.9 Thermogravimetric analysis

TGA and its derivative thermograms for different amount of MF incorporated PVAc-polyester nonwoven fabric composites are shown in Figures 7.9 (a) – (e). From the thermograms, it is found that all the samples undergone two-step thermal degradation process. Kim et al made a similar observation in their study on MF/PVAc blends, which was used as adhesives in engineering flooring. The first stage of degradation, which occurred at the temperature range 290-300°C, could be due to loss of alkyl chain and ether linkage present in the MF. At higher temperatures, the oxidation of activated methylene of the N-CH₂-O- may most likely occur via the formation of hydroperoxide [37]. The second stage degradation occurred in the temperature range 371-396°C may be due to the complete decomposition of fibre and matrix. With increase in the MF content, the thermal decomposition temperature of the composites shifted slightly towards higher temperature range than that of un-crosslinked composite, which confirms the enhancement of thermal stability of the polymer in the composite [38].

Table 7.5. Flammability characteristics of MF loaded PVAc-polyester nonwoven fabric composites

<table>
<thead>
<tr>
<th>PVAc/MF composition</th>
<th>Flammability characteristics</th>
<th>Flammability characteristics</th>
<th>Flammability characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ignition time (s)</td>
<td>Burning time (s) (Time given for ignition was 50 s)</td>
<td>Char length (cm)</td>
</tr>
<tr>
<td>100/0</td>
<td>Instantaneous</td>
<td>105</td>
<td>Completely burnt</td>
</tr>
<tr>
<td>100/5</td>
<td>Just a flicker appeared and then extinguished</td>
<td>Did not burn.</td>
<td>12.9</td>
</tr>
<tr>
<td>100/10</td>
<td>Just a flicker appeared and then extinguished</td>
<td>Did not burn.</td>
<td>11.9</td>
</tr>
<tr>
<td>100/15</td>
<td>Just a flicker appeared and then extinguished</td>
<td>Did not burn.</td>
<td>11.5</td>
</tr>
<tr>
<td>100/20</td>
<td>Just a flicker appeared and then extinguished</td>
<td>Did not burn.</td>
<td>10.9</td>
</tr>
</tbody>
</table>
Figure 7.9. TGA and its derivative thermograms of different amount of MF loaded PVAc-polyester nonwoven fabric composites viz., (a) 0, (b) 5, (c) 10, (d) 15 and (e) 15 parts by weight of PVAc.

The temperature range of decomposition, the percentage weight loss in each step and the percentage ash content for different amount of MF incorporated PVAc-polyester nonwoven fabric composites are given in Table 7.6. From Table 7.6, it can be observed that, the onset degradation values of the composites increased with increase in the MF content. This can be attributed to the formation of hydrogen bond between the PVAc and MF. The percentage ash content of the composites increases with increasing the MF.
content in the system. This increased percentage ash content is also an indication for the enhancement of thermal stability. The nitrogen units present in the MF resin do not allow

Table 7.6. Data obtained from TGA analysis for different amount of MF loaded PVAc-polyester nonwoven fabric composites

<table>
<thead>
<tr>
<th>PVAc/MF ratio</th>
<th>Process</th>
<th>Transition temp. range</th>
<th>Weight loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>( T_i )</td>
<td>( T_d )</td>
</tr>
<tr>
<td>100/0</td>
<td>1</td>
<td>290</td>
<td>342</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>391</td>
<td>440</td>
</tr>
<tr>
<td></td>
<td>Ash</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100/5</td>
<td>1</td>
<td>293</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>392</td>
<td>440</td>
</tr>
<tr>
<td></td>
<td>Ash</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100/10</td>
<td>1</td>
<td>295</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>396</td>
<td>410</td>
</tr>
<tr>
<td></td>
<td>Ash</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100/15</td>
<td>1</td>
<td>298</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>396</td>
<td>402</td>
</tr>
<tr>
<td></td>
<td>Ash</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100/20</td>
<td>1</td>
<td>300</td>
<td>352</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>398</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>Ash</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( T_i \) temperature at which decomposition starts; \( T_{+2} \) temperature at which decomposition rate is maximum; \( T_c \) temperature at which decomposition is completed

the composite for more combustion and hence, the ash content increases with increase in the MF content in the system.

The thermograms obtained during the TGA scans were analyzed to give the percentage weight loss as a function of temperature. The relative thermal stability of composites was evaluated by comparing decomposition temperatures at various percentage weight loss and IPDT values (Table 7.7). IPDT values represent the overall nature of the thermogram over the entire range of the TGA curves. From the Table 7.7, it can be observed that the thermal stability of the MF incorporated PVAc-polyester nonwoven fabric composites increased with increase in the MF content. The IPDT values of PVAc-MF crosslinked composites were higher compared to the un-crosslinked composite. Based on the OI values, it can be concluded that MF incorporated composites exhibits flame retardant nature.
Table 7.7. Data obtained from TGA analysis for different amount of MF loaded PVAc-polyester nonwoven fabric composites

<table>
<thead>
<tr>
<th>PVAc/MF ratio</th>
<th>Temperature at different weight loss ± 2 °C</th>
<th>IPDT ± 2.5%</th>
<th>OI ± 1%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_0$</td>
<td>$T_{10}$</td>
<td>$T_{20}$</td>
</tr>
<tr>
<td>100/0</td>
<td>180</td>
<td>326</td>
<td>337</td>
</tr>
<tr>
<td>100/5</td>
<td>220</td>
<td>327</td>
<td>342</td>
</tr>
<tr>
<td>100/10</td>
<td>230</td>
<td>330</td>
<td>342</td>
</tr>
<tr>
<td>100/15</td>
<td>240</td>
<td>330</td>
<td>343</td>
</tr>
<tr>
<td>100/20</td>
<td>242</td>
<td>330</td>
<td>346</td>
</tr>
</tbody>
</table>

Kinetics of thermal degradation

Kinetic parameters were evaluated from the TGA curves using the plots of Broido (BR) and Horowitz-Metzger (HM) methods. In order to know the activation energy of the PVAc-polyester nonwoven fabric composites containing different amount of MF, the complete thermogram was divided into two distinct sections according to their degradation steps/processes. The plots of $\ln [-\ln (1-\alpha)]$ versus $1/T$, and $\ln [-\ln (1-\alpha)]$ versus $\theta$ for different degradation processes and for different amount of MF incorporated PVAc-polyester nonwoven fabric composites are shown in Figures 7.10-7.11 respectively. Regression analysis carried out for all the plots. The mechanism of $R^2$ close to unity was chosen. The regression analysis gives the results of slopes, constants and $R^2$ values corresponding to thermal degradation for the selected temperature range. The $R^2$ values and calculated activation energy ($E_a$) for each thermal degradation process and for each method are tabulated in Table 7.8. BR and HM methods have shown almost identical values of $E_a$. From Table 7.8, it is clear that the first step degradation showed highest activation energy compared to second step degradation. This can be related to the percentage weight loss, which is more in first step compared to second step degradation process.

A relationship between the percentage weight loss and activation energy at different degradation steps for different amount of MF incorporated PVAc-polyester nonwoven fabric composites are shown in Figure 7.12 (for BR method). As the percentage
weight loss at the first step is more compared to the second step, the energy of activation will be higher in the first step. A similar behavior was also noticed for HM method.

Figure 7.10. Typical Broido (BR) plots for the determination of activation energies for; (a) first step and (b) second step weight loss
Figure 7.11 Typical Horowitz-Metzger (HM) plots for the determination of activation energies for; (a) first step and (b) second step weight loss

7.3.10 Morphology

The SEM microphotograph of the tensile fractured surface of different amount of MF incorporated PVAc-polyester nonwoven fabric composites are given in Figures 7.13 (a) to (d). The microphotographs confirm the adhesion between the fibre and the matrix. The number of fibre pullouts are minimum in 5 and 10 parts by weight MF loaded
composites [Figures 7.13 (a) and (b)]. The matrix deformation and inhibition of the propagating fracture path by fibre-matrix adhesion can be noted.

Figure 7.12 Relationship between the percentage weight loss and the activation energy for different amount of MF incorporated PVAc-polyester nonwoven fabric composites at different degradation steps for Broido method

Table 7.8 Activation energies calculated by Broido (BR) and Coats-Redfern (CR) methods for different amount of MF loaded composites

<table>
<thead>
<tr>
<th>PVAc/MF ratio</th>
<th>Degradation step</th>
<th>% Weight loss</th>
<th>Activation energies ± 1.5% (kJ/mol)</th>
<th>BR</th>
<th>R²</th>
<th>HM</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>100/0</td>
<td>I</td>
<td>58</td>
<td>128</td>
<td>0.991</td>
<td>134</td>
<td>0.993</td>
<td></td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>35</td>
<td>70</td>
<td>0.982</td>
<td>73</td>
<td>0.993</td>
<td></td>
</tr>
<tr>
<td>100/5</td>
<td>I</td>
<td>58</td>
<td>135</td>
<td>0.988</td>
<td>139</td>
<td>0.985</td>
<td></td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>32</td>
<td>77</td>
<td>0.998</td>
<td>68</td>
<td>0.988</td>
<td></td>
</tr>
<tr>
<td>100/10</td>
<td>I</td>
<td>54</td>
<td>128</td>
<td>0.987</td>
<td>113</td>
<td>0.984</td>
<td></td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>35</td>
<td>71</td>
<td>0.987</td>
<td>50</td>
<td>0.982</td>
<td></td>
</tr>
<tr>
<td>100/15</td>
<td>I</td>
<td>46</td>
<td>111</td>
<td>0.983</td>
<td>114</td>
<td>0.988</td>
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</tr>
<tr>
<td></td>
<td>II</td>
<td>41</td>
<td>71</td>
<td>0.993</td>
<td>70</td>
<td>0.990</td>
<td></td>
</tr>
<tr>
<td>100/20</td>
<td>I</td>
<td>44</td>
<td>112</td>
<td>0.987</td>
<td>113</td>
<td>0.990</td>
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</tr>
<tr>
<td></td>
<td>II</td>
<td>43</td>
<td>64</td>
<td>0.984</td>
<td>63</td>
<td>0.980</td>
<td></td>
</tr>
</tbody>
</table>
Figure 7.13 SEM microphotograph of the tensile fractured surface of PVAc-polyester nonwoven fabric composites containing different amounts of MF (a) 5, (b) 10, (c) 15 and (d) 20 parts by weight of PVAc.
7.4 CONCLUSIONS

The effect of different amount of MF incorporation into PVAc latex on the performance of polyester nonwoven fabric impregnated composites revealed that, the optimum dosage of MF into PVAc latex to achieve maximum performance is 10 parts. The increase in the MF content above 10 parts showed a little or no improvement in performance. From this study it can be concluded that, the composites have shown improved mechanical properties with the incorporation of MF resin. Chemical resistance of the composites has improved compared to PVAc film. The MF incorporated PVAc-polyester nonwoven composites exhibited increased chemical resistance compared to unfilled composite. Heat ageing studies revealed that, the composites have better dimensional stability at 150°C. Water absorption and thickness swelling of the composites both at room temperature and at boiling water have been reduced with increase in the MF content. The effect of incorporation of MF into the PVAc-polyester nonwoven fabric composites showed a reduced thickness swelling in cyclic humidity test. The water vapor exclusion studies of the composite revealed that the incorporation of MF into PVAc-polyester nonwoven fabric composites reduces the moisture uptake at higher humidity such as 90% RH because of reduction in number of free -OH groups. The vertical flammability test indicated that the PVAc/MF blend could be selected as a host matrix to fabricate flame retardant composites. Thermogravimetric analysis revealed that the incorporation of MF into PVAc-polyester nonwoven fabric composites enhanced the thermal stability. The oxygen index values supported the vertical flammability test result. The kinetics of thermal degradation revealed that, the activation energy is dependent on the percentage weight loss of the material.
PART A -SORPTION AND DIFFUSION OF WATER INTO PVAc/MF-POLYESTER NONWOVEN FABRIC REINFORCED COMPOSITES

This section deals with the effect of different weight ratio of (dry, wt/wt) melamine- formaldehyde and PVAc latex viz., 0/100, 5/100, 10/100, 15/100 and 20/100 on the water sorption and diffusion behavior of the composites were evaluated. The water sorption results have been analyzed using a Fickian mechanism of sorption and diffusion. Arrhenius activation energy for diffusion (E_D) and permeation (E_p) processes has been calculated.

7.5 INTRODUCTION

As the polymer composites are subjected to different varying environmental conditions, the knowledge on the sorption and diffusion of water into the composites is important. The mechanical properties of reinforced composites have been observed to be very sensitive to the presence of moisture because small molecules such as water can easily diffuse into the polymer matrix and altering its strength [39]. As the performance of any composites depend on the nature of matrix, fibers and the interfacial adhesion, it is essential to know the rate of water sorption into the composites. Moisture diffuses into polymers to different degrees depending on a number of molecular and microstructural aspects [40].

The nature of the fiber dictates the water permeability of an overall performance of composite [41]. All synthetic polymers absorb moisture in a humid atmosphere and when they are immersed in water [42]. Gorrasi et al [43] explained the sorption that depends on the hydrophilic character of the polymer and the nature of filler. Various parameters such chemical structure of resin, polarity, cross-linking density and impurities can make the diffusion process as non-Fickian [44]. Absorbed moisture acts as plasticiser to the matrix and in turn affects the mechanical performance of the composites by reducing the secondary force of attraction in the matrix [45-46]. In a composite, the fibre part and polymer matrix part differs significantly in their independent responses to moisture.
Extensive research studies have been carried out on water sorption behavior of FRP composites. The moisture sorption behavior of cellulose-MF composites by Devallencourt et al showed a dual mode sorption (Langmuir's and the Flory-Huggins modes) that depends upon the sorption test conditions [47]. The process of sorption and diffusion of water in anisotropic glass ribbon-reinforced composite films of controlled structural and physical characteristics were investigated by Mehta et al [39]. Bonniau et al [48] reported on the water diffusion of glass-epoxy composites. The influence of water absorption and the surrounding environment on the properties of epoxy matrix composites was discussed by Shen and Springer [49-50]. Several authors found that, the water absorbed by composite consists of molecules or groups of molecules linked by hydrogen bonds. In addition to this, the liquid can be absorbed by capillary action along any cracks, which may be at the fibre-matrix interface [51-54]. Vera et al [55] studied the effect of water sorption on the flexural properties of fully biodegradable (MaterBi-YR) composites. Recently, Satheesh Kumar and Siddaramaiah [56] reported the sorption and diffusion of water into jute nonwoven fabric impregnated NBR latex composites. It was found that the amount of NBR in the composite has a significant role to reduce the sorption and diffusion of water. A comparative study on the sorption behavior of water into TDI and HMDI based polyurethane (PU) membranes and their corresponding composites with polyester nonwoven fabric has been studied by Satheesh Kumar and Siddaramaiah [57].

A thorough literature survey revealed that, sorption and diffusion of water into the melamine-formaldehyde (MF) resin incorporated poly vinyl acetate (PVAc) – polyester nonwoven fabric composites have not been studied. This section explains the diffusion (D), sorption (S) and permeation (P) coefficients were estimated to study the transport behavior of water into the composites. To understand the type and behavior of transport, the empirical parameters n and K were calculated. The activation energy for the process of diffusion (E_D) and permeation (E_P) has been calculated.

7.6 EXPERIMENTAL

The fabrication of polyester nonwoven fabric impregnated PVAc/MF is explained in part A of chapter 6. The sorption experiments were performed and the results are analysed as per the procedure explained in part B of chapter 5.
7.7 RESULTS AND DISCUSSION

The percentage mass uptake ($Q_t$) of water versus square root of time for unfilled and MF loaded PVAc-polyester nonwoven fabric composites are shown in Figure 7.14. In all the samples the initial portion of the water absorption curve is linear, after which the

![Figure 7.14. Percent mass uptake ($Q_t$) of MF loaded PVAc-polyester nonwoven fabric composites at different temperatures.](image)
mechanism changes. Water diffusion in polymers was found to lead typical phenomena of composite swelling and physical relaxation. From the figure, it can be observed that the unfilled composite exhibited higher water uptake compared to the MF incorporated composites. The inherent water resistance nature of MF resin and the formation of crosslinked networks between MF – PVAc (Scheme 7.1- part A of this chapter) may result increased cross-link density and this could be the reason for lower water uptake in the MF incorporated composites [27]. According to Flory’s two-stage theory, the swelled polymer chain induces increased elasticity of chain structure and hence, inhibits the further absorption of water. However, the swelled polymer chain relaxes with time and subsequently increases the water absorption, which results stage wise equilibrium of water uptake.

The plots of \( \ln \left( \frac{M_t}{M_\infty} \right) \) versus \( \ln t \) were plotted to determine \( K \) and \( n \) and it is shown in Figure 7.15. The calculated values of the empirical parameters \( n \) and \( K \) for the composite – water systems at different temperatures are given in Table 7.9. The \( n \) value decreased with increase in the temperature. But the increase in \( K \) value with increase in temperature revealed that the interaction of water molecules with the composite is high as the temperature increases. The low value of \( n \) clearly indicates that the mechanism of water transport deviates from Fickian mode.

The calculated diffusion (D), sorption (S) and permeation (P) coefficient values of the water for MF incorporated PVAc-polyester nonwoven fabric composites are given in Table 7.10. From the table it can be noticed that, the diffusion coefficient of the water in unfilled composite is high compared to MF loaded composites. A significant reduction in the diffusion coefficient (D) of the water was noticed for the composites containing 5 and 10 parts by weight MF in PVAc. Further increase in the MF content showed a marginal reduction in D values. Generally, diffusion process is a thermally activated process, an increase in temperature found to increase the diffusion coefficient of the water. The increase in diffusion of water with increase in the temperature can be due to the development of micro cracks/voids on the surface and the bulk of the materials [58]. This can also be supported by Henry’s law mode, which states that the sorption proceeds through the creation of new sites or pores in the polymer. This hygrothermal effect on the composites can be explained with two mechanisms; (i) at the macroscopic level, absorption
Figure 7.15. The plot of $\ln t$ versus $\ln M_t/M_\infty$ of MF loaded PVA-c-polyester nonwoven fabric composites at different temperatures.
Table 7.9. Values of n and K for water - MF loaded PVAc composites with water

<table>
<thead>
<tr>
<th>PVAc/MF composition</th>
<th>Temp. (°C)</th>
<th>n (x 10^2)</th>
<th>K (x 10^2) (g/g min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100/0</td>
<td>30</td>
<td>8.9</td>
<td>40.7</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>7.8</td>
<td>46.6</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>7.0</td>
<td>49.1</td>
</tr>
<tr>
<td>100/5</td>
<td>30</td>
<td>8.0</td>
<td>46.4</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>5.2</td>
<td>61.5</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>2.5</td>
<td>77.4</td>
</tr>
<tr>
<td>100/10</td>
<td>30</td>
<td>7.3</td>
<td>49.1</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>4.2</td>
<td>68.4</td>
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<tr>
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<td>43.5</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>4.2</td>
<td>67.4</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>1.4</td>
<td>85.9</td>
</tr>
</tbody>
</table>

of water may be due to the matrix expansion and (ii) at the molecular level, the diffusing molecules of water may strain or rupture the intermolecular bond in the matrix and at the fibre-matrix interface. The sorption coefficient value of unfilled PVAc-polyester nonwoven composite at different temperatures lie in the range 248 x 10^{-2} - 287 x 10^{-2} g/g, which is higher compared to that of crosslinked composites (166 x 10^{-2} - 175 x 10^{-2} g/g). A marginal reduction in sorption values of water was noticed for the composites containing MF above 10 parts. The permeation coefficient, which is the net effect of sorption and diffusion coefficient, followed a similar trend as and S and D values. The P values of water for unfilled PVAc-polyester nonwoven fabric composite lie in the range 17.36 x 10^{-3} - 33.29 x 10^{-3} cm²/sec. The P values of water obtained for MF incorporated composites are significantly lower (0.03 x 10^{-3} - 2.84 x 10^{-3} cm²/sec) compared to unfilled composites. Table 7.11 shows the variation in equilibrium water content (M_w) of MF incorporated PVAc-polyester nonwoven fabric composites. It is observed that the water uptake of all the composites increased with increase in the sorption test temperature. This can be attributed to the fact that, at higher temperatures, an increase in free volume occurs due to the
increased movement of the chain segments of matrix [59-62]. The obtained \( M_m \) value is high for unfilled composite compared to MF incorporated composites.

**Table 7.10. Diffusion (D), sorption (S) and permeation (P) coefficients for MF loaded PVAc-polyester nonwoven composites**

<table>
<thead>
<tr>
<th>PVAc/MF composition (dry, wt/wt)</th>
<th>Temp. (°C)</th>
<th>Diffusion coefficient ( (D) ) ( (X 10^5 \text{cm}^2/\text{sec}) )</th>
<th>Sorption coefficient ( (S) ) ( (X 10^3 \text{g/g}) )</th>
<th>Permeability coefficient ( (P) ) ( (X 10^3 \text{cm}^2/\text{sec}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>100/0</td>
<td>30</td>
<td>7.00</td>
<td>248</td>
<td>17.36</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>8.40</td>
<td>252</td>
<td>21.17</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>11.6</td>
<td>287</td>
<td>33.29</td>
</tr>
<tr>
<td>100/5</td>
<td>30</td>
<td>0.13</td>
<td>177</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>0.87</td>
<td>190</td>
<td>1.66</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>1.42</td>
<td>191</td>
<td>2.69</td>
</tr>
<tr>
<td>100/10</td>
<td>30</td>
<td>0.06</td>
<td>167</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>1.10</td>
<td>174</td>
<td>1.91</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>1.38</td>
<td>176</td>
<td>2.43</td>
</tr>
<tr>
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<td>30</td>
<td>0.04</td>
<td>167</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
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<td>1.05</td>
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<td>1.81</td>
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<tr>
<td></td>
<td>70</td>
<td>1.30</td>
<td>175</td>
<td>2.23</td>
</tr>
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<td>166</td>
<td>0.03</td>
</tr>
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<td></td>
<td>50</td>
<td>1.05</td>
<td>172</td>
<td>1.81</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>1.30</td>
<td>175</td>
<td>2.23</td>
</tr>
</tbody>
</table>

The activation energy for the process of diffusion \( (E_D) \) and for the process of permeation \( (E_P) \) is estimated from the Arrhenius relation. The plots of \( \ln D \) and \( \ln P \) versus \( 1/T \) are shown in Figures 7.16 and 7.17. The values of \( E_D \) and \( E_P \) for MF incorporated PVAc-polyester nonwoven fabric composites are significantly higher compared to unfilled composites (Table 7.12). The values of \( E_D \) and \( E_P \) for unfilled composite are 11 and 14 kJ/mole respectively. The values of \( E_D \) and \( E_P \) for MF loaded composites lie in the range 50-84 kJ/mole and 51-78 kJ/mole respectively. The high activation energy was noticed with 10 part MF incorporated PVAc-polyester nonwoven fabric composites.

Attempts have been made to calculate the equilibrium sorption constants, \( K_S \) from consideration on the equilibrium process occurring in the liquid phase at constant temperature and pressure. The temperature dependent equilibrium sorption constant \( (K_S) \) values can be fitted to the vant Hoff's relation to estimate the enthalpy, (i.e., heat of
sorption) $\Delta H$ and standard entropy, $\Delta S$ of the sorption process. $\Delta H$ and $\Delta S$ were calculated from the slope and intercepts respectively by the vant Hoff's plot (Figure 7.18). The estimated $\Delta H$ and $\Delta S$ values are given in Table 7.11. Low values of $\Delta H$ for crosslinked composites suggest that there exists a mild interaction of the water penetrant with the

![Figure 7.16](image1.png)

**Figure 7.16.** The plot of $\ln D$ versus $1/T$ for MF loaded PVAc composites

![Figure 7.17](image2.png)

**Figure 7.17.** The plot of $\ln P$ versus $1/T$ for MF loaded PVAc composites
polymer matrix giving a high endothermic heat of sorption. The values of $\Delta H$ were positive suggesting that, the sorption is an endothermic process and it is dominated by Henry’s law mode, i.e., sorption proceeds through the creation of new sites or pores in the polymer. It is also noted that the 10-part MF loaded composite has low $\Delta H$ value compared to other systems. The calculated $\Delta S$ values are negative for all the systems. This suggests that, the water molecules are retained in the sorbed state.

Table 7.11. Equilibrium moisture content for MF loaded PVAc-polyester nonwoven composites

<table>
<thead>
<tr>
<th>PVAc/MF composition (dry, wt/wt)</th>
<th>Equilibrium moisture content ($M_m$) in %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temperature (°C) 30 50 70</td>
</tr>
<tr>
<td>100/0</td>
<td>148 152 186</td>
</tr>
<tr>
<td>100/5</td>
<td>77 87 89</td>
</tr>
<tr>
<td>100/10</td>
<td>67 74 76</td>
</tr>
<tr>
<td>100/15</td>
<td>66.5 73 76</td>
</tr>
<tr>
<td>100/20</td>
<td>66.0 73 75</td>
</tr>
</tbody>
</table>

Table 7.12. Values of activation energy for diffusion ($E_D$, kJ/mol), permeation ($E_P$, kJ/mol), enthalpy ($\Delta H$, kJ/mol) and entropy of sorption ($\Delta S$, J/mol) for unfilled and MF loaded PVAc-polyester nonwoven fabric composites

<table>
<thead>
<tr>
<th>PVAc/MF composition (dry, wt/wt)</th>
<th>$E_D$</th>
<th>$E_P$</th>
<th>$\Delta H$</th>
<th>$\Delta S$</th>
</tr>
</thead>
<tbody>
<tr>
<td>100/0</td>
<td>11</td>
<td>14</td>
<td>7.2</td>
<td>14.7</td>
</tr>
<tr>
<td>100/5</td>
<td>50</td>
<td>51</td>
<td>3.6</td>
<td>32.3</td>
</tr>
<tr>
<td>100/10</td>
<td>84</td>
<td>78</td>
<td>2.7</td>
<td>37.1</td>
</tr>
<tr>
<td>100/15</td>
<td>82</td>
<td>77</td>
<td>4.0</td>
<td>36.7</td>
</tr>
<tr>
<td>100/20</td>
<td>82</td>
<td>77</td>
<td>6.2</td>
<td>23.4</td>
</tr>
</tbody>
</table>
7.8 CONCLUSIONS

The sorption and diffusion of water in to PVAc-polyester nonwoven fabric composites was found to be dependent on amount of MF resin incorporated into PVAc and the temperature. The diffusion (D), permeation (P) and sorption (S) coefficient values were found to decrease with increase in the amount of MF resin into PVAc latex. This is due to increase in crosslink density and reduction in micro voids/free volume. The optimized dosage of MF into PVAc is 10 parts. The increase in temperature has increased the D, P and S values. The lower value of ‘n’ (less than 0.5) clearly revealed that the mechanism of water transport deviates from Fickian mode. The increased K values with increase in the temperature shows the high interaction of water penetrant with the composites. A drastical reduction in the water sorption and diffusion behavior was noticed with the MF incorporated composites compared to unfilled composite. E_D and E_P values found to be high in 10-part MF incorporated composites. The positive values of ΔH suggested that, sorption is an endothermic process and it is dominated by Henry's law mode. The negative values of ΔS, indicates that the structure of water molecules is retained even in the sorbed state.
7.9 REFERENCES

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