

CHAPTER IV RESULTS AND DISCUSSION

4.1 Effect of Fiber Content on the Mechanical Properties of the Composite

The effect of fiber content on the tensile and flexural properties of the composite is shown in Figure 4.1.

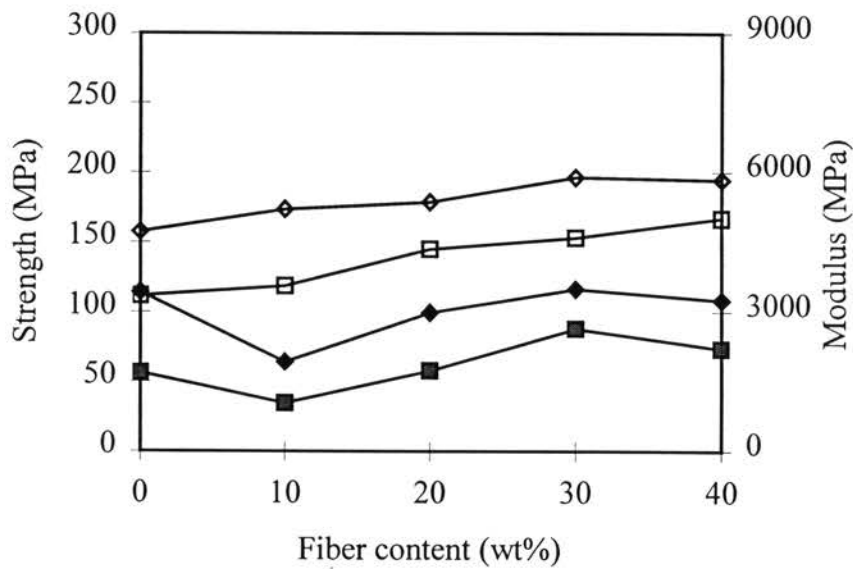


Figure 4.1 Tensile and flexural properties of kenaf fiber-UPE composites with different fiber contents.

- tensile strength
- tensile modulus
- ◆— flexural strength
- ◇— flexural modulus

It was observed that both the tensile and flexural properties increased with increase in fiber content up to 30 wt%. At 40 wt% fiber content, the strength decreased slightly while the modulus increased slightly. The flexural properties were significantly higher than the corresponding tensile properties. Both the tensile and flexural strengths of the fiber-UPE composites were less than the pure resin at low weight fractions of fiber. At low fiber content, the fibers may act as flaws in the composite leading to poor strength, (Devi *et al.*, 1997). Further increase in fiber content up to 30 wt% increased both the strength and modulus to the optimum value indicating that at that level of fiber content the composite contains a sufficiently high volume fraction of fibers to help support the load leading to higher strength. However, increasing the fiber content to 40 wt% resulted in a slight lowering in the strength. This is attributed to the increased fiber density leading to poor resin penetration. Devi *et al.* (1997) studied the mechanical properties of pineapple leaf fiber-reinforced polyester composites. They found that both tensile and flexural properties of the composites increased with fiber content up to 30 wt%. At 40 wt% of fiber content, the tensile properties continued to increase while the flexural properties showed a slight decrease. The decrease in flexural properties at high fiber content was attributed to poor dispersion of fibers in the polymer matrix.

Based on the above results, the fiber content in the present work was set at 30 wt% of the composite.

4.2 The Adsorption of Silanol on Fiber

The adsorption of silanol on the fiber at different silane concentrations, times, and temperatures was studied. The results in Figure 4.2 show that the amount of silanol adsorbed on fiber increased when the concentration of silane increased. At the same silane concentration, γ -MPS gave higher adsorption

than VTS. This may be because γ -MPS has a higher molecular weight than VTS leading to a higher weight gain at the same silane concentration. Chemical structures and molecular weights of these two silanes are presented in Table 4.1.

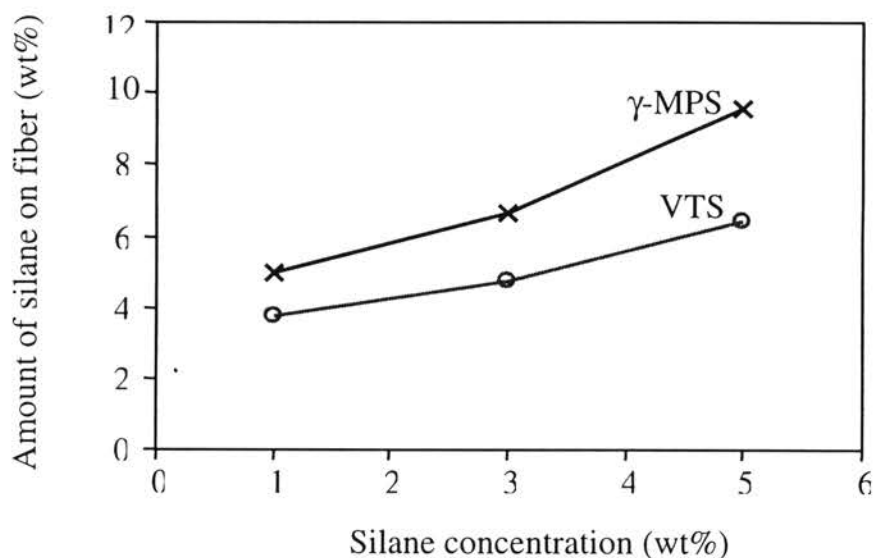


Figure 4.2 Adsorption of silanol on fiber at various silane concentrations.

Table 4.1 Chemical structures of γ -MPS and VTS.

Name of silane	Abbreviation	Chemical structure	MW
γ -Methacryloxypropyl trimethoxysilane	γ -MPS	$\begin{array}{c} \text{CH}_3 \\ \\ \text{CH}_2 = \text{C} - \text{COO}(\text{CH}_2)_3\text{Si}(\text{OCH}_3)_3 \end{array}$	248.35
Vinyltriethoxysilane	VTS	$\text{CH}_2 = \text{CHSi}(\text{OC}_2\text{H}_5)_3$	190.32

The silanol adsorption at different times is presented in Figure 4.3. The results show that when the time of treatment increased, the amount of silanol adsorbed on the fiber surface increased slowly up to 10 hours followed by a sharp increase at longer treatment times. Hydrolyzed silanes condense to oligomeric siloxanols when the solution is left to stand for a long time (Plueddemann, 1982). The adsorption of these higher molecular weight oligomers may be responsible for the sharp increase in the adsorption at long treatment time.

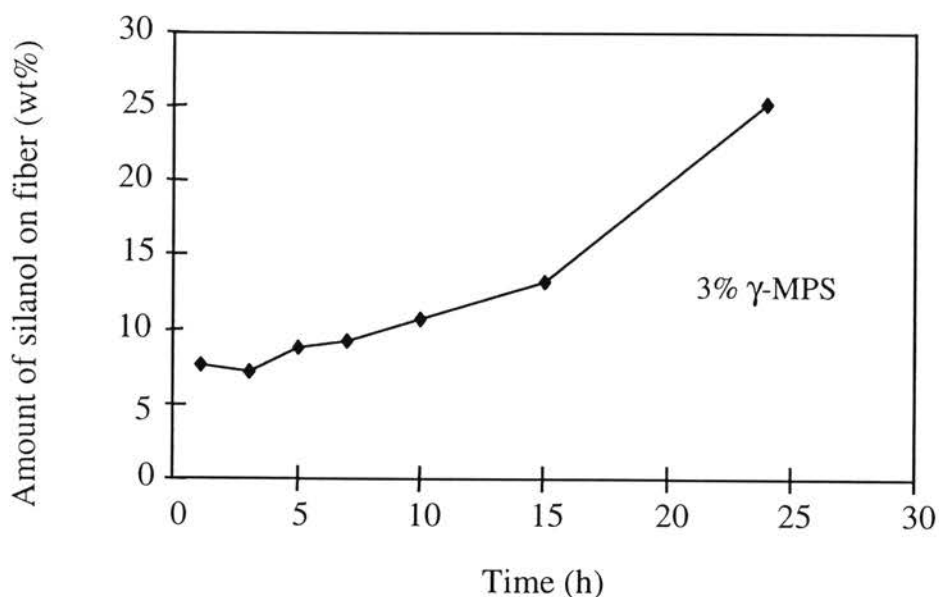


Figure 4.3 Adsorption of silanol on fiber at various treatment times.

In Figure 4.4, the variation in silanol adsorption with temperature in different silane concentrations is shown. The results show that, at 3 wt% silane concentration, the amount of adsorbed silanol increased sharply with temperature. At silane concentrations of 0.7 wt% and 1 wt% the silanol adsorption increased gradually at first followed by a sharp increase at higher temperatures. The high temperature may accelerate the condensation of hydrolyzed silanes leading to sharp increase in silanol adsorption.

Based on the above results, the conditions for silane treatment in this work were set at 1 wt% and 5 wt% of silane concentrations with treatment temperatures of 30°C and 50°C at a fixed time of 1 hour.

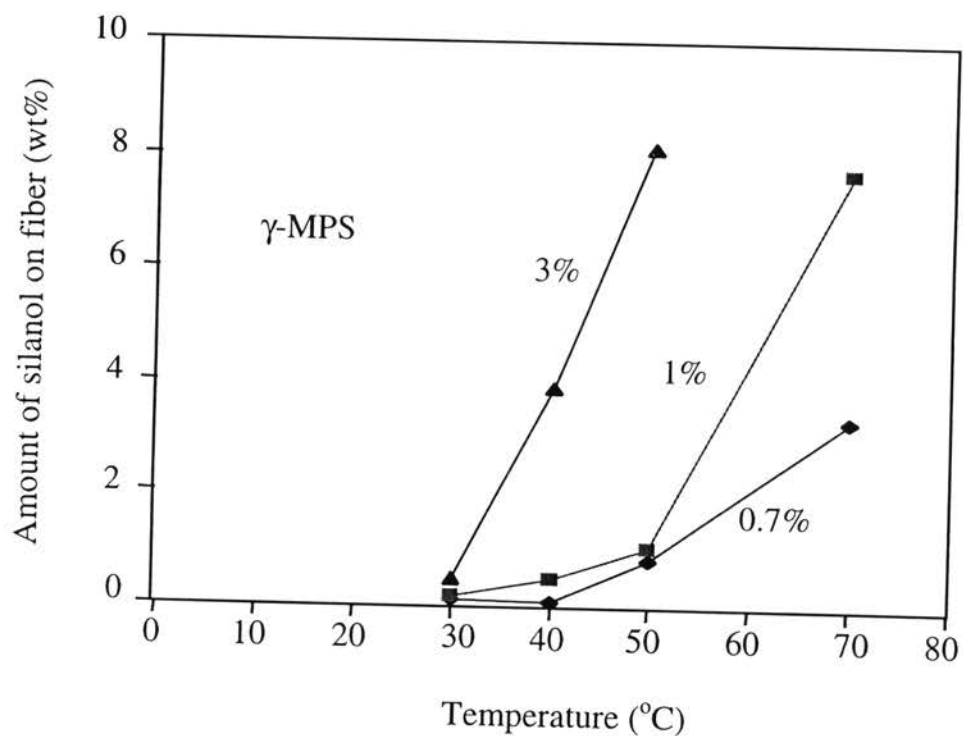


Figure 4.4 Adsorption of silanol on fiber at various temperatures.

4.3 Mechanical Properties of Treated Fiber-UPE Composites

The fiber-matrix adhesion was studied via mechanical properties of the composites. The mechanical properties were evaluated on composites containing the optimum amount of 30% fibers by weight. The effects of silane treatment with both γ -MPS and VTS on the mechanical properties of treated fiber-UPE composites are shown in Figures 4.5, 4.6, 4.7, and 4.8.

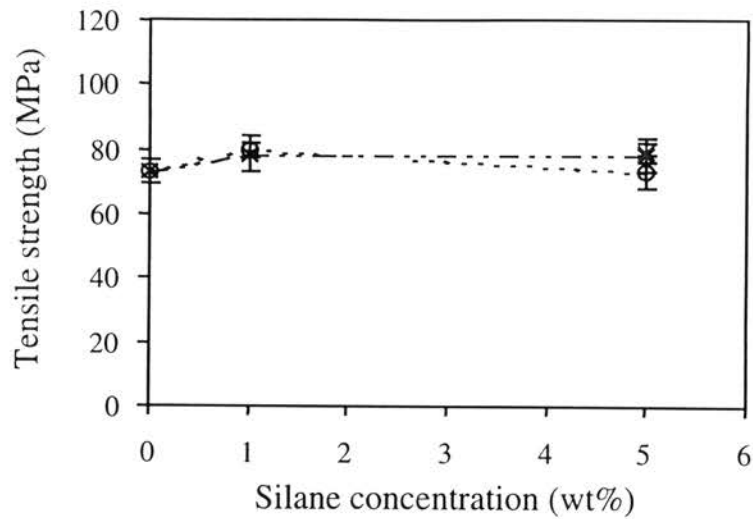


Figure 4.5 Tensile strength of composites vs silane concentration used in fiber treatment.

- x-- γ -MPS treated fiber composites
- ...o... VTS-treated fiber composites
- * Composite with fiber treated in 5% γ -MPS at 50°C

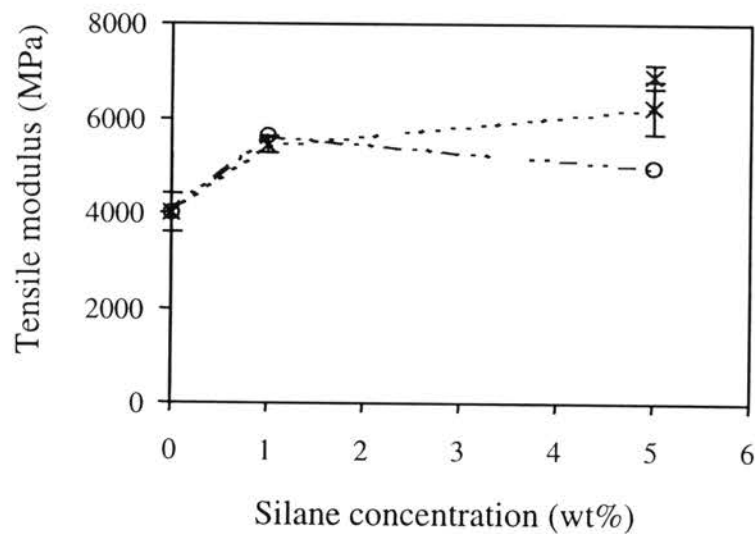


Figure 4.6 Tensile modulus of composites vs silane concentration used in fiber treatment.

- x-- γ -MPS treated fiber composites
- ...o... VTS-treated fiber composites
- * Composite with fiber treated in 5% γ -MPS at 50°C

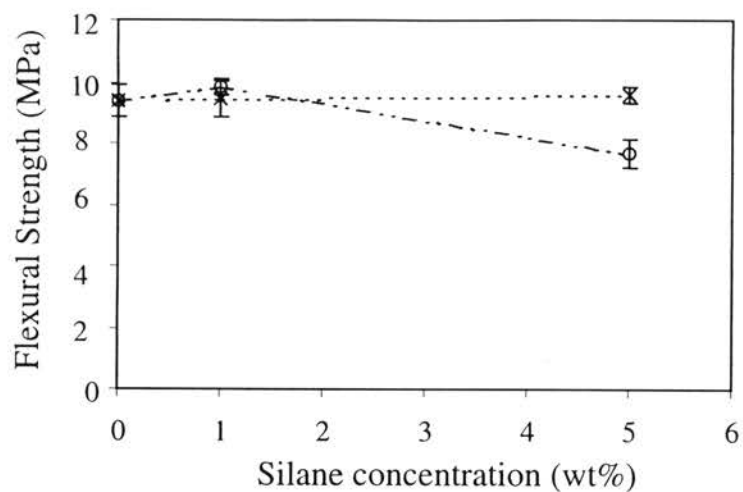


Figure 4.7 Flexural strength of composites vs silane concentration used in fiber treatment.

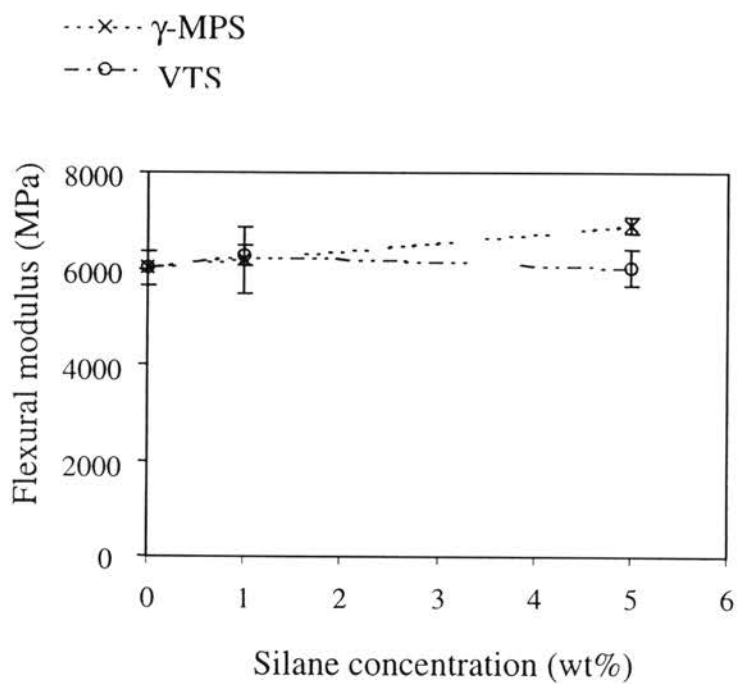


Figure 4.8 Flexural modulus of composites vs silane concentration used in fiber treatment.

···×··· γ -MPS
 ---○--- VTS

The results show that there is a slight improvement in both the tensile and flexural properties of the composites made from fibers treated in 1 wt% silane solution as compared with the untreated-fiber composite. The improvement indicates that both γ -MPS and VTS help to improve the fiber-matrix adhesion—most probably by the reaction of their reactive groups with the styrene-unsaturated polyester matrix. It is interesting to note also that VTS treated fiber gave composites of slightly better mechanical properties than γ -MPS at 1 wt% silane solution (Figures 4.5, 4.6, 4.7, and 4.8). This may be due to the much smaller size of VTS compared with γ -MPS, leading to higher packing of the VTS molecules on the fiber surface and hence more bonding with the fiber and polymer matrix can be obtained.

However, at higher silane concentration of 5 wt%, the two silanes showed distinctive difference in their effects on the mechanical properties of the composites. The γ -MPS treated fiber composite showed a slight improvement in mechanical properties with increase in silane concentration but deterioration in properties was found in the case of VTS. This difference may arise from the difference in the reactivity of the organofunctional groups in the two silanes (Section 1.3). In the case of γ -MPS, the high reactivity leads to improvement in fiber-matrix adhesion at high concentration. Whereas in the case of VTS, due to its low reactivity, not only does higher concentration not help to improve the fiber-matrix adhesion, but the increased amount of silane on the fiber surface may interfere with fiber-matrix interaction leading to lower mechanical properties.

The composite made from fiber treated in 5 wt% γ -MPS at 50°C was found to have the highest tensile properties. This is because at higher treatment temperature silanol adsorption increased sharper (Section 4.2) leading to greater fiber-matrix adhesion.

4.4 Water Absorption of Composites

The water absorption as a percentage of dry weight is plotted against time of immersion in Figures 4.9, 4.10, and 4.11 at room temperature, 70°C and 100°C respectively. The results show that, in the case of VTS, water absorption was greater than the untreated-fiber composite, and an increase in the amount of silane on the fibers led to an increase in water absorption indicating lower fiber-matrix adhesion at higher silane concentration. This may be due to the lower in relative reactivity of VTS in copolymerizing with styrene. In similar studies, Plueddemann (1982) observed that a vinyl silane layer did not polymerize completely with styrene-diluted resin during resin cure. Moreover, the results are also in agreement with the deterioration in the mechanical properties of the composite with increase in silane concentration.

In the case of γ -MPS, increase in silane concentration led to a reduction in water absorption. Plueddemann (1982) found that a methacrylate-functional silane could polymerize more completely during resin cure resulting in better fiber-matrix adhesion at higher silane concentration. The results are also in agreement with the improved mechanical properties (Section 4.3).

The composite made from fiber treated in 5 wt% γ -MPS at 50°C was found to have the lowest water absorption. The results are also in agreement with the improved tensile property (Section 4.3). This may be due to the higher adsorption of silane at higher temperature (Section 4.2) and the better penetration of the silane into the fiber. In addition, composites made from fibers treated with 5 wt% γ -MPS at 50°C were found to have lower water absorption than the untreated-fiber composite at all immersion times and temperatures tested.

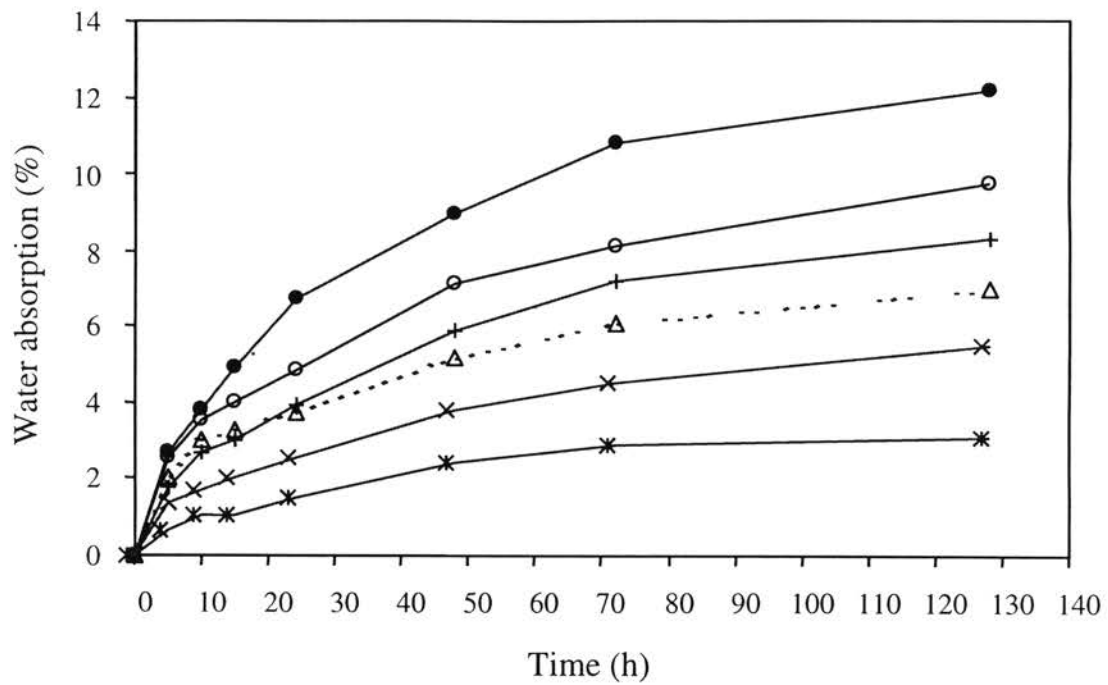


Figure 4.9 Water absorption of composites at room temperature at various times of immersion.

- Δ--- composite with untreated fiber
- composite with 1% VTS treated fiber
- composite with 5% VTS treated fiber
- +— composite with 1% γ -MPS treated fiber
- ×— composite with 5% γ -MPS treated fiber
- *— composite with fiber treated in 5% γ -MPS at 50°C

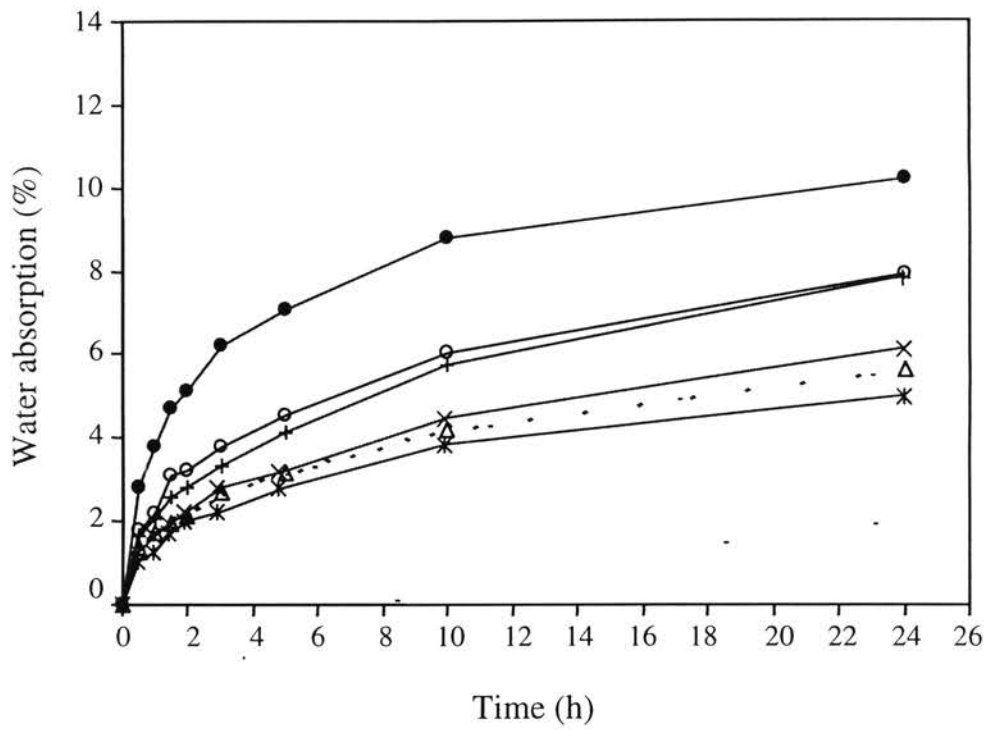


Figure 4.10 Water absorption of composites at 70°C at various times of immersion.

- Δ--- composite with untreated fiber
- composite with 1% VTS treated fiber
- composite with 5% VTS treated fiber
- +— composite with 1% γ -MPS treated fiber
- ×— composite with 5% γ -MPS treated fiber
- *— composite with fiber treated in 5% γ -MPS at 50°C

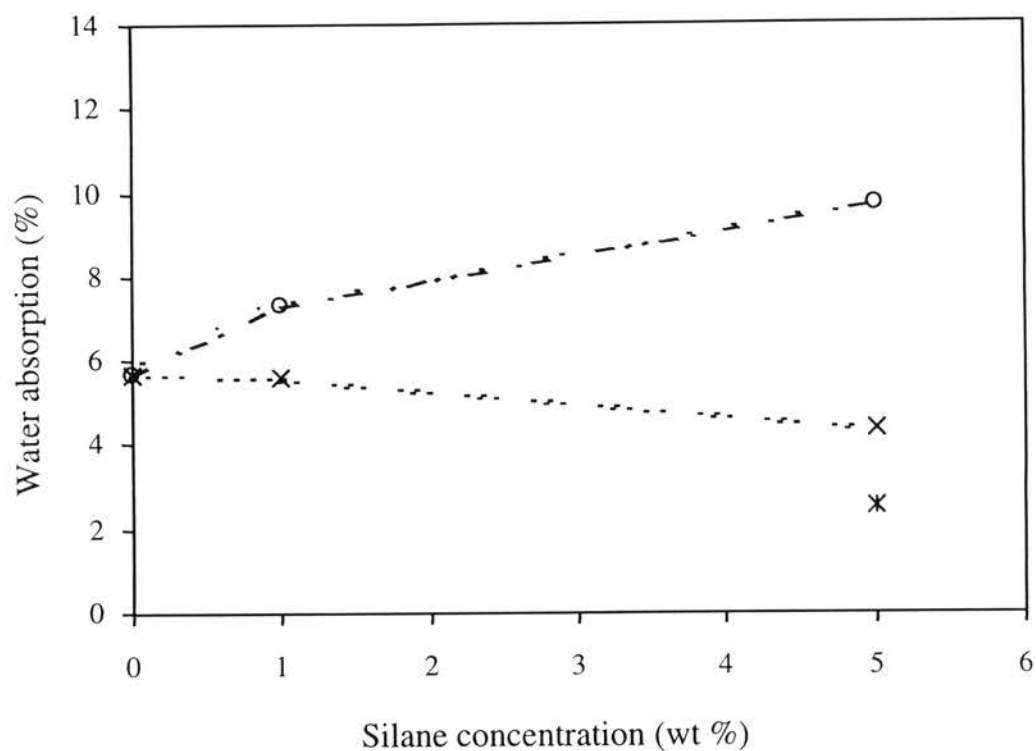


Figure 4.11 Water absorption of composites at 100°C for 2 hours.

- - x - - γ -MPS treated fiber composites
- - - o - - VTS-treated fiber composites
- * Composite with fiber treated in 5% γ -MPS at 50°C

4.5 Fractured Surfaces of Specimens from Tensile Testing

The surfaces of fractured specimens from tensile testing of the composites containing 10-40 wt% fiber content were examined with SEM and are presented in Figure 4.12. The fractured surfaces were seen to consist of many broken fiber ends, the amount of which increased with increase in fiber content. Some of the fiber ends were quite long. At a fiber content of 40 wt%, the fractured surfaces contained groups of fiber ends with no resin surrounding them, indicating poor resin penetration in-between the fibers.

Figure 4.13 compares the fractured surfaces of untreated- and silane-treated fiber composites. In untreated and 1 wt% silane-treated fiber composites, there are many long fiber ends on fractured surfaces indicating poor adhesion between the fiber and resin matrix. In the case of 5 wt% γ -MPS-treated fiber composite, there were fewer and shorter fiber ends projecting from the fractured surface indicating better fiber to matrix adhesion. For the composite utilising fiber treated at 5 wt% γ -MPS at 50°C, the fractured

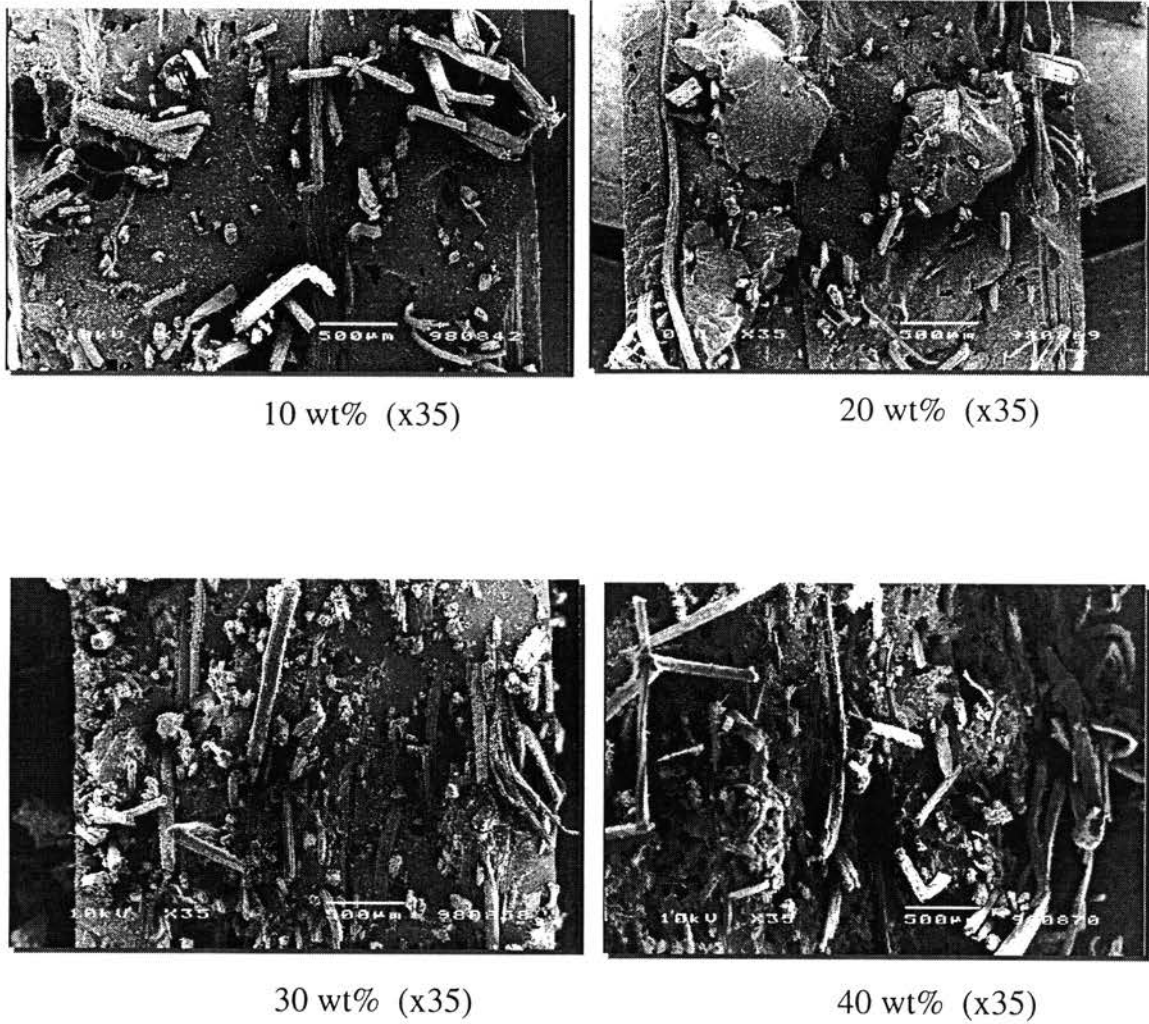


Figure 4.12 SEM micrographs of fractured surfaces of composites at various fiber contents.

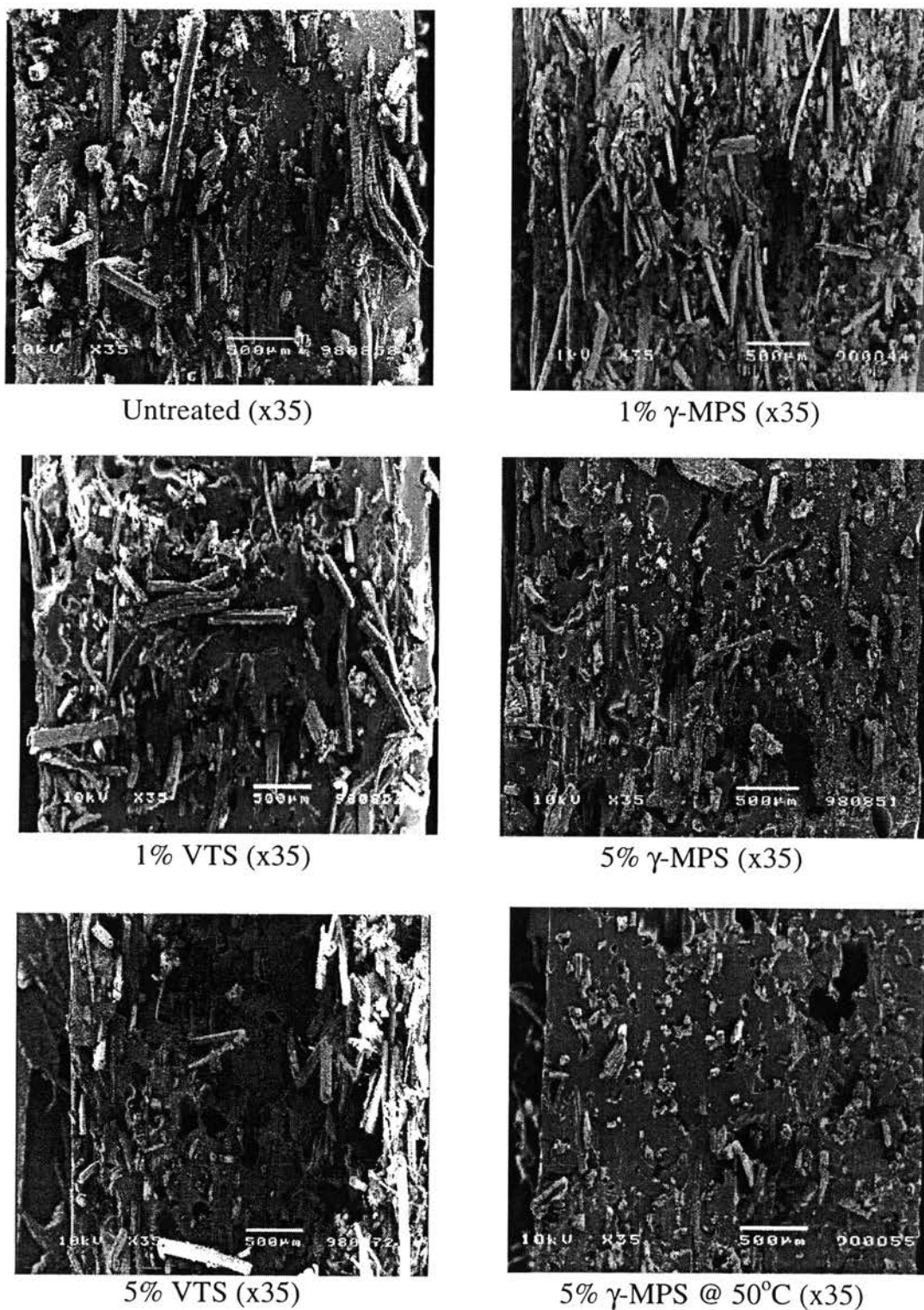


Figure 13 SEM micrographs of fractured surfaces of untreated and silane-treated fiber composites.