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Effect of fiber surface treatments on the fiber–matrix interaction in banana fiber reinforced polyester composites

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Abstract—Cellulosic fibers have been used as cost-cutting fillers in plastic industry. Among the various factors, the final performance of the composite materials depends to a large extent on the adhesion between the polymer matrix and the reinforcement and therefore on the quality of the interface. To achieve optimum performance of the end product, sufficient interaction between the matrix resin and the cellulosic material is desired. This is often achieved by surface modification of the resin or the filler. Banana fiber, the cellulosic fibers obtained from the pseudo-stem of banana plant (Musa sapientum) is a bast fiber with relatively good mechanical properties. The fiber surface was modified chemically to bring about improved interfacial interaction between the fiber and the polyester matrix. Various silanes and alkali were used to modify the fiber surface. Modified surfaces were characterized by SEM and FTIR. The polarity parameters of the chemically modified fibers were investigated using the solvatochromic technique. The results were further confirmed by electrokinetic measurements. Chemical modification was found to have a profound effect on the fiber–matrix interactions. The improved fiber–matrix interaction is evident from the enhanced tensile and flexural properties. The lower impact properties of the treated composites compared to the untreated composites further point to the improved fiber–matrix adhesion. In order to know more about the fiber–matrix adhesion, fractured surfaces of the failed composites where further investigated by SEM. Of the various chemical treatments, simple alkali treatment with NaOH of 1% concentration was found to be the most effective. The fiber–matrix interactions were found to be dependent on the polarity of the modified fiber surface.

Keywords: Banana fiber; polyester; silane treatment; polarity parameters; SEM; zeta potential.

1. INTRODUCTION

Scientists are currently investigating the effect of fibre pretreatments on the interfacial strength of lignocellulose/polymer composites. Thermoplastic and thermoset
composites based on natural fibres are being investigated for their long-term performance. The rationale behind these efforts is the techno-economical benefits of using natural fibres, which are currently being under-utilised, and which also have high specific properties. Other than these, industrial reasons also force scientists to investigate the effectiveness of natural fibres as reinforcement in polymer matrices.

Many major issues have been identified in the processing of natural fibre composites. One major issue is the lack of perfect bonding between the fibre and the matrix, which ultimately leads to debonding. Other than this, moisture uptake is another problem. Fibre–matrix adhesion is strongly dependent on the thermodynamic and the chemical states of the fibre surface. Surface area, surface energy, and the acid–base characteristics change with the nature of the substrate and these can be changed by the surface treatments [1].

Chemical modification of the matrix or the resin is one way in which higher interactions between the fibre and the matrix can be brought about. In the case of thermoplastic resins, modification of the matrix has been carried out [2]. Modification of the fibre by several chemical methods has been suggested and carried out in the case of thermoset matrices [3–5]. Treatment with alkali and also by other coupling agents like silanes, titanates, etc. have all been proved to be the best way to improve fibre–matrix adhesion.

Extensive research work carried out by Thomas and co-workers in this laboratory has proved the effectiveness of various natural fibres like sisal, pineapple leaf fibre, banana, jute, oil palm empty fruit bunch fibre, etc. to be effective reinforcement in various polymeric matrices [6–10]. Chemical modification done in certain cases was found to be effective in increasing the mechanical properties of the composites. Banana fibre, obtained from the pseudo-stem of banana plant (Musa sepientum) is a bast fibre with relatively good mechanical properties. Table 1 contains the mechanical properties of banana fibres of various diameters. This fibre was also found to be an effective reinforcement in polyester [10]. Treatment with silane A151 (vinyl triethoxysilane) proved to be effective in increasing the tensile properties of the composite in our earlier studies [9]. Polarity or acid–base characteristics were found to have a profound influence on the fibre–matrix interactions in

Table 1.
The mechanical properties of banana fibre

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Diameter of fibre ($\mu$m)</th>
<th>Initial Young’s modulus (GPa)</th>
<th>SD* Initial Young’s modulus (GPa)</th>
<th>Tensile strength (MPa)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>32</td>
<td>8</td>
<td>779</td>
<td>2.7</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>30</td>
<td>4</td>
<td>711</td>
<td>2.4</td>
</tr>
<tr>
<td>3</td>
<td>150</td>
<td>29</td>
<td>8</td>
<td>773</td>
<td>3.5</td>
</tr>
<tr>
<td>4</td>
<td>200</td>
<td>27</td>
<td>7</td>
<td>789</td>
<td>3.3</td>
</tr>
<tr>
<td>5</td>
<td>250</td>
<td>29</td>
<td>4</td>
<td>766</td>
<td>3.2</td>
</tr>
</tbody>
</table>
composites. \(\zeta\)-potential measurement and solvatochromic techniques have been used to investigate the hydrogen bond donating ability, hydrogen bond accepting ability and the overall polarity of the modified fibre surface [11]. Treatment of the banana fibre surface with various chemical agents and the polarity parameters obtained are reported in our earlier publication [11]. \(\zeta\)-potential measurements using streaming potential measurements have been employed by Bismarck et al. to characterise chemically modified jute fibres [12]. The electrokinetic measurements of the banana fibres were also done and the results were found to agree with those of the polarity parameter measurements [13].

In this communication we report on the effect of chemical modification of the fibres on the mechanical properties of the composites, namely, tensile, flexural and impact properties. The change in the surface morphology and the polarity of the cellulose fibres after treatment with various chemicals has been analysed. The influence of fibre–matrix adhesion on the macro-mechanical behaviour has been analysed by investigating the behaviour of the composite under tensile, impact and flexural loading. The effect of the various chemical modifications on the interfacial adhesion has been concluded and reported based on the mechanical performance of the material and also on the analysis of the failed surface.

2. EXPERIMENTAL

2.1. Materials used

Cellulose fibres were obtained from Sheeba Fibres and Handicrafts, Poovancode, Tamil Nadu. The various silanes, A174 (\(\gamma\)-methacryloxypropyltrimethoxysilane), A151 (vinyl triethoxysilane), A1100 (\(\gamma\)-aminopropyltriethoxysilane), were obtained from Sigma-Aldrich, India. Dynasylan F8261 (1H, 1H, 2H, 2H-perfluoro-octyl triethoxy silane) was obtained from ABCR GmbH and Co. NaOH and all other chemicals were of commercial grade.

2.2. Silane treatment for cellulose fibers

0.6% of the respective silane was mixed with an ethanol/water mixture in the ratio 6:4, mixed well and was allowed to stand for an hour. The pH of the solution was carefully controlled to bring about the complete hydrolysis of the silane by the addition of acetic acid/NaOH depending on the silane used. Neatly separated and cut cellulose fibre was dipped in the above solution and was allowed to remain there for 1 ½ hours. The ethanol/water mixture was drained out and the fibre was dried in air for half an hour, followed by drying in the oven at 70°C till the fibre was fully dry.

2.3. Treatment with NaOH

Cleaned and well-separated cellulose fibres were dipped in 0.5 and 1% solution of NaOH for half an hour and then washed in very dilute acid to remove any particles
of alkali. Washing was continued till the fibres were alkali free. The washed fibres were then dried in the oven at 70°C for 3 hours.

The structures of the various chemical agents used are given in Fig. 1.

2.4. Preparation of composites

Banana fibers were neatly separated by hand; adhering pith, if any, was removed and the fibers were cut to uniform size of 30 mm length. The fibres were then subjected to various chemical treatments. The modified fibers were evenly arranged in a mould measuring 150 × 150 × 3 mm³, and pressed into a mat. Composite sheets were prepared by impregnating the fiber with the polyester resin to which 0.9 vol% cobalt naphthanate (8% solution), and 1% (vol%) methyl ethyl ketone peroxide were added and the air bubbles were removed carefully with a roller. The closed mould was kept under pressure for 12 h, samples were allowed to post-cure at room temperature for 48 h and test specimens of the required size were cut.

2.5. Mechanical tests

Test specimens were cut from composite sheets. Tensile testing was carried out using FIE electronic tensile testing machine TNE-500 according to ASTM D638-76. Flexural tests were done according to ASTM D790. Five samples were tested in each set and the average value is reported. Impact test was done on a Charpy impact tester Instron Wolpert PW5 according to ASTM D256. A minimum of four samples
was tested in each case and the average value is reported. Fractography of the failed surfaces of the composites were examined by Scanning Electron Microscope after sputtering the surfaces with gold.

3. RESULTS AND DISCUSSION

3.1. Sodium hydroxide treatment

The banana fibre surface was treated with alkali of different concentration and the treated fibres were used for the preparation of composites. Enhancement of adhesion between fibre and matrix is demonstrated by mechanical tests. Reports are already in the literature regarding the effectiveness of NaOH in modifying the surface of other natural fibres [14]. Details of alkali treatment on the polarity parameters of banana fibre surface have already been reported [11]. The surface of the alkali treated fibres has also been characterised by electrokinetic measurements and FT-IR. The NaOH treatment degrades and removes practically all non-cellulose components. Solvatochromic measurements carried out by us on alkali treated fibres showed a definite change in the absorption peak compared to the untreated fibre showing a reduction in the number of acidic sites [11]. The changes in the surface structure can be explained as due to the changes in the supra-molecular structure because of interaction with alkali. The acceptor number calculated using the solvatochromic measurements revealed a value lower than that of the untreated fibre. The results are consistent with the ζ-potential measurements (Table 2).

Figure 2 shows the tensile stress–strain curves of the various treated fiber composites. The improvement in the tensile strength in the case of fibres treated with alkali of higher concentration can be attributed to the following reasons:

1. Due to alkali treatment, the cementing materials get dissolved. The interfibrillar region becomes less dense and and less rigid and the fibrils become more capable of rearranging themselves along the tensile deformation [15]. Other

<table>
<thead>
<tr>
<th>Treatment</th>
<th>i.e.p. values</th>
<th>$E_T$ (30) kcal (mol$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>2.6</td>
<td>58.58</td>
</tr>
<tr>
<td>Silane A151</td>
<td>3.4</td>
<td>65.83</td>
</tr>
<tr>
<td>Silane A174</td>
<td>3.2</td>
<td>60.44</td>
</tr>
<tr>
<td>Silane A1100</td>
<td>5.4</td>
<td>—</td>
</tr>
<tr>
<td>NaOH</td>
<td>3.8</td>
<td>61.01</td>
</tr>
<tr>
<td>Acetylation</td>
<td>2</td>
<td>—</td>
</tr>
<tr>
<td>Dynasylan</td>
<td>—</td>
<td>60.65</td>
</tr>
<tr>
<td>Si 69</td>
<td>3</td>
<td>59.01</td>
</tr>
<tr>
<td>$C_{18}$-T</td>
<td>2.8</td>
<td>—</td>
</tr>
</tbody>
</table>
authors have also reported on the change in crystallinity of alkali treated fibres because of the removal of the cementing materials, which leads to a better packing of cellulose chains [16].

(2) Increase in the surface area of the fibre due to the dissolution of lignin, hemicellulose and alien substances associated with the fibre. This results in a larger area of contact between the fibre and the matrix leading to increased tensile strength [17].

(3) Dissolution of waxy substances exposes the $\text{-OH}$ and the $\text{-COOH}$ groups on the fibre surface leading to increased polarity and decreased acidity of the fibre surface. This ultimately leads to increased polar–polar interaction with the matrix leading to higher tensile strength.

(4) The alkali sensitive bonds between the different components rupture leading to the increased homogeneity of the fibre surface [18].

(5) Alkali treatment increases the yarn toughness and affects the micro fibrillar angle and other structural parameters [19]. The SEM of the alkali treated fibre is shown in Fig. 3.

Other authors have reported on the influence of alkali treatment on the improvement in the properties of natural fibre composites [20]. Figure 2 shows the tensile stress–strain curves of the various treated fibres. The tensile strength is found to be the maximum for composites treated with NaOH. While the tensile strength is 58 MPa for the untreated composite, it is 70 MPa for the composites treated with 1% alkali. When alkali of a lower concentration is used, the tensile strength $I$ is found to be 65 MPa. However, the elongation of the samples is found to be lower than with other treated composites. The reason can be attributed to the improved
Effect of fiber surface treatments on the fiber–matrix interaction due to the treatment. Figure 4 shows the effect of chemical treatment on the tensile modulus. The tensile modulus is found to be the maximum for composites treated with 0.5% NaOH. The elastic moduli of natural fibres are
Figure 5. (a) Tensile fracture surface of the alkali treated fibre composite. (b) Surface of the alkali treated fibre.

found to increase with increasing degree of molecular orientation. Treatment with NaOH helps in the removal of fractions of cellulose of very low degree of polymerisation. The removal of low cellulose fractions and cementing materials lead to better orientation and packing of molecules. Figure 5a and b, shows the tensile fracture surface of the alkali treated fibre composites. The polyester particles sticking on the fibre surface and the broken fibres point to the improved fibre–matrix adhesion. Dissolution of the lignin effected by the alkali gives rise to free pores,
which improves the contact area between the fibre and the matrix. However, the impact strength, which is discussed in the coming section, is found to be the lowest for alkali treated fibres.

The flexural strength, which is indicative of the bending deformations, is also found to be the lowest in the case of alkali treated fibre. The flexural yield strength is found to be higher at lower alkali concentration. Figure 6 shows the variation of flexural yield strength with chemical modification. Flexural yield strength is found to be the maximum for composites treated with 1% NaOH. The ultimate flexural strength of the samples could not be determined, as the samples could not be broken under flexural load. What is reported is the flexural yield strength. Figure 7 shows the variation of flexural modulus with fibre treatment. The flexural modulus is found to be the lowest for composites treated with 1% NaOH. The stresses induced due to the flexural load are a combination of compressive and tensile stresses. Flexural properties are reported and calculated in terms of the maximum stress and strain that occur at the outside surface of the test bar. The change in free enthalpy due to the acid–base interaction can be calculated from the acid–base constants of the interacting phases by

$$-\Delta H_{ab}^{ab} = \frac{AN \cdot DN}{100},$$

(1)

using the theory of Guttman [21]. According to his theory, materials are characterised by a donor number and acceptor number and the change in free enthalpy is given by equation (1), where $\Delta H$ is the change in free enthalpy due to acid–base in-
interactions, and $AN$ and $DN$ the acceptor number and the donor number respectively. The values calculated for the alkali treated fibres are found to be 0.01.

In the case of impact strength, the value is found to be the lowest in the case of alkali-treated fibre. Adhesion and strong interaction, however, are not always necessary and advantageous to prepare composites of desired properties; plastic deformation of the matrix is the main energy absorbing process in impact, which decreases with increasing adhesion [22]. Figure 8 shows the variation of impact strength with chemical treatment. The result is consistent with the observation of the improved fibre–matrix interaction in the case of alkali treated fibres.

3.2. Silane treatment

Figure 1 shows the structures of the various silanes used. Reactive surface treatment assumes chemical reaction of the coupling agent with both of the components. Silane coupling agents are successfully used with fillers and reinforcements, which have reactive $\text{--OH}$ group on the surface. The adhesion is determined by the composition of the organofunctional group of the coupling agent. The effect of the organofunctional group of the silane is dependent on its ability to react with the polymer matrix. The bonding of the organofunctional group of the silane with the polymer can take place in several forms. It can form a copolymer, an interpenetrating polymer network, or diffuse into the polymer matrix and and cross-link at the fabrication temperature [23]. Optimization of the type and amount of the coupling agent is crucial in reactive treatment. Various silanes have been tried to modify the surface of fibres. Scheme 1 shows the general representation of the
Figure 8. Effect of chemical treatment on the impact strength.

interaction of silane with cellulose. Silanes undergo hydrolysis to form silanols, which further react with the $\text{C}^{-}\text{OH}$ groups of the cellulose. The organofunctional group of the silanes in turns form-interpenetrating polymer networks, with the polyester.

3.2.1. Silane A151 (vinyl triethoxysilane). The tensile strength of the samples treated with the silane A151 (vinyl triethoxysilane), is found higher than the tensile strength of untreated samples (Fig. 9). Our earlier studies indicated that the acceptor number, which is indicative of the electron accepting ability, is found highest for fibres treated with the silane A151 [10]. The $E_T(30)$ parameter which is indicative of the overall polarity is also found to be maximum for fibres treated with the silane A151. Electrokinetic ($\zeta$-potential) measurement is a useful method to characterise polymer surfaces. The isoelectric point (i.e.p.) is a measure of the acidity or basicity of a surface. The solid surface displays acidic character, if the value of i.e.p. is low. If i.e.p. is situated in the alkaline range, the solid surface contains basic groups [12]. The increased acidity values lead to increased polarity and thereby improved interactions in the case of silane A151-treated fibre composites. Fibres subjected to treatment with the silane A151 (vinyl triethoxysilane), after pre treatment with the alkali gave an i.e.p. value of 3.4.

Of the various silanes used, tensile strength is found to be the highest in the case of silane A151-treated fibre composites. The reason can be attributed to the improved interactions between the organofunctional group and the polyester matrix. SEM micrographs of the silane A151-treated fibre and the fracture surface of the
Scheme 1. Schematic representation of the interaction of silane with cellulose fibre.
Effect of fiber surface treatments on the fiber–matrix interaction

Figure 9. Effect of chemical treatment on the tensile strength of the composites.

Composite are shown in Fig. 10a and b. The improved adhesion in the case of treated fibre composites is evident from the broken fibres, which are visible, and the river patterns, which are present on the matrix. The tensile modulus is also found to be highest in the case of silane A151-treated fibre composites (Fig. 4). Unlike in the case of the alkali treated fibres, the flexural yield strength of the composite is found to be the highest in the case of silane A151-treated composites (see Fig. 6). The flexural modulus is also found to be the highest in the case of silane A151-treated fibre composites (Fig. 7). The impact strength however is lower than the untreated fibre composites (Fig. 8). The lowering of the impact strength is consistent with the improved fibre–matrix adhesion and the tensile strength. Improved interaction leads to a perfect bonding and thereby the failure of the composites occurs at low impact. For most composites, including short fibre systems, a sometimesespoused rule of thumb is that as the strength increases, the toughness decreases. While this is true for continuous fibre reinforced brittle matrices, it is not always the case for short fibre reinforced systems. The nature of the interface for the silane A151 (vinyl triethoxysilane)-treated fibre composite is shown in Fig. 10.

3.2.2. Silane A174 (γ-methacryloxypropyltrimethoxysilane). In the case of silane A174-treated fibres, the tensile stress–strain curve shows a slight decrease in tensile strength than that of A151-treated fibre (Fig. 2). Polarity parameter measurements have shown that the hydrogen bond donating acidity of the gamma-MPS is lower than that of the vinyl silane [11]. The overall polarity is also lower for the gamma-MPS. This lowering of the polarity can be given as the reason for the slight decrease in tensile strength of the composites prepared from silane A174-
Figure 10. (a) SEM of silane A151 treated fibre. (b) SEM of the tensile fracture surface of the silane A151 treated fibre composite.

treated fibre as compared to the silane A151-treated fibre (Table 3). The SEM photographs of the silane A174-treated fibre and the failed composite are shown in Fig. 11a and b respectively. It has been observed by other researchers that maximum wetting tension between an adhesive and a substrate is obtained when the surface energy of the substrate is as high as possible [24]. The surface free energy, it has been shown, can be expressed in terms of the acid–base interactions. The extent of acid–base interactions becomes lower in the case of A174 (gamma-MPS) treated
fibre composites compared to A151 treated fibres and this leads to the decreased interaction and thereby the decreased tensile strength. The flexural yield strength of the composites treated with silane A151 and silane A174 (gamma-MPS) are found almost the same (Fig. 6). The flexural modulus however, is slightly lower for the silane A174 (gamma-MPS) treated fibre composites (Fig. 7). However, the impact strength is found almost the same as that of the untreated fibre composite.

3.2.3. Silane F 8261(1H, 1H, 2H, 2H-perfluorooctyl triethoxy silane). Composites treated with the silane F8261 have given a comparatively lower value of tensile strength (Fig. 9). This points to the decreased adhesion between the fibre and the matrix. The reduced interactions can be expected to be due to the polarity values. The hydrogen bond donating acidity, $\alpha$, of materials is related to the surface polarity. Our earlier studies on the $\alpha$ value of the F8261 fibre gave a value that is low compared to that of the ones treated with A174 and A151. The value of the $\pi\alpha$ parameter which represents the overall polarity is also lower than that of the fibre treated with the silane A174 (gamma-MPS). This low polarity value is also indicative of the lower surface free energy. This leads to the reduced interaction with the polyester matrix. Other authors have reported on the lowering of surface energy by treatment with fluorocarbons [20]. The tensile modulus is also found to be unusually low. The polarity of the modified fibre surface is obviously not capable of forming good filler–matrix interactions. The flexural modulus also is found to be lower compared to the other silane treated fibre composites.

3.2.4. Silane A1100 ($\gamma$-aminopropyltriethoxysilane). Tensile strength of the composites made of silane A1100-treated fibre composite was observed to be comparable with that of the other silane treated composites. It is possible that silanols, formed by the hydrolysis of the alkoxy groups of the silanes, can self condense to form a thick layer of oligomeric silanol deposition in the fibre–matrix interface which can greatly reduce the efficiency of bonding [25]. The tensile modulus of the composites was also found unusually low. The flexural and impact strength however, gave values comparable to the other silane treated composites. SEM of the surface of the silane A1100-treated fibre revealed fibrillation and also regions where the cementing material has been dissolved out. These crevices lead

<table>
<thead>
<tr>
<th>Silane</th>
<th>Tensile strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A174</td>
<td>60</td>
</tr>
<tr>
<td>A151</td>
<td>61</td>
</tr>
<tr>
<td>F8261</td>
<td>48</td>
</tr>
<tr>
<td>Si 69</td>
<td>45</td>
</tr>
<tr>
<td>A1100</td>
<td>58</td>
</tr>
<tr>
<td>Untreated</td>
<td>57</td>
</tr>
</tbody>
</table>

Table 3. Tensile strength values of composites with different silane treated fibers
to better wetting and regions of contact for the matrix material, leading to improved tensile strength values.

3.2.5. Silane Si69, bis(triethoxilyl propyl) tetra sulphide. Composites made out of Silane Si69 treated fibres gave the lowest mechanical properties. The reason can be attributed to the lower compatibility between the organofunctional group and the polyester matrix. Zeta-potential measurements carried out on the fiber surface using the streaming potential method has given indication of the relation between the pH
and the surface potential (Table 2). The isoelectric points are indicative of the point where the surface charge is zero. The silane Si69-treated fibers have given an i.e.p. value of 3, slightly greater than that of the untreated fiber. The overall polarity of a solid surface is given by the $E_T(30)$ value, where $T$ stands for the transition energy. The $E_T(30)$ polarity parameter values are also approximately equal to that of the untreated fiber. The observation concludes that treatment with the silane Si69 is not very effective for cellulose fiber.

### 3.3. Acetylation

Acetylation has been proved to be an effective method for the modification of cellulose fiber surface. Only the impact properties of the composites have been investigated. The impact properties are found to be higher than those of alkali treated fibers and lower than that of the silane treated fibers. The lower impact strength values than the alkali treated fiber composite can be attributed to the comparatively lower fiber–matrix adhesion compared to the other treatments (Fig. 8). The probable reaction between the fiber and acetic anhydride can be represented as

\[
\text{cellulose} - \text{OH} + (\text{CH}_3\text{CO})_2\text{O} \rightarrow \text{cellulose} - \text{OCOCH}_3 + \text{CH}_3\text{COOH}.
\]

SEM of the acetylated fibres and of the impact fracture surface of the acetylated fibre composite revealed large pulled-out fibres showing weak adhesion between fibre and matrix.

### 3.4. Comparison of the effectiveness of different treatments

Silanes with different organofunctional groups (vinyl, methacryloxy, amine and fluorine) have been used to pre-coat the fibre in order to examine the influence of silane treatment on mechanical properties of the composites. The adhesion of the polysiloxane layer depends on the chemical composition of the organofunctional group of the coupling agent. The different chemical structure of the silanes leads to considerably different absorptions. The inter-diffusion of the polymer layers into the polysiloxane network gives rise to entanglements creating strong adhesion. Of the various silanes, silane A174 (gamma MPS), A151 (vinyl triethoxysilane), and A1100 have been proved to be reasonably good in improving adhesion in cellulose/polyester systems. The reason for the improved interaction can be attributed to the changed polarity values of the treated fibres. The higher polarity values lead to more polar–polar interactions leading to a strong interface. The tensile strength values of polyester filled with different silane treated fibres (0.6% silane) are given in Table 3. It is clear that silane treatment produced an increase in tensile strength as a result of improved adhesion between the fibre and matrix. Of the various silane treatments, the highest improvement in tensile strength is found to be for the silane with the vinyl functional group. The flexural and impact properties were also found to be relatively high for the silane A151 (vinyl triethoxysilane)-treated fibre composite compared to the other treated composites. However, of the
various chemical treatments, alkali treatment has proved to be the best as far as properties and cost are considered.

4. CONCLUSION

Natural fibres like celluloses and their synthetic counterparts often have a surface chemistry that is incompatible for perfect bonding. In order to elucidate the mechanism of interaction on a molecular level, various techniques such as spectroscopy, solvatochromism and zeta potential measurements have been employed. Proper combination of the different techniques is required for a true picture of the interface. Judicious surface modification leads to good interfacial strength and thereby improvement in properties.

Chemical modifications have improved the mechanical properties of banana fibre reinforced polyester composites. The highest improvement in properties is found to be for the alkali treated fibre composites. The improvement in properties due to alkali treatment is mainly due the better packing of the cellulose chains, after the dissolution of lignin, which is the cementing material. Silane treatment has also improved the mechanical properties of the composites. Of the various silanes used, silane A151 (vinyl triethoxysilane), has given the highest value. Silane F8261 (1H, 1H, 2H, 2H-perfluorooctyl triethoxy silane) and Si69 have adversely affected the mechanical properties.

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