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The Physicomechanical and Interfacial Properties of the Vetiveria Zizanioides Fiber Reinforced Polymer Composites

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ABSTRACT

The effects of chemical treatment and vetiveria zizanioides (vetiver) loading on the physicomechanical, morphological, and weather tests of the vetiver fiber (VF)-filled polypropylene (PP) composites were investigated. Raw VF was chemically treated with sodium dodecyl sulfate (SDS) and SDS-pretreated benzoyl chloride to increase its compatibility with the PP matrix. The mechanical properties of the PP/VF composites, including tensile strength, tensile modulus, impact strength, hardness, and water absorption, were increased by raising the fiber content to the optimum level of 30 wt%. The resultant composites' mechanical characteristics and water desorption were improved by adding SDS and SDS-pretreated benzoyl chloride for the VF. PP/VF composites containing benzoyl chloride after SDS pretreatment show better mechanical performance when compared to untreated and SDS-treated fiber composites. SEM studies showed that the treatment of the fibers enhanced the interfacial interaction between PP and VF, verifying the mechanical properties of the composites. Water absorption tests revealed that SDS-pretreated benzoyl chloride composites absorbed less water than untreated counterparts and even SDS-treated composites. Sodium dodecyl sulfate-pretreated benzoyl chloride composites exhibited less loss in tensile strength and tensile modulus during weather testing than sodium dodecyl sulfate-treated and untreated composites.

Keywords:
Composite, Vetiver fiber, Sodium dodecyl sulfate-treatment, Polypropylene, Mechanical features

1. Introduction

Using natural fibers rather than synthetic fibers to reinforce composite materials has received considerable attention in scientific research on new materials [1, 2]. The use of cellulose fibers (CFs) and agro-residues for strengthening in different thermoplastic and thermoset resins is currently the

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focus of research because of their high strength, hardness, and low concentration of weight ratio [3, 4]. Natural fiber composites are now extensively used in various fields, including civil construction, machinery construction, electrical and electronic apparatus, automobile industrial factory, aircraft manufacturing, and much more [5-7]. This is due to these materials' outstanding combination of physical and mechanical features.

Synthetic composites made of synthetic fibers with synthetic matrix bases, such as glass, carbon, nylon, and Kevlar, have been the subject of extensive research [8, 9]. Synthetic fiber-reinforced thermoplastic or thermoset composites are superior to natural fiber mixed composites in strength, durability, deterioration, and moisture resistance. Scientists prefer thermoplastic composites over thermosets because they can be produced cheaply and with less processing. Synthetic fiber use is dangerous for the environment because it is not sterile. Due to rising environmental consciousness, the matrix is being investigated daily as lignocellulosic components are created from fibers and thermoplastic/thermoset polymers as composites. Natural fibers have several advantages over typical plastic or synthetic components in terms of low cost, low density, adequate specified strength, renewability, recyclability, and biodegradability.

Plant fibers are renewable materials derived from agroforestry crops that can be used in a variety of engineering fields. Additionally, plant fibers are physically recyclable, renewable, and less hazardous to employees' safety and health. An appealing environmentally friendly substitute for using glass fibers as reinforcement in engineering composites is using plant fibers such jute, vetiver, caltropis gigantea, flax, and banana. Among other natural fibers, vetiver grass is one of the most appealing options for use as a reinforcing filler in polymer composites. The perennial bunchgrass Chrysopogon zizanioides, sometimes called vetiver and khus, belongs to the Poaceae family. The primary countries that grow vetiver grass are India, Bangladesh, Vietnam, Thailand, etc. Vetiver roots have good mechanical properties and can grow up to 5 meters long [10]. A lignocellulosic biofiber called vertiver grass fiber contains hemicellulose, cellulose-type-I, lignin, and other low molecular weight substances. VFs can replace glass fibers, especially when low-density and low-cost characteristics are taken into consideration. VFs can be recycled, are nonabrasive, and can be utilized for energy recovery because they have a high calorific value and present less health and safety issues when handling fiber products. Additionally, they exhibit high mechanical strength, low density, availability, biodegradability, safety from health risks, and inexpensive cost [11, 12]. To adopt natural fibers in large-scale engineering markets like the automotive and construction industries, they must have a superior price-performance ratio of low weight with eco-friendly attributes [13].

Chemical element performance plays a crucial role in determining the mechanical characteristics of the fiber in the natural fiber composite when choosing new fibers. Even though cellulose fibers have many advantages, they lessen the negative effects of high temperatures and the prevalence of moisture absorption. For various hydrogen bonds and hydrophilic VFs, hydroxyl groups act as cellulose. Due to flaws in the plastic material and fiber, manufactured composites, such as polar (hydrophilic) natural fibers and nonpolar (hydrophobic) thermoplastic matrix, have lessened mechanical properties [14]. By altering the natural fibers through chemical treatment, it is possible to advance the mechanical properties of the composites [15]. The chemicals can successfully interact with cellulose and activate the hydroxyl group, which can cause the polymer to take on the required properties. Sodium dodecyl sulfate is a popular anionic surfactant often employed in creating biomaterials [16]. Due to chemical interactions between the polar main group of sodium dodecyl sulfate and the polar group of fibers, it is anticipated that the presence of sodium dodecyl sulfate in coir fiber will lower the hydrophilic character [17]. On the other hand, it is typical to treat fibers with benzoyl chloride. The hydrophobic matrix is combined with benzoyl ($C6H5C=O$) to reduce natural fibre's hydrophilic nature and increase its interaction [18].

Polypropylene (PP) was chosen as the thermoplastic resin in this investigation because it possesses a number of exceptional properties, including transparency, superior surface strength, high impact strength, high thermal distortion temperature, and dimensional stability. PP is also excellent for mixing, filling, and strengthening. Natural fibers with PP are one of the potential beginning points for making composites of natural or synthetic polymers.

In the current study, unidirectional PP/VF composites were developed, and their physicomechanical properties were evaluated. The sodium dodecyl sulfate treatment and the subsequent sodium dodecyl sulfate pretreatment benzoylation treatment were employed to improve adhesion between these two opposed surfaces. No investigations have not been done on the physicomechanical properties of a composite made of vetiver fiber (VF) that has been treated with sodium dodecyl sulfate and then benzoylated after being pretreated with sodium dodecyl sulfate. The interfacial properties were evaluated by using SEM data. Weather tests and tests for water absorption were also carried out on enhanced composites to evaluate the suitability of the materials for a range of applications.

2. Experimental

2.1 Materials

Polyolefin Company Pvt. Ltd. in Singapore provided the matrix materials PP in pellets. PP had a melt flow index of 10 g/10 min (at 230°C and 2.16 kg), and its density was 0.9 g/cm3. Vetiver is a natural grass of Bangladesh, and its roots are widely used for religious, therapeutic, and medical uses. It is useful for fabricating natural fiber-reinforced composites since it is affordable and easily accessible. A Bangladeshi community provided the raw vetiver roots that were harvested. Table 1 [19] lists vetiver fibres' properties and chemical composition. Sigma Aldrich (St. Louis, Missouri, USA) provided the sodium dodecyl sulfate (SDS) in powder form, benzoyl chloride and ethanol (98%) for the experiment.

Table 1
Lists the characteristics and makeup of vetiver fibers [19]

Properties	Value
Density (g/cm^3)	1.5
Diameter (μm)	100-220
Tensile strength (MPa)	247-723
Young's modulus (GPa)	12.0-49.8
Failure strain (%)	1.6-2.4
Composition	**Value**
Cellulose	72.6%
Lignin	17%

2.2 Methodology

The SDS powder (5 wt% of VF) was dissolved in ethanol. After that, VF was gradually added to the mixture for 2 hours at room temperature. The modified fibers were filtered and dried for 24 hours at 70°C in an oven to remove ethanol residue. Pretreated VFs were submerged in a solution containing 150 mL of benzoyl chloride and 2L of a 5% SDS solution for one hour. Following modification, benzoylated fibers were filtered, immersed in ethanol for thirty minutes to remove unreacted chemicals, and then dried in an oven at 80°C for roughly 24 hours to achieve consistent weight. Table 2 lists the formulated compositions from a group of arranged formulations.

Table 2
Composition of PP composites

Ingredients (wt%)	Sample designation		
	PP/VF	PP/SVF	PP/SBVF
PP	100	100	100
PP/VF	0, 10, 20, 30, 40	-	-
PP/SVF	-	0, 10, 20, 30, 40	-
PP/SBVF	-	-	0, 10, 20, 30, 40

VF: Vetiver fiber; SVF: sodium dodecyl sulfate (SDS) treated VF; SBVF: SDS pretreated benzoylated VF

2.3 Preparation of VF-Reinforced PP Composite

PP pellets were used to make the PP sheet in a hot press machine at 170°C for 5 minutes at 8 MPa of pressure. The VFs were placed lengthwise on the PP sheet by using the manual rotation technique. In stages resembling PL-VFL-PL..., PP sheet layers (PL) were created by stacking VF layers (VFL), with two PP sheet as the outermost layers. A hot press at 180°C with a pressure of 10 MPa was used to create composite samples, which were subsequently cooled in a second press with the aid of two steel plates. The final composites were preserved at a 2 mm thickness.

2.4 Characterizations

Shimadzu UTM (Model AG-1, Japan) electrical weight cells of 6 kN were used to test the tensile characteristics of the composite sample following ASTM-D 638-03 standards. The tensile test was performed at 10 mm/min crosshead speed and a gauge length of 20 mm. The Izod impact strength was tested using an impact machine (model, Toyo Seiki Co., Japan) per ASTM-D 256 standards. The sample had the following measurements: 63.5 × 12.7 × 3 mm3. An HPE Durometer (model type 60578, Germany) was used to test the composite samples' hardness by DIN 53505 standards. According to those mentioned above, the mechanical characteristics of the unreinforced PP sheet were also examined. The conditions for all experiments were 25°C ± 2°C and 55 ± 5% relative humidity. The data were calculated as the average of five measurements.

A Zeiss Evo 50 scanning electron microscope was used to examine the SEM micrographs of all composite samples. The specimens' fracture edges were coated with a small layer of gold and inserted in an Al spit to spread the electric charge throughout the test.

The water absorption of untreated and treated composite samples was measured by dipping the sample into a beaker of 25°C water covered with water. The sample was taken out of the water, drained, and weighed following a continuous time break. The Accelerated Weathering Tester (Model Q-U-V, Q-Panel Company, USA) carried out the composite sampling.

Test samples included untreated, sodium dodecyl sulfate-treated, and sodium dodecyl sulfate-pretreated benzoyl chloride-treated composite samples. Over 500 hours, the treatment varied between 60 ± 2°C (sunshine) and 40 ± 2°C (condensation) over periods of 4 hours of sunshine and 2 hours of condensation. The specimens were dried in an oven for 30 minutes to investigate the effects of the weather, and their tensile properties were then assessed.

3. Results and Discussion
3.1 Mechanical Characteristics of Composite Materials

The interfacial adhesion between the fibers and the matrix, the fiber content, the fibres' length and orientation, and the composites' mechanical properties are all significantly influenced by the mechanical properties of the materials. An interfacial bond between the fiber and the matrix must be seen to determine composites' mechanical characteristics.

3.2 Tensile Features
3.2.1 Impact of VF content

The tensile properties of untreated and interfacially modified composites are shown in Figures 1 and 2 based on the amount of fiber. At 10 wt%, the composites' tensile characteristics clearly reflect those of the neat PP sample. More fiber (in weight%) cannot be added to composites to improve their tensile properties once they reach the crucial fiber content. This can be caused by poor interfacial adhesion between the fiber and matrix due to weak fiber dispersion in the PP matrix. According to the test results, PP has a tensile strength and modulus of 27.9 MPa and 835.2 MPa, respectively. As the fiber content rises from 10 to 30 wt%, adding VF to the PP matrix causes the composite's tensile strength to increase from 32.7 MPa to 38.1 MPa.

According to other researches, tensile strength has increased with fiber content [20, 21]. This characteristic is the main reason for an even stress transfer from the matrix to the fiber. However, adding greater fiber content (40 wt%) did not increase the tensile strength. More than 30 wt% fiber content has been associated with a propensity to decrease tensile strength. This is most likely because around 40 wt% fiber content, poorly dispersed fibers in the PP matrix begin to aggregate, causing a non-uniform transition to applied stress and weak fiber-matrix adhesion. However, the composites' tensile modulus increased continuously when VF was added to varied fiber loadings ranging from 10 to 30 wt% (Figure 2). Tensile modulus increased to 20%, 32%, and 73%, respectively, compared to virgin PP when VF's increased from 10 wt% to 30 wt%, and these values included 998.3 MPa, 1100.6 MPa, and 1445.2 MPa, respectively.

The tensile modulus value climbs and then declines as the fiber content rises up to 30 wt%. This property is the major factor causing an even stress distribution from the matrix to the fiber. The findings show that surface contaminants make it difficult for untreated fibers to engage effectively with the PP matrix. Tensile modulus decreases in composites at 40 wt% fiber loading. The mechanical characteristics of the composites deteriorate when the fiber content is higher (40 wt%) because there is more fiber agglomeration. If insufficient PP was available, the composite voids would be formed when PP no longer covered the fibers at greater fiber loading. It is well known that voids had an impact on most of the properties of composite materials [22]. Based on the findings, composites with a 30 wt% fiber content have the best mechanical properties. It has been established that a 30 wt% fiber content is the ideal fiber content for obtaining a better balance of mechanical properties in PP/VF composites.

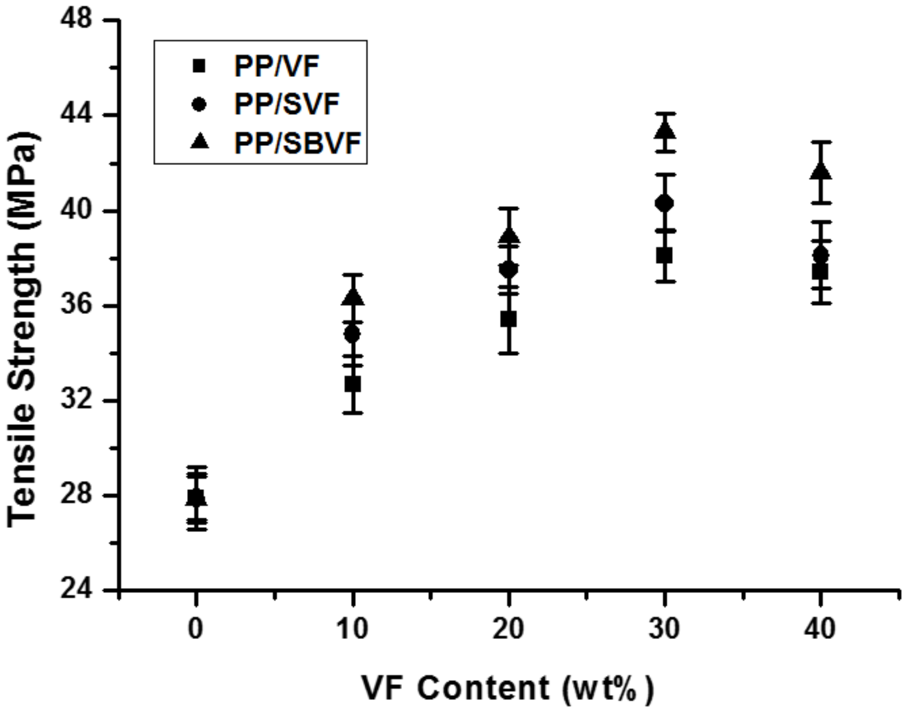

Fig. 1. Tensile strength of varied fiber loadings in PP/VF, PP/SVF, and PP/SBVF composites

3.2.2 Influences of sodium dodecyl sulfate treatment

The impact of sodium dodecyl sulfate treatment on the tensile strength of the PP/SVF composite is depicted in Figure 1. Tensile strength of the PP/SVF composite increased from 17%, 27%, and 37% to 32.7 MPa, 35.4 MPa, and 38.1 MPa, respectively, with an increase in load level from 10 to 30 wt%; however, it decreased with a further increase in VF content (40 wt%). With the PP matrix's aid, the VF's surface treated with sodium dodecyl sulfate had long alkyl chains that formed covalent bonds, increasing both the wettability and the interfacial bond between the VF and PP matrix. Due to the creation of chemical interactions between the polar head group of sodium dodecyl sulfate and the polar group of fibers, it is anticipated that the presence of sodium dodecyl sulfate in cellulose fibers will lower the hydrophilic character [23]. Due to the need for less fiber overlapping, one-way fiber orientation disperses the fiber and lowers fiber agglomerations. The one-way fiber arrangement reduced the likelihood of air penetration. When air is introduced, a tip shape is created, which results in a weak stress transfer between the matrix and the fiber. The composite's tensile strength decreases at a 30% SVF load. This might be caused by cellulose loss and the development of interior fiber fissures. Tensile modulus and VF load are correlated in Figure 2 both with and without sodium dodecyl sulfate treatment. The tensile modulus increased from 22% to 44% compared to virgin PP with a load level increase from 10 to 30 wt%, but dropped with a further increase in VF content (40 wt%). Using the same fiber content, the current range of tensile moduli is 1020.8 MPa to 1203.6 MPa. As a result, there is friction at the point where the VF particle and PP matrix meet, creating a stiff interface that prevents the polymer chain from moving freely. The improvement of tensile modulus may be associated with composites' higher rigidity due to VF loading. Compared to untreated fiber composites and sodium dodecyl sulfate-treated composites, the tensile properties of benzoylated fiber composites prepared with sodium dodecyl sulfate were found to be superior.

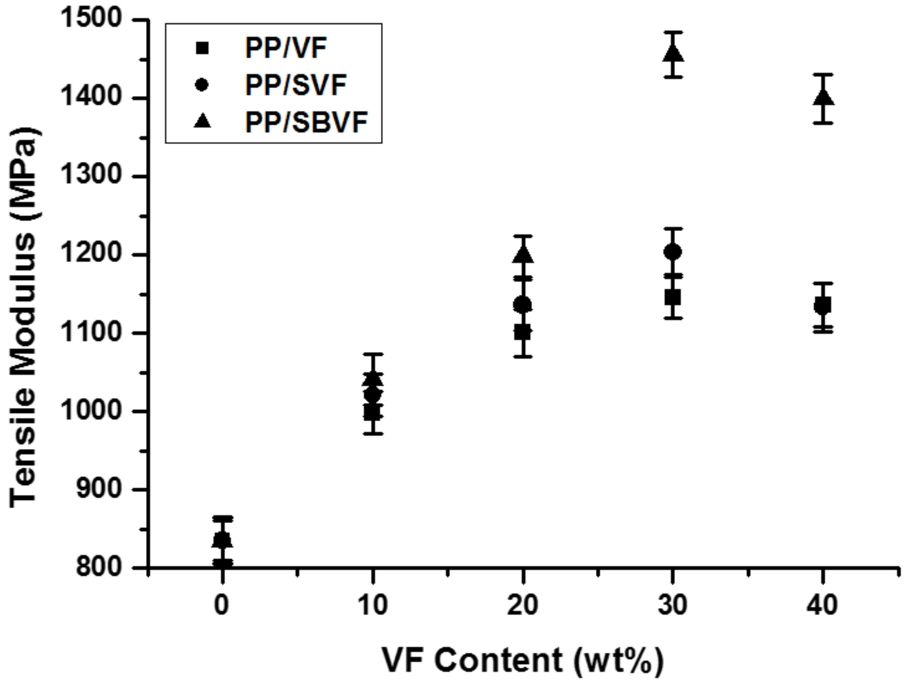

Fig. 2. Tensile modulus of composites made of PP/VF, PP/SVF, and PP/SBVF at various fiber loading

3.2.3 Impact of benzoylation treatment

Figures 1 and 2 depict the tensile characteristics of the PP/SBVF composites. The tensile strength and modulus of the PP/SBVF composite increased from 30%, 39%, 55% and 25%, 44%, 74%, respectively, as compared with virgin PP with an increase in load level from 10 to 30 wt%. However, these properties decreased with increased VF content (40 wt%). Improved tensile strength and modulus can be added to fibers through chemical modification, and a small amount of hemicellulose is transformed into benzoylated hemicellulose for better adhesion between the fiber and matrix. Similar to benzoylation, which involves encircling the hydroxyl groups found in VF's cell wall, benzoylation lowers polarity.

According to Figure 3 (iii), the benzoyl group has taken the position of the -OH group's hydrogen atoms. The likely reactions of VF with sodium dodecyl sulfate and (iii) VF with benzoyl chloride are depicted in Figure 3 (i & ii) and their respective probable reaction mechanisms. The addition of the benzoyl group reduces the hydrophilicity of fibers, giving them a more hydrophobic character and improving the mechanical properties of benzoylated composites [23].

This improves surfaces with better interaction with the hydrophobic matrix. Benzoylation causes the fiber surface to become extremely rough, which enhances fibrillation and improves mechanical interlocking with the PP, according to SEM analyses of benzoylated fibers (Figure 6c). Tensile properties of the composite from the SEM photomicrograph on the surface can support that the good bonding between benzoylated fibers and the PP matrix causes the improvement in tensile properties.

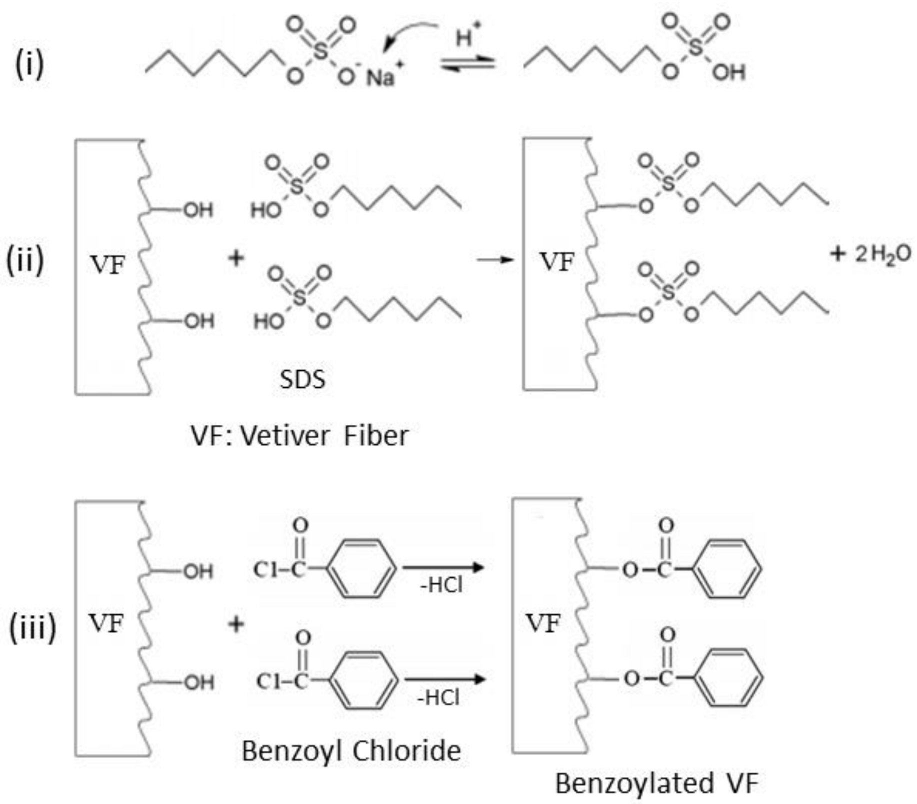

Fig. 3. Suggested mechanisms for the reactions of VF with sodium dodecyl sulfate (i & ii) and VF with benzoyl chloride are presented (iii)

3.2.4 Features of impact toughness and hardness

Impact strength can be described as the ability of a hard material to withstand being struck by anything with significant force, such as a hammer. Figure 4 depicts the variation in impact strength with varying VF loading for untreated and treated (sodium dodecyl sulfate or both sodium dodecyl sulfate and benzoylation) VF composites. From the diagram, it could be seen that the impact strength followed a similar pattern to the tensile characteristics. The best properties were noted at 30 wt% VF loading. This result suggests that the VF's ability to absorb energy was facilitated by the VF's strong interfacial bond with the PP. Impact strength reduces over 30 wt% of VF. It took more than 30 wt% of VF to wet the fiber with PP resin, and many voids (Figure 6a) led to a fiber-PP bond. Impact strength values for the treated PP/SVF and PP/SBVF composites were observed to steadily rise with an increase in fiber content up to 30 wt%, demonstrating that the fiber helps positively to absorb impact energy. Compared to untreated ones, PP/SVF and PP/SBVF composites showed significantly greater impact strength values. As a result of the increased mechanical interlocking sites produced by sodium dodecyl sulfate, fiber and PP exhibit enhanced interfacial debonding [24]. At this point, compared to untreated ones, the impact strength improved by 37% at 30 wt% fiber loading. On the other hand, compared to PP/SVF composite, the addition of benzoylated VF to PP implies an improvement in impact strength of 26%. According to Mishra et al. [25], the lowest interfacial debonding was the cause of this improvement in impact strength.

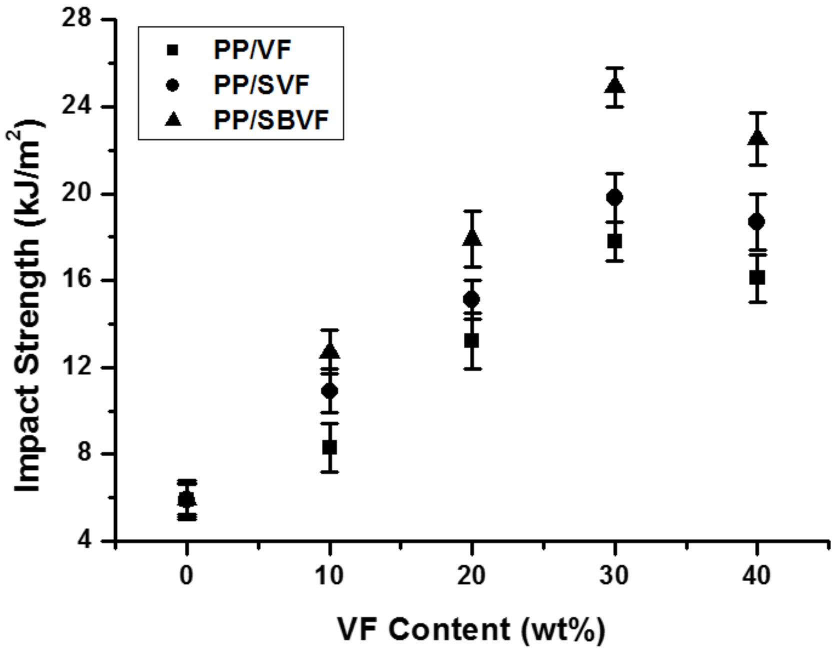

Fig. 4. Impact strength of composites made of PP/VF, PP/SVF, and PP/SBVF at various fiber contents

Figure 5 shows how the amount of fiber in PP/VF, PP/SVF, and PP/SBVF composites affects their hardness. Generally speaking, fibers that raise the modulus of composites raise the hardness of those materials in thermal applications. When compared to the PP/VF composite, which had a 30 wt% VF content, it was discovered that the hardness of the two types of modified composites improved by 3%, and 5.5%, respectively. In stiff composites, the presence of fillers in the PP matrix decreases the mobility of the polymer chains. A composite with two methods of treatment exhibits greater hardness than untreated composites. This is explained by the fact that there is a strong interfacial bond between PP and VF and that VF is well dispersed throughout PP, reducing voids.

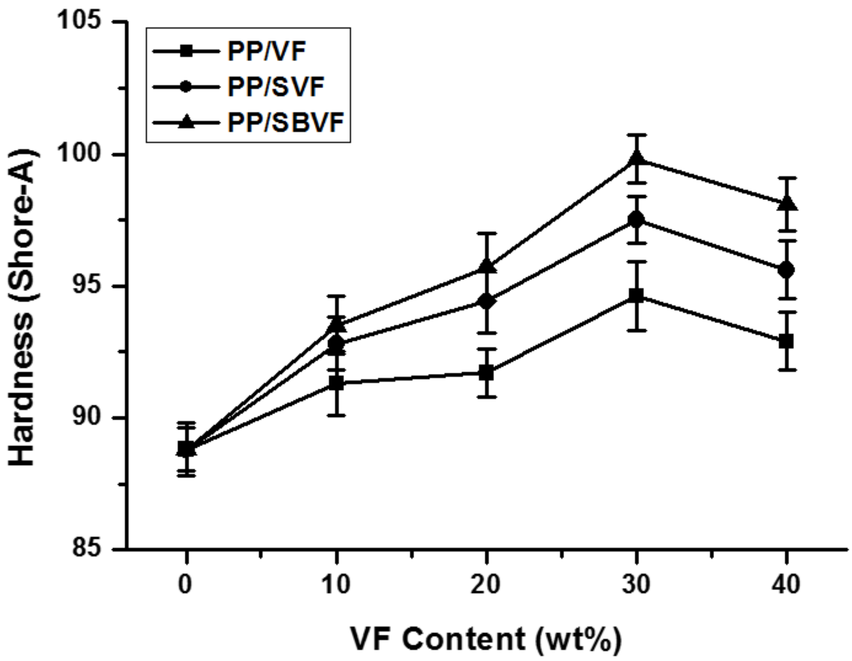

Fig. 5. Hardness of composites made of PP/VF, PP/SVF, and PP/SBVF at various fiber contents

3.3 Morphological Analysis

Tensile specimens of SEM were employed to detect fracture areas for VF-PP adhesion, which was implied from the mechanical properties anticipated in the preceding section. Figure 6 shows SEM micrographs of the fracture surfaces of the composites PP/VF, PP/SVF, and PP/SBVF. Weak adhesion between the VF surface and the matrix can be seen in the SEM micrographs (Figure 6, a). The incompatibility of these components caused the VF to include numerous big spaces and the fibers not to bond with the matrix. This composite's interfacial structure has been found ineffective at transferring stress. This result was consistent with the low tensile strength values in Figure 1. Compared to untreated specimens, treated specimens demonstrated better bonding. Composites that have undergone sodium dodecyl sulfate treatment have improved VF's surface roughness and dimensional stability, which improves VF's bonding with PP (Fig. 6, b).

Additionally, we noticed that the PP had somewhat muted the VF. In the case of PP/SBVF composites (Fig. 6, c), the VFs were somewhat lengthened throughout the fracture process, and most of the PP matrix was stuck to the surface of the VFs. Compared to PP/VF composites, fiber seems to be less extended in PP/SVF composites. This has demonstrated that VF and PP interact favorably. SEM photomicrographs demonstrate that sodium dodecyl sulfate treatment, or both sodium dodecyl sulfate and benzoylation treatment, increased the mechanical characteristics and moisture absorption properties of PP/VF composites.

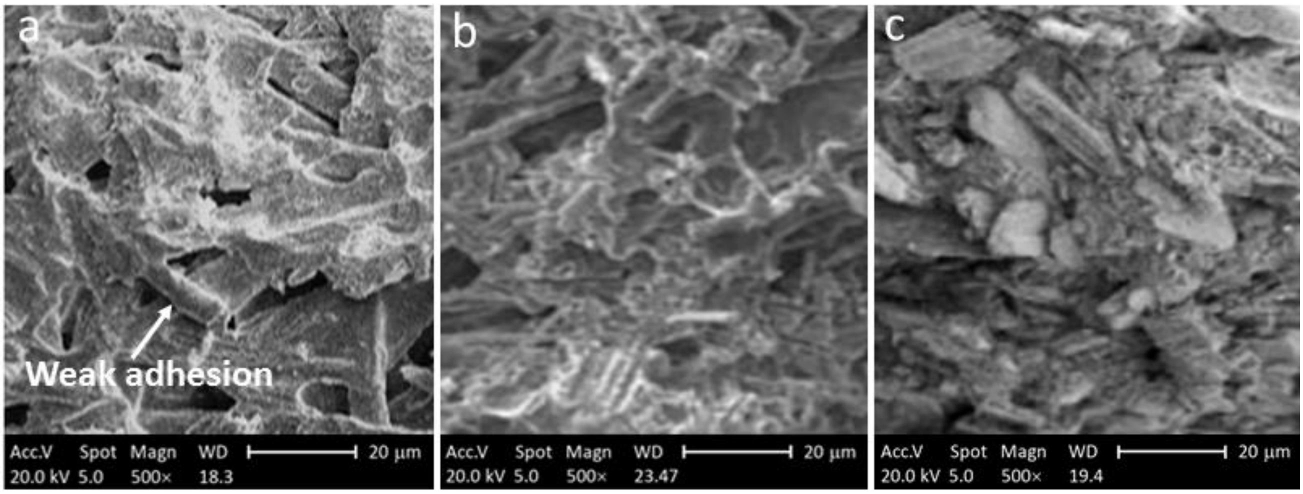

Fig. 6. SEM micrographs of the fracture surfaces of (a) untreated (PP/VF), (b) treated-PP/SVF, and (c) PP/SBVF composite at 30 wt% fiber content

3.4 Behavior of Water Absorption (WA)

Figure 7 displays the results of the WA values for the PP/VF, PP/SVF, and PP/SBVF composites as a function of water soaking time (24 h) and VF content. Significant issues impacting the composite's WA include the amount of VF content and the soaking time. In comparison to the WA of the 40 wt% VF-reinforced PP composite (1.57%), PP had a WA of 0.08%. The test findings show that due to the enhanced availability of cellulose -OH groups that can absorb water, the amount of WA produced after 24 hours of immersion in water ranged from 0.52% for 10 wt% fiber loading to 1.57% for 40 wt% fiber loading. Natural fiber-reinforced composites often exhibit brief moisture absorption due to incomplete wetting of VF through PP because of the presence of micro-voids in the VF-PP interface [26].

In comparison to the untreated composite, the WA of the PP/SVF composite falls by around 57% at a loading level of 40 wt%. The interfacial bond between the PP matrix and the VF may cause this. In contrast, benzoylated composites (PP/SBVF) with 40% fiber content displayed roughly 69% less WA than untreated samples. Further research revealed that the WA of PP/SBVF composites was lower than that of PP/SVF composites with 40% fiber content. The hydrophilicity of VF is reduced by benzoylation, and the fiber's surface becomes rough. The fiber's hydrophilic character is lessened, which increases its compatibility with hydrophobic PP and strengthens the bond between VF and PP with rough surfaces. The cause of WA reduction by benzoylated VF composites is this decrease in the hydrophilic character of VF and greater interfacial adhesion between VF and PP.

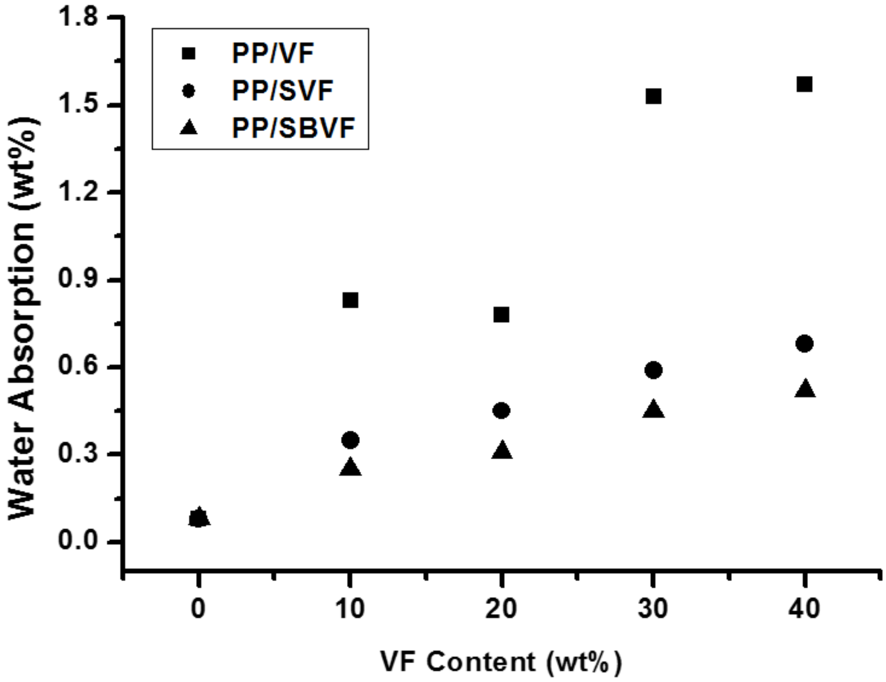

Fig. 7. WA values of PP/VF, PP/SVF, and PP/SBVF composites against various fiber loading as a function of water soaking period (24 h)

3.5 Effects of Weather

Untreated and treated samples were tested to simulate exposure to the sun and inclement weather throughout 500 hours of condensation in the periodic cycle. The specimens' tensile characteristics, including tensile strength (TS) and tensile modulus (TM), were periodically measured. Figures 8 and 9 show a decrease in the specimens' TS and TM due to the weather. In most observations, the TS loss of the untreated specimen was around 23%, whereas the TS loss of the PP/SVF and PP/SBVF treatment composites was approximately 11% and 8%, respectively. Similarly, TM loss in untreated specimens was approximately 21%, compared to 10% and 7%, respectively, for PP/SVF and PP/SBVF specimens. After exposure to severe weather for 500 hours, weather testing showed that treated specimens retained their tensile features (TS and TM), but untreated specimens lost them. The PP/SVF specimen shows improved weather acceptance and durability compared to other specimens.

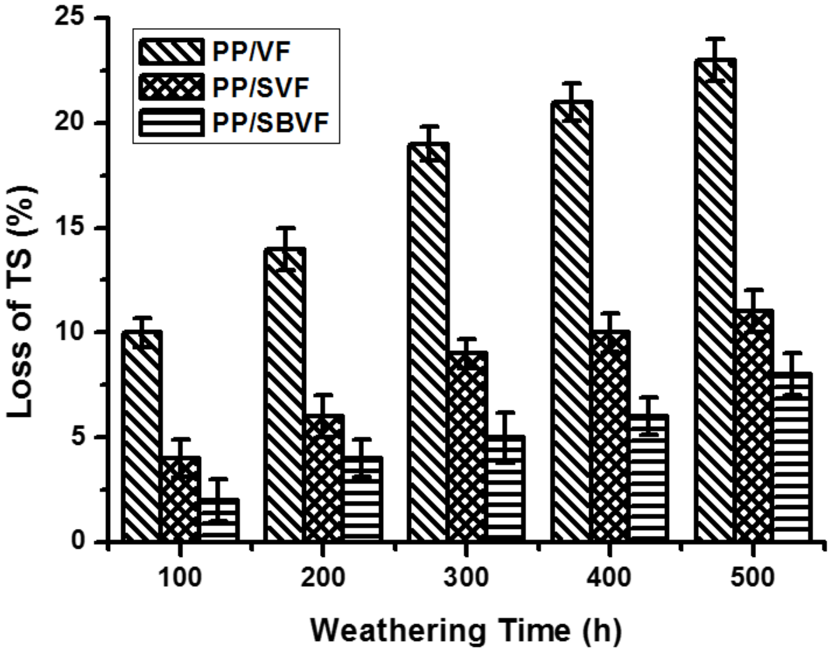

Fig. 8. Loss of tensile strength of the treated and untreated composites as a result of the weather simulation

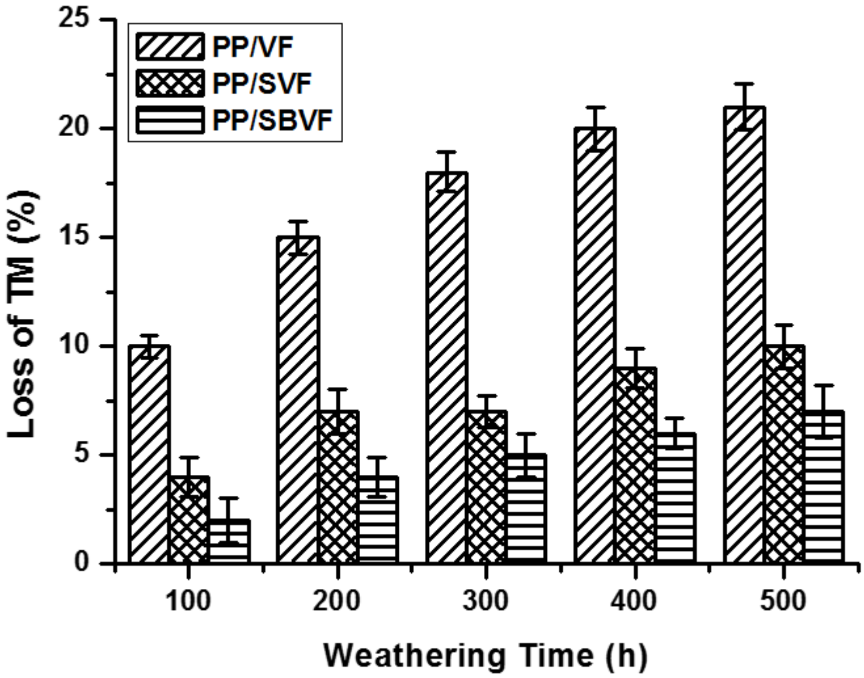

Fig. 9. Loss of tensile modulus of the treated and untreated composites as a result of the weather simulation

4. Conclusions

In this experiment, the basic characteristics of PP/VF composites were examined, and the impact of sodium dodecyl sulfate and VF benzoylation treatment on those properties was examined. In conclusion:

a) By increasing the fiber content to the optimum level of 30 wt%, the mechanical properties of the PP/VF composites, such as tensile strength, tensile modulus, impact strength, and hardness, were improved. However, compared to composites with 30 wt% fiber load, 40 wt% fiber load composites exhibit less favourable tensile properties.

b) Sodium dodecyl sulfate pretreated benzoylated vetiver fiber composites and sodium dodecyl sulfate treated vetiver fiber composites both had improved mechanical characteristics than untreated composites.
c) According to SEM results, vetiver fibers treated with sodium dodecyl sulfate or sodium dodecyl sulfate-pretreated benzoyl chloride have improved vetiver fiber dispersion and interfacial adherence to the PP matrix.
d) The outcomes of the water absorption test showed that sodium dodecyl sulfate-pretreated benzoyl chloride composites absorbed less water than untreated counterparts and even sodium dodecyl sulfate treated composites. During weather testing, it turned out that sodium dodecyl sulfate-pretreated benzoyl chloride composites showed less deterioration in tensile strength and tensile modulus than both sodium dodecyl sulfate-treated and untreated composites.

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