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An Analysis of the Mechanical Properties of Polyethylene Composites Reinforced with Short Vetiver Fibers

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REVIEW ARTICLE

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Abstract: Synthetic fibers (such as carbon, glass, ceramic fibers, etc.) are a cause of environmental concern, so natural fibers (such as vetiver, calotropis gigantea, flax, hemp, jute, etc.) are extensively used. In this study, the compression molding process was used to improve low-density polyethylene (LDPE) matrix composites reinforced with vetiver fiber (VF). Experiments were conducted by varying VF length, VF content, and fiber treatment time. The composites' static mechanical characteristics, including their tensile strength, tensile modulus, impact strength, compressive strength, compressive modulus and fracture toughness, were examined. Experimental results reveal that the static mechanical properties of composites increase with increasing VF length and VF content. The static mechanical properties show their maximum value at 5 mm VF length and 20 wt% of VF content. Conversely, as VF length and content grow, so does tensile modulus. The effects of sodium dodecyl sulfate (SDS) on VF are also studied at different concentrations, fiber sizes, and duration of treatment. Improvements in interfacial adherence between VFs and LDPE matrix have been found to improve the mechanical properties of SDS treatment composites, but the degree of improvement has been found to be dependent on the improvement of interfacial adhesions during SDS treatment improves mechanical properties. The composites reinforced with 20 weight percent fiber content, 5 mm in length, and 6 hours showed the best mechanical properties. Using a scanning electron microscope, morphological analysis is also carried out to track the fiber pull-out and fracture behavior of the composites.

Keywords: Vetiveria fiber, polyethylene, sodium dodecyl sulfate-treatment, SEM, and mechanical properties.

Introduction

The potential of polymer composites derived from natural fibers (NFs) as a substitute for composites derived from synthetic fibers has drawn increased attention in previous years. Because NF composites are lightweight, inexpensive, less likely to wear out tools, renewable, have acceptable thermal properties, have a reasonable strength and modulus, are environmentally friendly, and are durable, they have more advantages than synthetic fiber (SF) composites [1-3]. Based on their various sources (plants, animals, or minerals), natural fibers are categorized into a number of groups. The six types of NFs include wood flour (wheat husk, rice husk), straw fibers (corn, wheat, and rice straws), bast fibers (flax, hemp, jute, ramie, and kenaf), leaf fibers (sisal/henequen/coir/abaca/pineapple), seed/fruit fibers (cotton/kapok/coir), and grass fibers (bamboo, switch, grass, and miscanthus). When used as reinforcement in composites, these NFs provide excellent mechanical properties and pose no environmental risks. Because of their relative strength, durability, and low density, various forms of NF are typically used to strengthen plastics (both thermosets and thermoplastics) and achieve the mechanical properties of composites. For example, the automobile and furniture industries have already made use of them. To produce composites with the necessary qualities for a variety of applications, particulate fillers can be added to a polymer matrix [4]. For both financial and ecological reasons, the use of polymer composites comprising lignocellulosic resources such calotropis gigantea fiber, vetiver, abaca, jute, and coir is expanding.

Different plant parts can be used as reinforcement to create composites. Many NF composites have not yet been reinforced, despite the fact that many have been examined throughout the years. Vegetable zizanioides, or vetiver, is one among these; its roots are used for fortification. The novel NF (vetiver fiber, VF) used in this paper is obtained from a plant known scientifically as *Chrysopogon zizanioides*, formerly Vetiveria zizanioides. Commonly referred to as vetiver, vetiver is a perennial herb. The primary countries where vetiver grass is grown are Bangladesh, Vietnam, Thailand, and India. The roots of vetiver have good mechanical qualities and can reach a maximum length of 5 meters [5]. It has been shown in a study that adding vetiver leaves to the PP matrix as a filler increases the composite's tensile strength and Young's modulus when compared to virgin PP [6]. Another method is the utilization of vetiver roots as fibers in composite form with jute, glass, and vinyl esters. When the right reinforcing ratio and chemical treatment are applied, vetiver roots have been found to be the most suitable for strengthening a composite component. They can also be substituted for synthetic fibers [5]. Results from another study on the epoxy matrix composite reinforced with vetiver roots were comparable. Additionally, by providing pretreatment, it is determined that vetiver roots exhibit more uniform qualities and are appropriately linked to the matrix. [6]

The weight or volume percentage of the fiber, the fibers' chemical modification, the stacking of the fiber layers, and the strength of the link between the fiber and the matrix all have a significant impact on the NF composite's strength. Numerous researchers have looked at the morphological and mechanical characteristics of wood-plastic composites as well as the impact of fiber content and size. The effects of the fiber content and length/aspect ratio of rice straw fiber were investigated by Yao et al. [7]. Tensile modulus was shown to rise with increasing fiber content, while tensile strength and impact strength dropped. Moreover, a study on bark fiber discovered that inadequate fiber dispersion and poor bark-plastic adhesion caused mechanical characteristics to decline as fiber quantity increased [8]. While

lengthening the fiber has improved its modulus of elasticity and tensile strength, it has decreased its stiffness and tensile strain on failure.

Despite being commonly used in polymer composites, NFs' main disadvantages are that the hydrophilicity of the fiber and the hydrophobicity of the polymer cause them to be incompatible with the polymer matrix. These issues can be fixed by chemically changing the fiber surface. Furthermore, because of the fillers' propensity to create hydrogen bonds with one another during processing, these composites are commonly associated with agglomerations as a result of insufficient distribution [9-11]. Hydrogen bonds also hinder the formation of a well-bonded interface with a nonpolar matrix of polar hydroxyl groups on the surface of lignocellulosic matter because they inhibit the filler surface from wetting [10–12]. Numerous authors have conducted in-depth study on this topic [13–15]. In addition to wettability, dispersion, and filler-matrix interactions, filler treatments are essential for the production of natural filler-based composites. Consequently, when fibers undergo chemical treatment, the hydrophilic surface of the fibers and the hydrophobic surface of the polymer become more adherent. An earlier work on the VF surface treatment demonstrated that by improving the interfacial characteristics between the fiber and matrix, this treatment improved the mechanical performance of VF/PP composites [6]. No research has used the surface of VFs treated with sodium dodecyl sulfate (SDS), despite the fact that the properties of NFs have been extensively studied.

In this study, VF and low-density polyethylene (LDPE) served as NFs and matrices to create a plastic composite. To enhance the characteristics of VF/LDPE composites, VF was modified using the coupling agent SDS. SDS is widely utilized in the production of biomaterials and is acknowledged as an anionic surfactant [16]. Some researchers have reported utilizing SDS as a coupling agent to increase filler-matrix adhesion between cocoa pod husk-polypropylene, chitosan-polypropylene, and coconut husk-recyclable polypropylene [17–19]. In this study, the hot compression molding method was used to manufacture VF reinforced LDPE composites under various processing conditions. Understanding the impacts of fiber length, content, SDS treatment, and VF treatment duration on the tensile, compressive, and impact properties as well as fracture toughness of the resulting composites is the aim of this work. Lastly, a scanning electron microscope (SEM) was used to analyze the fracture surface's morphology. To further research in VF composite areas and NF polymer composites, it is critical to comprehend that behavior of VF.

Experimental

Ingredients

Pellets of thermoplastic LDPE homopolymer were supplied by BASF-YPC Co., Ltd., a Chinese company. With a density of 0.924 g/cm3, a melting index of 2.0 g/10 min at 190°C, and a weight of 2.16 kg, its grade was 2426H. Raw vetiver roots were gathered from Bangladesh's rural regions. Table 1 lists the mechanical and physical characteristics of vetiver fiber [6]. Sigma Aldrich (St. Louis, MO, USA) provided the ethanol (98%) and powdered sodium dodecyl sulfate (SDS).

Table 1. Physical and mechanical properties of VF and other natural fibers.

Properties	VF	Jute	Flax	Sisal	Coir
Density (g/cm^3)	1.5	1.3–1.4	1.5	1.4	1.1
Diameter (μm)	100-220	25-200	N/A	50-200	100-450
Tensile strength (MPa)	247-723	393–773	345–1100	468–640	131–175
Young's modulus (GPa)	12.0–49.8	13.0–26.5	27.6	9.4–22.0	4.0–6.0
Elongation at break (%)	1.6–2.4	1.1–1.5	2.7–3.2	3.0–7.0	15.0–40.0

Methods

Preparing the Sample

Preparing VF

To get rid of the contaminants, the vetiver root's fibers were first divided into sections that were 3, 5, and 7 mm long. They were then carefully cleaned with water. In order to lower the humidity to less than 4%, washed VFs were dehydrated in the sun for a full day. SDS powder was dissolved in ethanol at 50 degrees Celsius to create the SDS solution. Five percent of the fiber's weight was made up of SDS. After that, the mixture was allowed to reach room temperature. After adding VFs (10, 20, and 30 weight percent for each of 3, 5, and 7 mm lengths) to the solution for two hours with the proper fiber ratio, the mixture was dried in an oven at 80 degrees celsius for twenty-four hours to eliminate any remaining ethanol.

VF-LDPE Composite Preparation

To find out how fiber size, fiber content, and SDS treatment affected the mechanical properties of LDPE/VF composites, the hot compression molding process was used to create them. The VFs were primarily weighted in accordance with the necessary weight. After that, the VF pictures were cropped to 3–7 mm. Before each composite was made, the VFs were dried for 30 minutes at 80°C to remove any remaining moisture. The amount of LDPE that was required was weighted. To make it easier to remove the product, the mold's surface was thoroughly cleaned and then appropriately sprayed with silicone spray, a molding agent. Two processes were used to create thermoplastic composites. The LDPE granules were first compressed for approximately ten minutes at 150ºC and 8 MPa of pressure, after which the sheets were allowed to cool to ambient temperature. Second, untreated and treated VFs (10, 20, and 30 weight percent for each of 3, 5, and 7 mm length) were positioned at random among the LDPE sheets and deposited on the bottom die following the creation of the composite materials utilizing the film stacking method. As shown in both molds, the top die covered the bottom die. A hot compression molding machine was used to hold the die for 10 minutes at 160ºC and 10 MPa of pressure for approximately 15 minutes. The sample was carefully removed from the die after the pressure was released and the die had cooled to ambient temperature. The LDPE/VF composite processing method and the temperature-time-pressure profile utilized in composite manufacturing are shown in Figure 1.

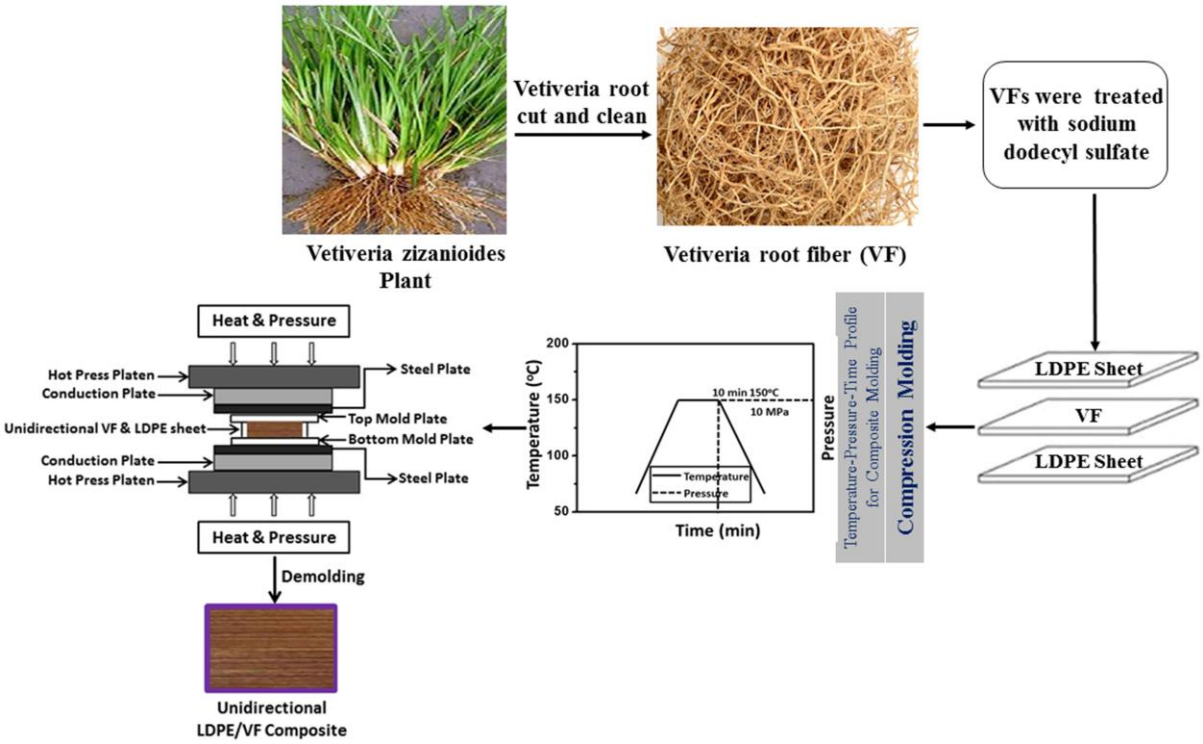


Figure 1. The processing profile and schematic representation of the produced LDPE/VF composite.

Characteristics of VF-LDPE Composite

The mechanical characteristics of polymer composites determine their potential practical use. The mechanical characteristics of the VF/LDPE composites with and without SDS have thus been ascertained. The same parameters (VF length, VF content, and SDS utilized during treatment) as previously described were used to evaluate the produced composites' tensile, compressive, and impact properties as well as their fracture toughness. The test specimens were the focus of multiple experiments following the creation of the composites. A digital micrometer was used to measure five points along the sample's length in order to calculate its average width. Tensile tests were performed using a Dual Column Digital Universal Testing Machine, UTM (Tinius Olsen H10KL) with a 30 kN load cell at a test speed of 5 mm/min in accordance with ASTM-D 638-14 standard. Composite samples are used to assess the effects of low velocity on instruments. An impact tester was used to conduct the testing in accordance with ASTM D 256. The compressive test and fracture toughness of VF/LDPE composites were measured using the same universal testing apparatus, the Tinius Olsen H10KL. Compressive test samples of 15 mm × 10 mm × 10 mm were obtained using ASTM D 3410. Fracture toughness (FT) is assessed in the crack opening mode (mode-I) by confirming ASTM D 5045 in a single edge notch bend configuration. Fracture toughness (FT) is assessed in the crack opening mode (mode-I) by confirming ASTM D 5045 in a single edge notch bend configuration. To calculate the average value, five samples were analyzed in

each case. All mechanical tests were conducted at a temperature of 25°C ± 2°C and a relative humidity of 55°5%.
A Zeiss Evo 50 scanning electron microscope was used to examine microstructural breakdowns that transpired in untreated and untreated fractured composite specimens under tensile conditions. The scan was conducted using a pre-centered tungsten hairpin filament, an 8 mm working distance, a 20 kV acceleration voltage, and a 3.0 nm resolution.

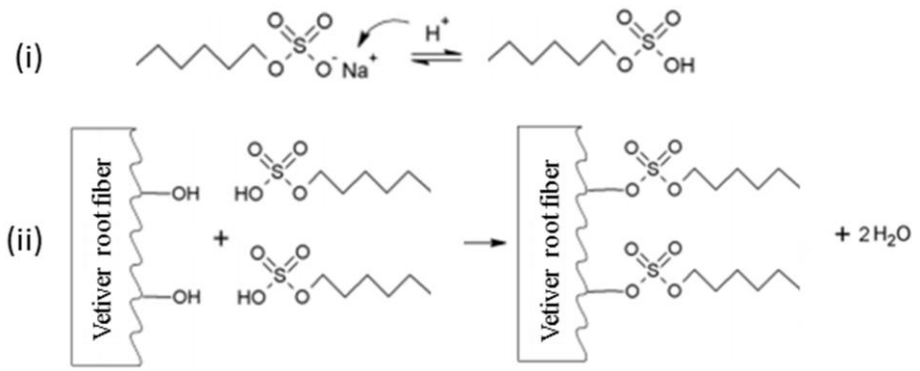
Results and discussions

Mechanical Properties of the Composites

Numerous factors influence the characteristics of fiber-polymer composites. The most important factors that significantly impact the properties of composites are fiber length, fiber content, the strength of the interfacial bond between fibers and polymers, and the length of time that fibers are treated. The impact of fiber length, fiber content, fiber treatment duration, and the strength of the interfacial bond between fibers and polymers are examined in relation to VF/LDPE composites.

Features of Tensile

Figure 2(a) and Figure 2(b) display the tensile strength (TS) of untreated and SDS-treated VF/LDPE composites, respectively, as a function of VF length and VF content. The composite's TS increases as the VF content rises to 20 weight percent, after which it falls. This can be decreased since improper adherence stops TS from increasing. As the VF concentration increases, VF builds up rather than disperses, and the resin is unable to moisten the VFs since it does not penetrate the two nearby VFs. With increasing VF to VF interaction, the chance of failure increases. Regardless of the VF content, Figure 2(a) shows that the TS of the composite increases as the VF length increases and eventually decreases. Generally speaking, the composite's characteristics are significantly impacted by the VF's length. Apart from its ability to hold VFs together, LDPE is crucial for the transfer of loads applied to VF. The ability of a fiber/polymer composite to transfer stress from the matrix to the fiber and fiber-matrix interaction determines its success. TS is lower for VF lengths under 5 mm since the length could not be enough for adequate load distribution. On the other hand, for composites with a long VF length (more than 5 mm), TS decreases. This might be the case since long VFs might not work well with LDPE. Therefore, there is improper bonding between VF and LDPE. The VF can also be pleated, however this results in less strength because there is no link between the pleated and open portions of the VF. Strength loss could be brought on by the VF tangling barrier. Composites with a fiber length of 5 mm and a fiber composition of 20 weight percent have a maximum TS of 31.2 MPa.
As a function of VF content, Figure 2(b) displays the TS of SDS-treated VF-reinforced LDPE composites rather than VF lengths. Up until VF length increases by 5 mm, the effect of SDS treatment on the composite's TS increases; beyond that, it decreases as VF length increases further. At 20 weight percent VF content, TS was also observed to increase to its maximum before decliningIn comparison to the untreated VF composite, the TS increased by 17% and 11%, respectively, as the VF length grew from 3 to 5 mm in 20 weight percent VF content. Then, as it increased to 7 mm, the VF length shrank. The long alkyl chain covalent bonds on the VF surface treated with SDS increased the interface contact between the VF and LDPE matrix, improving wetting with the LDPE matrix's assistance. Since the polar groups of SDS and VFs form a covalent link, it is anticipated that adding SDS to VFs will lessen their hydrophilic character [20]. Scheme 1 shows the schematic reaction between SDS and VF.



Scheme 1. The suggested schematic reaction between VF and SDS. SDS is an acronym for sodium dodecyl sulfate.

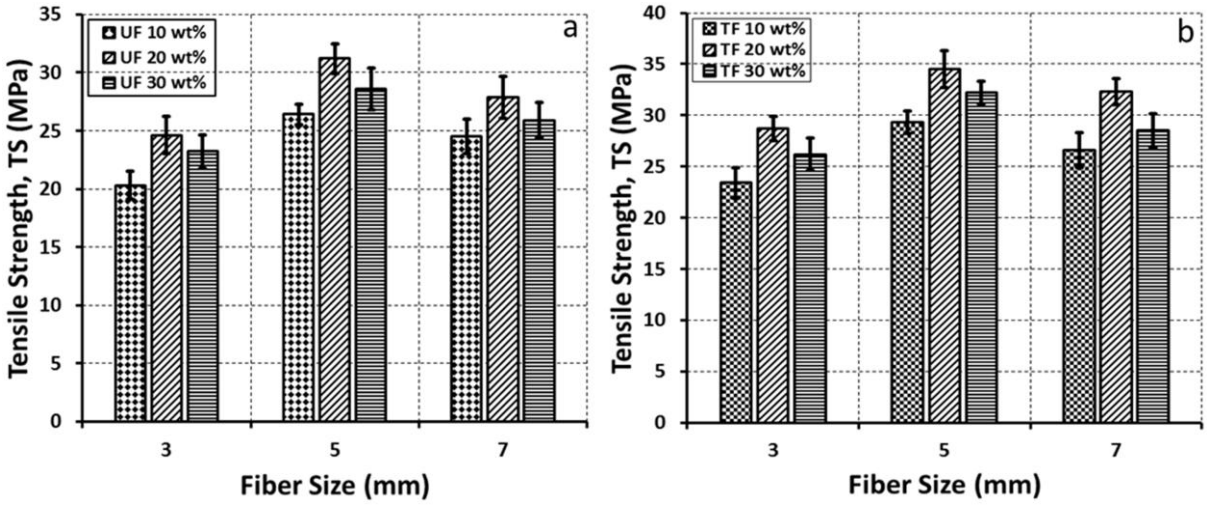


Figure 2. Tensile strength (TS) of (a) untreated and (b) treated VF-reinforced LDPE composites is affected by fiber size (mm) and fiber content (wt%).

Figure 3(a) shows how the tensile modulus (TM) of VF-reinforced LDPE composite is affected by both VF length and VF content. Young's modulus is a measure of the composite material's hardness that is dependent on the filler content. Higher VF content increases the rigidity of the VF/LDPE composite. It is evident that, independent of VF length, TM increases as VF content increases. As the VF content rises, the composite becomes more brittle, resulting in a steeper stress-strain curve. The slightly distinct microspaces created by the weak interfacial contact between VF and LDPE stop stress from spreading between them [21]. An increase in stiffness results from an increase in resistance as the VF content rises. The composites' TM increases in tandem with the VF length. Previously, researchers have observed a similar pattern [22]. Composites with 5 mm VF length and 20 weight percent VF content can achieve a maximum TM of 790.8 MPa. According to Mohammed et al. [23] at

30% weight percent of fiber loading, the TM of oil palm fiber-epoxy composites was 1.342 GPa.

The TM of VF reinforced LDPE composites treated with SDS for variations in VF length and weight (%) content is shown in Figure 3(b). In comparison to untreated composites, Adding VF content up to 30 weight percent for the 3 mm, 5 mm, and 7 mm size ranges increases TM by 30%, 32%, and 33%, respectively, as shown in Figure 3(b).VF reinforced composites treated with SDF had a greater TM than untreated VF composites because of modifications to the cellulose unit structure of VF. VF undergoes chemical treatment in conjunction with basic sodium dodecyl sulfate to decrease the cellulose units' -OH group. The women figure 3 (a,b)fiber-reinforced polymer composite ranged from 507 to 1025 MPa, whereas the TM range of SDS-treated composite was 676 to 1026 MPa [24].

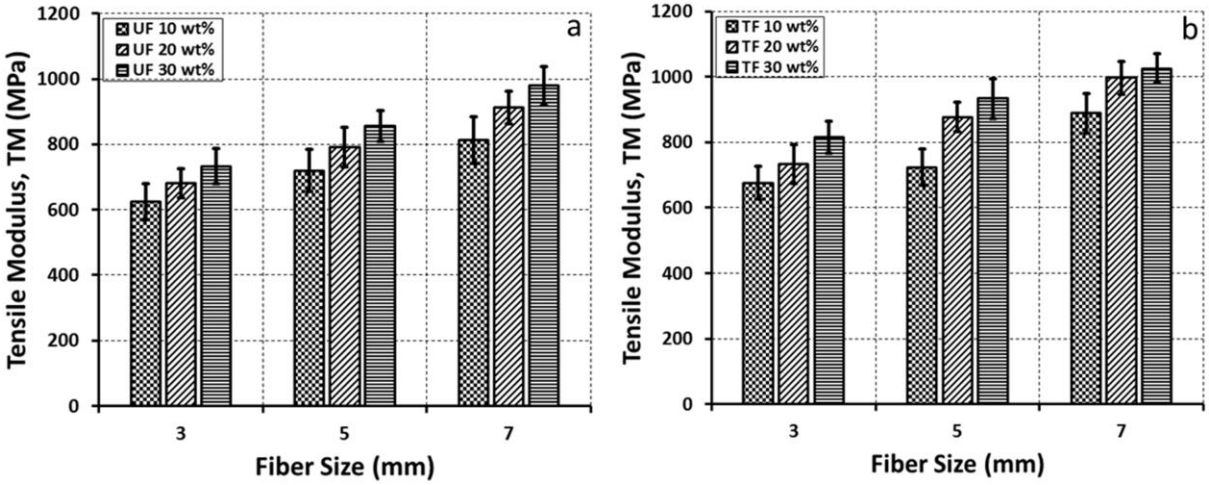


Figure 3. Tensile modulus (TM) of (a) untreated and (b) treated VF-reinforced LDPE composites is affected by fiber size (mm) and fiber content (wt%).

Properties of Compression

The effects of VF length and VF content on the compressive strength (CS) of untreated and treated VF/LDPE composites are compared in Figures 4(a) and 4(b).As the VF content increases up to 20 weight percent, regardless of the VF's length from 3 to 5 mm, Figure 4(a) shows that the CS increases and then decreases. Similar to the TS, the CS also exhibits this pattern. Better interface bonding between VF and LDPE, increased VF-LDPE compatibility, and stress transfer from LDPE to VFs are all results of the increased CS, which also causes the rise in VF content. For the 3 mm, 5 mm, and 7 mm size ranges, increasing the VF content up to 30 weight percent reduces CS by 15%, 26%, and 19%, respectively, compared to 20 weight percent VF composite, as shown in Figure 4(a). Weak VF-to-VF contact, void, and weak VF distribution in LDPE may be the causes of low CS in high VF content. Additionally, as additional VFs were added, more VF ends were produced. For untreated composites with a 5 mm VF length and a 20 weight percent VF content, a maximum CS of 7.6 MPa was recorded. However, the CS of the VF reinforced composites treated with SDF was higher than that of the VF composites that were not treated because the cellulose unit of VF underwent a structural change. The amount of CS is increased when VF is chemically treated with basic SDS, which lowers the cellulose unit's -OH. For composites with a 5 mm VF length and a 20 weight percent VF content, a maximum CS of 8.9 MPa has been recorded.

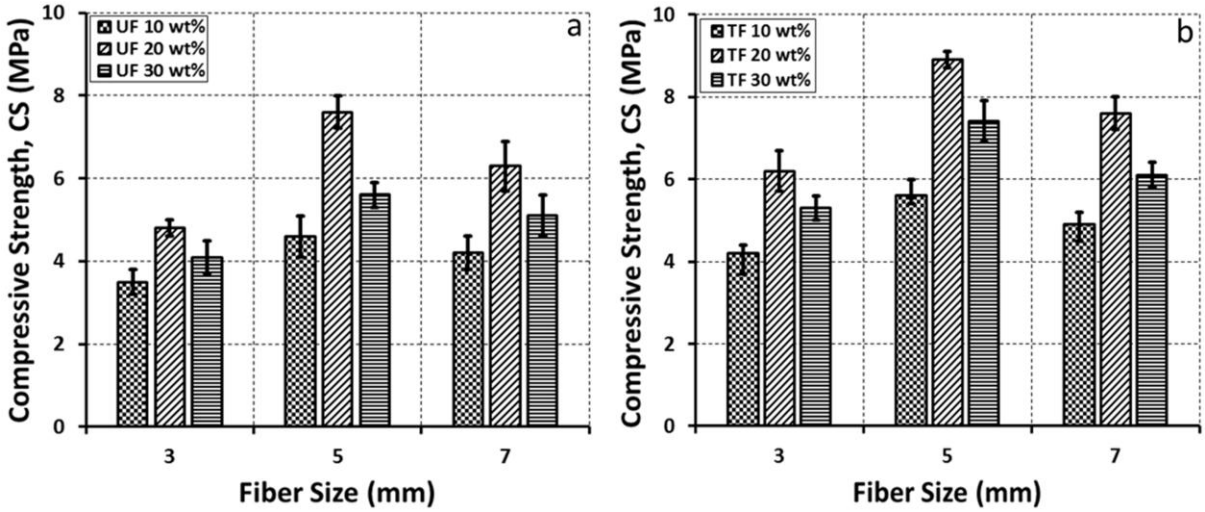
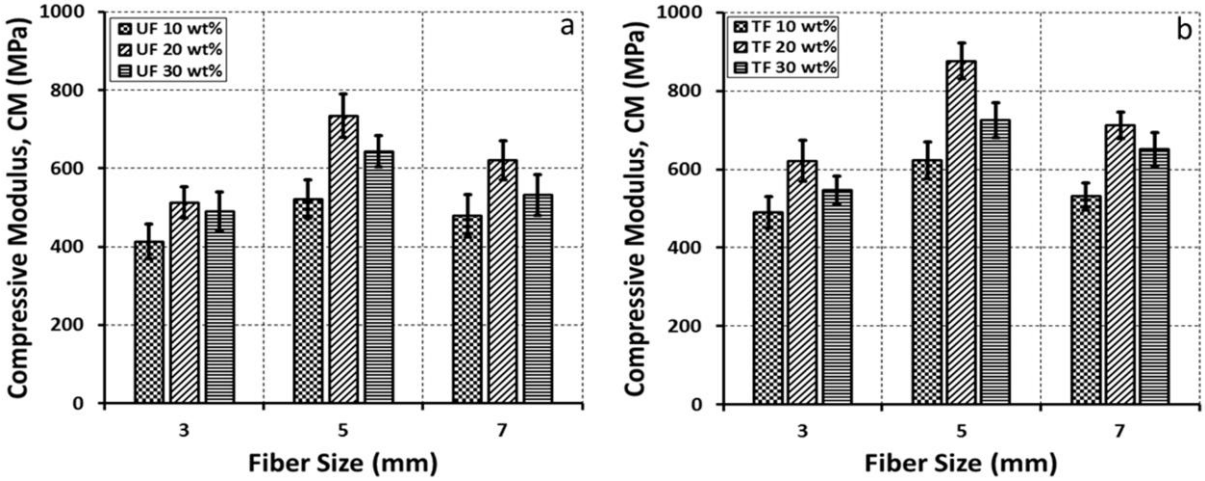


Figure 4. Impact of fiber size (mm) and fiber content (wt%) on VF-reinforced LDPE composites' compressive strength (CS) in both (a) untreated and (b) treated conditions.

Figure 5(a) The modulus of the VF affects the compressive modulus (CM) of the composite. and **Figure 5(b) illustrate how the CM of untreated and treated VF/LDPE composites is affected by the VF's length and content**,

respectively. The extended VF interaction with the LDPE with sufficient VF content



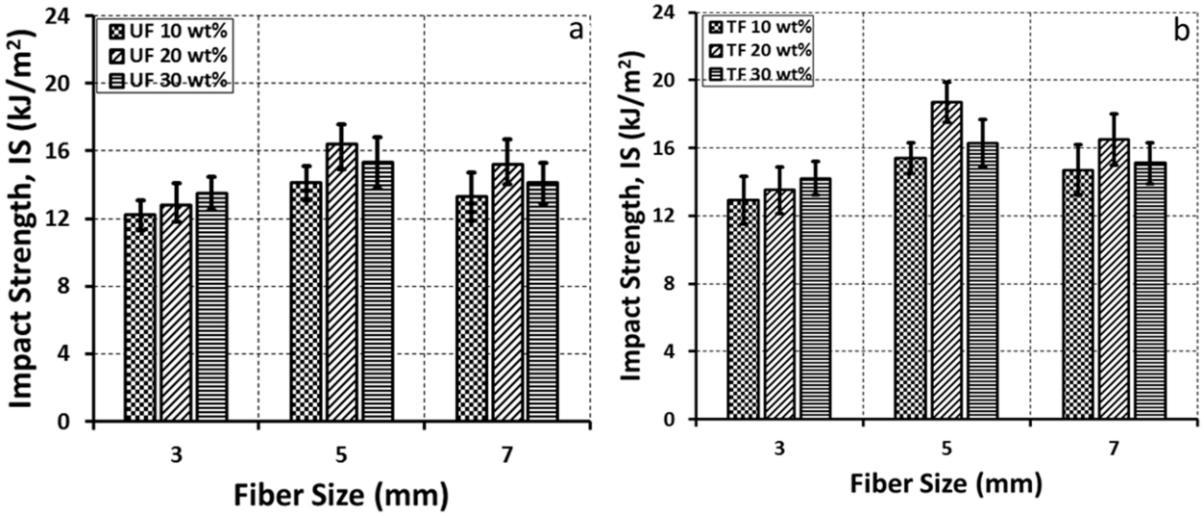
improved CM, while the maximum CM at 5 mm and 20% VF content of the system was observed. At 20 weight percent VF content, the ideal CM at 3 and 5 mm was noted. Because LDPE is insufficiently robust to block VF, the findings of a 7 mm VF length and a 30 weight percent VF content indicate that CM decreased. The maximum CM of composites with a VF length of 5 mm and a VF composition of 20 weight percent is 734.5 MPa. The identical pattern of elevated fiber concentration and decreased fiber length has been reported in the literature [25, 26].

Figure 5. Impact of fiber content (wt%) and size (mm) on compressive modulus (CM) of VF-reinforced LDPE composites that are (a) untreated and (b) treated.

Figure 5(b) shows how the VF content and VF size affect the CM of the VF reinforced LDPE composites treated with SDS. Because of structural alterations in the cellulose unit of VF, the figure 5(b) illustrates that the CM of treated VF reinforced composites was greater than that of untreated VF composites. The hydroxyl group of cellulose molecules is decreased when VF is chemically treated and basic SDS is added. Because of the tight adherence between the treated VF and the LDPE, the chemically treated composite had a higher CM.

Impact Feature

Impact strength (IS) measurement of the barrier that the composite offers against fracture under high-speed stress application. To put it another way, it's a gauge of how hard a composite is. IS is affected by the interfacial interaction between the reinforcement and matrix, as well as by both. Failure results from debonding between the matrix and fiber, which then triggers both a matrix fracture and a fiber fracture. The fiber pullout during fracture, however, is also a determining factor for IS. An important factor influencing the impact energy is the energy needed to extract the fiber from the matrix. The pull-out force and, thus, IS, rise as the amount of fiber increases. The effects of VF length and VF content on the IS of untreated and treated composites are demonstrated in Figure 6(a) and Figure 6(b), respectively. The IS rises to 20% VF content until the VF length and content increase, after which it starts to decline. Furthermore, a high VF content has been shown to increase the risk of VF agglomeration and stress the concentration, which lowers the energy needed for crack expansion. is raised to 20 weight percent of all composites that contain VF. The contents of the composite void are removed by VF's ability to absorb energy and compression



stress due to its good mixing properties with LDPE. The composites reinforced with 5 mm VF length at 20% VF content had a higher IS of 16.4 kJ/m2, which is 123.6% greater than that of virgin LDPE. Figure 6(b) illustrates how the VF size and content impact the IS of the improved VF reinforced LDPE composites. As the VF length increases, interface bonding raises the IS of the composite and develops the material nature between VF and LDPE, as shown in Figure 6(b) [27]. This is attributed to the impact that SDS therapy has on VF structure. NFs are composed of tiny fibrils that are joined by noncellulosic materials (such as lignin, pectin, hemicellulose, and wax and oil coating). Therefore, by forming an amorphous zone through noncellulosic extraction, SDS treatment alters the orientation of the densely packed crystalline cellulose sequence, changes the cellulosic molecular structure, and permits the fibrils to rearrange in the direction of the applied tensile load. During the extraction of these components, the fibers are also divided into smaller fibrils, which results in a decrease in the diameter of the fiber and an increase in the fiber's size ratio (length/diameter). SDS

treatment alters the hydrophilic properties of VFs, making them more compatible with the hydrophobic LDPE matrix, even though it also produces rough, clean fibrils that aid in bonding and mechanical interlocking. The LDPE and VF interface adheres better as a result.
Figure 6. Impact strength (IS) of (a) untreated and (b) treated VF-reinforced LDPE composites is affected by the fiber size (mm) and fiber content (wt%).

Fracture Toughness

Fracture toughness (FT) can be diagnosed using a number of methods, including the major groove depth method, J-integral method, compliance approach, etc. FT has been assessed for VF-reinforced LDPE composites utilizing a linear elastic fracture mechanics test from a crack ratio of 0.3 to a sample ratio, in accordance with ASTM D5045. Figures 7(a) and 7(b) display the FT findings of untreated and untreated VT composites based on the VF length and VF content, respectively. When the VF length is increased by 3 to 5 mm and the VF content is increased by 20 weight percent, the FT of the composite increases. When the VF content increases, the test value of FT also increases, indicating that the material is stronger and less likely to fracture. This could be the result of extrinsic hardening taking place behind the crack point after the crack has expanded [28]. Figure 7(b) demonstrates that the system's highest FT was recorded at 5 mm and 20% VF content, whereas the ideal FT at 3 mm and 5 mm was recorded at 20 weight percent VF content. Because of the strong adhesion between treated VF and LDPE, the FT of chemically treated VF reinforced composite was greater than that of untreated VF reinforced composites. Lower FT is achieved with a VF length of 7 mm and a VF content of 30 weight percent. Prolonged VF interaction with the LDPE that contained sufficient VF content improved FT. This results in interfacial adhesion between LDPE and VF. Because LDPE is insufficiently robust to block VF, the results of a VF length of 7 mm and a 30 weight percent VF content indicate that FT decreased. Composites having a 5 mm VF length and a 20 weight percent VF composition show a maximum FT of 5.8 MPa.

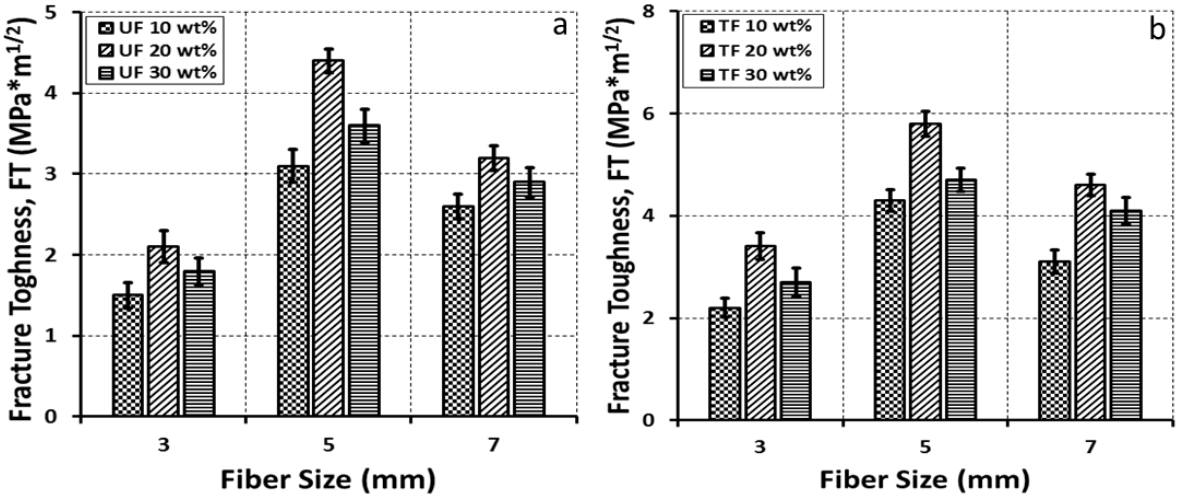


Figure 7. The impact of fiber size (mm) and fiber content (wt%) on the fracture toughness (FT) of VF-reinforced LDPE composites that are (a) untreated and (b) treated.

Impact of Length of Treatment for SDS

At constant VF length (5 mm) and VF content (20 wt%) at different treatment periods, the effects of SDS treatment duration on VF of all mechanical parameters, including strength (TS, CS, and IS), modulus (TM, and CM), and fracture toughness (FT), were also investigated. Figure 8(a) and Figure 8(b) display the TS, IS, CS, and TM, CM, and FT of

composites for SDS treatment durations of 2, 4, and 6 hours, respectively. It is evident that when the SDS treatment period increases up to six hours, all of the composite's mechanical properties increase significantly. The greatest rise in TS, IS, CS and TM, CM, and FT was observed after 6 hours of VF treatment, as opposed to 2 hours. This represents approximately 11%, 25%, and 18% and 8%, 13%, and 35%, respectively. This illustrates that the optimal holding duration is six hours, as seen in Figure 8. The improvement in the mechanical characteristics of the 6-hour treatment over the 2-hour treatment is mostly due to the establishment of the interfacial bond as a result of the SDS treatment. Because the SDS treatment improves the VF's surface roughness, its mechanical interaction with the LDPE matrix is improved. The primary wall of the VF dissolves the crystalline part of the parent cellulose when SDS is added. Because of the breakdown of the lignin and hemicellulose connected to VF, the surface becomes rougher. As a result, the VF's surface topography is altered for two hours of treatment to an uneven surface with subtle undulation for six hours. Improved mechanical interaction with the LDPE matrix is ensured by increasing the contact area by surface roughness. Additionally, SDS treatment of VF improves its surface smoothness, initiates chemical reactions, and, of course, raises the composite material's mechanical properties.

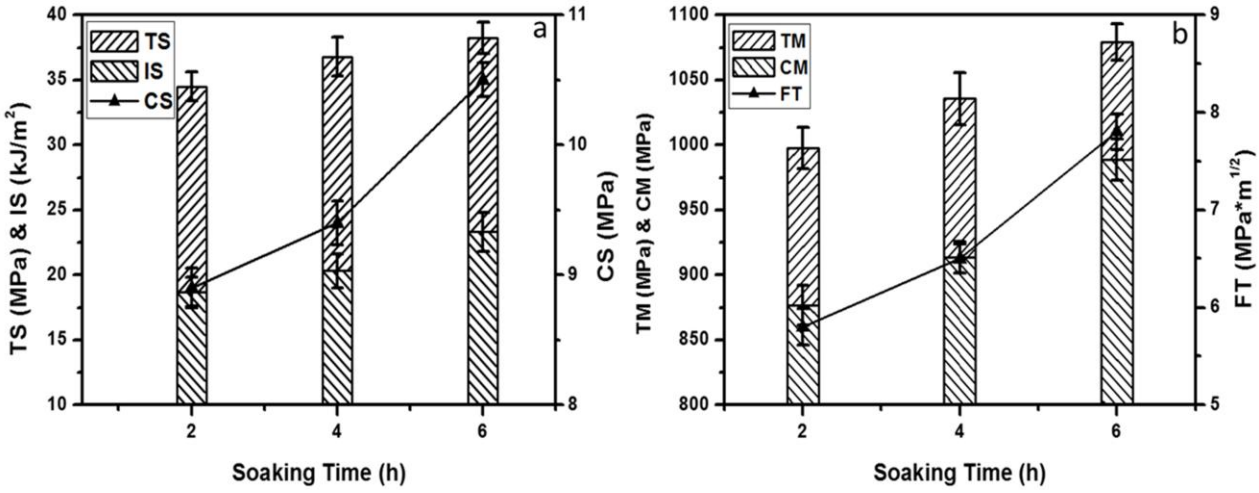


Figure 8. Effect of treatment period on (a) the tensile strength (TS), compressive strength (CS), and impact strength (IS) of composites as well as their (b) tensile modulus (TM), compressive modulus (CM), and fracture toughness.

Study of Fractography

Pullouts, cavities, microholes, matrix cracking, fiber attachment to the matrix, and matrix adhesive properties are examples of surface morphology that show how a cracked surface disintegrates. Samples of thermoplastic composites were fractographed using SEM after tensile testing, and the results are shown in Figure 9. A SEM picture of the composite's tensile fracture surface with a 3 mm fiber size and 20% weight percent VF content is shown in Figure 9(a). This is because of fiber pull out, fiber and matrix breaking, and fiber-matrix debonding, which results in the voids. Weak adhesion leads the VF to separate from the LDPE due to the tensile load, creating voids. Cracks were formed close to the gap area as a result of the sample's constant performance under the tensile strain. This crack progressively widens as the applied load pattern increases, finally leading to the complete breakdown of the composites. The interfacial structure of this composite is unable to effectively transfer stress because to imperfections and inadequate VF-LDPE interfacial adhesion. The low tensile

strength values shown in Figure 9(a) were in line with this outcome. Figure 9(b) shows the tensile fracture surface of a 5 mm fiber with a 20 weight percent VF content. It exhibits small gaps and good interfacial contact with the VF-LDPE matrix. Tensile tests revealed only minor fiber pull-outs that were encased in the LDPE matrix. In the microstructural imaging of a composite with a 7 mm VF length and 20 weight percent VF content, the main defects in the LDPE matrix are fiber pullout, matrix cracks, and cavities (Fig. 9, c). The illustration clearly shows that VFs disengage from the LDPE surface due to insufficient interfacial bonding. The surfaces of the pulled-out VFs are also observed to be clean. The treated samples showed better bonding than the untreated ones. The LDPE matrix is free of defects such as cracks and vacancies, but fiber pullouts are negligible in SDS-treated composites with a 5 mm VF length and a 20 weight percent VF content (Figure 9, d). It illustrates how SDS treatment has improved the interfacial binding between VF and LDPE, raising the properties above those of other composites.

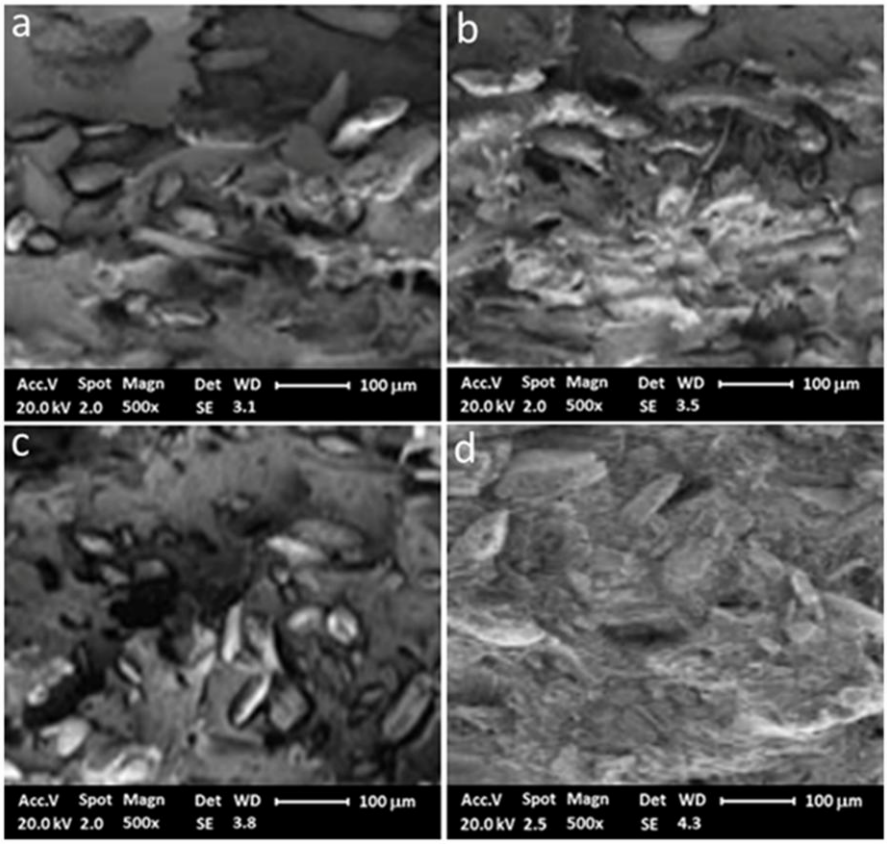


Figure 9. SEM micrograph showing the fractured surface of composites with 20 weight percent VF content: (a) untreated VF/LDPE (3 mm VF length), (b) untreated VF/LDPE (5 mm VF length), (c) untreated VF/LDPE (7 mm VF length), and (d) treated VF/LDPE (5 mm VF length).

Conclusions

In this work, new composites were made using VF and LDPE as thermoplastic resins. Composite samples have undergone tests for tensile, compressive, impact, and fracture toughness. The following results are drawn from an analysis of the shattered surface morphology of the tensile-tested samples:

(1) The mechanical characteristics and morphology of VF-reinforced thermoplastic LDPE composites are influenced by both the size of VF and the proportion of VF component.

(2) Composites' strength characteristics, including their tensile, compressive, impact, and fracture toughness, increase as the VF content rises to 20 weight percent before declining. The best VF content is therefore accessible at 20 weight percent for improved mechanical characteristics. Accordingly, increasing the strength characteristics and fracture toughness of composites can be achieved with a 5 mm VF length.
(3) Nevertheless, the composite's tensile modulus increases as the VF length and content increase up to 7 mm and 30 weight percent, respectively. However, the composite's compressive modulus increases as the VF length and content increase up to 5 mm and 20 weight percent, respectively. Composites with a 20 weight percent VF content and a 5 mm VF length had the highest compressive modulus.
(4) SDS-treated composites have better tensile, compressive, and impact properties as well as fracture toughness than any other composite. Composites treated with SDS exhibited improvements in tensile strength of 11%, tensile modulus of 5%, compressive strength of 17%, compressive modulus of 19%, impact strength of 14%, and fracture toughness of 32% when compared to untreated composites. For VF, a 6-hour treatment period was ideal.
(5) Several flaws in the untreated samples were clearly visible in SEM photomicrographs, and the SDS-treated samples showed a qualitative improvement in those flaws.

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