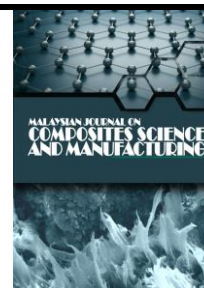




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Investigation on the Effect of Process Parameters on Mechanical Properties of Vetiver Fiber Reinforced LDPE Composites

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ABSTRACT

Natural fibers (NFs) are extensively used for the ecological concern of synthetic fibers. The benefits of NFs over man-made fibers are their easy accessibility, renewability, lightweight, biodegradability, high specific features, and low price. The key reasons for affecting the features of the composite are the length and content of the fiber and the time of treatment of the fiber. Consequently, the prediction about the optimal fiber length, fiber content and treatment time becomes important, so that composites with optimal mechanical properties can be prepared. The current study narrates an experimental investigation on the effect of process parameters, namely fiber condition (untreated and sodium dodecyl sulfate (SDS) treatment), fiber sizes (3, 5, and 7 mm), fiber contents (10, 20, and 30 wt%), and treatment time (2, 4, and 6 h) on vetiver fiber (VF)-reinforced low-density polyethylene (LDPE) composite. The VF-reinforced LDPE composites have been developed by hot compression molding method and then characterized by mechanical properties (e.g., tensile strength, tensile modulus, compressive strength and modulus, impact strength, and fracture toughness) and scanning electron microscopy (SEM). The results showed that the composites' tensile, compressive, impact properties and fracture toughness increased with increasing fiber size, fiber percentage, and treatment time. Afterwards, mechanical properties decreased by a certain size, percentage, and treatment time. SDS-treated VF-reinforced LDPE composite samples produced better tensile, compressive, and impact properties compared to the untreated composites. The composites reinforced with 20 wt% fiber content, 5 mm in length and 6 h showed the best tensile, compressive, impact properties and fracture toughness. The SEM study revealed that the SDS-treated fiber composite confirmed the homogeneous dispersion rather than the untreated composite. The composite properties reveal that VF can be a good candidate for polymer reinforcement.

Keywords:

Vetiveria fiber, Low-density polyethylene, Composite, Sodium dodecyl sulfate treatment, Mechanical properties

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1. Introduction

In earlier years, polymer composites made from natural fibers (NFs) have attracted more research due to their potential as an alternative to composites made from synthetic fibers. The advantages of NF composites are greater than those of synthetic fiber (SF) composites because NF composites have lightweight, reduced cost, reduced tool wear, renewability, good thermal features, reasonable strength and modulus, eco-friendly, and durability [1-3]. NFs are divided into several categories based on different sources (plants, animals, or minerals). NFs are divided into six types: Straw fibers (corn/wheat/rice straws), bast fibers (flax/hemp/jute/ramie/kenaf), leaf-fibers (sisal/henequen/coir/abaca/pineapple), seed/fruit fibers (cotton/kapok/coir), grass fibers (bamboo/switch/grass/miscanthus) and wood flour (wheat husk, rice husk) [4]. These NFs deliver very good mechanical features when used for strengthening composites and are free from environmental hazards. Due to their relatively high strength, endurance, and low density, different types of NFs are typically employed to strengthen plastics and achieve the mechanical properties of composites. For example, these NFs have already been applied in the furniture and automotive industries [5]. Composites for desired features can be made by adding cellulose fibers to a polymer matrix for a variety of applications [6]. Due to economic and environmental reasons, polymer composites filled with lignocellulosic substances such as calotropis gigantea fiber, vetiver, abaca, jute, and coir increase.

Composites can be made using dissimilar portions of plants as reinforcement. Even though a lot of NF composites have been researched throughout the years, a lot of them still lack reinforcement. One of these is vetiver zizanioides (vetiver) which roots are used for fortification. In this paper, polymer composites have been arranged using a new NF (vetiver fiber, VF) derived from a plant which scientific name is *Chrysopogon zizanioides*, formerly *Vetiveria zizanioides*. Vetiver is a perennial herb; its origins are generally known as vetiver. Vetiver grass is mainly cultivated in India, Bangladesh, Vietnam, and Thailand. Vetiver's roots can grow up to 5 m long and have good mechanical properties [7]. A study has been shown using vetiver leaves as a filler component in the PP matrix, and it has been informed that using VFs has increased the tensile strength and Young's modulus of the composite compared to virgin PP [8]. Another method uses glass fibers, jute, and vetiver roots as fillers, with vinyl esters resin forming in the hybrid composite. According to a report, vetiver roots are a good substitute for synthetic fibers to strengthen composite components. This may be achieved by carefully selecting the reinforcement ratio and applying the right chemical treatment [7]. Similar findings were obtained from another study using an epoxy matrix composite reinforced with vetiver root [9]. Furthermore, it is concluded that vetiver roots are more consistent in their mechanical and thermal properties and are properly bonded to the matrix by giving pretreatment [10].

The strength of NF composite largely depends on the fiber's weight or volume fraction, the fibers' chemical modification, the fibre layers' stacking, and the bonding strength between the fiber and the matrix. A lot of scientists have examined the mechanical features and morphology of vetiver-plastic composites and the effect of fiber surface modifications on the mechanical behavior of polymer composites. Vinayagamorthy [11] studied the influence of fiber surface modifications on the mechanical behavior of *Vetiveria zizanioides*-reinforced polymer composites. According to his findings, benzoylation increased the composite's tensile, compressive, and impact strengths by 113%, 56.78%, and 95%, respectively. After undergoing peroxide treatment, the composite's elongation increased throughout tension, flexure, and compression tests, and its flexural strength increased by 56.13%. Because the benzoylated composite's surface morphology revealed few flaws, benzoylation is advised for the best overall behavior and peroxidation for increased bending and elongation. When the fiber content was increased to the optimum level of 30 wt%. Zaman [12] found

that the mechanical properties of the PP/vetiver fiber composites, such as tensile strength, tensile modulus, impact strength, hardness, and water absorption, enhanced. For the VF, adding sodium dodecyl sulfate and sodium dodecyl sulfate-pretreated benzoyl chloride enhanced the resulting composites' mechanical properties and water desorption. Compared to untreated fiber composites and those treated with sodium dodecyl sulfate, PP/vetiver composites that include benzoyl chloride following your pretreatment exhibit superior mechanical performance.

Although there is a lot of use of NFs in polymer composites, the main disadvantages of using NFs are the incompatibility with the polymer matrix due to the hydrophilicity of the fiber and the hydrophobicity of the polymer, which can be overcome by chemical modification of the fiber surface. Moreover, these composites are frequently allied with agglomerations due to inadequate distribution due to the affinity of fillers to form hydrogen bonds with each other through processing [13-15]. Furthermore, it is difficult to create a well-bonded interface with a nonpolar matrix of polar hydroxyl groups on the surface of lignocellulosic matter because hydrogen bonds prevent wetting of the filler surface [16-18]. Many authors have researched this area [19-21]. Filler treatments are significant for developing natural filler-based composites and wettability, dispersion, and filler-matrix interactions. Therefore, the chemical treatment of fibers develops the adhesion between the fibers' hydrophilic surface and the polymer's hydrophobic surface. An earlier study on the VF surface treatment showed that this treatment enhanced the mechanical properties of VF/PP composites by enhancing the interfacial properties between fiber and matrix [8]. While the properties of NFs have been extensively studied, the surface of VFs treated with sodium dodecyl sulfate (SDS) has not been the subject of any research.

This research used low-density polyethylene (LDPE) as matrices and VFs as fillers to form a plastic composite. The coupling agent, SDS was used to modify VF to improve the properties of VF/LDPE composites. SDS is recognized as an anionic surfactant and is broadly used in synthesizing biomaterials [20]. Some researchers have reported that SDS was used as a coupling agent to increase filler-matrix adherence between coconut husk-recyclable polypropylene, chitosan-polypropylene, and cocoa pod husk-polypropylene [21-23]. This study prepared VF-reinforced LDPE composites under several processing parameters using the hot compression molding method. The goal of this work is to understand the effects of fibers content, fiber length, SDS treatment, and treatment time of VF on the tensile, compressive, and impact properties and fracture toughness of the produced composites were elucidated. Lastly, the morphology of the fracture surface was examined by scanning electron microscope (SEM). Understanding that VF's behaviour is important in promoting research direction in VF composite areas and NF polymer composites.

2. Experimental

2.1 Materials

Thermoplastic LDPE homopolymer pellets were provided by BASF-YPC Co., Ltd., China. Its grade was 2426H, with a density of 0.924 g/cm³ and a melting index of 2.0 g/10 min at 190°C, 2.16 kg. Raw vetiver roots were collected from rural areas of Bangladesh. The physical and mechanical properties of vetiver fiber are presented in Table 1 [8]. The sodium dodecyl sulfate (SDS) in powder form and ethanol (98%) were supplied by Sigma Aldrich (St Louis, Missouri, USA).

Table 1
Physical and mechanical properties of VF and other natural fibers [8]

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

2.2 Methodology

2.2.1 VF preparation

The vetiver root's fibers were cut into different sections of 3, 5, and 7 mm lengths and then thoroughly washed in water to eliminate its impurities. Washed untreated VFs were dehydrated in sunlight for 24 hours to reduce humidity to less than 4%. The SDS solution was prepared by dissolving SDS powder in ethanol at a temperature of 50°C. The amount of SDS utilized for treated VFs was 5% of the weight of the fiber. The solution was then cooled to room temperature. Subsequently, VFs (10, 20, and 30 wt% for each 3, 5, and 7 mm length) were added to the solution for 2 h with the appropriate fiber ratio and then dried at 80°C in an oven for 24 h to remove ethanol residue.

2.2.2 VF-LDPE composite preparation

LDPE/VF composites were fabricated using the hot compression molding method. Primarily, the VFs were weighed according to the required weight. To allow moisture to be removed, the VFs were dried at 80°C for 30 min before each composite was prepared. The required quantity of LDPE was weighted. The surface of the mold was carefully cleaned and properly sprayed over the mold surface with a molding agent (silicone spray) for easy removal of the product. Thermoplastic composites were made in two steps. Firstly, the LDPE granules were pressed at 150°C under a pressure of 8 MPa for about 10 min. Then the prepared sheets were cooled to room temperature. Secondly, composite materials were prepared using the film stacking method so that untreated and treated VFs (10, 20, and 30 wt% for each 3, 5, and 7 mm length) were randomly distributed between the LDPE sheets and placed on the bottom mold. The bottom mold was covered by the top mold as indicated in both molds. The mold was kept in a hot compression molding machine and then held at 160°C for 10 min at a pressure of 10 MPa for about 15 min. The pressure was released, the mold was cooled to room temperature, and the sample was carefully withdrawn from the mold. Figure 1 presents the processing method of LDPE/VF composite and the temperature-time-pressure profile used for composite production.

2.2.3 VF-LDPE Composite Characterizations

The possible practical application of polymer composites depends on their mechanical properties. For this purpose, the tensile, compressive, and impact properties and fracture toughness of the prepared composites were assessed using the same parameters (VF length, VF content, and SDS used during treatment) as mentioned above. After the composites were made, the test specimens underwent several experiments. The average width of the sample was determined by measuring five locations along the length of the sample using a digital micrometer. The tensile tests were carried out according to ASTM-D 638-14 standard using Dual Column Digital Universal Testing Machine, UTM

(Tinius Olsen H10KL), with 30 kN load cell at a 5 mm/min test speed. The instrumental impact of low velocity was tested in composite samples. The tests were performed according to ASTM D 256 using an impact tester. The compressive test and fracture toughness of VF/LDPE composites were measured using the same universal testing machine, Tinius Olsen H10KL. Compressive test samples with 15 mm × 10 mm × 10 mm were according to ASTM D 3410. Fracture toughness (FT) is assessed in crack opening mode (mode-I) according to ASTM D 5045 in a single-edge notch bend configuration. In each test, five samples were tested to get an average value. All the mechanical experiments were conducted in the atmospheric conditions of 25°C ± 2°C and relative humidity of 55 ± 5%.

Microstructural failures that occurred in untreated and untreated fractured composite specimens under tensile conditions were analyzed through a Zeiss, Evo 50 scanning electron microscope. The scan used a 3.0 nm resolution, 20 kV acceleration voltage, 8 mm working distance, and pre-centered tungsten hairpin filament.

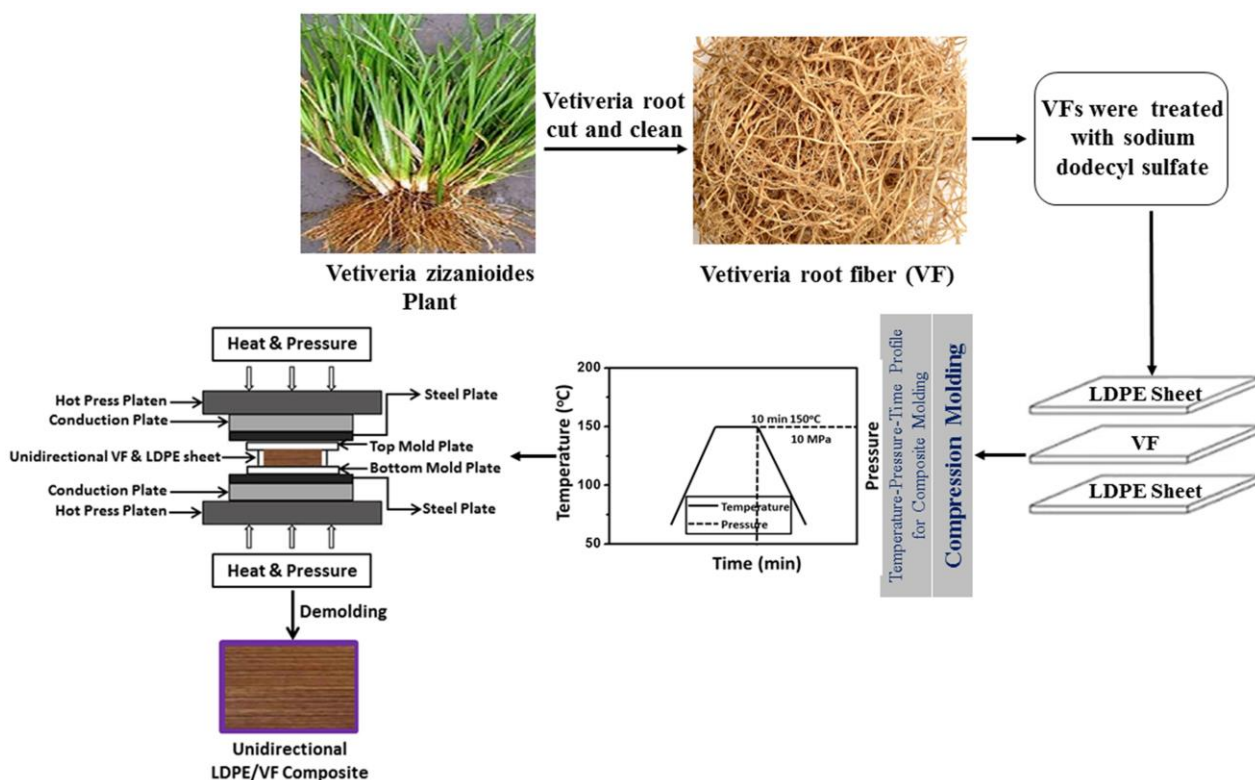


Fig. 1. The schematic illustration of the manufactured LDPE/VF composite and its processing profile

3. Results and Discussions

3.1 Mechanical Features of the Composites

The features of fiber-polymer composites depend on many reasons. Among the several reasons, fiber length, fiber content, the interfacial bond strength between fibers and polymers and fiber treatment time are the most vital reasons that considerably affecting the properties of composites. The effect of fiber length, fiber content, the interfacial bond strength between fibers, and polymers and fiber treatment time of VF/LDPE composites are discussed.

3.2 Tensile Features

The effect of VF length and VF content on the tensile strength (TS) of untreated and SDS-treated VF/LDPE composites is presented in Figures 3(a) and 3(b), respectively. The TS of the composite rises with rising VF content up to 20 wt% and then drops with a further rise of VF content. Since improper adherence stops the rise in TS, this can be decreased. As the VF content rises, VF accumulates instead of dispersing, and the resin cannot wet the VFs because the resin does not enter the two adjacent VFs. As VF to VF interaction increases, so does the chance of failure. Figure 3(a) shows that the composite's TS increases with rising VF length and then decreases regardless of VF content. In general, the length of the VF has a good effect on the properties of the composite. In addition to keeping VFs together, LDPE has an important role in transferring loads applied to VF. The effectiveness of a fiber/polymer composite depends on its capacity to transfer stress from the matrix to the fiber and fiber-matrix interface [24]. TS is lower for shorter VF lengths (less than 5 mm) because the length may not be sufficient for proper load distribution.

On the other hand, TS reduces for composites of long VF length (more than 5 mm). This could result from long VFs not being properly matched with the LDPE. So, inappropriate bonding between VF and LDPE occurs. In addition, the VF might be pleated, and there is no bond between the open and pleated parts of the VF, resulting in less strength. Loss of strength may be due to the VF tangle barrier. A maximum TS of 31.2 MPa is observed for composites with 5 mm fiber length and 20 wt% fiber content.

Figure 3(b) shows the TS of SDS-treated VF-reinforced LDPE composites as opposed to VF lengths as a function of VF content. The effect of SDS treatment on TS of the composite improved with rising VF length up to 5 mm and then decreased with further rises in VF length. Also, TS was found to rise to a maximum at 20 wt% VF content and then reduced. As the VF length increased from 3 to 5 mm in 20 wt% VF content, the TS of the composite increased by 17% to 11%, respectively, compared to untreated VF composite, then the VF length decreased with further increase in VF length (7 mm). The VF treated with SDS had long alkyl chain covalent bonds on the surface, which increased the wetting with the help of the LDPE matrix and increased the interface bond between the VF and LDPE matrix. The presence of SDS in VFs is expected to reduce the hydrophilic nature owing to the creation of chemical interactions between the polar group of SDS and the polar group of VFs through the covalent bond [17]. The schematic reaction between SDS and VF is shown in Figure 2.

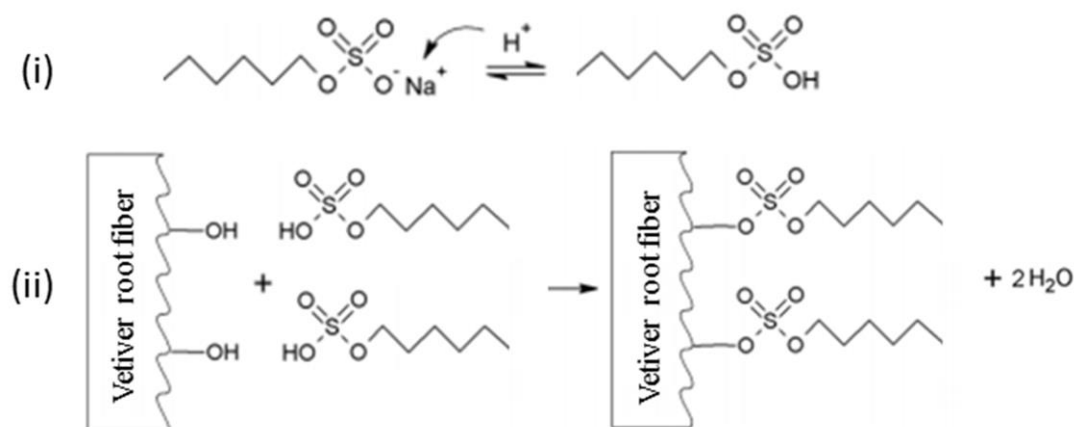


Fig. 2. The proposed schematic reaction between SDS and VF

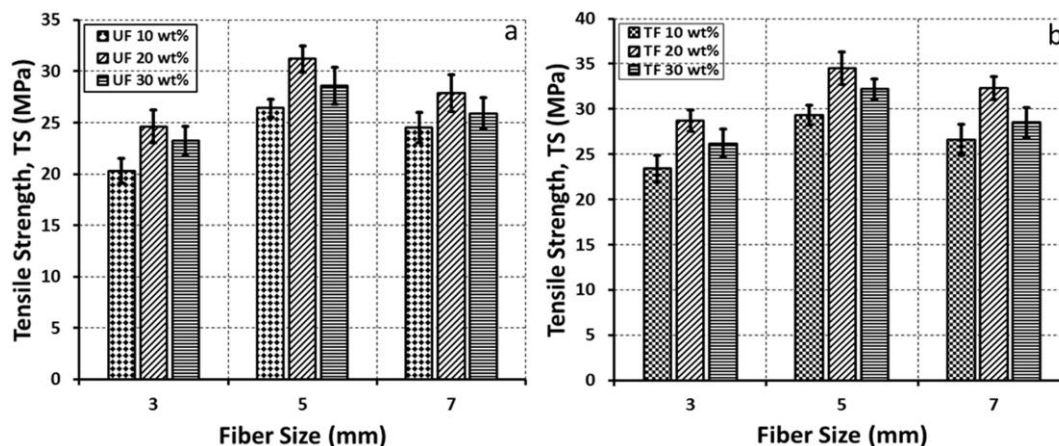


Fig. 3. Effect of fiber size (mm) and fiber content (wt%) on tensile strength (TS) of (a) untreated and (b) treated VF-reinforced LDPE composites

Figure 4(a) illustrates the effect of VF length, as well as VF content, on the tensile modulus (TM) of VF-reinforced LDPE composite. The stiffness of the composite material can be indicated by Young’s modulus, which depends on the filler content. The stiffness of the VF/LDPE composite is stronger in higher VF content. It can be noticed that TM increases with rising VF content regardless of VF length. Rising the VF content increases the composite’s brittleness, which makes the stress-strain curve steeper. The weak interfacial bond between VF and LDPE produces somewhat separate microspaces that prevent the spread of stress between them [25]. Thus, as the VF content rises, the degree of resistance rises, which in turn raises the stiffness. As the VF length rises, so does the TM of the composites. Researchers have noticed a similar trend in the past. A maximum TM of 790.8 MPa is available for composites with 5 mm VF length and 20 wt% VF content. Mohammed et al. [26] noted that the TM of oil palm fiber–epoxy composites were 1.342 GPa at 30 wt% of fiber loading.

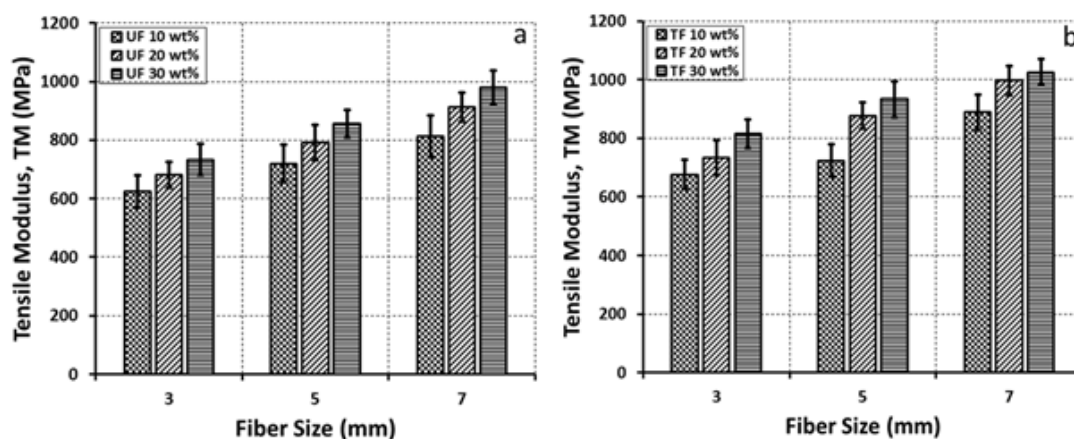


Fig. 4. Effect of fiber size (mm) and fiber content (wt%) on tensile modulus (TM) of (a) untreated and (b) treated VF-reinforced LDPE composites

Figure 4(b) shows the TM of SDS-treated VF-reinforced LDPE composites for the variations in VF length and content. As shown in Figure 4(b), adding VF content up to 30 wt% for the 3 mm, 5 mm, and 7 mm size ranges shows an increase in TM up to 30%, 32%, and 33 %, respectively, compared to untreated composites. Due to changes in the cellulose unit structure of VF, the TM of SDF-treated VF-reinforced composites was higher than that of untreated VF composites. Chemical treatment of VF combined with basic sodium dodecyl sulfate has reduced the -OH group of cellulose units. The TM

range of SDS-treated composite was 676-1026 MPa, and the same range of ladies finger fiber-reinforced polymer composite found elsewhere was 507-1025 MPa [27].

3.3 Compressive Properties

The effect of VF length and VF content on the compressive strength (CS) of untreated and treated VF/LDPE composites is shown in Figures 5(a) and 5(b), respectively. From Figure 5(a), it can be observed that the CS rises with rising VF content up to 20 wt% regardless of the length of the VF from 3 mm to 5 mm, and further, it reduces. The CS also follows the same trend as the TS. The increase in VF content is due to the increase in CS, leading to stress transfer from LDPE to VFs, higher VF-LDPE compatibility, and better interface bonding between VF and LDPE. As shown in Figure 5(a), adding VF content up to 30 wt% for the 3 mm, 5 mm, and 7 mm size ranges shows a 15%, 26%, and 19% reduction in CS, respectively, compared to 20 wt% VF composite. The causes for low CS in high VF content are possibly due to weak VF-to-VF interaction, void, and weak distribution of VF in LDPE. In addition, more VF ends were created as more VFs were added. For untreated composites with a 5 mm VF length and 20 wt% VF content, a maximum CS of 7.6 MPa was observed.

On the other hand, due to the change in the structure of the cellulose unit of VF, the CS of the composites made of SDF-treated VF-reinforced composites was higher than that of the untreated VF composites. Chemical treatment of VF with basic SDS reduces the -OH of the cellulose unit, thereby increasing the amount of CS. A maximum CS of 8.9 MPa has been observed for composites with 5 mm VF length and 20 wt% VF content.

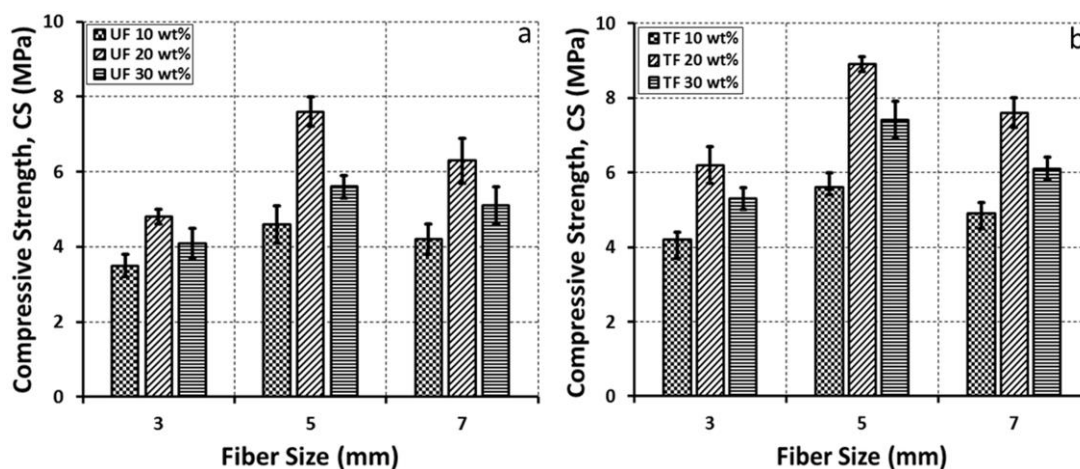


Fig. 5. Effect of fiber size (mm) and fiber content (wt%) on compressive strength (CS) of (a) untreated and (b) treated VF-reinforced LDPE composites

The modulus of the VF has an impact on the composite's compressive modulus (CM). The influence of VF length and VF content on the CM of untreated and treated VF/LDPE composites is shown in Figures 6(a) and 6(b), respectively. The optimal CM at 3 mm and 5 mm was observed in 20 wt% VF content, whereas the system's maximum CM at 5 mm and 20% VF content was observed. CM was enhanced by prolonged VF interaction with the LDPE with enough VF content. The results of VF length of 7 mm and 30 wt% VF content show that CM reduced because LDPE is not strong enough to inhibit VF [28]. A maximum CM of 734.5 MPa is observed for composites with 5 mm VF length and 20 wt% VF content. The same trend of high fiber content and fiber length reduction results has been reported in the literature [29].

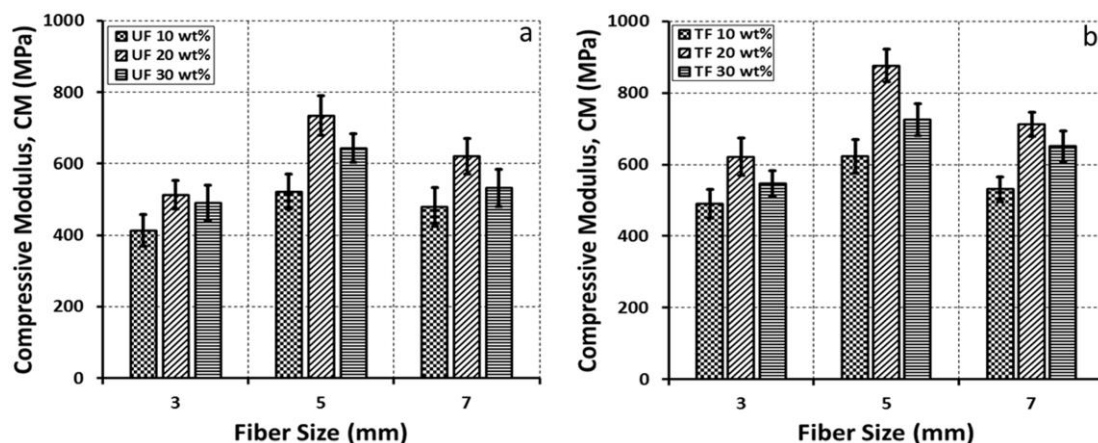


Fig. 6. Effect of fiber size (mm) and fiber content (wt%) on compressive modulus (CM) of (a) untreated and (b) treated VF-reinforced LDPE composites

The effect of VF content and VF length on the CM of the SDS-treated VF-reinforced LDPE composites is presented in Figure 6(b). The figure shows that the CM of treated VF-reinforced composites was higher than that of untreated VF composites due to changes in the structure of VF's cellulose unit. Chemical treatment of VF in combination with basic SDS reduces the hydroxyl group of cellulose units. The increased CM of the chemically treated composite was due to the strong adhesion between the treated VF and the LDPE.

3.4 Impact Properties

Measurement of the composite's impact strength (IS) against fracture during the application of high-speed stress. In another way, it is a determination of the energy the sample absorbs. IS is influenced by reinforcement and matrix and the interfacial bond between reinforcement and matrix. Failure occurs due to debonding between the fiber and the matrix, and, as a result, a matrix fracture and fiber fracture will occur. On the other hand, IS also depends on the fiber pull-out during fracture. The energy required to pull the fiber out of the matrix significantly affects the impact energy. Incorporating more fiber increases the pull-out force and hence the rise in IS. The effect of VF content and VF length on the IS of untreated and treated composites is shown in Figures 7(a) and 6(b), respectively. As the VF content and VF length increase, the IS also increases to 20% VF content and then decreases. Also, it was reported that high VF content increases the likelihood of VF agglomeration and stresses the concentration, requiring less energy for crack expansion. Meanwhile, IS increased to 20 wt% of all composites with VF content. The reasons are that VF may absorb energy and compression stress, and because VF and LDPE mix well together, this reduces the contents of the composite void. The higher IS of 16.4 kJ/m² is noted for the composites reinforced with 5 mm VF length at 20% VF content, which is 123.6% higher than the virgin LDPE.

The effect of VF content and VF length on the IS of the modified VF-reinforced LDPE composites is given in Figure 6(b). It can be observed in Figure 7(b) that interface bonding raises the IS of the composite with rising VF length and develops the mechanical bonding between VF and LDPE [30]. This is accredited to SDS treatment's influence on VF's structure. NFs are made up of small fibrils bonding together by noncellulosic substances (e.g. hemicellulose, lignin, pectin, wax and oil coating). As a result, SDS treatment changes the orientation of the highly packed crystalline cellulose sequence, modifies the molecular structure of the cellulosic material, and produces an amorphous region as a result of the noncellulosic extraction, which allows the fibrils to reorganize themselves

along the direction of the applied impact load. The extraction of these elements also divides the fibers into smaller fibrils, which increases the size ratio (length/diameter) of the fiber due to the reduction in its diameter. While SDS treatment produces clean and rough fibrils that facilitate both mechanical interlocking and bonding, SDS treatment also modifies the hydrophilic properties of VFs, making them more compatible with hydrophobic LDPE matrix. This outcome improved interface adhesion between LDPE and VF.

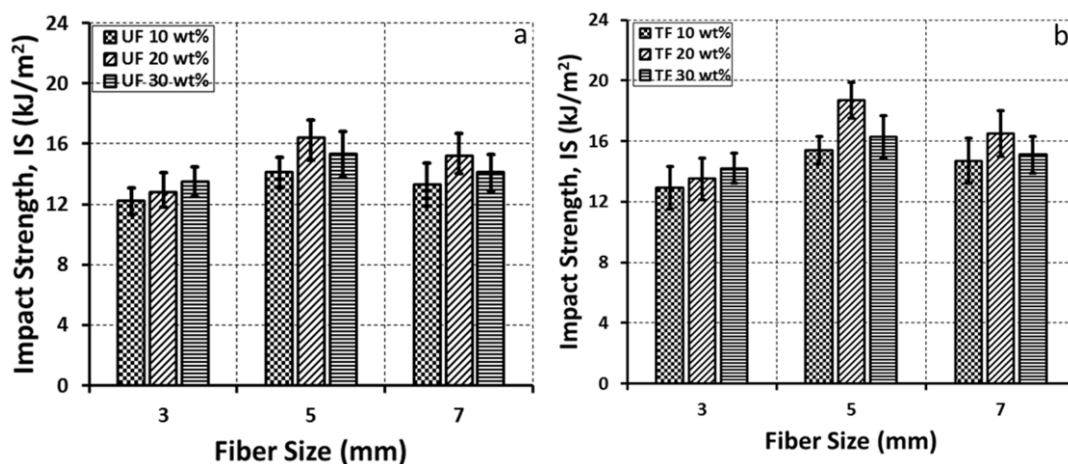


Fig. 7. Effect of fiber size (mm) and fiber content (wt%) on impact strength (IS) of (a) untreated and (b) treated VF-reinforced LDPE composites

3.5 Fracture Toughness

In the current research, fracture toughness (FT) has been evaluated using a linear elastic fracture mechanics test according to ASTM D5045 for VF-reinforced LDPE composites from a crack ratio of 0.3 to a sample ratio. The FT results of untreated and untreated VT composites, depending on the VF content and VF length, are shown in Figures 8(a) and 8(b), respectively. The FT of the composite increases with an increase of 3 to 5 mm VF length and 20 wt% of VF content. The test value of FT shows a rising trend with the rise of VF content, which shows the improved strength of the material to prevent fracture, and it may be the process of extrinsic hardening that works behind the crack tip after the crack expansion [31]. 7 mm VF length and 30 wt% VF content result in lower FT. It can be observed that the FT of chemically treated VF-reinforced composite was higher than that of untreated VF-reinforced composite. The increased FT of chemically treated composites was due to the strong adherence between treated VF and LDPE. It can be seen from Figure 8(b) that the optimal FT at 3 mm and 5 mm was observed in 20 wt% VF content, where the maximum FT of the system was observed at 5 mm and 20% VF content. Extended VF interaction with the LDPE with sufficient VF content improved FT. As a result, LDPE and VF now have acquired interfacial adhesion. The outcomes of VF length of 7 mm and 30 wt% VF content show that FT reduced because LDPE is not strong enough to inhibit VF. A maximum FT of 5.8 MPa is observed for composites with 5 mm VF length and 20 wt% VF content.

3.6 Effect of SDS Treatment Time

Figures 9(a) and 9(b) show the TS, IS, CS, TM, CM, and FT of composites for SDS treatment time (2, 4, and 6 h), respectively. Effect of SDS treatment time on VF of all mechanical properties such as strength (TS, CS and IS), modulus (TM, and CM), and fracture toughness (FT) in constant VF length (5

mm) and VF content (20 wt%) at varying treatment time were also studied. It can be observed that all the mechanical properties of the composite increase sharply with the rise in SDS treatment time up to 6 hours. Maximum increments in TS, IS, CS, TM, CM and FT were observed for 6 h of VF treatment, which is about 11%, 25%, and 18% and 8%, 13%, and 35%, respectively, when compared to 2 h treatment on VF. This proves that the most suitable holding time is 6 hours, as shown in Figure 9. The primary reason for the development in the mechanical properties of the 6-hour treatment compared to the 2-hour treatment is the development of the interfacial bond due to the SDS treatment. The SDS treatment increases the VF's surface roughness, which improves the material's ability to interlock with the LDPE matrix mechanically. The primary VF wall is where the crystalline region of parent cellulose dissolves during SDS treatment. The lignin and hemicellulose associated with VF dissolve, which causes the surface roughness to increase.

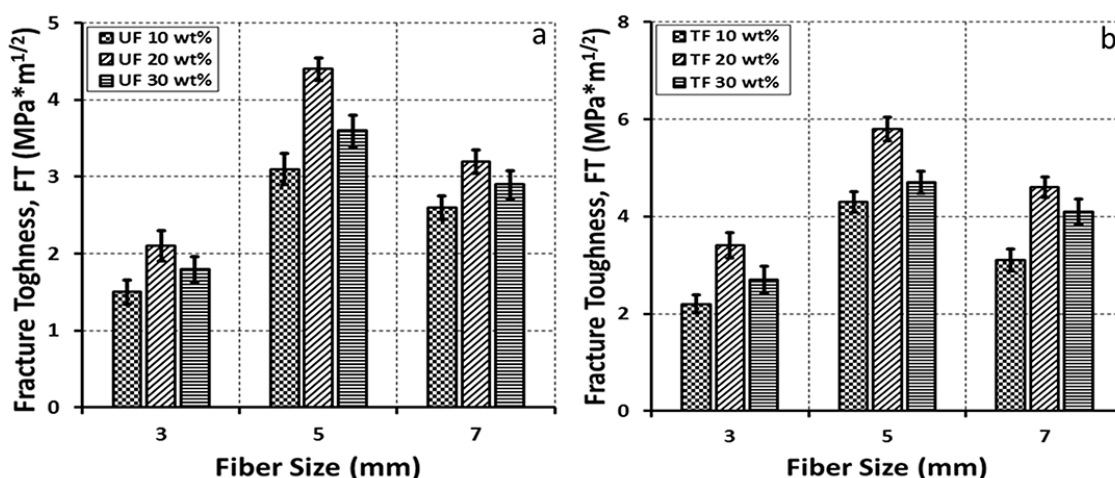


Fig. 8. Effect of fiber size (mm) and fiber content (wt%) on fracture toughness (FT) of (a) untreated and (b) treated VF-reinforced LDPE composites

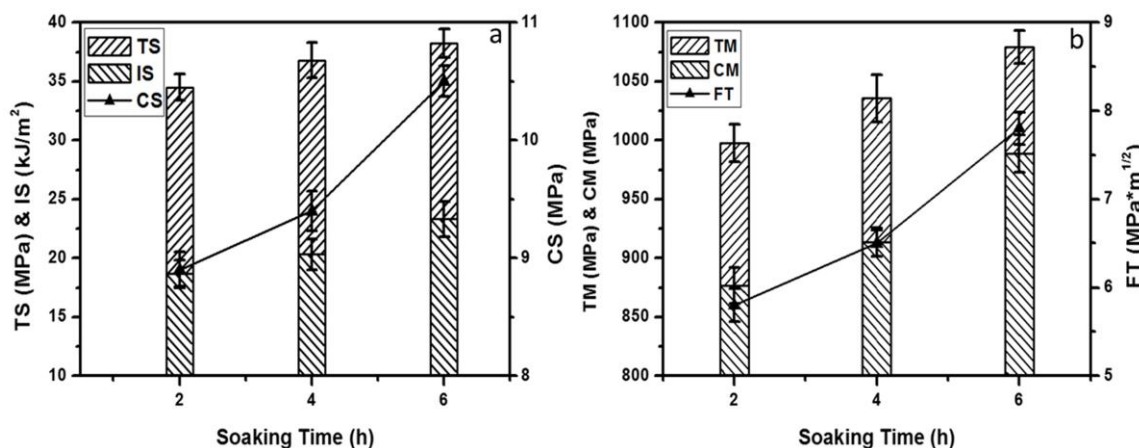


Fig. 9. Effect of treatment time on (a) tensile strength (TS), compressive strength (CS) and impact strength (IS) and (b) tensile modulus (TM), compressive modulus (CM), and fracture toughness of composites

For this reason, the surface topography of the VF for 2 hours of treatment is changed to an uneven surface with fine undulation for 6 hours of treatment. Increasing the surface roughness increases the contact area, ensuring better mechanical interlocking with the LDPE matrix. Furthermore, SDS treatment of VF enhances the smoothing of the surface of VF, creates chemical interactions, and, of course, improves the mechanical properties of the composite material.

3.7 Morphological Observation

Scanning electron microscopy (SEM) micrographs of fractured surfaces from the tensile test were conducted to examine the morphology of the thermoplastic vetiver fibre composites. The fractured surfaces of thermoplastic composites are shown in Figure 10. SEM micrograph of the composite's tensile fracture surface with a 3 mm fiber size and 20 wt% VF content is shown in Figure 10(a).

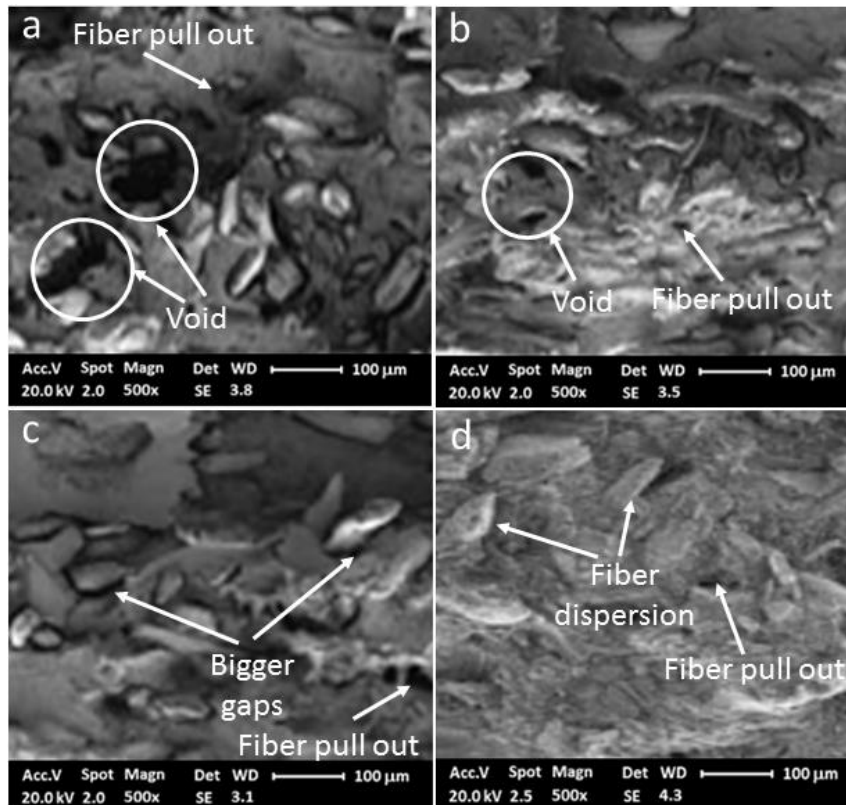


Fig. 10. SEM micrograph of a fractured surface of (a) untreated VF/LDPE (3 mm VF length), (b) untreated VF/LDPE (5 mm VF length) (c) untreated VF/LDPE (7 mm VF length), and (d) treated VF/LDPE (5 mm VF length) composites with 20 wt% VF content

As can be seen from Figure 10(a), there are areas where the VFs have been pulled out and where there are vacuum spaces around them. Because of the constant application of tensile force on the specimens, fractures formed in the void region. The applied load acting on the specimens causes the fracture to propagate, ultimately resulting in the composites' complete failure. This could be because of the poor adhesion between the VFs and the polymer matrix. These all point to irregularities and poor adhesion between VF and LDPE, which means that this composite's interfacial structure is unable to transfer stress efficiently. This finding aligned with the low tensile strength values shown in Figure 3(a). A tensile fracture surface with 20 wt% VF content for a 5 mm fiber size is depicted in Figure 10(b). It displays tiny gaps and strong VF and LDPE matrix interfacial contact. After tensile testing, only little fiber pull-outs that were covered in the LDPE matrix were seen. Dominant defects in the LDPE matrix are seen in the microstructural micrograph of a composite with a 7 mm VF length and a 20 wt% VF content (Fig. 10, c). It is evident from the figure that weak interfacial bonding causes the VFs to separate from the LDPE surface. Additionally, the clean surfaces of the pulled-out VFs are noted. VFs can be chemically treated prior to composite fabrication to increase the adhesion

between the fiber and matrix. By doing this, the fiber-matrix stress transfer will be improved, and the number of fiber pull-outs will be decreased, improving the tensile strength. Compared to untreated samples, treated samples exhibited superior bonding. The LDPE matrix of SDS-treated composites with a 5 mm VF length and a 20 wt% VF content (Figure 10, d) exhibits no defects such as fractures and voids but does show a few fiber pull-outs. It demonstrates that the interfacial adhering between VF and LDPE has been significantly enhanced by SDS treatment, improving the characteristics to a greater value than other composites.

4. Conclusions

In this research work, new composites have been made with vetiver fiber and low-density polyethylene resins. Composite samples have been tested for tensile, compressive, and impact properties and fracture toughness. The morphology of the fractured surface of the tensile-tested samples is studied. Both the size of vetiver fiber and the percentage of vetiver fiber content affect the mechanical properties and the morphology of composites. Strength properties such as tensile, compressive, and impact strength and fracture toughness of composites increase with increasing vetiver fiber content up to 20 wt% and then decrease. Consequently, 20 wt% of the best vetiver fiber content is available for better mechanical properties. Correspondingly, 5 mm vetiver fiber length effectively raises composites' strength properties and fracture toughness. However, the tensile modulus of the composite rises with rising vetiver fiber content up to 30 wt% and vetiver fiber length up to 7 mm. But the compressive modulus of the composite rises with rising vetiver fiber content up to 20 wt% and vetiver fiber length up to 5 mm. Maximum compressive modulus was obtained for composites with 5 mm vetiver fiber length and 20 wt% vetiver fiber content. Tensile, compressive and impact properties and fracture toughness of sodium dodecyl sulfate treated composite is superior to all other composites. A comparison of untreated and sodium dodecyl sulfate-treated composites showed that sodium dodecyl sulfate improved tensile strength by 11%, tensile modulus by 5%, compressive strength by 17%, compressive modulus by 19%, impact strength by 14%, and fracture toughness by 32%. The optimized treatment time for vetiver fiber was 6 h. SEM photomicrographs exhibited clear evidence of several imperfections in untreated samples and qualitative improvement of those imperfections in sodium dodecyl sulfate-treated samples.

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