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The Influence of Process Parameters on Tensile Properties of Vetiver Fiber-Reinforced Polymer Matrix Composites

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Haydar Uz Zaman[1,*]

[1] Department of Physics, National University of Bangladesh and Institute of Radiation and Polymer Technology, Bangladesh Atomic Energy Commission, P.O. Box-3787, Savar, Dhaka, Bangladesh

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ABSTRACT

Due to their outstanding specific strength and modulus, fiber-reinforced polymer composites have long been influential in a range of applications. Composites made of thermoplastic and vetiver fiber (VF) offer an alternative to synthetic polymers that cause environmental contamination. The advantages of natural fibers (like banana, sisal, coir, jute, vetiver, flax, hemp, kenaf, etc.) over conventional reinforcing fibers (glass and carbon fiber) are their ease of procurement, renewability, non-corrosive nature, light density, biodegradability, high specific energy (strength of density ratio), and low cost. In place of costly chemical treatment of VF in polymer composites, VF length management has been offered as a low cost and ecologically friendly alternative. In the current study, VF-reinforced low-density polyethylene (LDPE) composites were altered using the film process stacking method with the hot press compression molding technique using a variety of process parameters, including VF condition (untreated and sodium dodecyl sulfate (SDS) treatment), VF sizes (short VF < 3 cm and long VF > 3 cm), and VF percent (5, 10, and 15 wt%). The tensile modulus and modulus efficiency factor of the LDPE composite were studied in relation to the impacts of VF size, VF content, and SDS treatment. The results showed that a specific amount of tensile modulus and modulus efficiency factor was boosted by VF content up to 10 wt%, processing temperature up to 160°C, and SDS treatment during processing up to 5 hours due to an increase in load bearing and interfacial adhesion. The improvement in tensile modulus and its efficiency factor because of efficient load transfer is evidently attributable to long VF load transfers, which have had a favourable impact. The brittle nature of the fibers caused a loss in ductility.

Keywords:
Composite, Vetiveria Fiber, Low-Density Polyethylene, Sodium Dodecyl Sulfate-Treatment, Tensile Properties

1. Introduction

Because of the high cost and potential health and environmental hazards, synthetic fibers are being used less and less in polymer-based composites. In many areas of polymer composites today,

* *Corresponding author.*
E-mail address: haydarzaman07@gmail.com (Haydar Uz Zaman)

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the usage of natural fibers as an alternative fiber reinforcement material has grown quickly [1-4]. Nowadays, natural fiber composites are widely employed in a variety of industries, such as civil construction, mechanical construction, electrical and electronic equipment, automobile industry factories, aircraft production, and much more [5-8]. This is because these materials have such an excellent and unique combination of mechanical and physical properties. There has been a great deal of study done on synthetic composites comprised of synthetic fibers and synthetic matrix bases, like glass, carbon, nylon, and Kevlar [9, 10]. Synthetic fiber-reinforced thermoset or thermoplastic composites outperform natural fiber augmented composites due to their higher strength, durability, deterioration resistance, and moisture resistance qualities. In comparison to thermosets, thermoplastic composites are preferred by scientists because they require less processing and have lower production costs. Synthetic fiber use is quite dangerous for the environment because they are not sterile. As lignocellulosic components are made from fibers and thermoplastic/thermoset polymers as composites because of growing environmental consciousness, the matrix is being studied every day. Natural fibers have a number of benefits over conventional plastic or synthetic components, including low cost, low density, appropriate required strength, renewability, recyclability, and biodegradability.

Plant fibers, which come from agroforestry crops, are recyclable materials that can be applied in a number of engineering specialties. Plant fibers also present less safety and health risks for workers and are thermally recyclable and renewable. Plant fibers including jute, vetiver, caltropis gigantea, flax, and banana are attractive alternatives to glass fibers that are also environmentally beneficial for use as reinforcement in engineering composites. Vetiveria grass is one of the most desirable possibilities for usage as a reinforcing filler in polymer composites among other natural fibers. The perennial grass Chrysopogon zizanioides, usually referred to as vetiver, also goes by the name Vetiveria zizanioides. India, Bangladesh, Vietnam, Thailand, and other nations are the main producers of vetiver grass. The length of vetiver roots can reach five meters, and they have good mechanical properties [11]. Hemicellulose, cellulose-type-I, lignin, and other low molecular weight materials can be found in vertiver grass fiber, a lignocellulosic biofiber. In particular, when low density and low-cost characteristics are taken into consideration, glass fibers can be replaced with VFs. Because they have a high calorific value and provide less health and safety issues when handling fiber products, VFs can be recycled, are nonabrasive, and can be utilized for energy recovery. In addition, they have excellent mechanical strength, low density, availability, biodegradability, safety from health hazards, and low cost [12, 13]. NFs must have a superior price-performance ratio of low weight with eco-friendly features in order to be accepted in large-scale engineering applications like the automotive and construction industries [14].

Possesses a dominant position in relation to a variety of materials used in the plastics industry, including polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), and polythene (PE) [15]. After their useful lives, the usage of these materials for burning or landfilling results in environmental issues [16]. Reducing the usage of natural fiber blends in the production of composite materials will help solve this issue [17]. Natural reinforcing fillers used in plastic composites can be inexpensive and play a significant part in helping to solve ecological issues that we may face in the future [18]. In this study, a plastic composite was created using natural fibers and the polymers LDPE and VF as the matrix. A typical thermoplastic substance, LDPE is used to make plastic bags, washing bottles, dispensing bottles, and a variety of laboratory equipment that is molded. Because of their extended service lives and chemical stability, LDPEs pose environmental issues when they are disposed away. But without sacrificing the ecological and financial advantages of the materials, LDPE can be combined with natural filler to make composites for the specified technological use. Due to the polarity difference between the hydrophilic natural filler and the hydrophobic polymer matrix, the inclusion of unaltered natural fibers generally reveals the weak characteristics and inconsistencies of the composite [19-21]. The mechanical properties of composites can be improved by improving the interfacial adhesion between VFs and LDPE matrix by wetting agents. To improve the interfacial adhesion between fibers and polymers prior to the creation of composites, natural fibers are frequently chemically treated (e.g., alkaline treatment [6], silane treatment [22], and the use of compatibilizers [7]). This increases the mechanical properties of the composites. It is possible to enhance the coupling and contact between VF and LDPE matrix by using sodium dodecyl sulfate (SDS), which is a powerful coupling agent. However, no studies have been conducted using the surface of VFs treated with sodium dodecyl sulfate (SDS), despite the fact that natural fiber characteristics have been the subject of much research.

To improve the characteristics of the LDPE/VF composites, the SDS was used as a coupling agent in this study. In the manufacture of biomaterials, sodium dodecyl sulfate (SDS), an anionic surfactant, is frequently utilized [23]. SDS was reportedly utilized as a coupling agent to improve the filler-matrix adhesion between coconut shell-recycled polypropylene, according to some researchers [24]. In this study, LDPE composites reinforced with vetiver fiber were produced under various processing circumstances by hot compression molding. This study set out to determine the impacts of the tensile modulus, modulus efficacy factor, and ductility of the made composites on the amount of fiber used, the length of the fibers, the processing temperature, and the processing duration of the SDS treatment of VF.

2. Methodology

2.1 Materials

As a polymeric matrix, low-density polythene (LDPE) with a melting flow index (MFI) of 4.0 g/10 min was utilized, which was provided by Polyolefin Company, Pvt. Ltd., Singapore. The uncooked vetiver root was procured in Bangladesh from regional suppliers. Table 1 [25] lists the characteristics and constituents of vetiver fibers.

Table 1
Lists the traits and chemical composition of vetiver fibers [25]

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	
Cellulose	72.6%
Lignin	17%

2.2 Methods

2.2.1 VF-reinforced LDPE composite manufacturing

To strengthen the composites, VF was used in a variety of shapes, including untreated short fiber, USVF (less than 3 cm) and untreated long fiber, ULVF (more than 3 cm), respectively. The moisture content of the VFs was reduced to less than 4% by washing them with distilled water and then letting them dry outdoors in the sun for 48 hours. The VFs were dried and then cut with scissors to the specified lengths. With equal fiber volume contents of 0% (i.e., virgin resin), 10%, 20%, and 30%, respectively, short and long fiber composites were created at random with the fibers' distribution. The relationship shown below is used to compute the volume fraction of fiber (Vf) [26].

$$V_f = \frac{(W_f/\rho_f)}{(W_f/\rho_f) + (W_m/\rho_m)} \tag{1}$$

where, ρf and ρm are the reinforcement and matrix densities (in g/cm3), respectively, and Wf and Wm are the weights of the fiber and the matrix (in g), respectively. The fiber volume percent was calculated using an average density of 1.3 g/cm^3, with minimum and maximum values of 1.23 g/cm^3 and 1.32 g/cm^3, respectively. LDPE had a density of 0.92 g/cm^3, but VF had a different density. To ascertain the tensile modulus of a composite material, apply the modified principles of the mixing given in Eq. (2):

$$E_c = \alpha E_f V_f + E_m (1 - V_f) \tag{2}$$

$$\text{or,}\ \alpha = \frac{E_c - E_m (1 - V_f)}{V_f E_f} \tag{3}$$

where the terms E_c, E_f, E_m, V_f, and stand for the respective tensile moduli of the composite material, the fibers, the matrix, the fiber volume fraction, and the modulus efficiency factor. The modulus efficiency factor is influenced by a number of factors, including fiber length, position, distribution, and resin wetting of the fibers [27]. The tensile modulus of LDPE was 275 MPa, but the minimum and maximum VF moduli were 10.1 GPa and 19.6 GPa, respectively. The average value, 14.5 GPa, was utilized to determine the VF modulus efficiency factor.

LDPE sheets and LDPE/VF composite samples were produced using a hot press machine. The hot press machine comprises of two metal plates that can be heated electrically, pressed by an air piston to create pressure, and have a cooling system installed. The manufacturing of thermoplastic composites involved two processes. The LDPE granules were initially compressed for roughly ten minutes at 150°C and eight MPa of pressure, and then the sheets produced were cooled to ambient temperature using a cooling water system for the required ten to fifteen minutes. The second method used to construct the composite samples was the film stacking approach, in which the fibers were randomly arranged between two polymeric sheets before being heated by a hot press machine. To investigate the effect of fiber content and length on the tensile properties of composites, randomly arranged short and long fibers were sandwiched between two sheets of LDPE, then hot pressed under the same processing conditions.

SDS powder was dissolved in ethanol at a temperature of 40°C to create SDS solution. SDS was employed in an amount equal to 3% of the fiber's weight. The mixture was then cooled until it was at room temperature. Short VFs were submerged in this solution at room temperature for 1, 3, and 5 hours in order to study the impact of SDS treatment on the tensile modulus of produced composites. Then, 10 weight percent SDS-treated short VFs-based composites were produced utilizing the same machine and processing setup. To examine the impact of processing temperature on the tensile modulus of the created composite, five samples containing 10 weight percent of untreated short VF were prepared at various processing temperatures (120°C, 140°C, 160°C, 180°C, and 200°C).

2.2.2 Tensile testing of the generated samples

Using a Sinowon testing machine ST series, the samples' tensile characteristics were tested at room temperature at a constant speed of 4 mm/min. Five specimens with dimensions of 20 mm in width, 70 mm in length, and 2 mm in thickness were evaluated for each composite. The test was conducted in accordance with ASTM D638-14, which is the industry standard test technique for tensile characteristics of plastic.

3. Results and Discussion

3.1 Mechanical Features of Composite Material

The fiber-matrix interfacial bond strength, fiber content, fiber sizes, and processing temperatures were all significantly influenced by the tensile properties of composites. Based on the interfacial bonding and dispersion between the hydrophobic matrix and the hydrophilic filler, the composite's flexural characteristics are established. Figure 1 depicts the impact of short fiber contents on the tensile modulus of the composites that were created. Figure 1 shows that the tensile modulus of the composites generated increases with increasing fiber concentrations to reach its maximum value at 10 weight percent, at which point it begins to decline. The mobility of polymer chains is constrained under loading since it is commonly accepted that the increase in tensile modulus is brought about by the reinforcements' strong interfacial adherence and dispersion throughout the matrix. This outcome suggests that there is a good distribution of the fibers and that VFs have a significant reinforcing effect. Due to voids in the polymeric matrix caused by inadequate impregnation, the modulus of elasticity dramatically drops for a higher percentage of VFs. For example, a composite with a 15 wt% VF content has some weaker LDPE areas, which prevents stress from being transferred between LDPE and VF. On the other hand, mixing issues that arise during the manufacturing process can lead to voids and imperfections that can serve as a crack tip and hasten the premature failure of the composite [28].

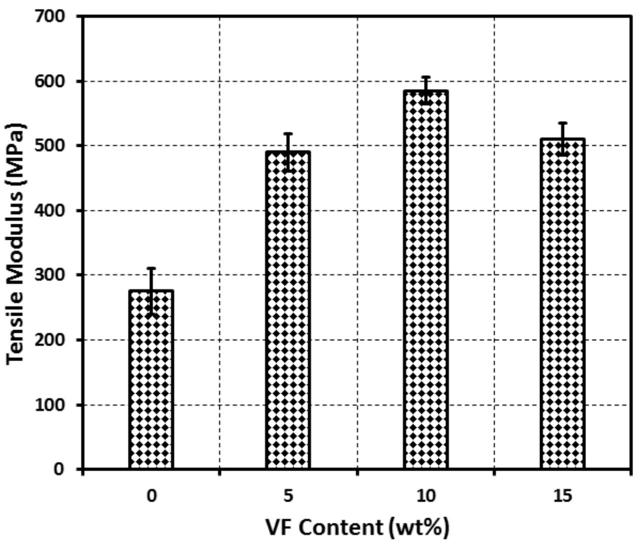

Fig. 1. Effect of untreated short VF (USVF) content on the manufactured composites' tensile modulus

Figure 2 shows that as the fiber volume fraction increased, the modulus efficiency factor fell. This suggests a loss in interfacial adhesion, which could be explained by the matrix's inability to impregnate the fibers.

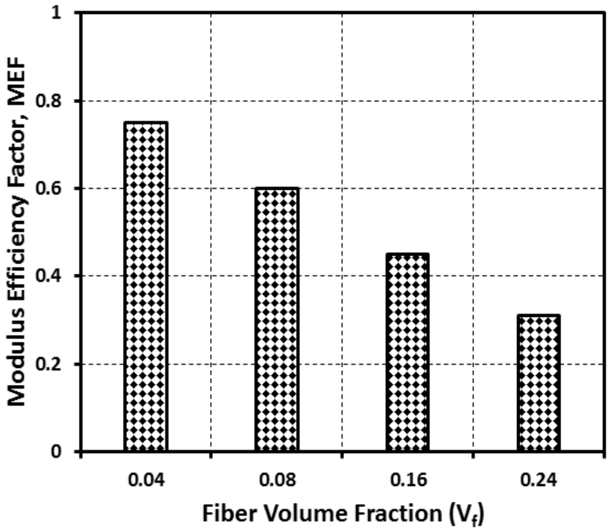

Fig. 2. Effect of untreated short VF (USVF) content on the manufactured composites' modulus efficiency factor (MEF)

Using the following equation (4), the ductility of composites was estimated as a percentage of elongation:

$$\%EL = \frac{L_f - L_0}{L_0} \times 100 \tag{4}$$

where, %EL, L_f, and L_0 are the samples' final and initial lengths, as well as the percentage of elongation. Figure 3 demonstrates that the ductility of LDPE decreases as VF concentration rises because the brittle character of the VFs limits the composites' plasticity behavior in comparison to the virgin LDPE matrix.

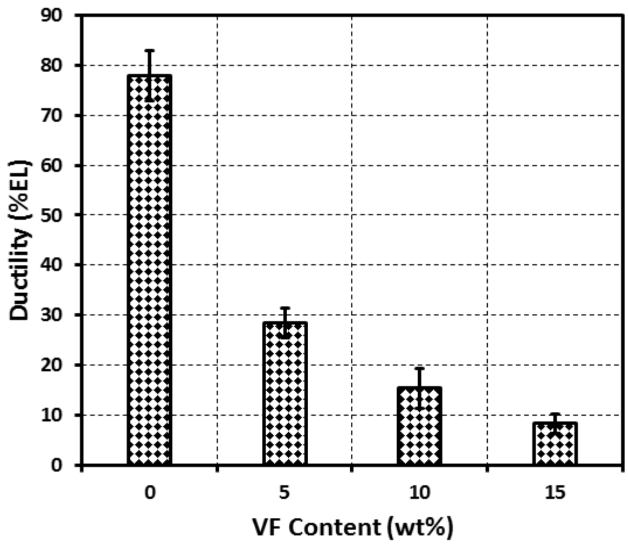

Fig. 3. Effect of untreated short VF (USVF) content on the manufactured composites' ductility (%EL)

Figure 4 shows that the tensile modulus of composites made from long fibers is greater than that of composites made from short fibers. This can be explained by the fact that the shearing process between the matrix and the fibers causes the tensile load applied to discontinuous fiber composites to be transferred to the fibers. A shear stress distribution is produced at the fiber-matrix interface by the polymeric matrix's greater strain than that of the nearby fibers. The shearing stress in the matrix, which is used to apply the tensile stresses to the fibers, is greatest close to the ends of the fibers, but the tensile stresses are zero at the ends of the fibers and gradually build to a plateau value in the middle of the fibers. As a result, the portions of the fibers close to the ends are under less stress than the midsection. The total length of fibers needed for the tensile load to plateau or reach its maximum value is frequently referred to as the fibers' critical length, and as a result, the stress borne by the fibers increases as their length grows. The tensile strength of composite materials was reported to increase as fiber length was increased [29].

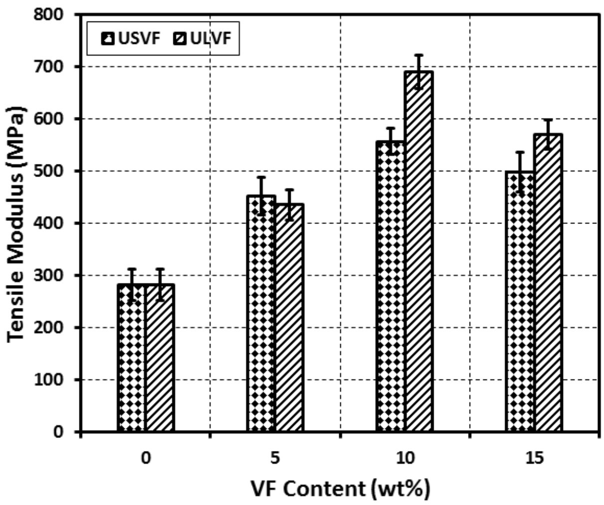

Fig. 4. Effect of fiber length on produced composites' tensile modulus

Figure 5 shows that the modulus efficiency factors for composites with long fibers are higher than those for composites with short fibers, which is related to how well stress is transferred from the polymeric matrix to the fibers when long fibers are utilized. Due to their effects on the impregnation of reinforcements, processing temperature, pressure, and time have a significant impact on the mechanical properties of composite materials. It has been reported that these variables had a significant impact on the tensile strength of unidirectional long Kenaf fiber-reinforced polylactic acid composite [30].

The tensile modulus of untreated long vetiver fiber, ULVF/LDPE composites is shown in Figure 6 as a function of the processing temperature. The tensile modulus of the composite produced is improved by increasing the processing temperature to 160°C, as can be shown in Figure 6. Raising the processing temperature improves volumetric flow, which is connected to how processing temperature affects the melting viscosity of LDPE. LDPE melting rate caused by a decrease in the viscosity of the polymeric molten state leads to improved compaction and fewer voids in the final composite. However as shown in Figure 6, increasing the processing temperature above 160°C lowers the tensile modulus of the resulting composites. This is related to the fact that cellulosic reinforcements start to lose their strength at temperatures above 160°C as a result of their structural degradation [31].

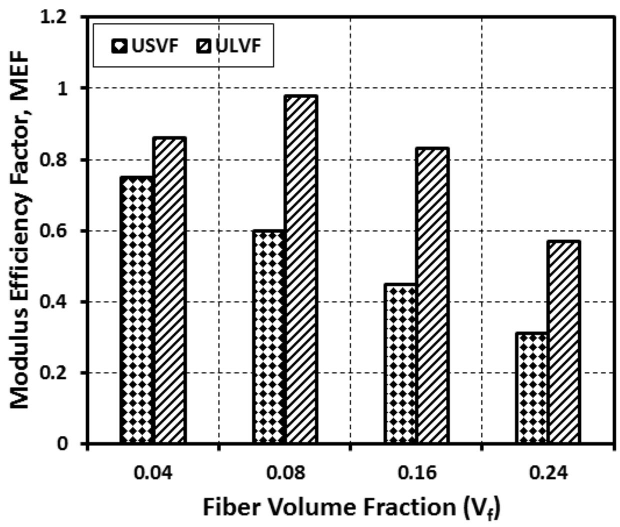

Fig. 5. Effect of fiber length on produced composites' modulus efficiency factor (MEF)

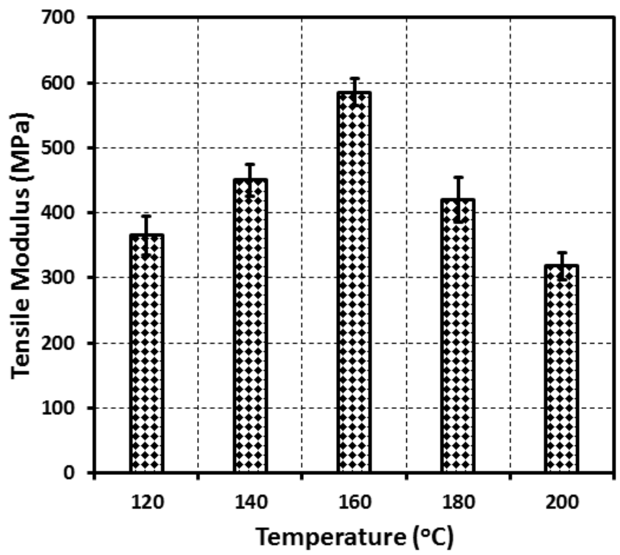

Fig. 6. Tensile modulus effects as a function of processing temperature

As can be seen in Figure 7, the modulus efficiency factor rises with processing temperature up to 160°C before beginning to fall. This rise is thought to be caused by an improvement in the degree of VF impregnation, which reduces the void content. The decrease in the modulus efficiency factor at higher temperatures is thought to be caused by VF degradation, which decreases their mechanical properties.

The tensile modulus and modulus efficiency factor of SDS treatment of VF-reinforced LDPE composites are shown in Figures 8(a) and 8(b) as functions of SDS treatment time. Figure 8(a) illustrates how the tensile modulus of the composites has increased as the SDS treatment period has increased. This is attributed to SDS treatment's impact on the development of VFs. Small fibril linkages that are connected to noncellulosic components including hemicellulose, lignin, pectin, wax, and oil coating material create NFs; as a result, SDS treatment changes the molecular structure of cellulosic materials by changing the arrangement of highly packaged crystalline cellulose. The removal of these components causes the fibers to be divided into smaller fibrils, increasing the fiber size ratio (length/diameter) because the fiber diameter is reduced, and allowing the fibrils to reorganize themselves in the direction of the applied flexible load. As well as producing clean, coarse fibrils that help with mechanical interlocking and bonding, SDS treatment also modifies the hydrophilic properties of VF, making them more compatible with the hydrophobic LDPE matrix. As a result, the LDPE matrix and VF exhibit better contact adhesion.

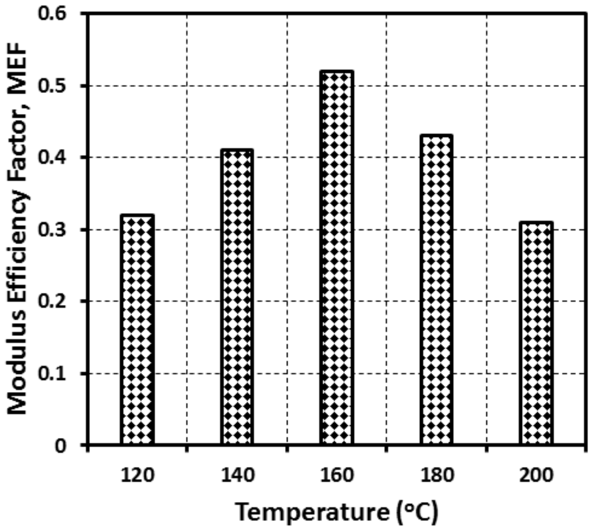

Fig. 7. Modulus efficiency factor effects as a function of processing temperature

The growth of the interfacial adhesion between the VFs and the LDPE matrix is connected to the modulus efficiency factor, which is shown in Figure 8(b) as increasing with time during the SDS treatment. The tensile and flexible characteristics of ramie fiber-reinforced epoxy composite were said to have been enhanced by using SDS-treated ramie fiber.

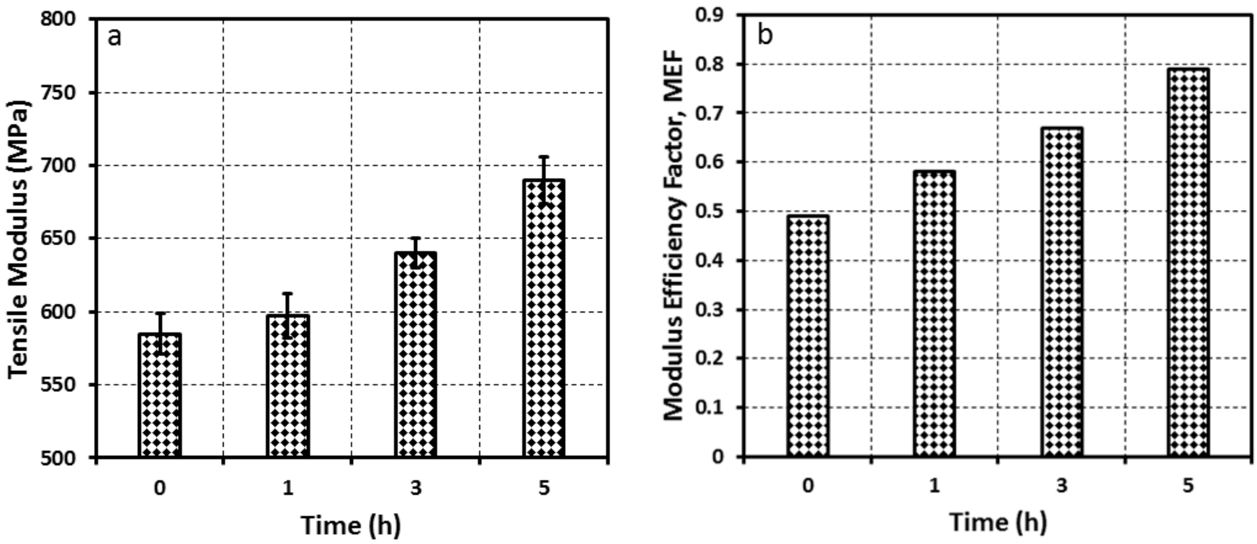

Fig. 8. (a)Tensile modulus, and (b) modulus efficiency factor of the produced composites as a function of the SDS treatment period

4. Conclusions

The tensile modulus of vetiver fiber-LDPE composites was shown to be improved by the incorporation of short vetiver fibers up to 10% weight percentage. Conversely, when high fiber concentrations were utilized, the tensile modulus fell because of inadequate impregnation, which raised the void content and lowered the modulus efficiency factor. Due to the brittle nature of fibers, on the other hand, the ductility of the composites was decreased by increasing the short fiber percentage. Due to the effectiveness of stress transfer between the matrix and the fibers as the fiber length increases, the degree of improvement in the tensile modulus of the composites was improved when long fibers were used. The modulus efficiency factor for long vetiver fibers-based composites is higher than that for short vetiver fibers-based composites. The processing temperature was found to affect the tensile modulus of the composites because it affects the viscosity of LDPE, which lowers the void content due to an improvement in the degree of vetiver fiber impregnation, leading to an increase in the modulus efficiency factor. However, when temperatures above 160°C were applied, the tensile modulus of the composites was reduced, which may be related to the degradation of the fibers. The interfacial adhesion between the fibers and the polymeric matrix is improved by SDS treatment, which also increases the modulus efficiency factor. This improvement in interfacial adhesion was found to improve the tensile modulus of the composites, though the degree of improvement was found to be dependent on the length of the SDS treatment.

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