Preparation and Characterization of *Sansevieria trifasciata* Fiber/High-Impact Polypropylene and *Sansevieria trifasciata* Fiber/Vinyl Ester Biocomposites for Automotive Applications

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Abstract. The increasing demand for vehicles is resulting in environmental problems, such as a higher demand for fossil fuels and higher CO_2 emissions. Lightweight materials, such as fiber-reinforced polymers, have been used in automotive components to reduce the weight, fuel consumption, and CO_2 emissions of vehicles. Natural fibers are often used as substitutes for glass fibers because they are abundant and require less energy to produce compared to glass fibers. The present research focused on the preparation and characterization of composites reinforced with *Sansevieria trifasciata* fiber (STF). High-impact polypropylene (HIPP) and vinyl ester (VE) were chosen and compared as matrix materials. The results showed that the mechanical properties of the produced biocomposites increased with increasing amounts of fiber, alkaline treatment, and unidirectional fiber orientation. A tensile strength of 59.77 MPa and a stiffness of 1.97 GPa were obtained for STF/HIPP composites with unidirectional alkali treatment and a 15% volume fraction of fiber. Moreover, a tensile strength of 121.1 MPa and a stiffness of 7.65 GPa were obtained for STF/VE composites with unidirectional alkali treatment and a 15% volume fraction of fiber. The STF/VE biocomposites were comparable to commercial glass fiber composites for automotive applications and even exhibited greater tensile strength properties.

Keywords: Biocomposites; High-impact polypropylene; *Sansevieria trifasciata*; Vinyl ester

1. Introduction

The increasing use of vehicles such as cars and motorcycles is causing environmental problems, such as high CO_2 emissions and a fossil fuel shortage. Lightweight materials, such as fiber-reinforced polymers, have been used in automotive components to reduce the weight, fuel consumption, and CO_2 emissions of vehicles (Ramesh et al., 2017). Fiber-reinforced polymers exhibit excellent mechanical properties. However, the use of glass fibers for reinforcement can bring about other environmental problems, as these fibers are non-degradable and require high energy for processing. Natural fibers are often used as substitutes for glass fibers because they are abundant and require less energy to produce compared to glass fibers. Recently, the utilization of polymers reinforced with natural fibers or biocomposites has been growing, especially for interior and exterior parts in the

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automotive industry (Thakur and Thakur, 2014; Väisänen et al., 2016). Biocomposites offer many advantages, such as high strength, low weight, biodegradability, corrosion resistance, and low cost (Sreenivasan et al., 2011; Najafi, 2013). Natural fibers are also biodegradable because they attract microorganisms (Surip and Jaafar, 2018). Some products for instance sports equipment, electronic housing or vehicle panel have been reported to use natural fibers, such as hemp, banana, kenaf, wood, and pulp fibers (Miléo et al., 2011; Faruk et al., 2012; Suharty et al., 2016; Ramesh et al., 2017; Sharath Shekar and Ramachandra, 2018). For example, Fatra et al. (2016) reported on the properties of alkaline-treated oil palm empty fruit bunch fiber-reinforced polypropylene composites. The results showed that the highest tensile strength (20.1 MPa) was achieved with an alkaline concentration of 5 wt.%, a soaking time of 36 h, and 3-cm fibers. In this case, the utilization of natural fibers is likely to decrease pollution and other environmental problems. Natural fiber materials have been proven to serve as effective alternatives to glass fiber reinforcement polymers.

According to the literature, natural fiber-reinforced composites (or biocomposites) exhibit mechanical properties comparable to those of glass fibers. More specifically, some studies have shown that the mechanical properties of flax, hemp, jute, and sisal fibers can compete with those of glass fibers (Gurunathan et al., 2015). Other research has shown that tensile and modulus properties tend to increase with increasing fiber volume fractions (Sankar et al., 2014). Although glass fiber is the primary reinforcement material used in composites for automotive applications, biocomposites have shown good potential for future development. The energy requirements for processing glass fiber exceed those of natural fiber. For example, 6,500 BTUs of energy are required to produce a single pound of kenaf fiber, whereas 23,000 BTUs are required to produce a single pound of glass fiber (Akampumuza et al., 2017). Over the last two decades, many works have aimed to apply biocomposites for automotive purposes. Furthermore, many researchers have reported on the advantages of natural fibers, such as their availability, non-toxicity, renewability, cost-effectiveness, and mechanical properties (e.g., toughness, strength, and stiffness; Rajak et al., 2019). Examples of biocomposite applications in the automotive industry include the rear panel shelves of the Mercedes-Benz C-Class models built in South Africa (made from sisal-reinforced composite), the inner door panels of the Opel Corsa (made from flax-reinforced polypropylene composites), and the interior door linings and panel of the BMW 7 Series (made using 24 kg of renewable materials). The use of natural fiber-based composites can reduce the weight of vehicles by 10–15% (Akampumuza et al., 2017).

In the present work, natural fiber biocomposites were derived from *Sansevieria trifasciata*, commonly called the "*lidah mertua* (in-law's tongue)" plant. This plant is plentiful in Asia and Africa and is often used for decoration. Several studies have discussed the potential use of *Sansevieria trifasciata* for reinforcement in a polymer matrix. Sreenivasan et al. (2012) investigated the tensile, flexural, and impact properties of randomly oriented short *Sansevieria* cylindrical fiber/polyester (SCFP) composites. Mechanical property tests revealed that these composites had a tensile strength of approximately 76 MPa, a Young's modulus of 1.1 GPa, and an elongation at break between 7% and 8.3%. The flexural strength of these composites was 84 MPa, the flextural modulus was 3 GPa, and the impact strength was 9.5 J/cm^2. Venkatachalam et al. (2016) investigated the tensile properties of S*ansevieria trifasciata* fiber (STF)-reinforced polyester composites with five different fiber lengths (2, 4, 6, 8, and 10 mm). The results showed that tensile strength increased as the fiber length increased. However, the elongation at break was not significantly affected by the fiber length. The highest tensile strength (40 MPa) was found at a fiber length of 10 mm. Mardiyati et al. (2016) studied the effects of alkali treatment on the mechanical and thermal properties of STF. Chesson-Datta methods were used to

determine the lignocellulose content of raw *Sansevieria* fibers and to investigate the effect of alkali treatment on the lignin content of these fibers. The obtained cellulose and lignin contents were 56% and 6%, respectively. Mechanical testing showed that the tensile strength increased from 647 MPa for raw fibers to 902 MPa for 5 wt.% NaOH-treated fibers. Zakaria et al. (2018) investigated the effects of fiber size (1 mm, 500 μm, 250 μm, and 125 μm) on the mechanical, morphological, and thermal properties of STF/natural rubber/high-density polyethylene (STF/NR/HDPE). The results showed that tensile strength and impact strength decreased and tensile modulus increased as filler loading increased. Furthermore, a fiber size of 125 μm produced the highest and most stable tensile strength and modulus values. However, previous results have not yet met the mechanical requirements for automotive applications. For comparison, the mechanical properties of commercial glass fiber composite include a tensile strength of 85 MPa, a modulus of elasticity or stiffness of 10.2 GPa in the 26 wt.% polyester resin matrix system, 28 wt.% glass fiber, and 46 wt.% minerals with an average density of 1,801 kg m^{-3} (Xia et al., 2016).

The present research aimed to develop STF biocomposites that would meet automotive application requirements in high-impact polypropylene (HIPP) and vinyl ester (VE) matrices. The selection of these materials was based on their relatively strong mechanical properties, as it is necessary to develop biocomposites with strong mechanical properties. The effects of fiber orientation and fiber content on mechanical properties were investigated as well. Finally, the mechanical properties (e.g., tensile strength, stiffness, and impact toughness) of these composites were analyzed and compared with those of a commercial-grade fiber-reinforced composite.

2. Methodology

2.1. Materials

The *Sansevieria trifasciata* leaves used in this study were sourced from Beluk, East Java. For the alkaline treatment, a 3% NaOH solution was prepared using commercial-grade NaOH from Bratachem. The matrices used to fabricate the biocomposites included VE from Bratachem and HIPP from Chandra Asri. The properties of these matrices are shown in Table 1.

Table 1 Properties of the polymer matrices used in this study

Matrix	Properties					Supplier	Reference
	Density (kg/m^3)	Melting Point (°C)	Izod Impact Strength (J/m)	Tensile Strength (MPa)	Elongation (%)		
HIPP	900	163	650	26	12	Chandra Asri	Technical Data Sheet (TDS)
VE	1,150	104–121*	250*	69–83*	4–7*	Bratachem	*(Holbery and Houston 2006)

2.2. Methods

The *Sansevieria* fibers were taken from the leaves using a mechanical retting method and then rinsed with water to remove any leaf components. Then, the fibers were left to dry at room temperature for one day. The lignocellulose content of the fibers was measured using the Chesson-Datta method. Next, the fibers underwent alkaline treatment. In the alkaline treatment process, 10 grams of STF were put into reflux with the 3% NaOH solution

at 100°C, with a fiber-to-solution ratio of 1:100 (Mardiyati et al., 2016). The heating process was carried out in two hours. Finally, the fibers were washed and neutralized with demineralized aqua and then dried at room temperature for one day. A schematic of the fiber preparation process is presented in Figure 1.
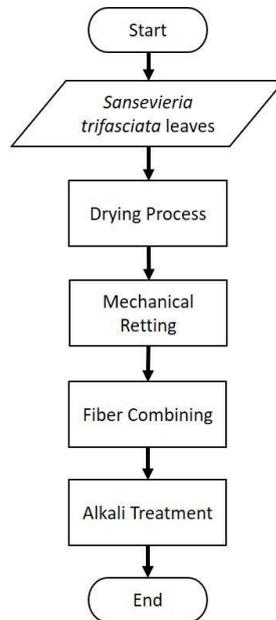
Figure 1 Schematic of the *Sansevieria trifasciata* fiber preparation process

The STF/HIPP biocomposites were made using hot compression molding at 180°C with 140 bars of pressure for 10 minutes. Meanwhile, the STF/VE biocomposites were made using compression molding at room temperature with 140 bars of pressure for 10 minutes and an aging time of two hours (Shieddieque et al., 2019). The fibers were arranged in unidirectional and random orientations with fiber volume fractions of 0%, 5%, 10%, and 15%. Figure 2 shows the preform biocomposites that resulted from the hot compression molding process with unidirectional and random fiber orientations.

(a)　　　　　　　　　　　　　　　　　　　　　　(b)

Figure 2 Preform biocomposites with: (a) unidirectional orientation; and (b) random orientation

The preform biocomposites were cut into 150 × 25 × 1.5 mm sections for the tensile test. The tensile test was carried out using a Tensilon RTF-1310 machine according to the American Standard for Testing and Material (ASTM) D3039 standard, with a gauge length of 100 mm and a crosshead speed of 2 mm min^{-1}. The average tensile strength and elongation at break values were obtained from three specimens. The impact test was carried out using a Tinius Olsen impact testing machine. The composites were cut into 125 cm × 8 cm × 8 cm sections with a 45° v-notch in accordance with ASTM D6110-04.

The densities of the biocomposites were determined in accordance with ASTM D792, and the constituent contents were determined in accordance with ASTM D3171. The fiber and fracture surface morphologies of the biocomposites were investigated using a JEOL JSM-6510 scanning electron microscope (SEM) with an accelerating voltage of 20 kV. The spectrum of functional groups of the STF was investigated using fourier transform infrared spectroscopy (FTIR). The moisture content of the fibers was determined in accordance with ASTM D2654.

3. Results and Discussion

### 3.1. Characterization of Sansevieria trifasciata Fiber (STF)

Lignocellulose describes all constituents containing cellulose, hemicellulose, and lignin. Although lignocellulose can be found in all parts of a plant's body, different percentages of lignocellulose content can be found in different parts and types of plants. Among the components of lignocellulose, cellulose is more desirable than hemicellulose or lignin. Therefore, an alkali treatment process is often carried out to obtain cellulose in a pure phase by dissolving lignin and hemicellulose. The high availability, good mechanical properties, and high degradation ability of cellulose make it worthy of utilization in the world of technology.

Table 2 shows the composition of lignocellulose in STF and other types of fiber. Although the hemicellulose content of STF is higher than that of other types of fiber, cellulose is the main constituent of STF; thus, STF can potentially be used to reinforce polymers. In the present study, hemicellulose and lignin were removed from STF through alkaline treatment (Mardiyati et al., 2016). The effects of alkaline treatment on fiber morphology have been discussed by other researchers (Shiddieque et al., 2018), and the morphologies of treated and untreated fibers can be seen elsewhere (Shieddieque et al., 2018). The surfaces of the alkaline-treated fibers became rougher than those of the untreated fibers. This condition improved the properties of the interface between the fibers and the matrices. Specifically, this roughness improved the interlocking between the fibers and the matrices and thus significantly increased the mechanical properties of the composites. Table 3 shows the improvements in mechanical properties exhibited by the STF after alkaline treatment. Furthermore, the results showed higher tensile strength and stiffness than other references. The tensile strength of the fibers contributed to the tensile strength of the composites according to the rule of mixtures (ROM). However, the ROM method can be applied based on assumptions, such as those of a homogeneous matrix, a lack of any voids, homogenous fibers, and good fiber arrangement in space (You et al., 2017). In the present study, the moisture content of the STF was 10%. However, some studies have reported natural fiber moisture contents in the range of 7–13 % (Faruk et al., 2012; Wolela, 2019).

Table 2 Composition of *Sansevieria trifasciata* fiber (STF) compared to references

| Fiber | Composition (%) | | | | Reference |
	Hemicellulose	Cellulose	Lignin	Hot water soluble	
STF	33	55	9	3	
Flax	21	71	2	6	Thakur and Thakur (2014)
Sisal	14	73	11	2	Thakur and Thakur (2014)

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Figure 3 shows the spectrum of functional groups of the STF before and after alkaline treatment, which was obtained through FTIR testing. The FTIR characterization results for the STF before and after alkaline treatment were normalized against the 896 cm^{-1} peaks, which correlated with the β-glucopyranose group on cellulose. The results indicated a decrease in absorbance at 1245, 1508, and 1760 cm^{-1} on the FTIR curve after alkaline treatment. This means that the hemicellulose and lignin in the fibers were reduced after alkaline treatment. The decrease in the peak at 1760 cm^{-1} indicates the presence of an ester group. The reduction in the ester group is closely related to the reduction of the C = O functional group, which can generally be found in hemicellulose. The decrease at 1508 cm^{-1} is closely related to the decrease in C = C, which is commonly found in lignin. Based on the FTIR characterization results (Figure 3), it can be concluded that the non-cellulose content of STF will decrease after alkaline treatment.
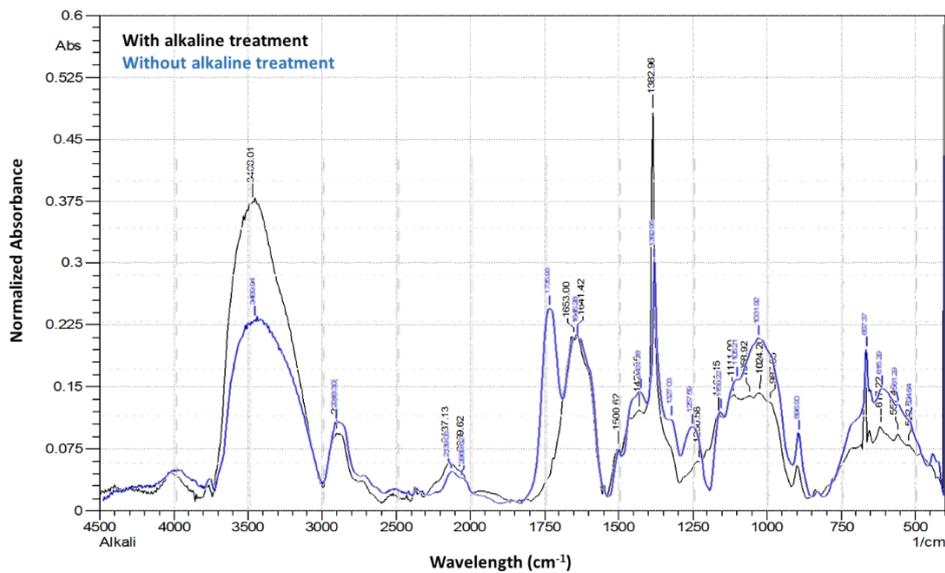
Figure 3 Fourier transform infrared spectroscopy (FTIR) results for *Sansevieria trifasciata* fiber (STF) before and after alkaline treatment

Table 3 The properties of *Sansevieria trifasciata* fiber (STF) compared to references

Fiber	Density (kg/m^3)	Diameter (μm)	Tensile Strength (MPa)	Young's Modulus (GPa)	Reference
Untreated STF	1,100	64.3	596	19.3	
Alkaline-treated STF	1,300	38.8	772	24.1	
STF	1,200	–	647–919	20.7	Pickering (2008)
STF	890	83–93	526–598	13.5–15.3	Sanjay et al. (2018)
Jute	1,460	–	393–800	10–30	Sanjay et al. (2018)
Sisal	1,450	50–300	227–400	9–20	Sanjay et al. (2018)
Ramie	1,500	–	560	24.5	Faruk et al. (2012)
Kenaf	–		930	53	Faruk et al. (2012)
Pineapple	800–1,600		400–627	1.44	Faruk et al. (2012)

3.2. Mechanical Properties of STF/HIPP and STF/VE Biocomposites

To achieve good biocomposite performance, it is essential to understand the effects of natural fibers on the mechanical properties of biocomposites. Mechanical properties—including tensile strength, modulus elasticity, impact strength, hardness, and toughness—

are useful for the classification of materials for various applications. The mechanical properties of biocomposites generally depend on the matrix material, the orientation of the fibers, the volume fraction of the fibers, and the interfaces between the matrix and the reinforcement. In the present study, the mechanical properties of biocomposites were tested with a tensile test and an impact test. Tensile properties are the most essential mechanical properties of biocomposites, as they indicate the average properties throughout the entire thickness of a biocomposite. Modulus elasticity is a mechanical property that indicates the stiffness of a solid material, defining the relationship between stress (force per unit area) and strain (proportional deformation) within the material. Moreover, an impact test indicates the ability of a material to resist fracture under stress applied at high speed. Poor impact strength is often listed as a major disadvantage of biocomposite properties. For example, the impact strength of bamboo/ polyactic acid (PLA) composite has been shown to decrease after the addition of bamboo fibers (Faruk et al., 2012). Additionally, the formation of a cavity during mold casting can reduce the impact strength of a composite (Pramono et al., 2017). However, impact strength tends to increase significantly after fiber treatment (Shieddieque et al., 2018). High impact strength is the result of good fiber and matrix adhesion, which effectively inhibits crack propagation (Huda et al., 2008).

Figure 4 displays the effects of fiber content and fiber orientation on the mechanical properties of STF/HIPP and STF/VE composites. In general, mechanical properties—such as tensile strength, stiffness (Young's modulus), and impact toughness—increased significantly as the fiber volume fraction increased.
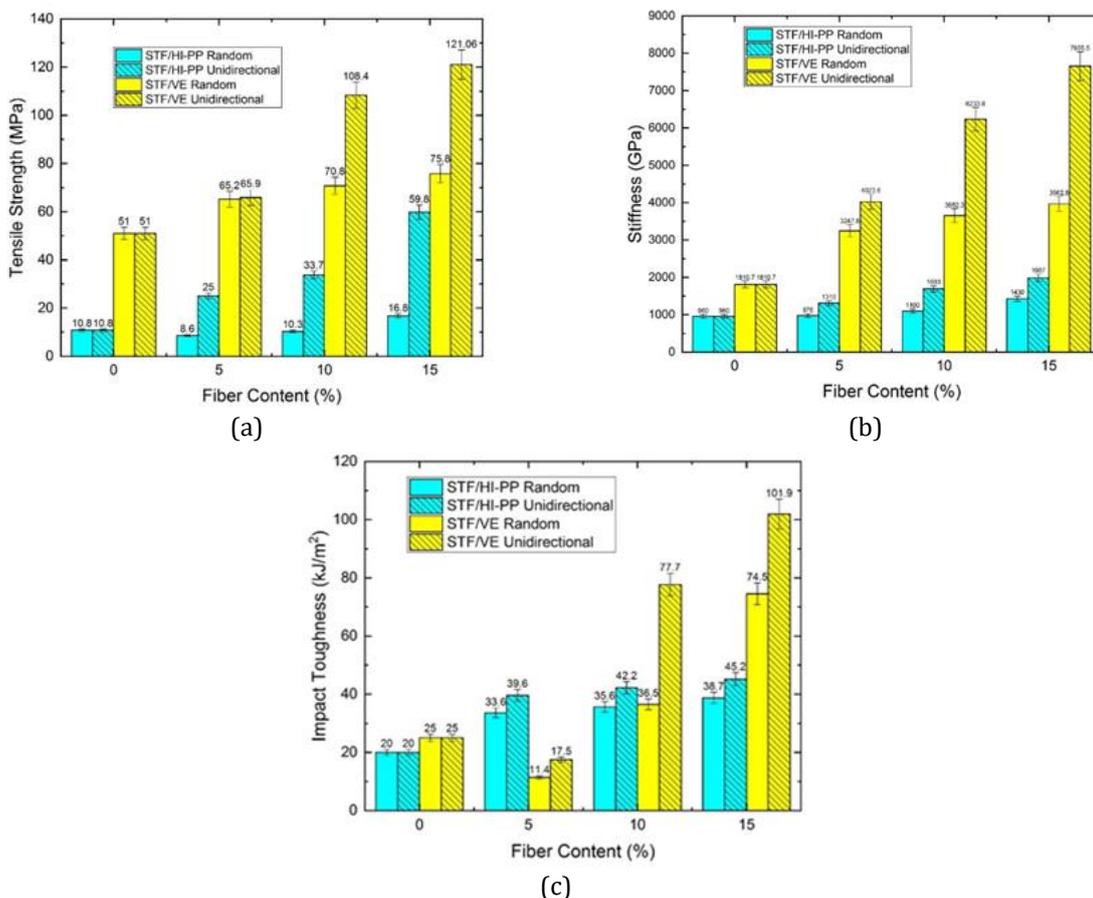

Figure 4 Mechanical properties of biocomposites as a function of fiber content: (a) tensile strength; (b) stiffness; and (c) impact toughness

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Notably, a unidirectional fiber orientation and 15% fiber volume yielded the strongest mechanical properties for both the STF/HIPP and STF/VS biocomposites. Meanwhile, the biocomposites with random fiber orientations showed less mechanical property improvement than those with unidirectional fiber orientations. The strong mechanical properties of the unidirectional fiber orientation might have been due to the high fiber density along the tensile direction, which enabled a mechanical interlocking mechanism and thus improved the mechanical properties of the biocomposites. Moreover, the ROM explains that higher fractions of fiber increase the strength and stiffness of areas close to the fibers, which are higher than the strength and stiffness of the matrix.

Figure 4 compares the mechanical properties of two different types of matrices: thermoplastic and thermosetting matrices. The thermoplastic matrix is represented by HIPP, and the thermosetting matrix is represented by VE. The biocomposite with a thermoset matrix (i.e., STF/VE) had stronger mechanical properties than the STF/HIPP biocomposite; this result was consistent with the initial natural properties of the thermoset matrix. The mechanical properties of the biocomposites created in the present study were compared with a commercial-grade glass fiber composite for automotive applications described by Xia et al. (2016). The mechanical properties of the commercial glass fiber composite included a tensile strength of 85 MPa, a modulus of elasticity or stiffness of 10.2 GPa, a 26 wt.% polyester resin matrix system, 28 wt.% glass fiber, and 46 wt.% minerals with an average density of 1,801 kg m^{-3}. The tensile strength of the STF/VE biocomposite with 15 vol.% fiber was 121 MPa, and the stiffness (modulus elasticity) of this biocomposite was 7.6 GPa. Thus, the tensile strength of the STF/VE biocomposite exceeded that of the commercial-grade glass fiber composite, and the modulus elasticity or stiffness of the STF/VE biocomposite was near that of the glass fiber composite.

3.3. Density and Pore Measurement Analysis

Figure 5a shows the density and void measurement results of the biocomposites. All of the composites had density values above those of their matrices, which were 895 kg/m^3 for the HIPP and 1,150 kg/m^3 for the VE.

(a)   (b)
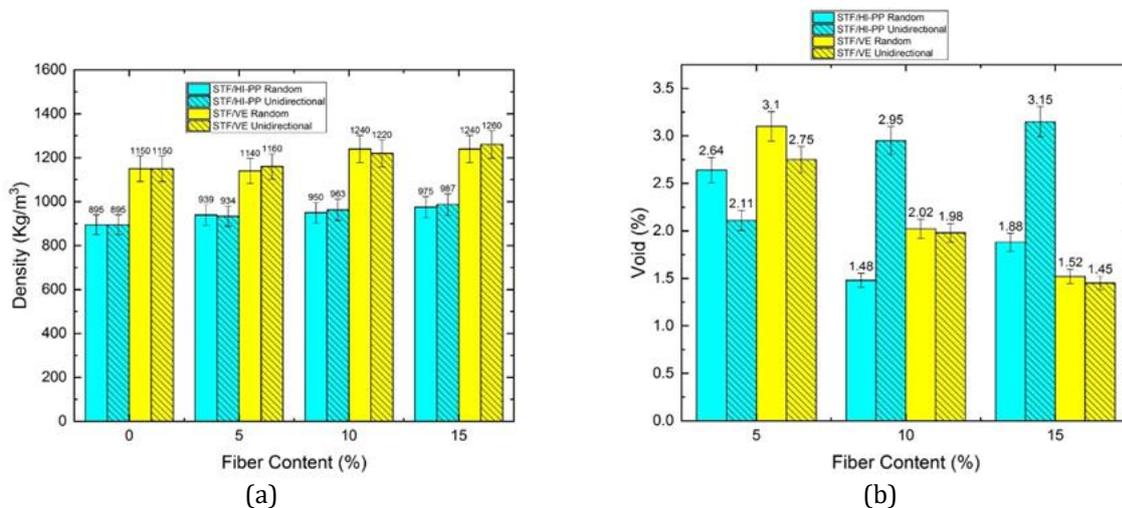
Figure 5 Measurement results for: (a) density; and (b) void content

Theoretically, STF/HIPP composites should have densities of 895–1,100 kg/m^3 for composites with non-alkali fibers and 895–1,300 kg/m^3 for composites with alkali fibers. Moreover, STF/VE composites should have densities of 1,100–1,150 kg/m^3 for composites with non-alkali fibers and 1,150–1,300 kg/m^3 for composites with alkali fibers. In the

present case, the produced composites met the rule of the mixture equation for composite density. The densities of the STF/HIPP and STF/VE biocomposites increased by approximately 10% with increasing fiber content up to 15 vol.%. Meanwhile, fiber orientation appeared to have no significant effects on the densities of the biocomposites.

Figure 5b illustrates the void percentages in the biocomposites. In the STF/VE biocomposite, the void decreased with increasing fiber content. Fiber orientation had no significant effect on the void. Meanwhile, the STF/HIPP biocomposite showed irregular results. This irregularity might have been caused by the fabrication process, which was difficult to control. A void can be caused by non-homogeneous fiber interconnection or poor adhesion between the matrix and the fibers. In the present study, the strongest mechanical properties were obtained with the lowest void content. Low void content indicates good adhesion between the matrix and the fibers, which results in strong mechanical properties.

3.4. Fracture Surface Morphology, as Indicated by Scanning Electron Microscope (SEM) Analysis

Figure 6 shows the fracture surface morphologies of the STF/VE biocomposites, which were observed using an SEM. Figure 6a displays the fracture surface of the randomly oriented STF/VE biocomposite, while Figure 6b shows the fracture surface of the unidirectionally oriented STF/VE biocomposite. Fiber pull-out was observed more frequently in the randomly oriented biocomposite than in the unidirectionally oriented biocomposite. Broken fibers were found on the fracture surface of the unidirectionally oriented biocomposite, indicating higher strength and stiffness. This result was consistent with the mechanical property results, which showed that the STF/VE biocomposite with a unidirectional fiber orientation exhibited higher properties values than that with a random fiber orientation.

(a)   (b)
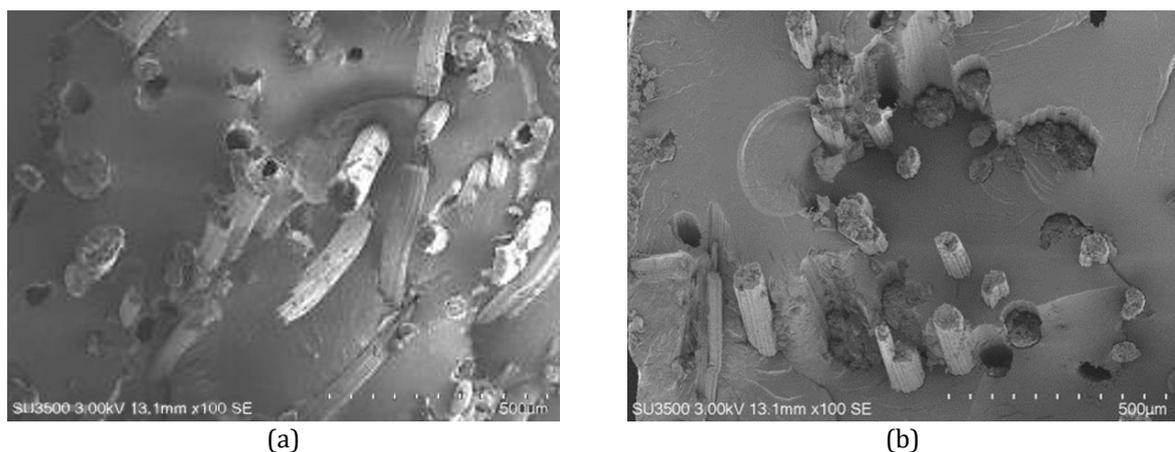
Figure 6 SEM images of the fracture surfaces of STF/VE biocomposites with: (a) random fiber orientation; and (b) unidirectional fiber orientation

The same phenomenon was observed in the STF/HIPP biocomposite, as shown in Figures 7a and 7b. Fiber pull-out was observed more frequently in the STF/HIPP biocomposite with a random fiber orientation, and broken fibers were observed more frequently on the STF/HIPP biocomposite with a unidirectional fiber orientation. Ramesh et al. (2017) reported similar characteristics in banana fiber-reinforced composites. The tensile rupture surfaces of unmodified banana fiber-reinforced composites exhibited fiber debonding, which left holes that indicated weak adhesion between the fibers and the matrix. On the other hand, the rupture surfaces of treated banana fiber-reinforced composites exhibited

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fiber breakage rather than pull-out, indicating good interfacial strength. In the present study, unidirectional fiber orientation corresponded to better adhesion between the fibers and the matrix, which led to higher tensile strength.

(a) (b)
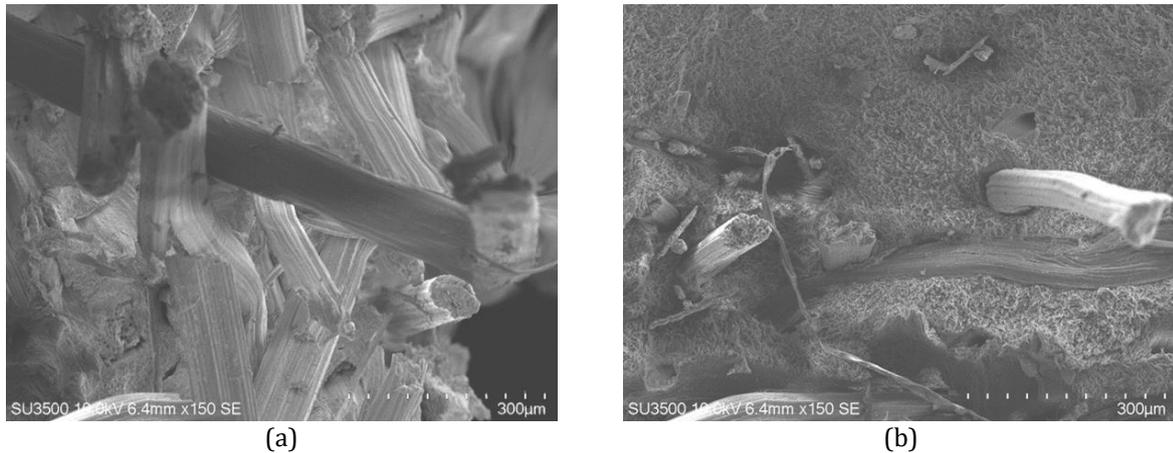
Figure 7 SEM images of the fracture surfaces of STF/HIPP biocomposites with a) random fiber orientation and b) unidirectional fiber orientation

4. Conclusions

The mechanical properties of the produced biocomposites improved with increased fiber content, alkaline treatment, and unidirectional fiber orientation. A tensile strength of 59.77 MPa and a stiffness of 1.97 GPa were obtained for the STF/HIPP composite with a unidirectional orientation, alkali treatment, and a 15% volume fraction of fiber. Moreover, a tensile strength of 121.1 MPa and a stiffness of 7.65 GPa were obtained for the STF/VE composite with a unidirectional orientation, alkali treatment, and a 15% volume fraction of fiber. The tensile strength of the STF/VE biocomposite exceeded that of a commercial-grade glass fiber composite (85 MPa), and the modulus elasticity or stiffness of this biocomposite was near that of the glass fiber composite (10.2 GPa). This means that STF shows good potential for future use in automotive applications.

Acknowledgements

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