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PAPER

Effects of fiber loadings and lengths on mechanical properties of *Sansevieria Cylindrica* fiber reinforced natural rubber biocomposites

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Abstract

In this present investigation, *Sansevieria cylindrica* fiber was used as a reinforcement in a natural rubber matrix. Various biocomposite samples with different fiber contents (lengths and loadings) were fabricated, using compression molding process and vulcanizing technique by maintaining the temperature around 150 °C. From the results obtained, mechanical properties: tensile strength, modulus elongation at break and tear strength of 10.44 MPa, 2.36 MPa, 627.59% and 34.99 N respectively, were obtained from the optimum composite sample with length and loading of 6 mm and 20 wt% composition, respectively. The maximum hardness was observed at 76.85 Shore A from the composite sample of 6 mm and 40 wt%. The optimum properties can be attributed to the presence of strong interfacial adhesion between the *Sansevieria cylindrica* fiber and the natural rubber matrix. The mechanisms of failure of the biocomposites at their interfaces were examined and analyzed, using scanning electron microscopy (SEM). The micrographs obtained from SEM further confirmed that the *Sansevieria cylindrica* fibers were surrounded with more amount of natural rubber which can exhibit strong interfacial bonding between fiber and matrix. The optimal composites of this work can be used in general, abrasion resistant conveyor belt.

Introduction

Recently, material scientists and engineers have been paying close attention to natural fibre-reinforced polymer composites, primarily because of the need to develop a more environmentally friendly material and partially replace the synthetic fibres currently used in fibre-reinforced composites. Low cost, lightweight, high specific properties, recyclability, etc are some of the advantages of choosing natural fibre-based composites. Natural fibers (NF) are fibers that come from different sources, including plants like flax, hemp, and cotton, animals like silk and wool, and even geological processes like basalt. These fibers can be used to reinforce composite materials [1, 2]. In contrast to more common technological fibers like carbon, glass, and Kevlar [3, 4], natural fibers are known for their eco-sustainability [5–7]. The impact of adding natural fibers to natural rubber has not been extensively researched. However, there has been recent interest in using natural fibers as a means of reinforcing

natural rubber. This approach can offer benefits such as increased hardness and a reduction in the need for fillers like carbon black, which are typically used to enhance the practicality of rubber [8]. Several attempts have been made to produce rubber composites using natural fibers, usually in the form of short chopped fibers. This method is sustainable and effective because rubber can serve as an appropriate matrix for crop waste, resulting in good mechanical performance [9]. Natural Fiber Composites would be used to replace traditional materials like metals and wood in various applications low weight, greater strength to weight ratio, and stiffness characterization [10].

The properties of fiber composites depend on various factors, including the length and orientation of fibers and the weight percentage of the matrix. *Sansevieria Cylindrica* fiber extracted from the concerned plant for its potential use in rubber and polymer matrix is explored by Sreenivasan *et al* [11, 12]. *Sansevieria Cylindrica* (SC) is a species of Sansevieria that is a member of the Asparagaceae family and is also known as Spear Sansevieria. Several studies on the use of this fiber are found in [13–15] It was reported that extraction and processing of this fiber are very simple and based on mechanical properties exhibited, this fiber is found to be potential reinforcement for the manufacturing of lightweight materials. Investigations on the effects of fiber length and content on the mechanical properties of *Sansevieria Cylindrica* Fiber Composite (SCFP) exhibited higher properties. It was observed by Kumar *et al* [16] that *Sansevieria Cylindrica* reinforced rubber composites had higher flexural strength compared to silk and drumstick composites while varying volume percentage of fibre. Reinforcing *Sansevieria Cylindrica* fiber reinforced in the epoxy matrix is attempted by Mala Ashok Kumar *et al* [17]. Hybridizing the fiber with jute is also explored and found to exhibit promising results. Di-electric properties of hybrid composites made from SC, silk, and drumstick in the epoxy matrix were also explored by Ashokkumar and Ramchandra [18]. The mechanical properties of *Sansevieria Cylindrica* fiber/Zawa flour composites were found to increase by increasing the wt% of fiber. On the other hand, it was also noted that the addition of fiber more than 4 wt% resulted in no significant improvement in the properties [19]. Reinforcement of *Sansevieria Cylindrica* in the polyester matrix was attempted by Sakthivel *et al* [20]. It was observed that wt% of the fiber is a predominant factor that helps in altering the properties of the composites.

Attempts to modify the *Sansevieria Cylindrica* Fiber and exploring the physics mechanical characteristics are also found in the literature [21]. Strong coloration between fiber content with mechanical properties variation was observed by *Sansevieria Cylindrica* fiber in the polyester matrix [22]. *Sansevieria Cylindrica* treated with 5% sodium hydroxide solution for 30 min when used as reinforcement has shown good enhancement in mechanical properties [23], [24]. Potassium permanganate treatment was performed on *Sansevieria Cylindrica* fiber and reinforced in a polymer matrix, it was observed that the properties of the composites improved compared to the untreated fiber composites [25].

It has been thoroughly understood from the literature that natural fiber with natural matrix composites can be an alternate for synthetic matrix and synthetic fiber composites. Though the use of *Sansevieria Cylindrica* fiber in the polymer-based matrix was found in literature, the authors believe that the use of *Sansevieria Cylindrica* fiber in rubber matrix is not yet much explored by researchers. A novel attempt is made in order to explore the properties of *Sansevieria Cylindrica* fiber in natural rubber matrix composites in turn also find suitable applications for replacement of synthetic matrix composites.

In this present study, a complete bio-composite made by reinforcing ***Sansevieria Cylindrica* fiber** in natural rubber matrix constituents is attempted and the properties are explored, aiming at the replacement of support mounts for engine blocks. The effects of fiber loadings and lengths on the mechanical properties of the composite samples were determined. It was evident that the optimum biocomposite sample can be a suitable alternative to some plastics, synthetic fibers, and similar natural fiber reinforced polymeric composites to support the concept of environmental sustainability.

Experimental procedures

Materials

Natural rubber (NR) of ISNR-5 was procured from the Rubber Research Institute of India, Kottayam, Kerala. Compounding ingredients used in the research, such as zinc oxide (ZnO), stearic acid, sulfur, antioxidant 2-2-4-trimethyl-1-2-dihydroquinoline (TDQ), N-Cyclohexyl-2-benzothiazole sulphenamide (CBS) and tetramethylthiuram disulphide (TMTD) were supplied by Samira Chemicals, Kottayam. Various biocomposite samples were prepared and designated as P1, P2, P3 and P4. Table 1 shows the components of the natural rubber composites and untreated *Sansevieria cylindrica* fiber used in the present investigation.

Fiber preparation

Sansevieria cylindrica fibers were extracted from *Sansevieria cylindrica* plant leaves, which were harvested from farms at Tirunelveli, Tamil Nadu, India. Sansevieria cylindrica fibers were separated using a mechanical method

Table 1. Components of natural rubber composites and untreated *Sansevieria Cylindrica* fiber.

Constituent	P1 (wt%)	P2 (wt%)	P3 (wt%)	P4(wt%)
Natural rubber	79.5	71.9	65.0	57.8
Stearic acid	2.0	1.6	1.0	0.6
Zinc oxide	5.0	4.4	3.7	2.8
TDQ	1.0	0.9	0.8	0.7
CBS	1.0	0.9	0.8	0.7
TMTD	0.1	0.1	0.1	0.1
Sulfur	2.5	2.3	1.8	1.5
Untreated *Sansevieria cylindrica* fiber	10	20	30	40

known as 'decortication,' which was described in detail in a previous study by Sreenivasan *et al* [21]. Each of these leaves is about 30 mm thick and grows to a height of 1000 mm to 2000 mm, allowing it to generate fiber over a length of around 900 to 1800 mm for practical use. Following these long fibers, small segments of fiber with varied lengths of 3, 6, and 10 mm were cut using a fibre cutting machine. The fibers were washed several times with water to remove unwanted materials that were observed on surfaces of the fibers. Then, the fibers were dried in air. The advantage of using this Sansevieria cylindrica natural fibre is its abundance and affordable cost (3 USD kg^{-1}). Similarly, natural rubbers are an easily available product at a cost of 1.5 USD kg^{-1}.

Preparation of composites

Two-roll mill with dimension of 150 × 300 mm and friction ration of 1:1.25 was used for the fabrication of the samples. The fabrication process of the fiber/rubber composites was carried out in accordance with the ASTM D 3184-80 standard. Figure 1 depicts a graphical illustration of the step-by-step method of manufacturing rubber composites for all the combination of fiber wt%. The mill opening was kept at 0.2 mm. Rubber was initially masticated. The temperature of the mill was kept under control, by maintaining the nip gap and timing throughout its operation. Nip gap and the ratio of the mill roll speed were kept identical for all the passes in all combinations. Compounding materials were added in a proper proportion along with chopped fibers and blended carefully to avoid breakage of the fibers and ensure that many fibers were aligned along the grain path. After enough grinding, a proper mixture of compounding materials (rubber and fiber) was obtained. Finally, 3 mm rolled sheet was prepared, followed by other longer lengths of 6 and 10 mm consecutively. The various biocomposite sample categories prepared along with their respective detailed fiber lengths, weights and rubber loadings are presented in table 2.

Mechanical testing

Tensile test

Measurement of tensile properties was carried out with a crosshead speed of 500 mm min^{-1}, using Schimadzu Model AG1 Universal Testing Machine. Testing was carried out using ASTM D 412-87 standard. The tensile properties, such as tensile strength, modulus and elongation at the break were determined. Five samples in each specimen is tested and average values are reported.

Tear test

The ASTM D 624-81 standard was used to determine the tear property of each of the biocomposite samples, using UN Nick 90° angle. The samples were cut from molded sheets in the mill grain direction. The test was conducted on Zwick UTM, maintaining a crosshead speed of 500 mm min^{-1} at 28 °C and the tear results were obtained. The average value of tear strength obtained after testing five samples in each specimen is reported.

Hardness test

Hardness was measured using Durometer Shore A type with a calibrated spring, which was used to give indentation power according to ASTM 2240-81 standard. The load released by the spring varied with indentation. Readings were recorded by contacting the sample with sample recognizer and indenting it for 15 seconds. The average value obtained after testing five samples in each specimen is reported.

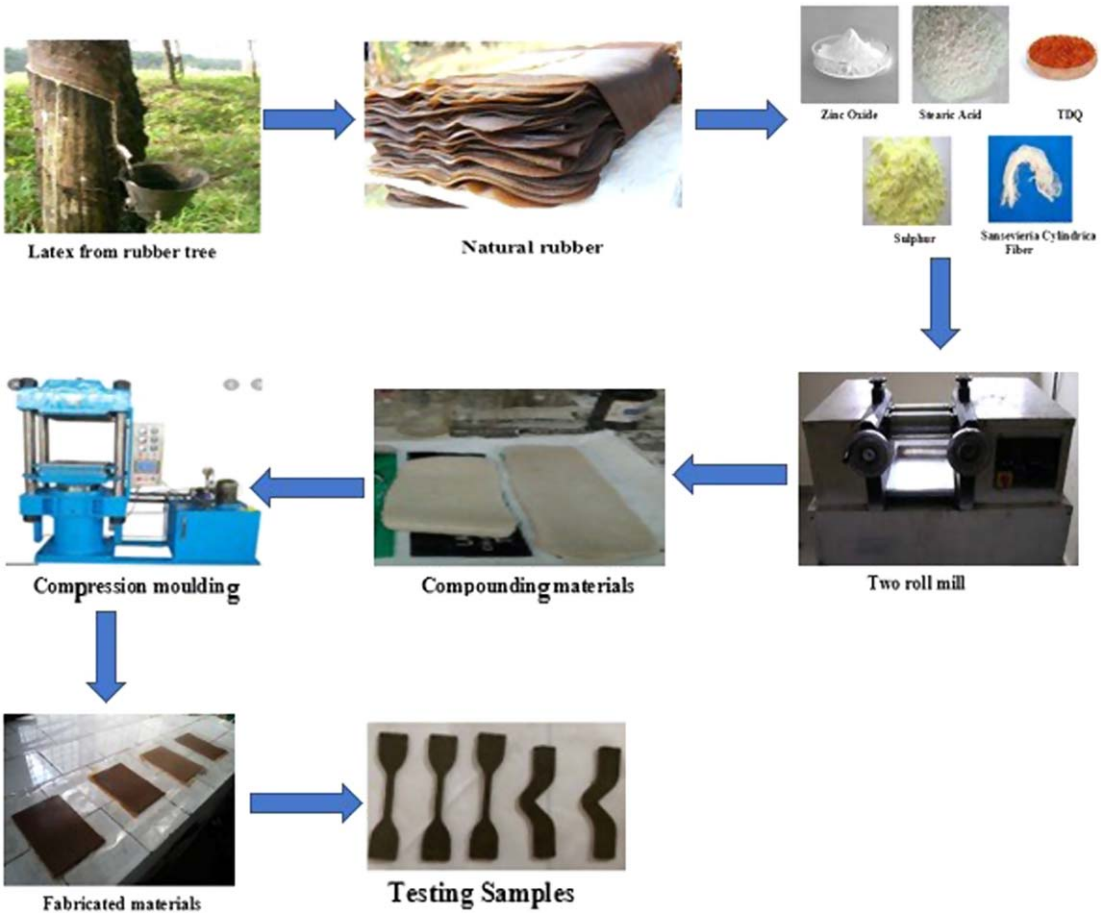


Figure 1. Graphical illustration of the step-by-step method of manufacturing rubber composites.

Table 2. Various sample categories.

Constituents (mm)	Fiber weight (wt%)	Rubber weight (wt%)
Natural Rubber	—	100.0
3	10 (P1)	79.5
	20 (P2)	71.9
	30 (P3)	65.0
	40 (P4)	57.8
6	10 (P1)	79.5
	20 (P2)	71.9
	30 (P3)	65.0
	40 (P4)	57.8
10	10 (P1)	79.5
	20 (P2)	71.9
	30 (P3)	65.0
	40 (P4)	57.8

Microscopic examination

Scanning electron microscopy (SEM) images of the samples were captured, using Hitachi S-4100 field emission scanning electron microscope. The samples were coated with plasma sputtering to avoid charging under the electron beam. SEM examination was carried out at a voltage of 5 kV.

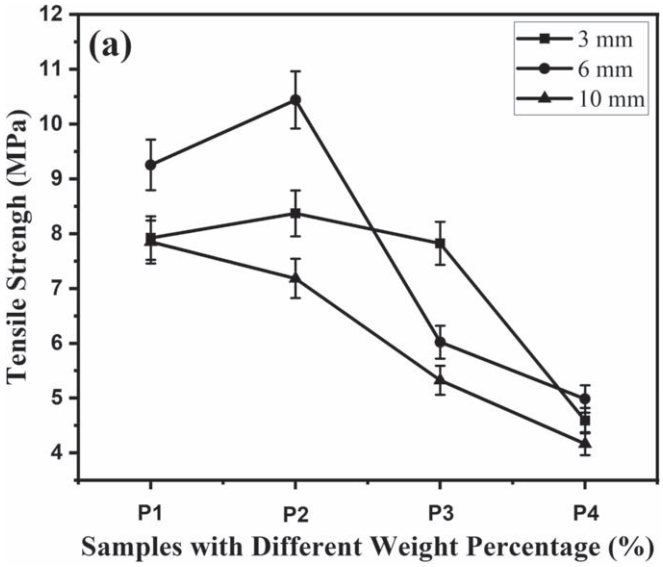


Figure 2. Effects of the fiber contents on the tensile strengths of the various samples.

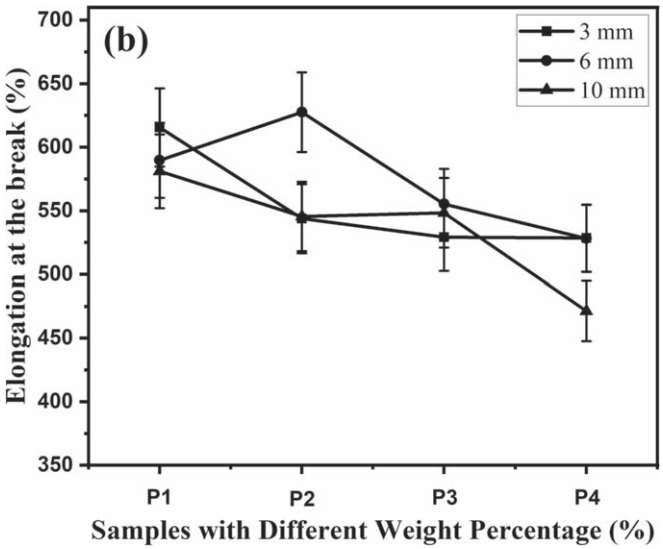


Figure 3. Effects of the fiber contents on the elongation at break of the various samples.

Results and discussion

Tensile properties

Figures 2–4 show the mechanical properties (elongation at break, tensile strengths and moduli) obtained from all the various samples. It was observed that the tensile stress increased gradually with the fiber contents.

The tensile strength of pure natural rubber was observed to be 6.98 MPa, as shown in figure 2. The composite sample P2–6 mm exhibited the maximum tensile strength of 10.44 MPa, when compared with other samples. This value was higher than that of pure natural rubber. The study shows that increasing the fibre length and weight % enhances the tensile strength for the 6 mm threshold value. Further increases in fibre length and weight % of fibres can produce fiber buildup, and the fiber-fiber interaction becomes dominant, resulting in a loss in tensile strength [26], [27]. This best performance can be attributed to the dry, coarse and uneven texture on the surfaces of dry raw fibers. Therefore, it supported improvement of the mechanical properties by enhancing the interfacial bond between the rubber matrix and fiber, in addition to the advantages of compression molding technique used. Consequently, an excellent fiber-matrix mechanical interlocking and adhesion were formed and consequently, it resulted to an improvement in the tensile strength. An enhanced or a better fiber-matrix interlocking helped in the effective load transfer from the matrix to the fibers.

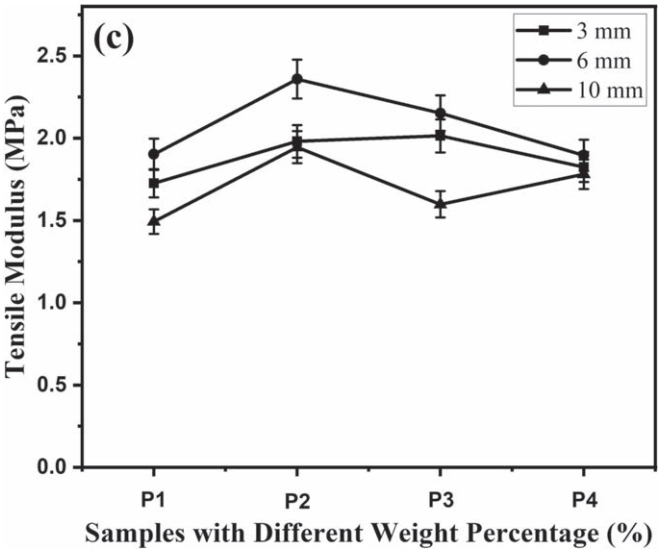


Figure 4. Effects of the fiber contents on the tensile moduli of the various samples.

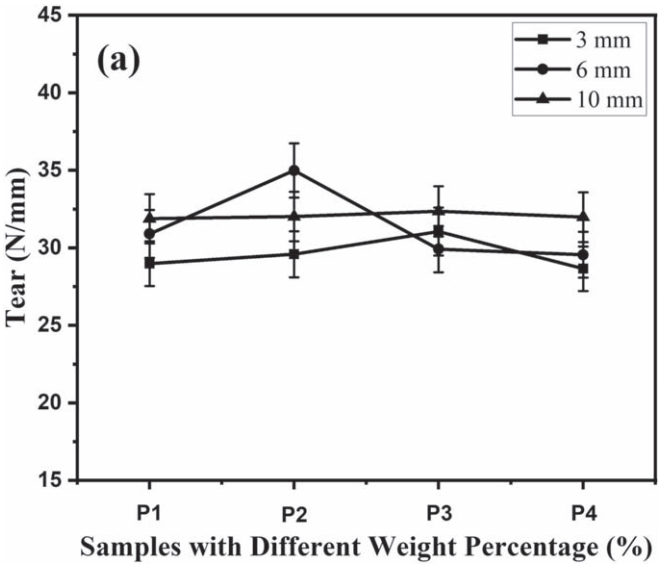


Figure 5. Effects of the fiber contents on the tear strengths of the various samples.

More also, figure 3 as well as 4 show the elongation at break and moduli of the biocomposite samples with various fiber and rubber contents. The pure natural rubber recorded an elongation at break of 583.66%. The composite sample P2–6 mm exhibited the maximum elongation at break of 627.59%. This optimum result was remarkable, higher than that of pure natural rubber sample. This can be traced to the increase in fiber contents: loading and length of the fibers. Similarly, the same composite sample P2–6 mm recorded the highest tensile modulus of 2.36 MPa. Summarily, it was evident that the optimum composite sample P2–6 mm exhibited maximum elongation at break, tensile strength and modulus of approximately 627.59%, 10.44 and 2.36 MPa, respectively, when compared with other composite counterparts and pure rubber sample.

Tear strengths

Figure 5 show that the tear strength of natural rubber was 28.05 N mm^{-1}. Fiber reinforced polymeric biocomposite sample P2–6 mm exhibited higher tear strength, when compared with other fiber/rubber composites. Also, sample P2–6 mm recorded a tear strength of 34.99 N mm^{-1}. This was due to the rough, coarse and the dry surface texture of the raw fibers, which consequently aided good mechanical and physical bonding from interlocking of the fibers and rubber matrix. This bonding resulted to a better matrix-fiber load transfer.

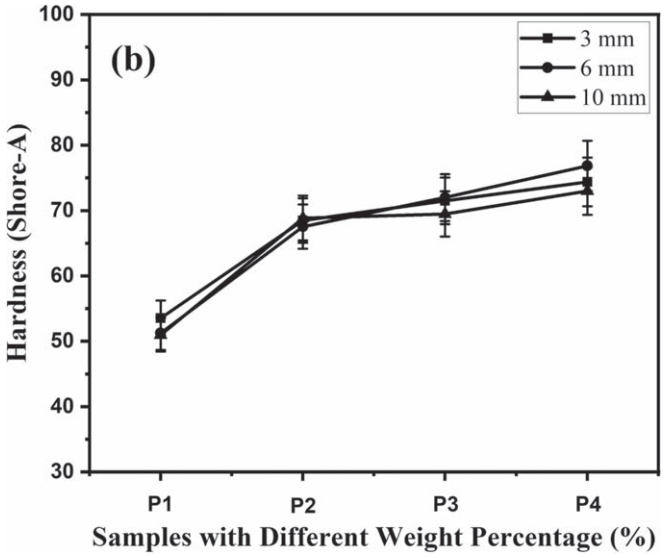


Figure 6. Effects of the fiber contents on the hardness values of the various samples.

Hardness properties

The hardness values of all the various samples are shown in figure 6. The hardness value of pure natural rubber was observed at 49.87 Shore A. Sample P4–6 mm sample recorded the maximum value of hardness, when compared with all the composite and pure rubber samples. The maximum value of hardness was up to 76.85 Shore A, followed by sample P4–3 mm composition with 74.39 Shore A. It can be observed that the elastomeric property reduced when the fiber content increased, while hardness increased evidently. A similar type of observation was reported in the filler reinforced polymer nanocomposites [26], where the hardness improved slightly as the filler amount increased.

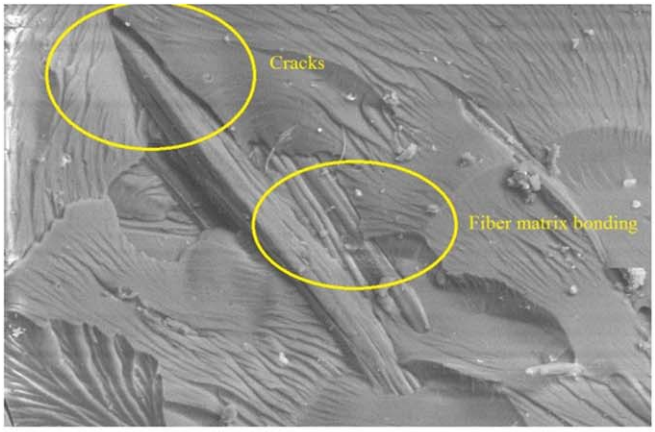
Comparison between the present sample and other similar composites

A comparison of the three mechanical properties (hardness, tensile and tear strengths) of the optimum *Sansevieria cylindrica* fibers reinforced natural rubber biocomposite sample with some similar biocomposite samples is presented in table 3. *Sansevieria cylindrica* fiber reinforced natural rubber composite in the present study recorded highest hardness strength of 76.85 Shore A, when compared with other similar composite samples (table 3). Similarly, both tensile and tear strength values of the optimum *Sansevieria Cylindrica* fiber reinforced natural rubber composite samples were greater than that of coir fiber reinforced natural rubber composite as well as bagasse ash silica reinforced styrene-butadiene rubber composite. The values of relevant comparative properties of the similar biocomposites were obtained from literature [28–30].

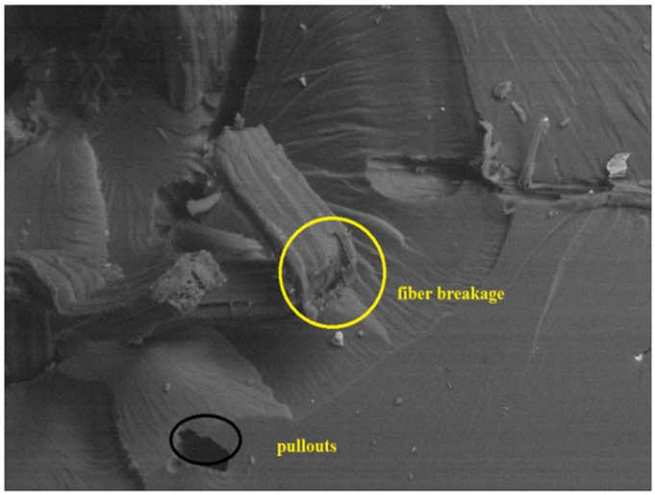
In addition, in case of tensile and tear strengths, the bagasse ash silica (BASi) reinforced natural rubber composite recorded the maximum strengths of 21.94 MPa and 43.59 kN m^{-1}, respectively. The improvement can be attributed to a better scattering and distribution of BASi agglomerates than the *Sansevieria Cylindrica* fiber in the same natural rubber matrix. This was evident by its relatively outstanding tensile strength (table 3). It can also be observed that the tear strengths of both BASi reinforced styrene-butadiene rubber as well as natural rubber and styrene-butadiene rubber composites were reduced, due to the addition of styrene-butadiene rubber matrix to BASi reinforcement, which compromised the properties of both pure natural rubber matrix and BASi content/reinforcement. In other words, it resulted to a weaker BASi-styrene-butadiene rubber interaction, when compared with BASi-natural rubber interaction. In case of styrene-butadiene rubber-based composites, when BASi loading was increased, there was no much change in its tear strength in comparison with the *Sansevieria cylindrica* fiber reinforced natural rubber composite. These results further supported the reason why the present composite sample possessed competitive and better properties, when compared with other similar composites. Upon all this property analysis, it was found that the General, Abrasion Resistant Conveyor Belt could be considered the suitable application for this work. Since then, the specific requirements for tensile strength, elongation, hardness, and tear strength towards that application have been achieved by the optimal composites. A JIS standards used to measure the mechanical properties general purpose conveyor belt is as follows: Tensile Strength—8–18 MPa, Elangation – >400%, Tear Strength—25–45 kN m^{-1}, Hardness—50–65. These values were achieved for the combination of natural rubber and 25 wt% of carbon block composites.

Table 3. Comparison of mechanical properties of the present sample with other similar composites.

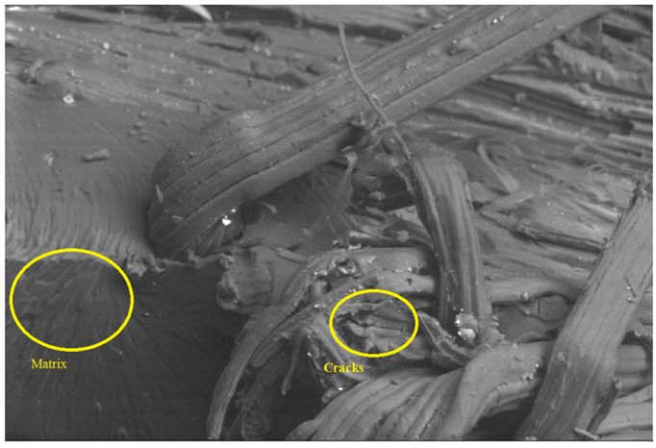
S/no	Fiber / reinforcement	Matrix	Orientation	Tensile (MPa)	Tear (kN/m)	Hardness	References
1	*Sansevieria cylindrica*	Natural rubber	Random	10.44	34.99	76.85	Present work
2	Coir	Natural rubber	Random	7.60	33.00	55.00	[26]
3	Bagasse ash silica (BASi)	Natural rubber	Random	21.94	43.59	49.75	[27]
4	Bagasse ash silica (BASi)	Styrene-butadiene rubber	Random	6.92	33.13	59.25	[27]
5	Bagasse ash silica (BASi)	Natural rubber and styrene-butadiene rubber	Random	10.83	37.60	56.00	[27]
6	Jute	Natural rubber	Longitudinal Transverse	7.60 6.70	36.10 40.60	75.00	[28]



(a)



(b)



(c)

Figure 7. (a) SEM images showing tensile Fractured surface of 6 mm 20 wt %). (b) SEM images showing tensile Fractured surface of 6 mm 10 wt %. (c) SEM images showing tensile Fractured surface of 6 mm 40 wt%.

Microscopic examination

The SEM images of the tensile fractured surfaces of the rubber *Sansevieria cylindrica fiber* composites are shown figure 7. The 6 mm 20 wt % composites has exhibited the highest tensile strength compared to all other composites. The mechanism of failure clearly shows that the fiber has contributed for load transfer (figure 7(a)). Good adhesion between the fiber and matrix as seen in figure 6(a), has supported the composite for this higher value of tensile strength. The composite failure due to crack formation due to strong bond of the fiber, where the

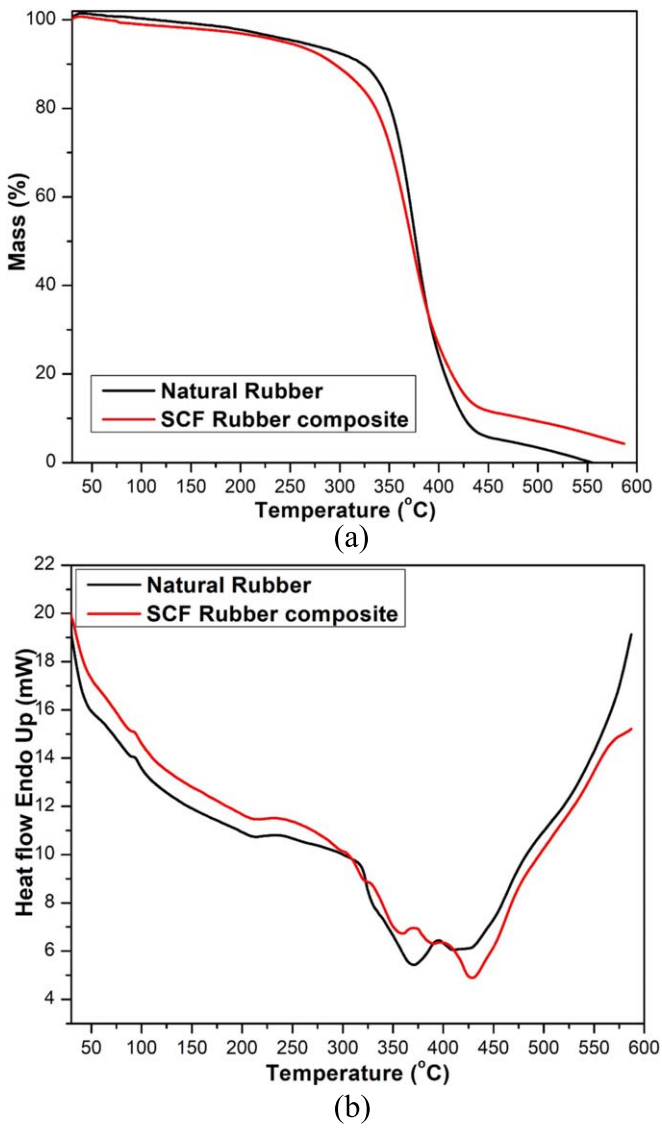


Figure 8. (a) Thermal properties images of TGA. (b) Thermal properties images of DSC.

matrix failure has occurred is also seen in the image. Comparing 6 mm 20 wt% (figure 7(a)) images with 6 mm 10 wt% (figure 7(b)) and 6 mm 40 wt% (figure 7(c)), it is noted that the failure is mostly due to matrix failure rather than fiber pull out and weak interface of matrix and fiber. Optimal concentration of fiber is also an important parameter, where more the fiber more the chances of the fiber to behave like an inclusion rather than a reinforcement can be seen in figures 7(a) and (c). Crack propagation in the direction of fiber orientation and in other directions are also visibly seen in the images 6(b) and (c).

Thermal properties of composite

Figure 8(a) shows the thermogram curves of the pure natural rubber and the SC fiber-reinforced rubber composites. Three stages of mass losses, namely glassy region, mixed region, and rubbery region, were observed in both cases, with different rates of degradation in each stage. During the glassy region the mass loss, occurred at 100 to 200 C due to the evaporation of the moisture content in both cases. In the later stage of initial degradation, pure rubber showed better performance than the composites. The reduction of chain mobility in natural rubber might lead to slower diffusion of degradation [31, 32]. Further, the increasing thermal degradation in the SC fiber-reinforced rubber composites could have happened due to the removal of excessive water molecules present inside the SC fiber pores. During the second stage, the major mass loss of about 60% occurred between 350 °C and 400 °C, which indicates the decomposition of different additives in the natural rubber and SCF rubber composite. From 450 °C onwards, the rubbery region started, where SCF rubber composites showed better performance than the rubber until the end of the testing condition. The presence of chemical

compositions in the SCF, such as cellulose, hemicellulose, and lignin constituents, requires additional thermal load to accelerate the mass loss in the composites. In contrast, the increasing rate of mass loss was noticed at the decomposition peak at 394 °C, which occurred due to the depolymerization of the natural rubber matrix. Around 5% of mass was found in the composite at closer to 600 °C, whereas complete degradation occurred in the rubber at the early temperature of 550 °C.

Figure 8(b) shows the degradation over time as determined by differential scanning calorimetry (DSC) for both natural rubber and SCF rubber composite blends in nitrogen. As can be seen in the figure, it appears that the Sansevieria cylindrica rubber composite shifts up the degradation peak for natural rubber. However, some previous endothermic cellulose degradation peaks are also visible [33].

Endotherms indicate that natural rubber melts around 100 °C, as seen in DSC curves. However, after this point, the scan in nitrogen changes a lot. The DSC trace of SCF rubber composite in nitrogen reveals a sizable degradation exothermic peak with a maximum of 350 °C. The SCF natural rubber shows a broad degradation endotherm extending from 370 to 430 °C.

Conclusions

Successful fabrication of *Sansevieria cylindrica* fiber/natural rubber reinforced composites and effects of various fiber loadings and lengths on their tensile (strength, modulus and elongation at break), tear, hardness and thermal properties have been investigated in this study. Based on the results obtained from this experimental work, the following conclusions can be deduced.

The properties of the composites varied with the change in their fiber length. The maximum values of tear strength, elongation at break, tensile strength and modulus were 34.99 N mm^{-1}, 627.59%, 10.44 MPa and 2.36 MPa, respectively, as obtained from optimum composite sample P2–6 mm. Also, both tensile and tear strength values of the optimum composite sample were greater than that of coir fiber reinforced natural rubber as well as bagasse ash silica reinforced styrene-butadiene rubber composites, as compared with the same properties of similar biocomposites reported in literature.

The addition of fiber to the rubber matrix increased the hardness property of the composite, which was related to strength. The maximum hardness of 76.85 Shore A was obtained from another composite sample P4–6 mm.

Among the aforementioned mechanical behaviors, composite sample P2–6 mm exhibited better tensile and tear properties, while composite sample of P4–6 mm recorded a better hardness response when compared with the pure natural rubber only.

Moreover, *Sansevieria Cylindrica* fiber reinforced natural rubber composites showed higher hardness value of 76.85 Shore A with a random orientation of fiber reinforcement in a rubber matrix when compared with other fiber reinforced composite samples. Importantly, this value was higher than that of similarly reported composites in literature: bagasse ash silicon, coir and jute fibers reinforced natural rubber composites as well as bagasse ash silica reinforced natural rubber and styrene-butadiene rubber composites. A greater thermal resistance is offered by this composite as a result of the SC fiber being reinforced in the rubbery region.

Evidently, the results obtained from this innovative study have established that *Sansevieria Cylindrica* fiber reinforced natural rubber biocomposite provided superior properties than some of the existing similar biocomposites. Therefore, as a promising, low-cost, biodegradable, sustainable and environmentally friendly biocomposite, it can successfully replace many already existing synthetic fiber and similar natural fiber reinforced polymeric biocomposites used in various engineering applications.

As a result of the improved tensile strength, modulus, elongation, tear, and hardness values, the optimal composites with a combination of 6 mm and 20 wt. percent SCF reinforced rubber composite can be used as support mounts for engine block.

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Data availability statement

No new data were created or analysed in this study.

Declarations

Funding

Researchers Supporting Project number (RSP2023R54), King Saud University, Saudi Arabia.

Conflicts of interest

None.

Availability of data and material

The raw/processed data required to reproduce these findings cannot be shared at this time as the data also forms part of an ongoing study.

Code availability

Not applicable

Authors' contributions

Sivasubramanian Palanisamy: Collected primary data, contributed in draft, checked the draft, and overall manuscript prepared and finalized the contents. Mayandi Kalimuthu: Contributed in writing. Shanmugam Dharmalingam: Contributed in writing. Azeez Alavudeen: Contributed in writing. Rajini Nagarajan: Supervised and contributed in writing. Sikiru Oluwarotimi Ismail: Contributed in writing. Suchart Siengchin: Contributed in writing. Faruq Mohammad: Contributed in writing. Hamad A. Al-Lohedan: Contributed in writing.

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