SISAL FIBRE REINFORCED POLYMER COMPOSITES FOR STRUCTURAL APPLICATIONS: A BRIEF REVIEW

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ABSTRACT

Sisal fibre is one of lignocellulosic fibre that is widely used as reinforcing material in polymer-based composites. The fibres can be produced from leaf part that traditionally can be used to make twines, ropes, and string. This is due to sisal fibre has high value of tensile strength and Young Modulus besides having ability in high impact strength and low density. Nowadays, sisal fibre can be reinforced with either thermoset or thermoplastic matrix. For thermoplastic composites, it has ability to be recycled due to the thermoplastic materials can be remolded and reshaped. However, lack of study has been established to show the recent progress on mechanical performance of the sisal fibre reinforced polymer composites for structural applications. Hence, this review was expected to analyse the current status, challenge and future perspectives of sisal fibre reinforced polymer composites of structural applications. This review could benefit the manufacturing sector in providing green-based materials without jeopordizing the mechanical performance of the products.

Keywords: *Sisal fibre, Polymer Composites, Structural applications*

1.0 INTRODUCTION

Sisal fibre, depicted in Figure 1(a), is a lengthy organic fibre derived from the leaves of the sisal plant, a species of agave indigenous to Mexico. Sisal fibre is a frequently utilised natural fibre that is highly cultivable. It exhibits a brief regeneration cycle and thrives organically in meadows and railway fencing [1]. Approximately 4.5 million tonnes of sisal fibre are manufactured on a global scale annually. Tanzania and Brazil are the primary producers [2]. Sisal is indigenous to the tropical and subtropical parts of North and South America, although it is currently extensively grown in tropical countries in Africa, the West Indies, and the Far East [3].

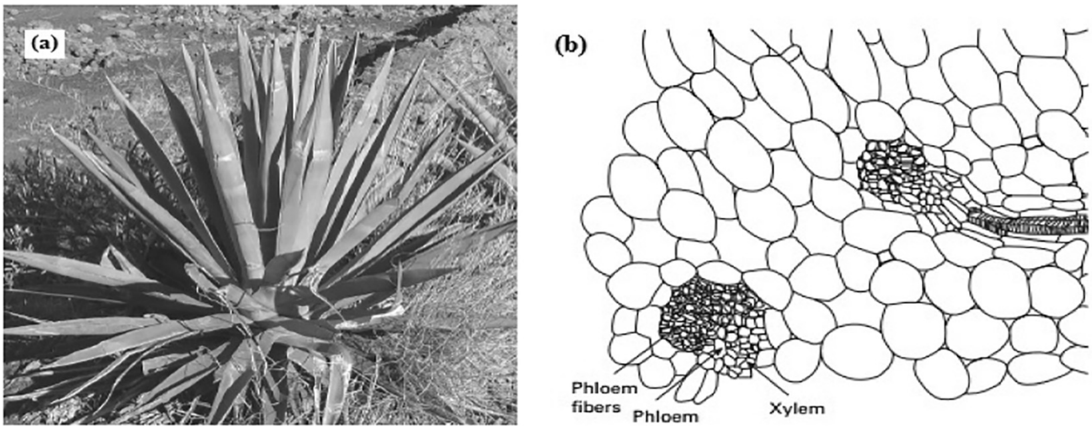

Figure 1: (a) Sisal plant and (b) Transverse section of a sisal leaf shows phloem and xylem fibres[4]

Next, each leaf of sisal plants including 1000-1200 fibre bundles containing of 4% fibre, 0.75% cuticle, 8% dry matter, and 87.25% moisture that contain phloem and xylem (Figure 1(b)) [1]. A typical leaf weighing about 600g contains about 3% fibre by weight and each leaf contains about 1000 fibres.

Sisal sheets contain three types of fibres: mechanical fibres, ribbon fibres, and wood fibres [3]. Mechanical fibres originate mainly from the perimeter of the leaves. It has a slightly thick horseshoe shape and hardly splits during the extraction process. These are the most commercially useful sisal fibres. Ribbon fibres occur in association with a conductive web in the midline of the blade. Figure 1 shows a cross-section of a sisal sheet and shows where mechanical and ribbon fibres are obtained [3]. The associated conductive web structure of the tape fibres gives them considerable mechanical strength. The xylem fibres are irregularly shaped and are opposed to the ligamentous fibres by vascular connections as shown in the Figure 2. They are made up of thin-walled cells that can be easily broken and lost during the extraction process.

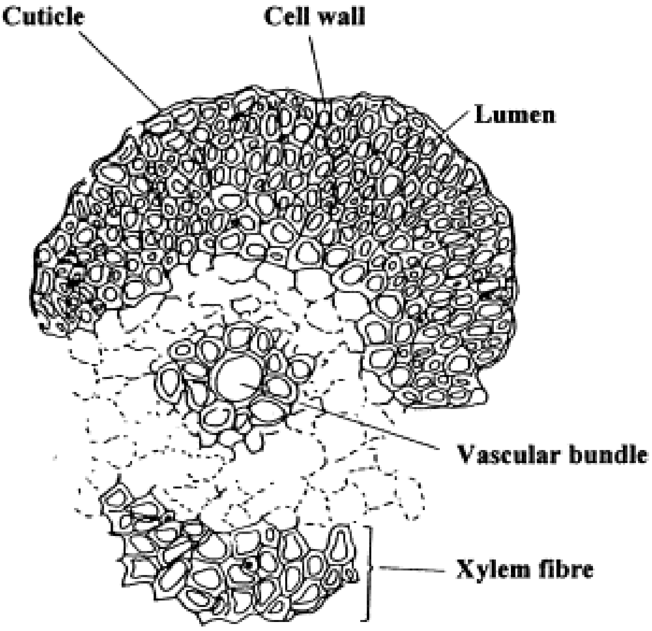

Figure 2: Sisal stem structure [3]

Table 1 compares the physical and mechanical properties of sisal fibre with different herbal and artificial fibres. The table shows that sisal fibre has a comparable specific strength and modulus with respect to textile fibre and lingo-cellulosic bast fibre.

Table 1: Mechanical Properties of Sisal Compared with Other Natural/Synthetic Fibres [5,6]

Fibres	Density (g/cm^3)	Tensile Strength (MPa)	Young's Modulus (GPa)
Sisal	1.33 - 1.5	400 - 700	9.0 - 38.0
Bamboo	0.6 - 1.1	140 - 800	11 - 32
Coir	1.2	175-220	4.0 - 6.0

The chemical composition of sisal fibre varies relying on location, age, etc [7]. Like different herbal fibres, sisal fibre includes cellulose, lignin, hemicellulose, and moisture [8]. The moisture content material and chemical composition of sisal fibres are proven in Table 2.

Table 2: Chemical Composition and Moisture Content of Sisal Fibre [5,6]

Cellulose (%)	Hemicellulose (%)	Lignin (%)	Moisture content (%)
65 - 68	10 - 22	9.9 - 14	10 - 22

2.0 MANUFACTURING PROCESS OF SISAL FIBRE/POLYMER COMPOSITES

The sisal fibres, which were approximately 4 mm in length, were derived from sisal strands that were 700 to 800 mm long [9]. The mechanical properties of fibre reinforced polymer composites are influenced by several aspects, including the type of fibre and matrix used, the adhesion between the fibre and matrix, the dispersion of the fibres, the orientation of the fibres, and the production procedures employed. Figure 3 illustrates the variables that impacted the mechanical characteristics of sisal fibre composites.

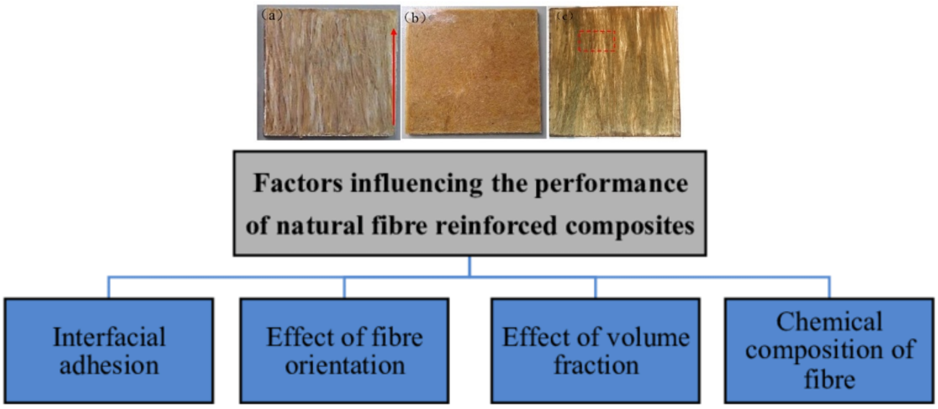

Figure 3: Factors affecting the mechanical performance of sisal composites [10]

The many types of fibres, such as bast, leaf, stem, and root, are classed based on their origin and exhibit variations in cellulose content. Typically, plant fibre exhibits greater strength and stiffness compared to the alternative [11]. The qualities of fibres primarily rely on their chemical composition and structure, which are influenced by factors such as the specific type of fibre utilised, the technique of extraction, the timing of harvesting, the growth circumstances, the process of decortications, the maturity of the fibres, the degree of retting, and any technical alterations applied. Sisal fibre is typically obtained in significant quantities from the leaves of the plant by the retting process, prior to being utilised as a reinforcing element.

In addition, the matrix has a limited impact when it comes to applying tensile force to the composites. Nevertheless, the compressive, in-plane shear, and interlaminar strengths are significantly affected by the specific matrix employed [12]. Research conducted over the years has shown that sisal fibre is highly compatible with a wide range of thermoset and thermoplastic matrices.

Moreover, the mechanical properties of the composites are significantly impacted by the bonding between the fibre and matrix. When there is a strong interfacial connection, reinforced polymer composites effectively transmit the applied stress to the fibres [3]. The plant-based fibre typically exhibits weak bonding due to the hydrophilic character of the fibre and the hydrophobic nature of the resin. To address this limitation, one could employ mechanical interlocking, chemical bonding, electrostatic bonding, inter-diffusion bonding [13], coupling agent, and chemical pre-treatment [14].

Furthermore, the effective dispersion of fibres within the matrix leads to enhanced bonding, resulting in improved mechanical properties of composites. The dispersion of fibres is often influenced by the length of the fibres (short or long) as well as processing parameters like pressure and temperature [15,16].

The production process of sisal composites could be significantly enhanced by optimising the fibre orientation. An increase in the fibre orientation relative to the fibre loading resulted in a decrease in both strength and modulus. Remarkably, composites exhibit their optimal mechanical performance when the orientation of the fibres is parallel to the direction in which they are being loaded [17–19].

Finally, the qualities varies for each procedure as a result of utilising distinct processing pressure, temperature, and speed. Sreekumar et al. [20] produced sisal fibre polyester composites by compression moulding and resin transfer moulding processes to investigate their mechanical properties. The produced RTM composites exhibited increased tensile strength, Young's modulus, flexural strength, and flexural modulus, as demonstrated by the study.

3.0 MECHANICAL PROPERTIES OF SISAL FIBRE REINFORCED POLYMER COMPOSITES

Several polymers can be reinforced with sisal fibre, including epoxy, polystrene and polypropylene. Within this set of matrices, there are three prevalent composites that incorporate sisal fibre reinforcement: sisal fibre reinforced polypropylene composites, sisal fibre reinforced epoxy composites, and sisal fibre reinforced polystyrene composites. Table 3 provides a summary of recently conducted research that assess the mechanical properties of composites made from sisal fibres and polymer materials.

Table 3: Comparative Mechanical Properties of Sisal Fibre Polymer Composites with Different Types of Sisal Fibre Reinforcement [21]

Fibre Treatment	**Matrix**	**Fibre content (wt%)**	**Young's Modulus (GPa)**	**Elongation at break (%)**	**Tensile Strength (MPa)**	**Flexural Strength (MPa)**	**Impact Strength ($\frac{KJ}{m^2}$)**
Untreated	PP	20	0.88	10.5	24	-	15
Alkali Treated	PP	20	0.86	12.5	25	-	16
Heat Treated	PP	20	0.94	12.0	26	-	19
Untreated	Epoxy	50	460	-	275	200	-
Alkali Treated	Epoxy	50	275	-	340	225	-
Heat Treated	Epoxy	50	460	-	300	250	-
Untreated	PS	20	1.00	8.00	43	-	-
Benzoylation	PS	20	1.01	7.00	45	-	-

Note that - PP: Polypropylene and PS: Polystyrene

The sisal fibre can be strengthened by incorporating different polymer matrices, such as polypropylene, polystyrene, and epoxy. The strength and stiffness of sisal fibre composites might vary depending on the matrices used in the composite system. From this perspective, the proportion of sisal fibre can range from 20 to 50% in terms of loading, resulting in varying levels of strength. Moreover, the type of treatment applied to the sisal fibres can have an impact on their ability to reinforce the polymer matrix, hence affecting the mechanical properties of the composites. Finally, the selection of a certain polymer matrix in combination with sisal fibres can have an impact on the overall mechanical performance and impact strength of the composites.

Table 3 shows that both alkalisation and heat treatment greatly improve the tensile strength, Young's modulus, elongation at break, and impact strength of the composites [22]. The higher mechanical capabilities of alkali-treated and heat-treated sisal fibre/PP composites, with having the same amount of fibre, can be attributed to the improved adhesion between the fibre and the PP matrix, as well as the inherent qualities of the treated fibres. Moreover, the inclusion of processed fibres into the epoxy matrix leads to increased tensile and flexural strengths in comparison to untreated sisal composites. It should be emphasised that the flexural strength of heat-treated sisal fibre composites is inferior to that of alkali-treated sisal fibre epoxy composites [23]. In addition, Table 3 demonstrates that the tensile strength of the composites is further improved by modifying the fibres with polystyrene.

4.0 CURRENT STRUCTURAL APPLICATION OF SISAL FIBRE REINFORCED POLYMER COMPOSITES

The use of sisal fibres into polymer composites greatly enhances their physical and mechanical characteristics. Sisal composites are utilised in the production of several essential components, including door panels, roof panels, floor linings, wall insulation, and structural applications. Many researchers have tried hybrid sisal fibre with other natural fibres to make novel fibres. The recent progress of sisal fibre reinforced polymer composites are shown in Table 4.

Table 4: Comparative Mechanical Properties of Sisal Fibre Polymer Composites with Different Types of Sisal Fibre Reinforcement

Composites	Resin	Application	Properties tested	References
Sisal/Kenaf	Epoxy	Car Bumper	Tensile test, impact test, hardness test, water absorption	[24]
Sisal/Bamboo	Polyester	Interior door panel	Tensile, compressive, impact and flexural tests	[25]
Sisal /Banana/ Roselle	Epoxy	Automobile parts (Visor in two-wheeler, Indicator cover, Rear view mirror, seat cover in two-wheeler)	Tensile test, Hardness test, Moisture Absorption Test Scanning Electron Microscopy	[26]
Sisal/Kenaf	Epoxy	Semi structural application	Mechanical Properties (i.e. modulus, percentage elongation, impact strength and tensile strength), TGA, Water Absorption, DMA	[27]
Sisal/Tea Waste	Epoxy	Dashboards, base of seats, rear and front bumpers, paneling of aircraft interior, brake pedal, materials for soundproofing, speaker compartment,	Mechanical Testing (Tensile test, Flexural test, Izod impact test), FTIR Analysis, Acoustical Properties – Impedance Test tube Method, Scanning Electron Microscopy (SEM)	[28]
Sisal / Palm	Epoxy	Semi Structural, door panels, window frames	Mechanical test (tensile, flexural, impact), sound absorption, SEM	[29]

Sisal and kenaf fibres with special epoxy resin for automotive bumpers [24]. Tensile strength, impact resistance, hardness, and water absorption are examined. Tensile testing show which material can endure force before breaking. Hardness tests measure surface resistance to indentation and abrasion, whereas impact testing measure collision energy absorption. Water absorption tests are essential for assessing wet-weather durability. Example: sisal and bamboo fibres in polyester resin for interior door panels [25]. Tensile, compressive, impact, and flexural tests are performed on this composite. Flexural and compressive tests determine the material's bending and pushing strength. These qualities are essential for interior applications that require mechanical strength and aesthetics. An epoxy composite of sisal, banana, and roselle fibres examines its microstructural properties and suitability for automotive components [26]. Composites are used for visors, indicator covers, rearview mirrors, and two-wheeler seat covers. Tensile strength, hardness, moisture absorption, and SEM analysis are performed on this composite. SEM shows the fiber-matrix interface, ensuring adequate adhesion and distribution, which are crucial to mechanical performance. In further work, Prabhu et al. [28] may examine how this composite passes strict mechanical and acoustical norms for automotive and aerospace applications. Sisal and Tea Waste fibres are mixed with epoxy resin for dashboards, seat bases, bumpers, aircraft interior panelling, brake pedals, soundproofing, and speaker chambers. FTIR, acoustical properties, SEM, tensile, flexural, and Izod impact tests are performed on the composite. FTIR analyses chemical bonding and compositions, may highlight how this composite improves residential and commercial structural integrity and acoustics. Epoxy resin with sisal and palm fibres for semi-structural applications, door panels, and window frames. Tensile, flexural, impact, sound absorption, and SEM testing are done. These tests assure the composite's strength, flexibility, impact resistance, and acoustic performance for building and construction.

In summary, the table demonstrates the wide range of uses and thorough examination of natural fibre composites, illustrating their capacity to substitute traditional materials in many sectors. These composites provide a diverse array of mechanical and physical qualities that are customised to meet individual requirements by utilising natural fibres such as sisal, kenaf, bamboo, banana, roselle, tea waste, and palm in conjunction with resins like epoxy and polyester. The continuous research and development in this domain has the potential to result in wider acceptance of these eco-friendly materials, hence decreasing the ecological footprint and enhancing the efficiency and longevity of designed goods. The majority of researchers are now utilising epoxy-based composites, which are generally not the polymers of choice for automakers. In addition to that, packaging materials such as bags, boxes, and containers, which were formerly constructed of wood, have now been substituted with a more cost-effective sisal reinforced composite. Boats can be constructed by substituting the traditional polymer composite fibres with sisal as a kind of reinforcement [30]. Furthermore, sisal has the potential to be used in the construction of corrugated roof panels that include strength, affordability, and exceptional fire resistance [31]. Asbestos fibres possess the capacity to induce cancer. Corrugated roof panels are constructed using sisal fibre cement, which serves as a safe and efficient alternative to asbestos fibres while also being environmentally benign.

5.0 CONCLUSION

Sisal fiber reinforced polymeer composites are now widely used in various applications. It can be seen that the sisal fibre reinforced polymer composites have high mechanical strength and stiffness and could provide lighter weight which highly potential for structural application. For instance, sisal fiber reinforced epoxy composites are utilized in automotive parts such as car bumpers, visors for two-wheelers, indicator covers, rearview mirrors, dashboards, speaker compartments, and soundproofing materials.

Looking ahead, sisal fiber's numerous applications suggest it should be more widely adopted. Its environmental friendliness and biodegradability make it an excellent option for floor coverings. Additionally, sisal fiber is valuable in the cordage industry for making ropes, baler, and binder’s twine. Lower quality sisal fiber is suitable for paper production.

In the automotive industry, sisal fiber can be used in car doors, panels, and package holders to reduce fuel consumption. In the construction industry, short sisal fibers are used to make high-quality sofas, washing mats, and other pulp construction materials. Other applications include dartboards, buffing cloths, handicrafts, and filter manufacturing.

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REFERENCES

[1] Satyanarayana KG, Ravikumar KK, Sukumaran K, Mukherjee PS, Pillai SGK, Kulkarni AG. Structure and properties of some vegetable fibres - Part 3 Talipot and palmyrah fibres. J Mater Sci 1986;21:57–63. https://doi.org/10.1007/BF01144699.

[2] Chand N, Tiwary RK, Rohatgi PK. Bibliography Resource structure properties of natural cellulosic fibres - an annotated bibliography. J Mater Sci 1988;23:381–7. https://doi.org/10.1007/BF01174659.

[3] Bisanda ETN, Ansell MP. Properties of sisal-CNSL composites. J Mater Sci 1992;27:1690–700. https://doi.org/10.1007/BF00542934.

[4] Senthilkumar K, Saba N, Rajini N, Chandrasekar M, Jawaid M, Siengchin S, et al. Mechanical properties evaluation of sisal fibre reinforced polymer composites: A review. Constr Build Mater 2018;174:713–29. https://doi.org/10.1016/j.conbuildmat.2018.04.143.

[5] Zainudin ES, Aisyah HA, Nurazzi NM, Kuzmin A. A Review on Natural Fibres Based Composite Filament for 3D Printing. J Nat Fibre Polym Compos 2023;2:1–7.

[6] Chandrasekar M, Ishak MR, Sapuan SM, Leman Z, Jawaid M. A review on the characterisation of natural fibres and their composites after alkali treatment and water absorption. Plast Rubber Compos 2017;46:119–36. https://doi.org/10.1080/14658011.2017.1298550.

[7] Fauzi MFM, Asyraf MRM, Hassan SA, Ilyas RA, Khan T. Hybrid Kenaf Fibre/Fibreglass Meshes Reinforced Thermoplastic ABS Composites based on Quasi-Isotropic Mechanism: A Brief Review. J Nat Fibre Polym Compos 2023;2:1–9.

[8] Asyraf MRM, Hazrati KZ, Sheng DDCV, Rafidah M, Ashraf W, Madenci E, et al. Lignocellulosic Sugar Palm Fibre-Reinforced Thermoplastic Composites: Mechanical, Thermal and Dynamic Mechanical Properties. Fibers Polym 2023;24:2625–39. https://doi.org/10.1007/s12221-023-00224-6.

[9] Pantano A, Militello C, Bongiorno F, Zuccarello B. Analysis of the Parameters Affecting the Stiffness of Short Sisal Fiber Biocomposites Manufactured by Compression-Molding. Polymers (Basel) 2022;14. https://doi.org/10.3390/polym14010154.

[10] Puglia D, Biagiotti J, Kenny JM. A review on natural fibre-based composites - Part II: Application of natural reinforcements in composite materials for automotive industry. J Nat Fibers 2004;1:23–65. https://doi.org/10.1300/J395v01n03_03.

[11] Madsen B, Lilholt H. Physical and mechanical properties of unidirectional plant fibre composites-an evaluation of the influence of porosity. Compos Sci Technol 2003;63:1265–72. https://doi.org/10.1016/S0266-3538(03)00097-6.

[12] Zini E, Scandola M. Green composites: An overview. Polym Compos 2011;32:1905–15. https://doi.org/10.1002/pc.21224.

[13] Zhou Y, Fan M, Chen L. Interface and bonding mechanisms of plant fibre composites: An overview. Compos Part B Eng 2016;101:31–45. https://doi.org/10.1016/j.compositesb.2016.06.055.

[14] Pickering KL, Abdalla A, Ji C, McDonald AG, Franich RA. The effect of silane coupling agents on radiata pine fibre for use in thermoplastic matrix composites. Compos Part A Appl Sci Manuf 2003;34:915–26. https://doi.org/10.1016/S1359-835X(03)00234-3.

[15] Kamarul Bahrain SH, Mahmud J, Ismail MH. Arenga pinnata–silicone biocomposite properties via experimental and numerical analysis. Medziagotyra 2018;24. https://doi.org/10.5755/j01.ms.24.3.18296.

[16] Arao Y, Fujiura T, Itani S, Tanaka T. Strength improvement in injection-molded jute-fiber-reinforced polylactide green-composites. Compos Part B Eng 2015;68:200–6. https://doi.org/10.1016/j.compositesb.2014.08.032.

[17] Nurazzi NM, Norrrahim MNF, Sabaruddin FA, Shazleen SS, Ilyas RA, Lee SH, et al. Mechanical performance evaluation of bamboo fibre reinforced polymer composites and its applications: a

review. Funct Compos Struct 2022;4:015009. https://doi.org/10.1088/2631-6331/ac5b1a.

[18] Amir AL, Ishak MR, Yidris N, Zuhri MYM, Asyraf MRM, Zakaria SZS. Influence of Woven Glass-Fibre Prepreg Orientation on the Flexural Properties of a Sustainable Composite Honeycomb Sandwich Panel for Structural Applications. Materials (Basel) 2023;16. https://doi.org/10.3390/ma16145021.

[19] Fitri MFM, Asyraf MRM, Hassan SA, Ilyas RA. Unveiling the physico-mechanical properties of kenaf yarn fiber-reinforced acrylonitrile butadiene styrene composites: Effect of quasi-isotropic lay-up sequences. Polym Compos 2024. https://doi.org/10.1002/pc.28414.

[20] Sreekumar PA, Joseph K, Unnikrishnan G, Thomas S. A comparative study on mechanical properties of sisal-leaf fibre-reinforced polyester composites prepared by resin transfer and compression moulding techniques. Compos Sci Technol 2007;67:453–61. https://doi.org/10.1016/j.compscitech.2006.08.025.

[21] Karthick R, Aruna M. A Review on Mechanical Behaviour of Polymers/ Sisal Fiber Reinforced Composites Material. Int J Sci Dev Res 2018;3:190–9.

[22] Joseph K, Thomas S, Pavithran C. Effect of chemical treatment on the tensile properties of short sisal fibre-reinforced polyethylene composites. Polymer (Guildf) 1996;37:5139–49. https://doi.org/10.1016/0032-3861(96)00144-9.

[23] Zhong JB, Lv J, Wei C. Mechanical properties of sisal fibre reinforced ureaformaldehyde resin composites. Express Polym Lett 2007;1:681–7. https://doi.org/10.3144/expresspolymlett.2007.93.

[24] Ramasubbu R, Madasamy S. Fabrication of Automobile Component Using Hybrid Natural Fiber Reinforced Polymer Composite. J Nat Fibers 2022;19:736–46. https://doi.org/10.1080/15440478.2020.1761927.

[25] Getu D, Nallamothu RB, Masresha M, Nallamothu SK, Nallamothu AK. Production and characterization of bamboo and sisal fiber reinforced hybrid composite for interior automotive body application. Mater Today Proc 2020;38:2853–60. https://doi.org/10.1016/j.matpr.2020.08.780.

[26] Chandramohan D, Bharanichandar J. Natural fiber reinforced polymer composites for automobile accessories. Am J Environ Sci 2014;9:494–504. https://doi.org/10.3844/ajessp.2013.494.504.

[27] Yorseng K, Rangappa SM, Parameswaranpillai J, Siengchin S. Influence of accelerated weathering on the mechanical, fracture morphology, thermal stability, contact angle, and water absorption properties of natural fiber fabric-based epoxy hybrid composites. Polymers (Basel) 2020;12:1–14. https://doi.org/10.3390/polym12102254.

[28] Prabhu L, Krishnaraj V, Gokulkumar S, Sathish S, Ramesh M. Mechanical, Chemical and Acoustical Behavior of Sisal – Tea Waste – Glass Fiber Reinforced Epoxy Based Hybrid Polymer Composites. Mater Today Proc 2019;16:653–60. https://doi.org/10.1016/j.matpr.2019.05.142.

[29] Dhandapani N, Megalingam A. Mechanical and Sound Absorption Behavior of Sisal and Palm Fiber Reinforced Hybrid Composites. J Nat Fibers 2022;19:4530–43. https://doi.org/10.1080/15440478.2020.1863893.

[30] Srinivasakumar P. Sisal and its Potential for Creating Innovative Employment Opportunities and Economic Prospects. IOSR J Mech Civ Eng 2013;8:01–8. https://doi.org/10.9790/1684-0860108.

[31] Bisanda ETN. The manufacture of roofing panels from sisal fibre reinforced composites. J Mater Process Tech 1993;38:369–79. https://doi.org/10.1016/0924-0136(93)90209-O.