Composites Science and Technology

Mohammad Jawaid
Anish Khan *Editors*

Vegetable Fiber Composites and their Technological Applications

Springer

Composites Science and Technology

Series Editor

Mohammad Jawaid, Lab of Biocomposite Technology, Universiti Putra Malaysia, INTROP, Serdang, Malaysia

Composites Science and Technology (CST) book series publishes the latest developments in the field of composite science and technology. It aims to publish cutting edge research monographs (both edited and authored volumes) comprehensively covering topics shown below:

- Composites from agricultural biomass/natural fibres include conventional composites-Plywood/MDF/Fiberboard
- Fabrication of Composites/conventional composites from biomass and natural fibers
- Utilization of biomass in polymer composites
- Wood, and Wood based materials
- Chemistry and biology of Composites and Biocomposites
- Modelling of damage of Composites and Biocomposites
- Failure Analysis of Composites and Biocomposites
- Structural Health Monitoring of Composites and Biocomposites
- Durability of Composites and Biocomposites
- Biodegradability of Composites and Biocomposites
- Thermal properties of Composites and Biocomposites
- Flammability of Composites and Biocomposites
- Tribology of Composites and Biocomposites
- Bionanocomposites and Nanocomposites
- Applications of Composites, and Biocomposites

To submit a proposal for a research monograph or have further inquries, please contact springer editor, Ramesh Premnath (ramesh.premnath@springer.com).

More information about this series at http://www.springer.com/series/16333

Mohammad Jawaid · Anish Khan
Editors

Vegetable Fiber Composites and their Technological Applications

Springer

Editors
Mohammad Jawaid
Laboratory of Biocomposite Technology
INTROP
Universiti Putra Malaysia
Serdang, Selangor, Malaysia

Anish Khan
Center of Excellence for Advanced
Materials Research
King Abdulaziz University
Jeddah, Saudi Arabia

ISSN 2662-1819 ISSN 2662-1827 (electronic)
Composites Science and Technology
ISBN 978-981-16-1853-6 ISBN 978-981-16-1854-3 (eBook)
https://doi.org/10.1007/978-981-16-1854-3

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature
Singapore Pte Ltd. 2021
This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

In this book, we focus on eco-friendly, biodegradable, and sustainable vegetable fiber composite preparation, properties, and industrial applications. It is time to explore green materials, so we decided to discuss the latest technological aspects of vegetable fiber composite made from the biopolymer that are biodegradable. The vegetable fiber composite materials for the production of biocomposite because it is biocompatible, cheap and easy available, low density with high strength, and good mechanical properties. Present book discusses various properties and applications of composite materials made from renewable biomaterial and biofibers. They are more eco-friendly as compared by the composite made from synthetic fibers.

This book will help researchers, scientists, and industries to understand the need of vegetable fiber composites for the development of safe and sustainable products for various applications. The characterization of vegetable fiber composites plays a crucial role to find out its potentiality in different real-world applications. It elaborates the physical, mechanical, morphological, structural, thermal, and electrical properties of native or modified fibers-based polymer composites.

Present book covers a review on hybrid vegetable/glass fiber epoxy composites, mechanical and acoustic properties of wool/glass hybrid composites, potential applications of Peristophe roxburghiana in textiles, lightweight vegetable-based hybrid laminated composites, electrochemical sensing applications of vegetable fiber-based porous carbon materials, vegetable fiber pretensioning influence on the composites, improvement of fiber matrix adhesion of vegetable natural fibers by chemical treatment, study of thermal degradation of a phenolic resin, vegetable fibers, and derived composites, waste management and application of coconut biomass and fiber, chemical modifications on physical properties of banana fiber-reinforced polyester composites, review on hemp fiber-reinforced polymer composites, vegetables fibers and its composite for packaging products, modification of vegetable fiber for natural fiber composites, Ag nanoparticles/jute fibers bionanocomposites as an efficient fungi-free material for the automobile industry, tribological behavior of glass fiber-reinforced polyamide gears, identification of vegetable fiber origin, various natural fibers and green nano-reinforcements such as microcrystalline cellulose, cellulose nanocrystals, and bacterial cellulose, development of vegetable fiber-mortar composites of improved durability, roles of vegetable fibers in green chemistry, tribological behavior of glass/sisal fiber-reinforced polyester composite, and the understanding of fluorination process to hydrophobic natural fibers.

We are highly thankful to all authors who contributed chapters and provide their valuable ideas and knowledge in this edited book. We attempt to gather all the scattered information of authors from diverse fields around the world (Malaysia, Jordan, USA, Turkey, India, Saudi Arabia, Bangladesh, Oman, and Sweden) in the areas of vegetable fibers-based composites and its applications and finally complete this venture in a fruitful way. We greatly appreciate contributor's commitment for their support to compile our ideas in reality.

We are highly thankful to the Springer Nature-Singapore team for their generous cooperation at every stage of the book production.

Serdang, Malaysia Mohammad Jawaid
Jeddah, Saudi Arabia Anish Khan

Contents

About the Editors

Mohammad Jawaid is currently working as Senior Fellow (Professor) at Biocomposite Technology Laboratory, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia (UPM), Serdang, Selangor, Malaysia, and also has been Visiting Professor at the Department of Chemical Engineering, College of Engineering, King Saud University, Riyadh, Saudi Arabia, since June 2013. He has more than 20 years of experience in teaching, research, and industries. His area of research interests includes hybrid composites, lignocellulosic-reinforced/filled polymer composites, advance materials: graphene/nanoclay/fire retardant, modification and treatment of lignocellulosic fibers and solid wood, biopolymers and biopolymers for packaging applications, nanocomposites and nanocellulose fibers, and polymer blends. So far, he has published 50 books, 70 Book chapters, more than 350 peer-reviewed international journal papers, and several published review papers under top 25 hot articles in science direct during 2013–2019. He also obtained two patents and six copyrights. H-index and citation in Scopus are 57 and 15427, and in Google scholar, H-index and citation are 71 and 21918. He is Founding Series Editor of Composite Science and Technology Book Series from Springer Nature and also Series Editor of Springer Proceedings in Materials, Springer Nature, and also International Advisory Board Member of Springer Series on Polymer and Composite Materials. He worked as Guest Editor of special issues of *SN Applied Science*, *Frontiers in Sustainable Food Systems*, *Current Organic Synthesis and Current Analytical Chemistry*, *International Journal of Polymer Science*, and *IOP Conference Proceeding*. He is also Editorial Board Member of *Journal of Polymers and The Environment*, *Journal of Plastics Technology*, *Applied Science and Engineering Progress Journal*, *Journal of Asian Science, Technology and Innovation*, and the *Recent Innovations in Chemical Engineering*. Besides that, he is also Reviewer of several high-impact international peer-reviewed journals of Elsevier, Springer, Wiley, Saga, ACS, RSC, Frontiers, etc. Presently, he is supervising 12 Ph.D. students (five Ph.D. as Chairman, and seven Ph.D. as Member) and six master's students (one master as Chairman, and five master as Member) in the fields of hybrid composites, green composites, nanocomposites, natural fiber-reinforced composites, nanocellulose, etc., 26 Ph.D. and 13 master's students graduated under his supervision in 2014–2020. He has several research grants at university, national, and international levels on polymer composites of around 3 million Malaysian ringgits (USD 700,000). He also delivered plenary and invited talks in international conferences related to composites in India, Turkey, Malaysia, Thailand, the UK, France, Saudi Arabia, Egypt, and China. Besides that, he is also Member of technical committees of several national and international conferences on composites and material science. Recently, he received Excellent Academic Award in Category of International Grant-Universiti Putra Malaysia-2018 and also Excellent Academic Staff Award in industry High-Impact Network (ICAN 2019) Award, beside that Gold Medal Community and Industry Network (JINM Showcase) at Universiti Putra Malaysia. He also received Publons Peer-Review Awards 2017 and 2018 (Materials Science), Certified Sentinel of Science Award Recipient 2016 (Materials Science) and 2019 (Materials Science and Cross-field). He is also Winner of Newton-Ungku Omar Coordination Fund: UK–Malaysia Research and Innovation Bridges Competition 2015. Recently, he got Fellow and Chartered Scientist from Institute of Materials, Minerals, and Mining (IOM), UK. He is also Life Member of Asian Polymer Association and Malaysian Society for Engineering and Technology. He has professional membership of American Chemical Society (ACS) and Society for polymers Engineers (SPE), USA.

Dr. Anish Khan is currently working as Assistant Professor in Chemistry Department, Center of Excellence for Advanced Materials Research (CEAMR), King Abdulaziz University, Jeddah, Saudi Arabia. He completed Ph.D. from Aligarh Muslim University, India, in 2010 and Postdoctoral from School of Chemical Sciences, University Sains Malaysia (USM), on the topic of electroanalytical chemistry in 2010. He is working in the field of synthetic of polymers composite, organic–inorganic electrically conducting nanocomposites, cation exchanger, natural fiber composite, metal organic framework's composite, and their properties and applications as sensor. He has published more than 200 research articles, 70 chapters, 35 books in referred international publishers and more than 20 international conferences/workshop. He is Member of American Nano Society, and his field of specialization is polymer nanocomposite/cation exchanger/chemical sensor/microbiosensor/nanotechnology, application of nanomaterials in electroanalytical chemistry, material chemistry, ion exchange chromatography and electro-analytical chemistry, dealing with the synthesis, characterization (using different analytical techniques), and derivatization of inorganic ion exchanger by the incorporation of electrically conducting polymers. Preparation and characterization of hybrid nanocomposite materials and their applications, polymeric inorganic cation exchange materials, electrically conducting polymeric, materials, composite material use as sensors, green chemistry by remediation of pollution, heavy metal ion-selective membrane electrode, and biosensor on neurotransmitter.

Hybrid Vegetable/Glass Fiber Epoxy Composites: A Systematic Review

Roberta M. Neves, Francisco M. Monticeli, José Humberto S. Almeida, and Heitor Luiz Ornaghi

1 Introduction

Nowadays, the increasing pressure about the preservation of natural resources and political awareness on exploring green alternatives to decreasing global fossil fuel emission [1]. Vegetable fibers arise from natural resources and they fulfill the renewability and marketing apse requirements. In the last four decades, thermoset composites with vegetable fibers have been extensively studied are mainly applied in the automotive interior components [2]. There is an increasing demand for applying natural composites in other areas, such as in civil structures due to their low density, good processability, low abrasion, and high resistance to corrosion [3]. However, the application is restricted to low-medium components and they cannot yet substitute com synthetic fiber composites, such as glass fiber structures. Seeking at minimizing these drawbacks and aiming to broaden the range of applications, there are increasing studies in hybrid synthetic/vegetable fiber-reinforced composites. When the fibers are adequately combined, the resulting properties can be comparable to pure synthetic fiber composite and hence replace synthetic fibers, depending upon the application [4-10].

R. M. Neves
Federal University of Rio Grande do Sul, PPGE3MAv. Bento Gonçalves 9500, Porto Alegre, RS, Brazil

F. M. Monticeli
Department of Materials and Technology, Sao Paulo State University, Guaratinguetá, SP 12516-410, Brazil

J. H. S. Almeida
Department of Mechanical Engineering, Aalto University, 02150 Espoo, Finland

H. L. Ornaghi (✉)
Federal University for Latin America Integration (UNILA), Edifício Comercial Lorivo - Av. Silvio Américo Sasdelli, 1842 - Vila A, Foz do Iguaçu, PR 85866-000, Brazil

M. Jawaid and A. Khan (eds.), *Vegetable Fiber Composites and their Technological Applications*, Composites Science and Technology,
https://doi.org/10.1007/978-981-16-1854-3_1

Hybrid composites are tailorable materials, which are driven by the role of fibers arrangement in the composite system. The behavior of hybrid composites considers the contribution of each reinforcing phase (the type of reinforcement, geometry, etc.), in which the composite can be manufactured aiming at taking the best characteristics of each fiber. There are innumerous studies regarding glass/vegetable hybrid composites that can be found in the literature in different databases [4, 10–12]. Often, the chosen research topic is not immediately found in the performed searches, and when a review on this particular chosen topic is carried out, several times, it is identified that previous studies on the same topic have already been done, invalidating the approach. In this context, a systematic review is a powerful tool that helps the readers to rapidly find the lacks and most studied topics of a specific subject.

2 Systematic Review

Different than a conventional literature review, a systematic review aims to *identify, evaluate, and summarize the findings of all relevant individual studies* over a defined issue, *making the available evidence more accessible to decision-makers* [13]. Primarily, the protocol is employed based on a severe and rigorous scientific search allowing anticipate potential problems and indicating gaps in knowledge, which can be used as a starting point for developing new researches. An important characteristic is that some granting agencies require a systematic review to justify the planned research [14]. Another important characteristic is preventing arbitrary decisions (by respecting inclusion criteria and extraction of data), then, it follows a protocol.

Systematic reviews are very widespread in the area of medicine and health care. Some systematic reviews were published regarding low health literacy and health outcomes [15], insomnia, complementary medicine [16], and renal cancer [17]. In the polymeric fields, very few studies were released following the PRISMA protocol [18, 19]. However, until now, in the composites field, there is no systematic review that follows PRISMA methodology focusing on their mechanical, thermal, and dynamic mechanical properties, especially when it comes to vegetable fibers/cellulose chemically modified/epoxy composites.

Hence, the main aim of this book chapter is to compile data between 2016 and 2020, about composite laminates with epoxy resin as matrix and hybrid glass/vegetable fibers as the reinforcing phase. We focus on thermal, mechanical, and dynamic mechanical properties, as well as the manufacturing process to verify a future trend or gaps in this area. Moreover, we list the obtained data regarding the reinforcement type and processing method.

3 Systematic Review Methodology

The methodological guidelines outline the Transparent Reporting of Systematic Reviews and Meta-Analyses (PRISMA)[1] in which a determined protocol is followed before carrying out this systematic review. This protocol aims to rationale, hypothesize, and plan the review, being a guide. In this book chapter, three different literature databases are considered, and only research papers focused on recent studies in glass/vegetable fiber hybrid composites using epoxy resin as a matrix are taken into consideration. More details are presented next.

Papers are selected using Scopus (www.scopus.com), Web of Science (www.webofknowledge.com), and SciFinder (https://sso.cas.org/) databases. The terms of search are: ([epoxy] AND [hybrid] AND [composites] AND [natural] AND [glass] AND [fiber]). We choose the word "natural" instead "vegetable" because no paper was found with this term, despite being a well-accepted term in the field. The results are limited to papers published from 2016 to 2020. The identified articles have their titles and abstracts assessed independently by two reviewers (Neves, R.M., and Ornaghi Jr, H.L.) to screen their allocation in the systematic review.

This book chapter focuses on recent studies in the hybrid glass/vegetable fiber composites field. The type of vegetal fiber, manufacturing process, and thermal, mechanical, and dynamic mechanical properties are listed excluding microscopies (e.g. scanning electron microscopy—SEM, and optical microscopy) and chemical analyzes (e.g., FTIR, XRD, NMR) as well other results such as flammability, aging, wettability, and water absorption.

4 Results of Data Collection

The study selection can be better visualized in the flowchart (Fig. 1), in which the records for every database are identified as well the exclusion criteria and selected papers by eligibility. The total search is of 285 studies, including all chosen databases. In this step, conference papers, review studies, studies not presented in English language, book chapter, editorial, letters, and notes are not considered. With only research papers remaining, some studies which do not account for the present systematic review methodology are excluded: studies with other matrices other than epoxy resin [12 studies], no hybrid composites (7 studies), hybrid composites other than epoxy glass/fiber/vegetable fibers (14 studies), hybrid composites with epoxy matrix but without vegetable fibers as reinforcement [15], vegetable hybrid composites with epoxy matrix but without glass fiber as reinforcement [67], and composites that add another material as a third component [38] are excluded. After this step, 132 studies remained. From these, 84 are excluded for duplicity on the databases. After all, 48 meet all selected criteria, then composing the current systematic review.

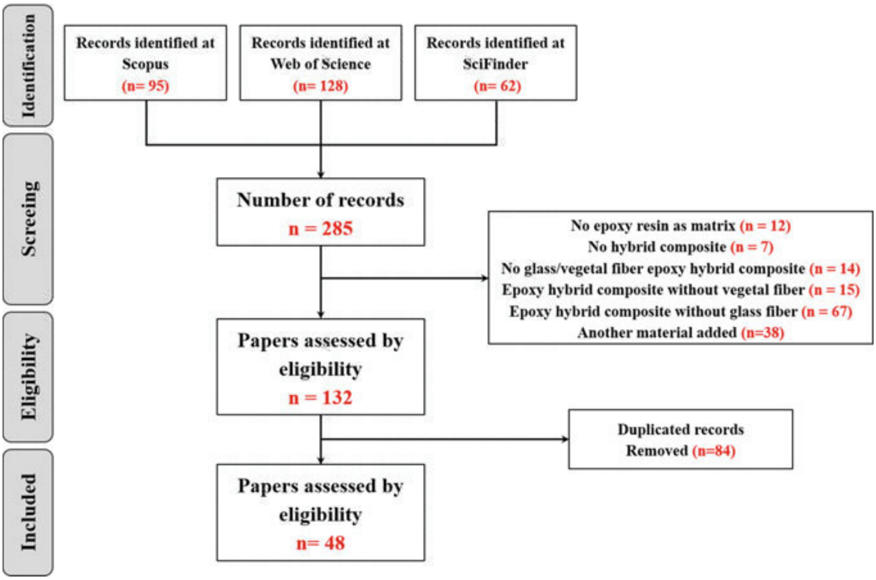

Fig. 1 Systematic review flowchart following PRISMA protocol

The type of glass fiber (chopped, unidirectional, and woven), natural fiber (chopped, continuous mat, woven, and powder), and composite are presented in Fig. 2. Highlighting the frequency of appearance in the selected research papers.

5 Results and Discussion

Table 1 presents all results of the 48 selected papers according to PRISMA flowchart (Fig. 1) summarized in the systematic review search. The type of fiber, processing manufacturing, and the description of thermal, mechanical, and dynamic mechanical properties are described in Table 1.

6 Conclusion and Future Perspectives

In this study, a systematic review on glass/vegetable hybrid composites between 2016 and 2020 was performed. The type of reinforcements and manufacturing processes were included. Thermal, mechanical, and dynamic mechanical properties were also targeted. The systematic review proved to be a useful tool for both young and the experienced researchers as a guideline in a specific(s) subject(s). It easily indicates the trends and lacks in a searched topic. This study showed an enormous lack of thermal

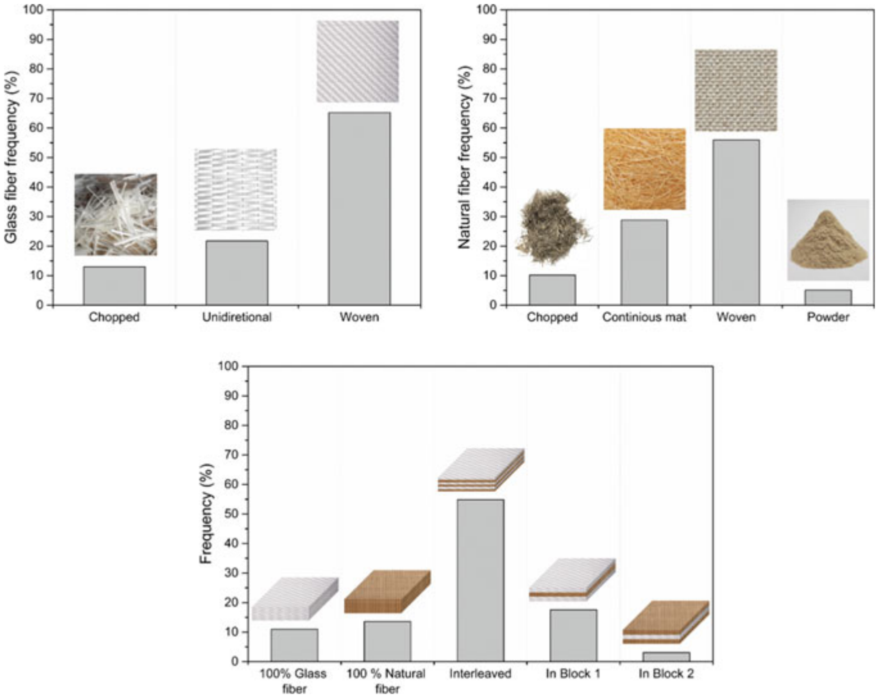

Fig. 2 Frequency of the glass fibers, natural fiber, and type of composites found on the systematic review

and dynamic mechanical properties that can be explored for further research. The main studied aspect is at the mechanical properties point of view, which include impact, flexural, compressive, and tensile tests, independently of the reinforcement. Hand lay-up is the most employed manufacturing process, which is certainly associated to the low cost of this process. Finally, the most employed type of both glass and vegetal fiber was woven fabric, being the interleaved composite the most used. Consequently, the fast and easy identification of studies and the possibility of new combinations of reinforcements/manufacturing processes and tested properties make the systematic review a powerful tool in any scientific field.

Vegetable fibers will be continuously employed, and the studies evaluated here pointed out that there is a growing trend for different reasons given ecological appeal and environmental benefits or combination with synthetic fibers for different applications. The weight reduction, easy formability, low cost and ease-processing are some of the many advantages promoted by the vegetal fibers even when combined with synthetic fibers. As a result, glass/vegetable hybrid composites will keep being applied in interior automotive components to add an eco-friendly character while still meeting design requirements [67]. In addition, the possibility to chemically/physically modify vegetable fibers aiming to improve their physical–chemical properties is attractive, although it is still ineffective from the mass production point

Table 1 Thermal, mechanical, and dynamic-mechanical properties of the hybrid composites

References	Hybrid composite type	Natural fibser type	Process	Properties		
				Thermal	Mechanical	Dynamic-mechanical E': glassy region
[20]	Interleaved Hygrothermaly aged Pineapple leaf fiber (PALF)/glass (G): **Dry** (non-aged); **Wet** (aged) **i.** 4P **ii.** PGPG **iii.** PGGP **iv.** GPPG	PALF (P)	Hot compression molding	–	Tensile results: **Dry** X_t (MPa): **i.** 47.1; **ii.** 62.6; **iii:** 68.0; **iv:** 119.2 **Wet** X_t (MPa): **i.** 32.0; **ii.** 35.3; **iii:** 42.8; **iv:** 58.8 **Dry** E_t (GPa): **i.** 3.0; **ii.** 4.1; **iii:** 3.2; **iv:** 5.1 **Wet** E_t (GPa): **i.** 1.9; **ii.** 2.8; **iii:** 3.1; **iv:** 2.2 3-point bending results: **Dry** X_b (MPa): **i.** 78.1; **ii.** 124.6; **iii:** 130.4; **iv:** 170.7 **Wet** X_b (MPa): **i.** 58.3; **ii.** 96.1; **iii:** 83.6; **iv:** 94.9 **Dry** E_b (GPa): **i.** 2.9; **ii.** 4.4; **iii:** 2.1; **iv:** 3.3 **Wet** E_b (GPa): **i.** 1.2; **ii.** 1.4; **iii:** 1.2; **iv:** 1.6	–
[21]	Interleaved Banana/Glass (G): **i.** G8 **ii.** G4B1G3 **iii.** G3B2G3 **iv.** G3B3G2	Banana (B)	Hand lay-up	--	3-point bending results: X_b (MPa): **i.** 430; **ii.** 470; **iii:** 350; **iv:** 270	–

(continued)

Table 1 (continued)

References	Hybrid composite type	Natural fibser type	Process	Properties		
				Thermal	Mechanical	Dynamic-mechanical E': glassy region
[22]	Interleaved Calotropis Procera (CP)/glass (G)/epoxy (E) **i.** 0/0/100 CP/G/E **ii.** 20/0/80 CP/G/E **iii.** 15/5/80 CP/G/E **iv.** 10/10/80 CP/G/E **v.** 5/15/80 CP/G/E **vi.** 0/20/80 CP/G/E	Calotropis procera (CP)	Hand lay-up	–	$\mathbf{X_t}$**:** **i.** 35 MPa **ii.** 37 MPa **iii.** 42 MPa **iv.** 46 MPa **v.** 47 MPa **vi**. 53 MPa $\mathbf{E_t}$**:** **i.** 1351 MPa **ii.** 1896 MPa **iii.** 2364 MPa **iv.** 2626 MPa **v.** 2763 MPa **vi**. 2983 MPa	**i.** 2243 MPa **ii.** 2533 MPa **iii.** 2878 MPa **iv.** 2954 MPa **v.** 3102 MPa **vi**. 3151 MPa @40 °C

(continued)

Table 1 (continued)

References	Hybrid composite type	Natural fibser type	Process	Properties		
				Thermal	Mechanical	Dynamic-mechanical E’: glassy region
[23]	Interleaved Flax (F)/Glass (G): **Aged** and **non-aged**: i. FFFFFFFF ii. FGGGGGGF iii. FFGGGGFF iv. FFFGGFFF v. GFFFFFFG vi. GGFFFFGG vii. GGGFFGGG viii. GGGGGGGG	Flax (F)	Hand lay-up	–	3-point bending results: **Non-aged**: **i.** 22 GPa; **ii.** 24 GPa; **iii.** 22 GPa; **iv.** 22 GPa; **v.** 33 GPa; **vi.** 41 GPa; **vii.** 52 GPa **Aged**: **i.** 10 GPa; **ii.** 18 GPa; **iii.** 13 GPa; **iv.** 12 GPa; **v.** 26 GPa; **vi.** 38 GPa; **vii.** 48 GPa	–

(continued)

Table 1 (continued)

References	Hybrid composite type	Natural fibser type	Process	Properties		
				Thermal	Mechanical	Dynamic-mechanical E’: glassy region
[24]	Interleaved Sisal (S)/Glass (G) **i.** $[G]_{12}$ **ii.** $[S]_{12}$ **iii.** $[G/S]_6$	Sisal	Hand lay-up	–	3-point bending results: **i.** 788 MPa; **ii.** 107 MPa; **iii.** 365 MPa	–

(continued)

Table 1 (continued)

References	Hybrid composite type	Natural fibser type	Process	Properties		
				Thermal	Mechanical	Dynamic-mechanical E’: glassy region
[25]	Interleaved Flax (F)/Glass (G): **Aged** in salt fog. Samples with circular holes with 4, 8, and 10 mm. **i.** GFA (non-aged); **ii.** GFB [30 days aging]; **iii.** GFC (60 days aging)	Flax (F)	Vacuum-assisted resin infusion	–	Maximum bearing stress: **D = 4 mm**: **i.** 200 MPa; **ii.** 164 MPa; **iii.** 157 MPa **D = 8 mm**: **i.** 180 MPa; **ii.** 175 MPa; **iii.** 152 MPa **D = 10 mm**: **i.** 159 MPa; **ii.** 125 MPa; **iii.** 107 MPa	–

(continued)

Table 1 (continued)

References	Hybrid composite type	Natural fibser type	Process	Properties		
				Thermal	Mechanical	Dynamic-mechanical E': glassy region
[26]	Interleaved Mustard cake powder (M)/Glass (G)/epoxy/E) **i.** 0/40/60 (M/G/E); **ii.** 10/40/50 (M/G/E); **iii.** 0/60/40 (M/G/E); **iv.** 10/50/50 (M/G/E); **v.** 0/80/20 (M/G/E); **vi.** 10/80/10 (M/G/E);	Mustard cake powder (M)	Hand lay-up	–	X_t (MPa): **i.** 28; **ii.** 35; **iii:** 90; **iv:** 97; **v.** 110; **vi.** 135 X_b (MPa): **i.** 164; **ii.** 251; **iii:** 172; **iv:** 313; **v.** 192; **vi.** 538 SBS (MPa): **i.** 1.7; **ii.** 2.0; **iii:** 2.5; **iv:** 2.6; **v.** 2.9; **vi.** 3.1	–

(continued)

Table 1 (continued)

References	Hybrid composite type	Natural fibser type	Process	Properties		
				Thermal	Mechanical	Dynamic-mechanical E’: glassy region
[27]	Interleaved Pine apple (PA)/Glass (G): **i.** GPPP; **ii.** GGPP; **iii.** GGGP; **iv.** GGGG; **v.** PPPP	**Pine apple (PA)**	Hand lay-up	–	X_t (MPa): **i.** 130; **ii.** 144; **iii:** 168; **iv:** 194; **v.** 115 X_c (MPa): **i.** 98; **ii.** 115; **iii:** 138; **iv:** 175; **v.** 87 X_b (MPa): **i.** 115; **ii.** 132; **iii:** 141; **iv:** 131; **v.** 102 I (J/m): **i.** 260; **ii.** 345; **iii:** 379; **iv:** 411; **v.** 214	–

(continued)

Table 1 (continued)

References	Hybrid composite type	Natural fibser type	Process	Properties		
				Thermal	Mechanical	Dynamic-mechanical E’: glassy region
[28]	Interleaved Jute (J)/Glass (G): **i.** J6; **ii.** G6; **iii.** GJ4G; **iv.** JG4J; **v.** CJ4C; **vi.** CGGGGC; **vii.** JGCCGJ; **viii.** CGJJGC; **ix.** CCGGJJ	Jute (J)	Hand lay-up	–	S (MPa): **i.** 23; **ii.** 61; **iii:** 31; **iv:** 56; **v.** 27; **vi.** 63; **vii.** 52 ; **viii.** 51; **ix.** 51 G (GPa): **i.** 0.8; **ii.** 2.8; **iii:** 1.2; **iv:** 2.7; **v.** 0.9; **vi.** 3.7; **vii.** 1.0 ; **viii.** 1.7; **ix.** 1.3	–

(continued)

Table 1 (continued)

References	Hybrid composite type	Natural fibser type	Process	Properties		
				Thermal	Mechanical	Dynamic-mechanical E': glassy region
[29]	Interleaved Jute(J)/Glass(G) and Flax (F)/Glass (G) **i.** J4; **ii.** GJJG; **iii.** FFFFFFFF; **iv.** GGFFFFGG	Jute (J) and Flax (F)	Hand lay-up	–	X_t (MPa): **i.** 47; **ii.** 70; **iii:** 76; **iv:** 127 E_t (GPa): **i.** 4.9; **ii.** 6.8; **iii:** 4.6; **iv:** 4.0	–

(continued)

Table 1 (continued)

References	Hybrid composite type	Natural fibser type	Process	Properties		
				Thermal	Mechanical	Dynamic-mechanical E’: glassy region
[30]	Interleaved Cotton /G)/Glass (G): $V_f =$ 20%: **i.** C; **ii.** G; **iii.** C/G; $V_f = 30\%$: **iv.** C; **v.** G; **vi.** C/G	Cotton (C)	Hand lay-up	–	X_t (MPa): **i.** 45; **ii.** 82; **iii:** 84 **iv:** 57; **v.** 87; **vi.** 90 X_b (MPa): **i.** 52; **ii.** 60; **iii:** 67; **iv:** 64; **v.** 70; **vi.** 72 I (J/m^2): **i.** 80; **ii.** 141; **iii:** 145; **iv:** 98; **v.** 182; **vi.** 190	–
[31]	Unidirectional Flass (F)/Glass (G): **i.** $[0_{G2}/0_{F12}/0_{G2}]$; **ii.** $[0_{G2} \pm 45_{F12}/0_{G2}]$	Flax (F)	Hot compression	–	X_c (MPa): **i.** 262; **ii.** 232 E_c (GPa): **i.** 24; **ii.** 15 ν: **i.** 0.37; **ii.** 0.58 Fatigue: $E_0{}^*$: **i.** 15 (7% loss); **ii.** 10 (0% loss)	–

(continued)

Table 1 (continued)

References	Hybrid composite type	Natural fibser type	Process	Properties		
				Thermal	Mechanical	Dynamic-mechanical E': glassy region
[32]	Interleaved Kenaf (K)/Glass (G): **i.** 100% G; **ii**. 100% K; **iii**. 25% GF + 75% KF; **iv.** 30% GF + 70% KF; **v.** 50% GF + 50% KF; **vi**. 70% GF + 30% KF; **vii**. 75% GF + 25% KF	Kenaf (K)	Hand lay-up	–	F_t (kN): **i.** 46; **ii.** 11; **iii:** 14 **iv:** 19; **v.** 26; **vi.** 33; **vii.** 37	–

(continued)

Table 1 (continued)

References	Hybrid composite type	Natural fibser type	Process	Properties		
				Thermal	Mechanical	Dynamic-mechanical E’: glassy region
[33]	Interleaved Jute (J)/Glass (G): **i**. Jute/epoxy; **ii**. 45:55 J:G; **iii**. 30:70 J/G; **iv**. Glass/Epoxy	Jute (J)	Hand lay-up	–	X_t (MPa): **i.** 143; **ii.** 283; **iii:** 329 **iv:** 428 E_t (GPa): **i.** 8; **ii.** 12; **iii:** 13; **iv:** 16	–

(continued)

Table 1 (continued)

References	Hybrid composite type	Natural fibser type	Process	Properties		
				Thermal	Mechanical	Dynamic-mechanical E': glassy region
[34]	Interleaved Jute (J)/Kenaf (K)/Glass (G): **i**. GGGGG; **ii**. JJJJJ; **iii**. KKKKK; **iv**. JKJKJ; **v.** KJKJK; **vi**. GJJJG; **vii**. GKKKG; **viii.** GJKJG; **ix**. GKJKG	Jute (J) and kenaf (K)	Vacuum bagging	–	I_{Izod} (J/m): **i**. 1469; **ii**. 122; **iii**. 152; **iv**. 134; **v.** 171; **vi**. 792; **vii**. 897; **viii.** 860; **ix**. 1078 SBS (MPa): **i**. 18; **ii**. 5; **iii**. 6; **iv**. 5; **v.** 6; **vi**. 8; **vii**. 11; **viii.** 9; **ix**. 13	–

(continued)