

# SUSTAINABLE NATURAL FIBER COMPOSITES

## *The Synergy of* **FLAX** *and* **SISAL**



NATURAL  
RENEWABLE



SUSTAINABLE  
SOLUTIONS



STRONGER  
TOGETHER



NATURE INSPIRED.  
PERFORMANCE DRIVEN.  
A GREENER FUTURE.



### AUTHORS

Arghya Gupta • Akhtarujjaman Sarkar  
Soumojit Dasgupta • Sumit Chabri



BIOBASED



ECO-FRIENDLY



HIGH  
PERFORMANCE



SUSTAINABLE  
INNOVATION



# **SUSTAINABLE NATURAL FIBER COMPOSITES**

*The Synergy of Flax and Sisal*

---

**Arghya Gupta**

**Akhtarujjaman Sarkar**

**Soumojit Dasgupta**

**Sumit Chabri**

**Copyright © 2026 Arghya Gupta, Akhtarujjaman Sarkar, Soumojit Dasgupta, Sumit Chabri**

All rights reserved.

No part of this publication may be reproduced, stored in a retrieval system, transmitted, distributed, or utilized in any form or by any means, whether electronic, mechanical, photocopying, recording, scanning, or otherwise, without the prior written permission of the Publisher, except in the case of brief quotations embodied in critical reviews, scholarly works, and other non-commercial uses permitted under applicable copyright legislation.

**ISBN No.:** 978-81-686149-1-8 (Digital Download and Online)

First published in June, 2026 by

**Learnet Publishing**

19/B, Kali Kumar Majumder Road, P.O. Santoshpur Avenue, P.S. Survey Park, Kolkata – 700075, West Bengal, India

**Email IDs:** [learnetpublishing@gmail.com](mailto:learnetpublishing@gmail.com) | [info@learnetpub.co.in](mailto:info@learnetpub.co.in)

**Mobile No. / WhatsApp:** +91-9836423405

**Websites:** [www.learnetpub.co.in](http://www.learnetpub.co.in) | [www.jctmg.in](http://www.jctmg.in)

**MRP:** INR 499 (Digital Edition)

© The authors have asserted their moral rights to be identified as the authors of this work in accordance with applicable copyright laws.

The views and opinions expressed in this publication are those of the individual author(s) and do not necessarily reflect the views, policies, or positions of Learnet Publishing. The publication of this work does not imply endorsement by the Publisher of any opinions, findings, conclusions, or recommendations contained herein.

Every reasonable effort has been made to ensure the accuracy, reliability, and completeness of the information presented in this publication. However, neither the authors nor the Publisher shall be liable for any loss, damage, liability, or expense incurred or suffered that is claimed to result from the use of the information contained in this work.

The responsibility for the originality, authenticity, and integrity of the content rests solely with the respective author(s). Any claims relating to plagiarism, copyright infringement, defamation, data misuse, or other legal matters arising from the content shall remain the sole responsibility of the author(s), and the Publisher disclaims any liability in this regard.

The use of registered names, trademarks, service marks, trade names, or product names in this publication does not imply that such names are exempt from the relevant protective laws and regulations and may therefore be used freely.

Cover design and production by **Learnet Publishing**.

# Preface

The increasing demand for environmentally sustainable materials has transformed the direction of modern materials science and composite engineering. Conventional synthetic fibre composites, though mechanically strong and widely used, present serious environmental challenges due to their non-biodegradability, high energy consumption during production, and difficulties associated with recycling and disposal. In response to these concerns, natural fibre reinforced composites have emerged as a promising alternative, offering renewable, lightweight, biodegradable, and cost-effective solutions for engineering applications.

Among the numerous natural fibres investigated worldwide, flax and sisal fibres have attracted particular attention because of their unique and complementary properties. Flax fibre, a bast fibre, exhibits excellent stiffness, tensile strength, and low density, making it suitable for lightweight structural applications. Sisal fibre, a leaf fibre, contributes superior toughness, impact resistance, and thermal stability. The hybridisation of these two fibres therefore provides an opportunity to design composite systems that combine stiffness, strength, toughness, and durability within a single sustainable material framework.

This book, *Sustainable Natural Fiber Composites: The Synergy of Flax and Sisal*, has been written to provide a comprehensive understanding of hybrid natural fibre composites reinforced with liquid resole phenolic resin and enhanced through advanced ceramic fillers such as zirconia ( $ZrO_2$ ) and titanium dioxide ( $TiO_2$ ). The work explores the scientific foundations, processing methodologies, interfacial engineering, thermal behaviour, mechanical performance, and multifunctional characteristics of these sustainable composite systems.

Special emphasis has been placed on the role of phenolic resins due to their exceptional fire resistance, low smoke generation, thermal stability, and compatibility with natural fibres when processed under controlled curing conditions. Furthermore, the incorporation of zirconia and titania fillers introduces significant improvements in fracture toughness, thermal management, UV protection, moisture resistance, and wear behaviour, enabling the development of high-performance eco-friendly composites suitable for semi-structural and structural applications.

The motivation behind this book arises from the growing need for sustainable engineering materials in automotive, aerospace interiors, railway systems, building materials, marine

structures, sports equipment, and green infrastructure. While considerable research exists on individual natural fibres or conventional polymer matrices, there remains a limited number of detailed resources focusing specifically on hybrid flax–sisal composites combined with phenolic resin systems and ceramic nano/micro-fillers. This book aims to bridge that gap by integrating fundamental science with practical composite fabrication strategies.

Throughout the chapters, I have attempted to present both theoretical concepts and practical considerations in a clear and systematic manner. Topics such as fibre morphology, extraction methods, surface treatments, fibre–matrix adhesion, curing kinetics, thermal degradation, fire behaviour, filler dispersion, and hybrid architecture have been discussed with scientific depth while maintaining accessibility for students, researchers, and practising engineers.

I sincerely hope this book will serve as a valuable reference for researchers working in sustainable materials, polymer science, nanocomposites, and green manufacturing technologies. It is also intended to inspire further innovation toward environmentally responsible composite systems capable of meeting the demanding requirements of modern engineering applications.

Finally, I express my gratitude to the researchers, scientists, and academic communities whose contributions in the fields of natural fibres, polymer composites, ceramic fillers, and sustainable materials have provided the scientific foundation upon which this work has been developed. I also acknowledge the importance of interdisciplinary collaboration in advancing the future of green composite technologies.

I hope this book contributes meaningfully to the advancement of sustainable composite materials and encourages future generations to pursue environmentally conscious engineering solutions.



# **Acknowledgement**

I sincerely express my gratitude to Narula Institute of Technology for providing the academic support and research environment necessary for completing this book, Sustainable Natural Fiber Composites: The Synergy of Flax and Sisal.

I am thankful to the faculty members, colleagues, and students for their encouragement and valuable support throughout this work. I also acknowledge the contributions of researchers and authors whose studies in natural fibre composites and sustainable materials greatly inspired this book.

# Contents

Chapter	Title	Page Numbers
<b>Chapter 1</b>	<b>Introduction to Natural Fibre Composites</b>	<b>1–30</b>
	1.1 Rationale for Natural Fibres in Structural Composites 1.2 Bast Fibres (Flax) vs. Leaf Fibres (Sisal): Morphology, Extraction, and Properties 1.3 Limitations of Natural Fibres: Moisture Absorption, Thermal Stability, Fibre-Matrix Adhesion 1.4 Role of Thermoset Resins: Why Liquid Resole Phenolic Resin + Hardener 1.5 Scope of the Book: Hybridisation and Ceramic Filler Enhancement	
<b>Chapter 2</b>	<b>Matrix and Filler Systems – Phenolic Resole, Zirconia, and TiO<sub>2</sub></b>	<b>31-72</b>
	2.1 Chemistry and Curing of Liquid Resole Phenolic Resin with Matching Hardener 2.2 Advantages of Phenolic Resin for Natural Fibres: Fire Resistance, Low Smoke, and Thermal Stability 2.3 Functional fillers: Zirconia (ZrO <sub>2</sub> ) – toughness and wear resistance 2.4 Titanium Dioxide (TiO <sub>2</sub> ) – UV Shielding, Photocatalytic Effect, and Interface Modification 2.5 Filler Dispersion Strategies for Nanoscale and Microscale Particles in Resole	
<b>Chapter 3</b>	<b>Fabrication Methods for Hybrid Composites</b>	<b>73-111</b>
	3.1 Fibre Surface Treatments for Flax and Sisal to Improve Interaction with Phenolic Matrix	

	<p>3.2 Hand Lay-up, Compression Moulding, and Vacuum Bagging with Resole Resin</p> <p>3.3 Optimising Fibre Volume Fraction (Flax/Sisal Hybrid Ratios)</p> <p>3.4 Incorporating ZrO<sub>2</sub> and TiO<sub>2</sub>: Mixing Sequence, Sonication, and Curing Cycles</p> <p>3.5 Post-Curing and Defect Minimisation (Voids, Fibre Wet-Out)</p>	
<b>Chapter 4</b>	<b>Mechanical and Physical Properties</b>	<b>112-124</b>
	<p>4.1 Tensile, Flexural, and Impact Behaviour – Effect of Flax/Sisal Hybridisation</p> <p>4.2 Role of ZrO<sub>2</sub> in Improving Fracture Toughness and Interlaminar Shear Strength</p> <p>4.3 Role of TiO<sub>2</sub> in Hardness, UV Degradation Resistance, and Outdoor Durability</p> <p>4.4 Moisture Absorption Behaviour and Filler Influence on Diffusion</p>	
<b>Chapter 5</b>	<b>Thermal, Thermo-Mechanical, and Tribological Performance</b>	<b>125-136</b>
	<p>5.1 Thermal Stability (TGA) and Degradation Kinetics of Phenolic/Flax/Sisal</p> <p>5.2 Dynamic Mechanical Analysis (DMA): Storage Modulus, Tan Delta, and Glass Transition</p> <p>5.3 Heat Deflection Temperature and Flame Retardancy Due to Phenolic + Fillers</p> <p>5.4 Abrasive and Sliding Wear Resistance – Contribution of ZrO<sub>2</sub></p> <p>5.5 Filler Synergy: Combined Effect of TiO<sub>2</sub> and ZrO<sub>2</sub> on High-Temperature Performance</p>	
<b>Chapter 6</b>	<b>Applications, Ageing, and Future Outlook</b>	<b>137-151</b>

	<p>6.1 Potential Applications: Automotive Interior Panels, Structural Insulation, Semi-Structural Components</p> <p>6.2 Accelerated Ageing: Hydrothermal, UV, and Thermal Cycling</p> <p>6.3 Recyclability and End-of-Life Options for Phenolic/Natural Fibre Composites</p> <p>6.4 Challenges: Filler Agglomeration, Fibre Degradation During Cure, Cost Trade-Offs</p> <p>6.5 Future Directions: Surface-Functionalised Fillers, Bio-Phenolic Matrices, and Multifunctional Composites</p>	
<b>Bibliography</b>		<b>152-153</b>

# SUSTAINABLE NATURAL FIBER COMPOSITES.

The Synergy of **FLAX** and **SISAL**

## AUTHORS' BIOGRAPHY



### 1<sup>st</sup> Author: ARGHYA GUPTA, M.Tech

He serves as an Assistant Professor in the Department of Mechanical Engineering at Narula Institute of Technology, Kolkata. With over 12 years of teaching experience, he holds a B.E. in Mechanical Engineering from Bengal Engineering and Science University and an M.Tech. in Manufacturing Engineering from West Bengal University of Technology. He is currently pursuing his Ph.D. at Indian Institute of Engineering Science and Technology Shibpur. His academic contributions include active participation in numerous national and international conferences, along with publications in reputed journals and conference proceedings. Dedicated to advancing education and research, he is deeply involved in various academic initiatives, fostering innovation, technical excellence, and critical thinking in the field of mechanical engineering. He is also a member of The Institution of Engineers (India).



### 2<sup>nd</sup> Author: AKHTARUJJAMAN SARKAR, M.Tech

He is currently serving as an Assistant Professor in the Department of Mechanical Engineering at Narula Institute of Technology, Kolkata, with over 11 years of teaching experience. He obtained his M.Tech. degree from Jalpaiguri Government Engineering College and is presently pursuing his Ph.D. at National Institute of Technology Durgapur. His research is rooted in Materials Engineering, with a strong focus on materials development, characterization, and their applications in modern engineering systems. He has presented his research work at several national and international conferences and has published numerous papers in reputed journals. Passionate about academic excellence and innovation, he actively integrates research with teaching to inspire critical thinking and scientific curiosity among students. He is also a proud member of The Institution of Engineers (India).



### 3<sup>rd</sup> Author: SOUMOJIT DASGUPTA, M.Tech

He is presently serving as Assistant Professor in Mechanical Engineering Department at JIS College of Engineering, Kalyani, an Autonomous Institution under JIS GROUP, West Bengal, INDIA. He pursued B.Tech (ME) in 2009 and M.Tech (Production Technology & Management) in 2016, both from Jalpaiguri Govt. Engineering College, West Bengal. He is pursuing Ph.D. from Maulana Abul Kalam Azad University of Technology, West Bengal in collaboration with Indian Institute of Science (IISc), Bengaluru. His area of research includes weldability study of aluminium based metal matrix composite. He has published more than 30 research papers in Journals, National and International Conferences and Book Chapters. He received the Best Project Award in Faculty Development Program on Smart Manufacturing at DY Patil International University, Pune in 2022.



### 4<sup>th</sup> Author: SUMIT CHABRI, M.Tech, PhD

He is working as Professor and Head of the Mechanical Engineering Department at Narula Institute of Technology, Agarpara, Kolkata, with over 16 years of teaching experience. He holds M.Tech and Ph.D. degree from Bengal Engineering and Science University, Shibpur (now IEST Shibpur). An accomplished researcher, he has published 32 papers in SCI and Scopus-indexed journals and authored two books published by New Delhi Publishers. He has supervised 10 M.Tech dissertations and currently guides one Ph.D. scholars. His research focuses on Materials and Manufacturing Engineering. He is an active member of professional organizations such as the Institution of Engineers (India), Indian Institute of Metals, ISTE, Materials Research Society of India, and CEGR. He received the "Young Engineers Award 2020-2021" from the Institution of Engineers (India) and the "Eminent Educator of the Year 2024" award by the All-India Eminent Faculty Council. He has led several sponsored research projects including one on enhancing solubility in binary immiscible systems funded by IEI, a government-backed entrepreneurship initiative in West Bengal, and recently coordinated a 6-day AICTE-ATATL Faculty Development Programme in 2024.



Learnet Publishing

Address

19/B, Kali Kumar Majumder Road,  
P.O.- Santoshpur Avenue,  
P.S.- Survey Park,  
Kolkata - 700075, West Bengal, India

[www.learnetpub.co.in](http://www.learnetpub.co.in) | [www.jctmg.in](http://www.jctmg.in)

[learnetpublishing@gmail.com](mailto:learnetpublishing@gmail.com) | [info@learnetpub.co.in](mailto:info@learnetpub.co.in)



NATURAL  
RENEWABLE



SUSTAINABLE  
SOLUTIONS



STRONGER  
TOGETHER



ECO-FRIENDLY

ISBN 978-81-686149-1-8

