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DEPARTMENT OF MECHANICAL & MANUFACTURING ENGINEERING
FACULTY OF ENGINEERING

# ADVANCED ENGINEERING MATERIALS AND COMPOSITES: PROPERTIES, FABRICATION AND APPLICATIONS

*Chief Editors:*
**MOHD SAPUAN SALIT**
**AZMAH HANIM MOHAMED ARIFF**

# Advanced Engineering Materials and Composites: Properties, Fabrication, and Applications


**Chief Editors:**

Mohd Sapuan Salit
Azmah Hanim Mohamed Ariff



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**PREFACE**

Welcome to a journey into the forefront of engineering. In this book, we delve into the world of advanced materials and composites, where innovation meets necessity, shaping the future of technology and society.

From the International Conference on Advanced Engineering Materials and Composites (ICAEMC 2024), we bring you insights, discoveries, and aspirations shared by industry leaders, academics, researchers, and policymakers. Together, we explore the latest advancements in material science, pushing boundaries and redefining possibilities.

In these pages, you will find a synthesis of cutting-edge research, promising technologies, and visionary applications. From aerospace marvels to sustainable infrastructure solutions, the significance of materials cannot be overstated.

As we navigate through these chapters, we invite you to join the conversation, envision the possibilities, and embark on a journey of discovery and transformation. Together, let us pave the way toward a brighter, more resilient future, where science and creativity intersect to drive progress.

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# Foreword

**Dean of Faculty of Engineering**
**Universiti Putra Malaysia (UPM)**
**Prof. Ir. Dr. Mohd Zainal Abidin Ab. Kadir**

It is my great pleasure to introduce this book, which encapsulates the essence of the International Conference on Advanced Engineering Materials and Composites (ICAEMC2024). It serves as a testament to the collective efforts of researchers, scientists, engineers, and industry leaders who convened to explore the latest advancements in the field.

In the realm of engineering, the pursuit of excellence knows no bounds. It is a journey marked by relentless curiosity, innovation, and the relentless quest for knowledge. The pages within this volume bear witness to the dedication and ingenuity of those who are committed to pushing the boundaries of what is possible. It contains a comprehensive overview of the latest research, innovative technologies, and potential applications in the realm of advanced engineered materials and composites. From exploring new materials and composite solutions to addressing pressing global challenges, the work presented here reflects our unwavering commitment to excellence and our shared vision for a brighter, more sustainable future.

The importance of materials in addressing modern engineering challenges cannot be overstated. From aerospace and automotive, to renewable energy and healthcare, the applications of advanced materials are vast and diverse. They hold the key to unlocking breakthroughs in performance, efficiency, sustainability, and safety, reshaping the landscape of technological innovation. Through interdisciplinary collaboration and cross-sector partnerships, we have the opportunity to tackle some of the most pressing challenges facing society today. By harnessing the power of science, technology, and innovation, we can create a more sustainable, equitable, and prosperous future for all.

In closing, I invite you to embark on a journey of discovery and transformation as you explore the pages of this volume. May it inspire you to push the boundaries of what is possible and to make a positive impact on the world around you.

“Welcome to the world of advanced engineering materials and composites. May your exploration be fruitful, and your contributions enduring.”

**Prof. Ir. Dr. Mohd Zainal Abidin Ab. Kadir, FASc FIET**
**Dean of Faculty of Engineering, Universiti Putra Malaysia**

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# Welcoming Message

**Chairman of ICAEMC 2024**
**Prof. Ir. Dr. Mohd Sapuan Salit**

Assalamualaikum warahmatullahi wabarakatu and Salam Sejahtera

It is my pleasure to welcome everyone to the International Conference on Advanced Engineering Materials and Composites 2024 (ICAEMC 2024). This conference is hosted by the Advanced Engineering and Composites Research Centre (AEMC), Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia. The theme of the ICAEMC 2024 is *Advanced Engineering Materials and Composites: Properties, Fabrication and Applications*. This conference had successfully brought together researchers (keynote speakers, invited speakers, paper presenters and participants) from within and outside the country including from South East Asia, South Asia, Middle East and Africa.

The three-page extended abstracts published in a book titled 'Advanced Engineering Materials and Composites: Properties, Fabrication and Applications' were accepted for presentation at the ICAEMC 2024 held at Faculty of Engineering, Universiti Putra Malaysia from 20-21 May 2024. Over 66 papers have been authored by academics, researchers and postgraduate students covering a broad range of advanced engineering materials and composites research under the topics of advanced composites, textile composites, advanced ceramic and glass, advanced polymers and rubbers, smart materials, metallurgy, additive manufacturing, 1D and 2D materials, and nanocellulose composites. Post conference, selected papers will be published in journals indexed in Web of Sciences and Scopus and in edited books to be published by well-known international publishers. During the conference we are also giving out awards for the paper presenters (Best paper awards and Best Presenter Awards).

On behalf of the organizing committee, I would like to take this opportunity to thank our distinguished speakers and participants, who will be sharing their expertise I believe that this two-day conference will benefit the participants. We welcome you to Malaysia; particularly to Serdang, Putrajaya and Kuala Lumpur.

My heartiest congratulation goes to organizing committees, international advisory committees, and sponsors in the organization of the ICAEMC 2024, who significantly contribute to the success of this conference. Thanks to the sponsors; Crest NanoSolutions (M) Sdn. Bhd., Semarak Ilmu Publishing and Ant Spirits Sdn Bhd. and hope you find the conference useful and enjoyable.

**Prof. Ir. Dr. Mohd Sapuan Salit, FTWAS, FSAE, FASc**
**ICAEMC 2024 Chairman**

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# Welcoming Message

**Co-Chairman of ICAEMC 2024**
**Prof. Madya Dr. Zulkiflle b. Leman**

On behalf of the organizing committee, it is with great pleasure that I extend a warm welcome to all delegates joining us from across the globe, particularly from Pakistan, Indonesia, Bangladesh, Thailand, and Malaysia, for the International Conference on Advanced Engineering Materials and Composites 2024 at the esteemed Faculty of Engineering, Universiti Putra Malaysia. Your presence enriches this gathering with diverse perspectives and invaluable expertise, fostering meaningful exchanges and collaborations at the forefront of engineering innovation. As we embark on this journey of knowledge-sharing and discovery, may this conference serve as a platform for fruitful discussions, insightful presentations, and lasting connections. Here's to a memorable and rewarding experience for all. Welcome, and let's explore the boundless horizons of advanced engineering materials and composites together!

**Prof. Madya Dr. Zulkiflle b. Leman**
**ICAEMC 2024 Co-Chairman**

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**KEYNOTE SPEAKER 1**

**Prof. Dr. Yasir Nawab**
Professor at National Textile University, Faisalabad, Pakistan

**PROFILE**

**Prof. Dr. Yasir Nawab**, is a Professor at National Textile University, Pakistan, Adjunct Professor at NC State University, USA and Visiting Professor at Northumbria University, UK. He did Ph.D. in Mechanical Engineering with a focus on fiber-reinforced composite materials from Université de Nantes, France, and Post-doc & HDR (Habilitation à Diriger des Recherches) from University of Le Havre Normandy, France. He is listed among top 2% scientists in the world by Elsevier in 2023. He has 19 years of research & industry experience gained while working with known national and international industries dealing with complete value chain of textiles and composite materials. He led development of several innovative technologies/ industrial solutions which are successfully licensed/transferred to industry for commercialization. He has experience to lead multidisciplinary projects involving cross-functional and multi-institutional teams. He has completed 24 funded R&D projects worth PKR. 158 million (One million USD), whereas 3 research projects worth PKR 231 million (1.8 million USD) are in progress. He is the founding Director of National Centre of Composite Materials. He has authored over 150 peer-reviewed journal articles, 9 books, 10 patents and 54 conference communications. Eleven Ph.D. and 55 MS engineering students have completed their degrees under his supervision. He is a fellow of the Higher Education Academy, UK, Textile Institute, UK, Pakistan Academy of Engineering, and International Society for Development and Sustainability- Japan, member of several national and several international professional bodies. He has been awarded HEC's Best University Teacher Award in 2017, Dice Leadership Award in 2018 and National Engineering Excellence Award by IEP in 2024.

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## ABSTRACT

## IMPROVING STRUCTURE AND PROTECTION PERFORMANCE OF COMPOSITES FOR AEROSPACE APPLICATIONS

The composite materials represent the most value-added class of materials finding applications in automotive, sports, structures, medical, aerospace, etc. The global composite market is expected to reach $130 billion approximately in 2024 and is expanding at a CAGR of 7.8 %. This extensive market growth is the result of continuous research and development in the domain of composite materials for specific requirements. The aerospace industry continually seeks innovative solutions to enhance the structure and protection performance of composites. Most recent developments include the Fiber Metal Laminates (FML), Composite Metal joining, and achieving EMI Shield and stealth properties using nano reinforcements. FML is a hybrid material produced by the combination of metals and resin-impregnated fibers combining the stiffness and lightweight of composite with the toughness and damage tolerance of metals.

Composite-metal joining is crucial to assembling any aerospace structure, due to the high proportion of both composites and metals. Some of the most commonly used techniques include mechanical joining (riveting), adhesive bonding, and a combination of both. Nasreen et. al. (2019) reported that mechanical treatment of metal with subsequent anodizing improves the metal-metal joint stiffness by 36% while reducing damping by 23%. Similarly for metal-composite joints, chemical etching and anodizing of composite and metal adherents respectively improves the stiffness by 34% and reduces the damping by 20%.

Another important aspect related to aerospace structure is the electromagnetic interference (EMI) shielding and stealth properties. Ahmad et al. (2022) reported that composites fabricated with dielectric fillers (MWCNT) and magnetic nanofillers (titanium oxide) show improved electrical and thermal conductivity. However, tensile modulus, strength, and drop weight impact performance was found to be better for cobalt oxide, nickel oxide, and zinc oxide, respectively. Thus, the integration of dielectric or magnetic material fillers helps to minimize radar detection, improve mechanical performance, and enhance aircraft survivability.


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## KEYNOTE SPEAKER 2

**Prof. Ir. Ts. Dr. Saiful Amri Mazlan**
Professor at University Technology Malaysia, Kuala Lumpur

### PROFILE

**Prof. Ir. Ts. Dr. Saiful Amri Mazlan** is a distinguished academician and researcher specializing in Smart Materials particularly in Magnetorheological (MR) Materials. He currently holds the position of Head of iKohza in the Engineering Materials and Structures (eMast) at the Malaysia-Japan International Institute of Technology, University Technology Malaysia, Kuala Lumpur. He is also a visiting Professor at Tokyo City University, Japan, and Adjunct Research Fellowship at University of Business & Technology, Jeddah, Saudi Arabia. With a Ph.D. from Dublin City University, Republic of Ireland, Professor Saiful has demonstrated a commitment to advancing the frontiers of materials engineering. His supervision experience, with 20 Ph.D. and 13 Masters students graduated under his guidance at the main supervisor level, underscores his commitment to nurturing the next generation of researchers. His expertise is reflected not only in his extensive publication record, but also in his professional qualifications, including being a Professional Engineer (Ir.) and Teknologis Profesional (Ts.) certified. He has served as the Professional Interview Board member at the Institution of Engineers, Malaysia. His work continues to profoundly impact the advancement of technology and engineering practices, both nationally and internationally. Moreover, Professor Saiful's contributions extend beyond research, as evidenced by his significant administrative roles. He has appointed as the Director of Administration at the Office of Deputy Vice Chancellor (Research and Innovation), UTM Kuala Lumpur, and as the Head of Department for Mechanical Precision Engineering at MJIIT, UTM Kuala Lumpur.

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# ABSTRACT

## EXPLORING THE BOUNDLESS POTENTIAL OF SMART MAGNETIC COMPOSITE MATERIALS

This exploration delves into the boundless potential offered by smart magnetic composite materials, a mushrooming area within materials science and technology with implications for diverse applications. The integration of magnetic responsiveness into composite materials represents a paradigm shift, introducing dynamic properties that respond to external stimuli, particularly magnetic fields. The significance of this advancement lies in its ability to enhance the functionality and adaptability of composite materials, thereby enhancing their performance and longevity in various applications. By utilizing the influence of magnetic fields, these materials, notably smart, demonstrate tunable mechanical and rheological properties, offering a level of control and versatility previously unattainable in conventional composites. Central to the effectiveness of smart magnetic composites are the types of matrices and particles employed, which dictate the nature and extent of their responsiveness to magnetic stimuli. Furthermore, the introduction of additives, extending across a spectrum from macro to nano scales and encompassing both liquid and solid forms, serves to further enhance the capabilities and applicability of these materials. The recent addition of smart composites into additive manufacturing (AM) not only enhances the industry's capabilities but also unlocks unprecedented potential for innovation and exploration. This convergence of magnetic responsiveness, tailored matrices, and additive enhancements creates fertile ground for advancing the boundaries of material design and engineering. As researchers navigate the complexities and challenges of this emerging field, they are poised to unlock new frontiers in the development of smart-intelligent composite materials, paving the way for a new era of advanced functionality and performance across a wide array of limitless possibilities.


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## KEYNOTE SPEAKER 3

**Dr. Agung Efriyo Hadi**
Universitas Abulyatama Aceh, Indonesia

## PROFILE

**Dr. Agung Efriyo Hadi**, an accomplished professional, holds the title of Ir. Insinyur Profesional in Mechanical Engineering from The Institution of Engineers Indonesia (PPI) since 2020 and earned his Ph.D. in Material Engineering from Universiti Putra Malaysia, Selangor, Malaysia in 2011. With a rich background, he began his journey as a lecturer at the engineering faculty of Universitas Malahayati in Bandar Lampung in 2002, following years of experience in the support engineering division of the automotive industry from 1997 to 2001. During this time, he specialized in analyzing issues and failures of spare parts within vehicle combustion engines. As a senior lecturer, Agung's research interests revolve around green material concerns, particularly in natural fibre composites, and mechanical and material engineering. His contributions to the field are evident through numerous publications in international journals and presentations at seminars. Currently serving his second term as Rector of Universitas Abulyatama Aceh, Indonesia, Agung continues to make significant strides in academia and beyond.

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## ABSTRACT


## EXPERIMENTAL INVESTIGATION OF THE MECHANICAL PROPERTIES OF WOVEN ABACA (*MUSA TEXTILIS*) FIBER-REINFORCED EPOXY COMPOSITES

Abaca fiber which is also known as *Musa textilis* is a tropical banana species grown primarily for its fiber. It has several advantages when used as a reinforcement in polymer composites due to its great mechanical performance, high cellulose content, low cost, and abundant availability. It is important to note that the structure of the fibers used as reinforcing materials is a critical aspect of fabricating a strong polymer composite. Therefore, this study was conducted to determine the effects of layering and fiber orientation on the mechanical properties of woven abaca-reinforced epoxy composites. This involved applying hand lay-up technique and hydraulic press molding to produce 2, 3, and 4 layers of woven abaca-reinforced epoxy composites after which the mechanical properties were analyzed based on its orientation in the warp and weft direction. The results showed that increasing the number of layers from 2 to 4 did not affect the tensile and flexural properties at every layered stacking sequence of the fiber. Meanwhile, the material in the warp direction showed higher tensile and flexural properties than the weft direction. This means the number of layers and orientation of the woven abaca in epoxy composite significantly affects the composites' mechanical properties.


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## KEYNOTE SPEAKER 4

**Ir. Dr. Abdul Azim Abdul Rahman**
Steelcase Office Solutions (M) Sdn Bhd, Malaysia

## PROFILE

**Ir. Dr. Abdul Azim Abdul Rahman**, a Professional Engineer registered under Board of Engineer Malaysia (BEM) with over 20 years' experience in Product Research, Design and Development. He experienced in designing products, components, parts & system in various industries e.g., Electronics, Automotive, Office Furniture and Manufacturing System. Ir. Dr. Azim started his career with Shimano Components (M) Sdn Bhd designing high end crank shaft and gear system for bicycle. He then worked with SONY EMCS Malaysia Sdn Bhd for over 6 years in Mechanical R&D TV/LCD division. He's one of the innovators for TV with woofer system. He's also pioneer group in designing LCD for SONY. Currently Ir. Dr. Azim works with Steelcase Office Solutions (M) Sdn Bhd as a Product Engineering Director leading the team in Asia Pacific and some category for North America for Product Development.

He was under EXPATRIATE assignment in North America (Grand Rapids, MI), designing Global mid-range chair for mature and emerging market in 2015. He has experienced working around the world, America, Japan, China, India, France, Italy, Taiwan, Vietnam, Korea, Indonesia, Germany, Thailand, Hong Kong, Australia, UK, Mexico and Singapore. Hold 15 patents from USA, Europe, China, India & Malaysia. He is also currently Adjunct Professor at UPM under Mechanical and Manufacturing Dept.

He's leading multi locations team in Asia; KL (Malaysia), Foshan & Dongguan (China), Singapore, and Pune (India) converting from insight into products.
He received a lot of awards throughout his career, recently in Germany he won GOLD at International Trade Fair "Ideas-Inventions-New Products" iENA for his innovation on the machine that help on stabilize process of plastic material.

Ir. Dr. Azim graduated in Mechanical Engineering majoring in Automotive from University Technology PETRONAS. He's also graduated in Doctor of Engineering from University Putra Malaysia (UPM). He's a member of Mechanical Technical Division, The Institution of Engineers, Malaysia. He is also a Malaysia Industry Standards Committee on Plastics & Plastic Products as well as Technical Committee of ergonomics at work.

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# ABSTRACT

## GLOBAL PRODUCT DEVELOPMENT: GLOBAL STANDARD, LOCAL FLAVOR, DESIGN FOR SUSTAINABILITY (DFS) – FROM INSIGHT INTO PRODUCT

Globalization pressures have significantly impacted Product Development practices across various industries. A new paradigm emphasizes collaborative design by skilled engineering teams scattered globally. Best practices are shifting from local collaboration to global collaboration, transforming Product Development (PD) in diverse industries. This paper examines the 5 key drivers for Global Product Development: Lower Cost, Process Enhancement, Global Growth, Resource and Material Optimization, and Technology Access.

Global product development offers optimization in resource, time, quality, and cost. However, balancing local and global requirements presents challenges. Striking equilibrium ensures waste reduction, cost control, simplification of processes, streamlined product offerings, and standardized quality.

Achieving a balance between global and local requirements involves adopting good practices. The concept of "MINIMUM Viable Product" offers insights. Key success factors include Management Priority, Process and Product Modularity, Core Competence, Intellectual Property (IP), Data Quality, Infrastructure, Governance, Project Management, Collaborative Culture, and Change Management.

Sustainability is a global concern integrated into early-stage product development. A robust and structured development process encompasses concepts, innovation, material selection, manufacturing, supply chain, logistics, and production. Sustainability aligns with three pillars: i. Responsible Material Usage, ii. Circular Design, and iii. Carbon Footprint Reduction.

Global Product Engineering is reshaping Product Development practices, influenced by factors like cost, growth, and sustainability. Balancing global and local requirements requires careful consideration and adherence to good practices. Success hinges on prioritizing key factors, embracing modularity, managing IP, fostering collaborative culture, and incorporating sustainability early in the process. Sustainable development aligns with responsible material usage, circular design, and carbon footprint reduction.


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## INDUSTRIAL SPEAKER 1

**Mr. Cowen Tan**
Crest Group of Companies

## PROFILE

**Mr. Cowen Tan** is based in Crest Group of Companies, as a product business development manager responsible for Advanced Microscopy Solutions for Malaysia. He also task to expand the visibility and coverage of Surface Analysis Solutions including X-Ray Photoelectron Spectroscopy (XPS), AUGER (AES), TOF-SIMS and Mechanical Tester Solutions to R&D market.

In his course of work, he has supported various customer in the research & development (R&D), electronics and semiconductor industry by providing system solution through bridging the application expertise of applications team and end-user's research and development needs.

## ABSTRACT

### ADVANCED SURFACE CHARACTERIZATION TECHNIQUES FOR POLYMERIC, GLASS AND CERAMIC MATERIALS

The presentation highlighting the features, capabilities, and practical use of a range of Advanced Surface Characterization Techniques: AFM, AFM-IR, Nanoindentation and Optical Profilometry for property measurement of polymeric, glass and ceramic materials.

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## INDUSTRIAL SPEAKER 2

**Dr. Nor Azwadi Che Sidik**
Director of Semarak Ilmu Publishing and Akademia Baru Publishing

## PROFILE

**Dr. Nor Azwadi Che Sidik** was born in Kelantan, Malaysia on 23rd September 1977. Dr. Nor Azwadi received B.Sc. (2001, Kumamoto Univ., Japan), M.Sc. (2003 UMIST, UK), and Ph.D. (2007, Keio Univ., Japan) degrees in Mechanical Engineering. During his appointment with Universiti Teknologi Malaysia (Sept. 2001 - Feb. 2024), Dr. Nor Azwadi has published 410 indexed articles in SCOPUS/WOS with h-index 56 and 9190 citations. Among his excellent achievements are:

- Founder and Director of Semarak Ilmu Publishing and Akademia Baru Publishing
- Top Research Scientist Malaysia
- Malaysia Research Star Award
- The Standford List of World Top 2% Researcher
- Adjunct Profesor, Universitas Pendidikan Indonesia

## ABSTRACT

### INTRODUCING SCOPUS INDEXED JOURNALS OF SEMARAK ILMU PUBLISHING: FROM ZERO TO SCOPUS INDEXED

Semarak Ilmu Publishing started in 2022 as a publisher of two journals in fluid mechanics and heat transfer area, now has expanded where more than 50 of our journals are being indexed locally and internationally. Our journals cover various research areas such as social sciences, business, education, management as well as various engineering fields. We have gained trusts from researchers around the globe shown not only in the grown number of article submissions over the years but also in the quality of articles submitted by highly cited researchers.

## CHAPTER 1

# MECHANICAL PERFORMANCE EVALUATION OF GRAPHENE NANOPLATELETS/POLYLACTIC ACID (GNP/PLA) BIOCOMPOSITE

Vasi Uddin Siddiqui[1], S.M. Sapuan[1*], Mohd Roshdi Hassan[2]

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**ABSTRACT**
Carbon materials have been prominent in the realm of composite materials due to their expansive surface area, adjustability, exceptional strength, and wide-ranging applicability in various fields, ranging from electronics to pharmaceuticals. Graphene nanoplatelets (GNPs) have drawn interest for their potential use as a reinforcing material in combination with biopolymers. This study employed GNPs to improve the mechanical properties of polylactic acid (PLA) through the compression molding technique. In order to achieve thorough mixing of various loadings (1, 5, 12 PHR) of GNPs with PLA, the Brabender mixing technique was employed prior to casting the materials. Out of all the samples, the samples with a weight ratio of 5 PHR of GNP to PLA exhibited the highest level of tensile strength. Further morphology investigations to confirm the significant mixing of GNPs with PLA at this level of loading is needed. Fabricated materials offer a viable substitute for glass fiber-reinforced polymer composites in several high-strength applications, including aerospace, automobile, and construction. Additionally, they provide more environmentally friendly alternatives.
*Keywords:* Graphene nanoplatelets; Polylactic acid; Mechanical properties; Biocomposite; Sustainability.

## INTRODUCTION

Polylactic acid (PLA) is a linear aliphatic polyester thermoplastic derived from renewable sources such as sugar beet and cornstarch [1]. It is known for its biocompatibility, low energy loss, transparency, high strength, resistance to water and fat penetration, and low carbon dioxide consumption during production. However, PLA also has limitations such as hydrophobicity, fragility at room temperature, low thermal resistance, slow degradation rate, permeability to gases, lack of active groups, and chemical neutrality [2–4]. To overcome these limitations, researchers have turned to nanotechnology, specifically the use of GNPs. GNPs are part of the graphene family and their use as fillers in PLA-based composites is widespread [2,5]. They have the potential to increase the breaking properties of PLA and preserve this polymer from thermal degradation and photo-oxidation. The integration of GNPs into PLA to form a GNP/PLA biocomposite has been shown to improve mechanical properties and speed up the degradation kinetics compared to neat PLA and composites loaded with GNP only. This makes GNP/PLA biocomposites a promising material for various applications.

This paper aims to evaluate the mechanical performance of GNP/PLA biocomposites. The study will examine the effect of amounts of GNPs to PLA on the mechanical properties of the resulting biocomposite. The findings from this study will contribute to provide insights into the role of GNPs in enhancing the mechanical performance of PLA, thereby paving the way for the development of more efficient and sustainable materials.

## METHODOLOGY

PLA with high molecular weight (170,000 g•mol$^{-1}$) was procured from Natureworks™ LLC (USA). Graphene Nanoplatelets were supplied from GO Advanced Solutions Sdn. Bhd., Malaysia. A calculated amount of PLA and GNP mixed after dried at 50°C for 24h. GNP/PLA biocomposites were prepared and homogenized using a Brabender mixer at a temperature of 190°C using the melt intercalation process. The ratio of GNP loading varied at 1, 5, and 12 PHR. The mixed samples were subjected to hot press compression molding to prepare the sheet sample for further characterization. The stress-strain study was conducted using a INSTRON 3366 Universal Testing Machine (UTM) and tested in accordance with the ASTM D638-14 standard under ambient conditions with 10kN cell load weight using crosshead speeds of 2 mm•min$^{-1}$. Moreover, three-point bending as per ASTM D790-17 standard for flexural test was also performed.

## RESULTS AND DISCUSSION

### *Mechanical properties*

The mechanical properties of a PLA/GNP biocomposite were investigated by analyzing its tensile, and flexural properties. The objective was to observe the impact of GNP loading on these properties, as depicted in Figure 1. Biocomposites prepared with different loading of GNP concentration showed better mechanical properties than neat PLA.

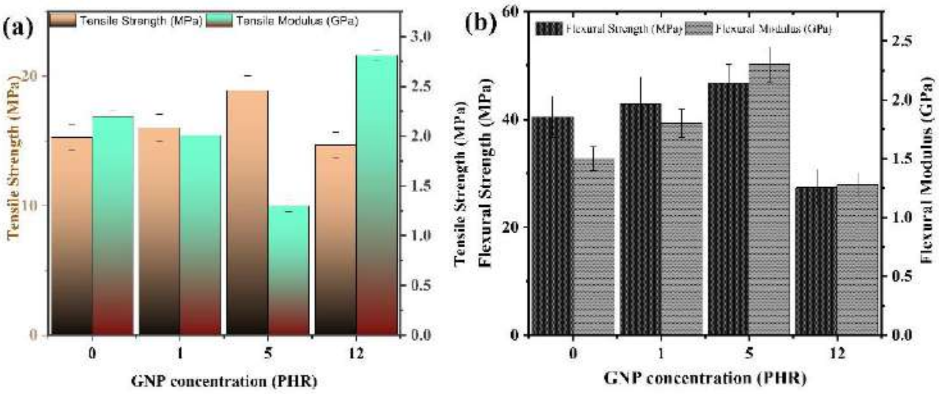


**Figure 1 (a).** Tensile strength and tensile modulus and (b) Flexural strength and flexural modulus of different GNP loading biocomposites.

The stress-strain curves provide tensile modulus (E), and tensile strength to evaluate the toughness of the material. The tensile results were the average values of five samples showing the highest strength with 5PHR GNP loading as shown in Fig. 1(a). The value of tensile strength has been increased 23.72% compared to neat PLA. An increase in GNP loading in PLA matrix increases the strength showing the strong adhesion between components and less defects [6].

Furthermore, the biocomposite with 5PHR GNP loading showed the highest increase in flexural strength of 15.53% among all the different concentrations of GNP loading than neat PLA as shown in Fig. 1(b). However,12PHR sample showed the lowest flexural strength (27.4 MPa) and flexural modulus (1.27 GPa) among all the biocomposites and reduces 32.34% than neat PLA. The significant improvement in mechanical properties resulted a good dispersion of GNP in PLA matrix and vice-versa. Comparable results were obtained by Shen et al. [7] using three-roll milling and planetary centrifugal mixing. Similar results have also been reported by Agustina et al [8] that used different GNP sizes with epoxy matrix found highest tensile strength for low loading (0.3wt%) of GNP and decreased in higher loading.

## CONCLUSION

In this study, the fabrication of GNP/PLA biocomposites was achieved by solvent blending methodology as reported in literature to observe the dispersion effect on mechanical behavior. These steps provided good mechanical strength with loading of 5PHR GNP biocomposites. Concludingly, the low loading of GNP provides good dispersion, less agglomeration, and strong interfacial interaction between matrix and the nanosheets. Result in observed the most optimized composition among the biocomposites that provide the superior mechanical strength, in terms of improved Young's modulus and strength. Furthermore, the utilization of GNPs presents a compelling avenue for enhancing mechanical properties and industries such as aerospace, automotive, and electronics stand to benefit significantly from these advancements.

## ACKNOWLEDGEMENT

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## CHAPTER 2

# INNOVATIVE ECO-FRIENDLY MATERIAL SYNTHESIS: GRAPHENE FILLED GREEN EPOXY BIO NANOCOMPOSITES


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**ABSTRACT**

Graphene is an allotrope of carbon which is widely used in advanced nanocomposites, and it is gaining a lot of attention from the scientific community because of which research on lightweight and sustainable materials has expanded in search of novel materials. Graphene nanoplatelets (GNP) are used in the bio composite to improve its mechanical properties. The initial findings, which were validated by FE-SEM, demonstrated that GNPs were optimally dispersed with nanocomposites. Due to the low percentage of GNP loading, which demonstrated an improved mechanical property. The mechanical results, which included a tensile test and a hardness increment, were likewise consistent with previously published data. In conclusion, the findings demonstrated notable gains in the performance of green nanocomposite materials with modest weight percentages of GNP and CNF.


*Keywords:* Graphene nanoplatelets; Green epoxy; Mechanical properties; Thermal properties; Hybrid composite


## INTRODUCTION

The scientific world is giving graphene, an allotrope of carbon that is extensively employed in sophisticated nanocomposites, a lot of attention. The material graphene was discovered in 2004 by Konstantin Novoselov and Andre Geim. Stacks of graphene layers make up graphene nanoplatelets (GNPs).  graphene material made up of stacks of graphene layers is called graphene nanoplatelets (GNPs) [1]. They are employed as nanofillers and are usually 5–50 nm thick with a platelet-like form. The strength, stiffness, and fracture resistance of the resultant composite material are all improved by the addition of GNPs to polymers. An interesting kind of bio-sourced resin is bio epoxy resin, commonly referred to as green epoxy resin. It is made from renewable precursors such lignin, unsaturated vegetable oils, saccharides, tannins, cardanol, terpenes, and rosins. A proportion of the substance's naturally occurring carbon is usually used to indicate how much of the material is bio-based in bio-epoxy [2].

**METHDOLOGY**

The GNP-reinforced green epoxy nanocomposites were prepared using solution blending: GNP nanoparticles were dissolved in acetone through sonication, then epoxy was added and sonicated again. Acetone was evaporated and stirring facilitated epoxy-GNP mixing. Curing hardener was added and mixed by hand. The mixture was poured into a coated steel mold, precured at room temperature, and post-cured in an oven. Samples were then prepared using a vertical bandsaw.

**RESULTS AND DISCUSSION**

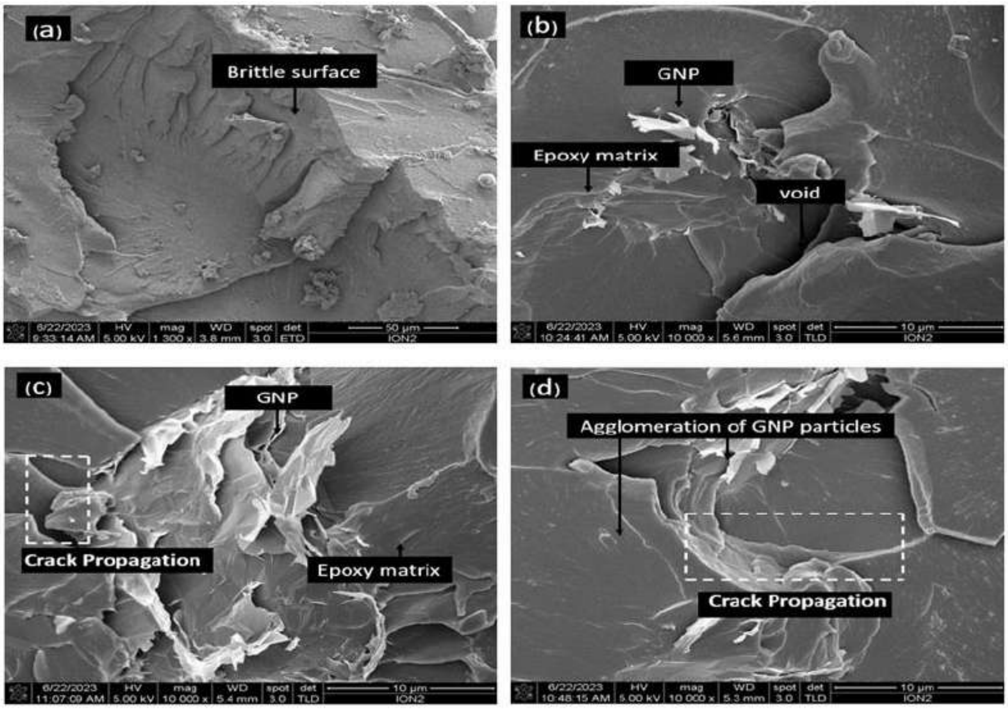


**Figure 1.** FE-SEM micrographs of fractured surface of neat and nanocomposites from tensile test with different GNPs loadings, (A) neat epoxy composite, (B) 0.1 wt% of GNPs, (C) 0.25 wt% of GNPs, (D) 0.5 wt % of GNPs.

The fracture surface morphology in Figure 1 A demonstrated the neat epoxy composite's brittle character. This was due to the material's poor resistance to crack initiation and propagation under load, which resulted in low fracture toughness. Even though the GNP loading is lower in Figure 1 B, there are still some empty contents and strong GNP-epoxy matrix bonding. It's because decreasing GNP loading improves mechanical characteristics. Figure 1 C, which has 0.25 weight percent of GNP loading, shows FE-SEM confirmation of a good homogenous dispersion of GNPs. Compared to other figures, this one has a very low amount of empty content. Due to stress concentration, the agglomeration of GNPs particles in Figure 1 D is what causes the nanocomposites' strength to decrease. The impact of GNP loading on the mechanical properties of nanocomposites is not only dictated by the proportion of GNPs in terms of weight [3]. The dispersion method, dispersant use, and functionalization are further affecting factors. The use of organic solvent is another important factor in determining an increase in mechanical properties [4][5].

## CONCLUSIONS

GNP reinforcement up to 0.1 wt% in green epoxy showed improved mechanical properties, with a peak in tensile strength and low void content in flexural strength. Higher loadings led to decreased properties due to nonuniform dispersion and agglomeration, confirmed by FE-SEM.

## ACKNOWLEDGMENTS

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CHAPTER 3

# EFFECT OF GRAPHENE NANOPLATELETS AND NANOCELLULOSE ON MECHANICAL AND ELECTRICAL PROPERTIES OF BIOBASED POLYMER COMPOSITES

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**ABSTRACT**
The effect of graphene nanoplatelets and nanocellulose (CNF) on the mechanical and electrical properties of biobased polymer composites has been discussed. Graphene nanoplatelets (GNP) are used in the bio composite to improve its mechanical and thermal properties. It also provides the effective electrical insulation or conduction; the composites are loaded with varying loadings of GNP electrical conductivity. The initial findings demonstrated that GNPs were optimally dispersed with nanocomposites. Low percentage of GNP and CNF loading demonstrated an improved mechanical result, which showed increment in tensile, flexural, impact and hardness. The study also found that the graphene nanoplatelets and nanocellulose had a synergistic effect on the properties of the biobased polymer composites. The results of the study can be used to develop new and improved biobased polymer composites that have better mechanical, thermal, and electrical properties Overall, the findings demonstrated notable improvement in the performance of biobased polymer composites with modest weight percentages of GNPs.
*Keywords:* Graphene nanoplatelets; Nanocellulose; Mechanical properties; Hybrid composites

## INTRODUCTION

Fossil fuels are currently the most common energy source in the world and are used to generate most power. Energy-related issues have become major strategic objectives, affecting security, coordinating efforts, and the sustainable socioeconomic growth of countries as the use of fossil fuels increases and environmental degradation increases [1].

Hybrid organic–inorganic nanocomposites that combine inorganic functional materials with renewable smart materials and are produced in an ecologically responsible manner have garnered significant attention recently. Their many benefits and unique qualities are the reason for this attention. Due to our reliance on limited and diminishing non-renewable resources, creating, and improving these hybrid materials has become more important. They are thought to be essential for developing useful materials of the future and encouraging environmental sustainability [2].

## MATERIALS AND METHODS

The commercial green epoxy resin, SR Green Poxy 28 (Part A), was supplied by Mecha Solve Engineering, located in Kuala Lumpur, Malaysia, together with its hardener, SD 3304 (Part B). At 30°C, the viscosity of green epoxy was 4500 mPa s, its density was 1.17 ± 0.01 and its gel time was 3.45 hours. Oil palm CNF that had been spray-dried was acquired from Zoepnano Sdn. Bhd. at Putra Science Park in Serdang, Selangor, Malaysia. CNF had an opaque white physical appearance. The sample had a 99% cellulose content, a neutral pH, a diameter of less than 50 nm, a DLS of 40 nm to 25 nm, an onset temperature of around 300 °C, and a total deposition temperature of about 600 °C. Acetone was utilised as the dispersion solvent and was sourced from Evergreen Engineering & Resources in Selangor, Malaysia.

## METHODS

CNF and GNP reinforced green epoxy nanocomposites were synthesized by solution blending, involving dispersion of nanoparticles, addition of polymer solution, solvent removal, and curing. Precise weighing, sonication, solvent evaporation, mixing, curing, and molding processes were carefully executed to prepare samples for testing.

*Characterization*

*Mechanical testing*

Tensile strength, flexural strength, Rockwell hardness, and impact strength were among the mechanical properties of the nanocomposites. Five samples were examined for each test, and when necessary, the average value and standard deviation were determined.

*Electrical properties*

The test was conducted on 4-point prob. It was found that all the samples were insulator as7% is the minimum required loading to make samples conductive.

## RESULTS AND DISCUSSION

Tensile strength of CNF/GNP green epoxy hybrid nanocomposites varied with CNF loading: 0.1 wt.% CNF exhibited an increase compared to neat epoxy. Higher CNF loadings led to decreased tensile strength, suggesting enhanced rigidity and robustness due to fibrillar interphase formation and improved CNF-Epoxy interaction. This trend highlights the importance of optimal CNF loading for reinforcing epoxy matrices [3]. Enhanced interface quality, characterized by static adhesion strength and interfacial stiffness, contributed to this improvement [4]. However, excessive CNF addition led to decreased mechanical properties due to weaker van der Waals forces between nanocellulose and polymer matrix [5].

## CONCLUSIONS

In this work, the impacts of innovative low loading CNF/GNP green epoxy hybrid nanocomposites —in which the green epoxy resin contains 28% carbon from biomass—are investigated in relation to the low-loading reinforcement of cellulose nanofibers (CNF) and GNP. Due to its low void content, the sample with the strongest flexural strength at 0.1 weight percent CNF and GNP loading also had the highest tensile strength than the control sample.

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## CHAPTER 4

# ENVIRONMENTAL ACCOUNTABILITY IN THE FURNITURE INDUSTRY: A LIFE CYCLE ASSESSMENT APPROACH

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**ABSTRACT**
In an era of heightened environmental consciousness, the furniture industry faces mounting pressure to adopt sustainable practices. With increasing global concern over resource depletion and pollution, businesses are under pressure to minimize their environmental impact. Our study delves into the intricate web of environmental impacts within this sector, employing a comprehensive life cycle assessment (LCA) framework. Focusing on a ubiquitous office chair, we scrutinize each phase—from raw material extraction to disposal. Surprisingly, the assembly process emerges as a hidden hotspot, demanding further scrutiny. By integrating LCA findings into decision-making processes, manufacturers can optimize resource use, minimize emissions, and enhance circularity. This research underscores the urgency of environmental accountability and charts a path toward a greener, more responsible furniture industry.
*Keywords:* Furniture industry; Life cycle assessment; Resource optimization; Sustainability.

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## INTRODUCTION

The furniture industry plays a pivotal role in shaping our living environments, offering functional and aesthetic solutions to meet our needs[1]. However, the production and consumption of furniture come with significant environmental and social implications[2]. As concerns about sustainability grow, there is an increasing demand for assessing the environmental and social impacts of products throughout their life cycles[3]. In response to this demand, life cycle assessment (LCA) has emerged as a valuable tool for evaluating the sustainability of products, including those in the furniture industry[4].

In the context of the furniture industry, sustainability involves addressing various challenges, such as resource depletion, pollution, greenhouse gas emissions, waste generation, and social inequalities within the supply chain.

## LIFE CYCLE ASSESSMENT (LCA) AND ITS APPLICATION IN FURNITURE INDUSTRY

The life-cycle assessment of environmental products (LCA) examines and evaluates the effects on the environment of a set of procedures pertaining to the creation, utilization, and disposal of certain items (goods or services)[5].A method used to identify and minimize the environmental effects associated with a process, product, or activity is called life cycle assessment (LCA). It does this by tracking and measuring material and energy consumption, waste production, and possible environmental effects over the course of the product's life cycle[6].

The examination of environmental impacts across the furniture life cycle reveals the interconnectedness of various stages and the complexity of addressing sustainability challenges within the industry. By understanding the environmental implications of raw material extraction, manufacturing, transportation, use, and end-of-life disposal, stakeholders can identify opportunities for improvement and implement strategies to minimize negative environmental footprints. Moving forward, a holistic approach that considers the entire life cycle of furniture products is essential for achieving sustainability goals and mitigating environmental impacts in the furniture industry. Figure 1 shows different components of LCA.

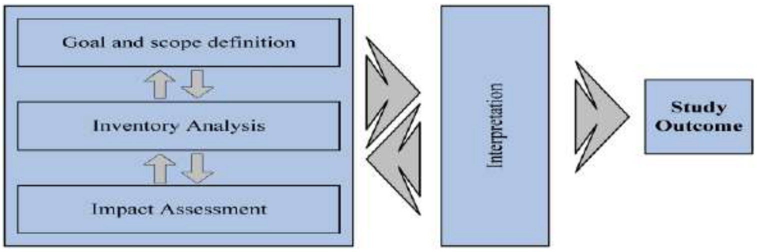


**Figure 1.** Components of Life cycle assessment [7].

## CONCLUSIONS

In conclusion, the paper underscores the crucial role of LCA in evaluating sustainability within this sector. Through an extensive analysis, it becomes evident that LCA provides a comprehensive framework for assessing environmental impacts throughout the entire lifecycle of furniture products. The paper highlights the various methodologies, tools, and case studies employed in LCA studies within the furniture industry, emphasizing their significance in informing decision-making processes towards more sustainable practices. However, it also reveals certain limitations and challenges, such as data availability, standardization issues, and the need for broader stakeholder engagement.


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## CHAPTER 5

# THE EFFECT OF GRAPHENE OXIDE LOADING ON PROPERTIES OF DIFFERENT STYRENIC MATRICES

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**ABSTRACT**

The incorporation of efficient nano-fillers into different polymeric matrices in order to improve the overall performance of these polymers has become a worldwide milestone aimed to be achieved by different academic and industrial counterparts around the world. In this work, a comparative study represented by adding a weight fraction of 1.0 wt. % graphene oxide (GO) to different polymers made of styrene monomer represented by polystyrene (PS), and styrene acrylonitrile (SAN) was carried out. Solution casting was the adopted approach employed for preparing the neat polymers and their nanocomposites. The resulted nanocomposites of PS/GO, and SAN/GO underwent to different kinds of structural, morphological, thermal, and mechanical investigations. The initial outcome referred to an improvement of different properties for the prepared nanocomposites compared to the neat polymers. In addition, a comparison was made in order to compare the amount of improvement achieved by each polymer by incorporating same loading of GO nano-sheets. The promotion of SAN/GO nanocomposites recoded superiority compared to PS/GO nanocomposites, and the host matrix of SAN showed better performance compared to the pure PS. The potential applications associated to this work are food packaging, automotive, fire retardance materials, and different daily life applications represented by hoses, furniture, sport goods, and home appliances.

*Keywords:* Polystyrene, Acrylonitrile Butadiene Styrene, Graphene Oxide, Solution casting, Physical Properties.

## INTRODUCTION

Polymer Graphene Nanocomposites PGN's can be considered as a heterogeneous system which is formed from a polymer matric reinforced with graphene or graphene oxide GO that has nano-scale dimensions. Since its first emergence in 2004, graphene and its polymeric nanocomposites have been the focus of world-wide research in many laboratories in academia and industry, with the aim of harnessing its potential for the various applications in which these material could be used. These applications include flammability resistance, barrier properties, different kinds of sensors (electrochemical sensors, biosensors, etc...), and supercapacitors [1, 2]. PS and SAN are a couple of unique polymers derived from "Styrene" monomer. PS is a transparent, brittle, and has a high resistance to water. On the other hand, SAN has a high dimensional stability, and a good resistance to thermal variations compared to PS [3]. GO is a water soluble nanomaterial that can be synthesized through significant oxidation process for graphite which consequently lead to form an abundance of oxygenated functional groups at the basal plane and peripheries of the exfoliated graphene sheet [4]. Solution casting is a unique method that can be employed to prepare PGNs. In this method, a co-solvent is used to dissolve polymer beads, and to obtain a stable suspension of GO. The two solutions are mixed altogether with the employment of many dispersive techniques in order to guarantee a homogeneous dispersion of GO nano-sheets within the obtained polymer film [5]. This work aims to investigate the properties of PS, SAN and their GO nanocomposites as these polymers are efficient matrices derived from styrene monomer, and reinforcing them with 1.0 wt. % using solution casting approach is a good strategy to promote different properties of these polymers.

## METHODOLOGY

Improved Hummers' method was used to prepare GO. Details were mentioned in a previous work [6]. Tetrahydrofuran THF was used to dissolve the beads of PS and SAN. It was also used to obtain a stable suspension of GO. Both polymers were reinforced by 1.0 wt. % in order to assess the performance of the neat polymers with their nanocomposites. The procedure of preparing PGN's was also reported in a disseminated study [7]. Fourier transform infrared spectroscopy FTIR (Perkin Elmer, USA) was employed to characterize the spectral features of GO, PS, SAN, and the nanocomposites. The resolution was 4.0, and the scan speed was 0.2 $cm.sec^{-1}$. Scanning electron microscopy SEM (Inspect F, Poland) was used to investigate the morphological properties of GO, neat polymers, and nanocomposites. Samples were coated with gold using a specific sputtering unit, and the current employed in coating process was 15 mA. Thermal gravimetric analysis TGA (Perkin Elmer, USA) was employed for investigating the thermal properties for the materials included in the study. The atmosphere was $N_2$, temperature range was (25-700) ºC, and the heating rate was 10 $C.min^{-1}$. Differential scanning calorimetry DSC (Perkin Elmer, USA) was utilized for finding glass transition temperature $T_g$ for the pure polymers and their nanocomposites. Temperature was ramped from (25-240) ºC, and the heating rate was 10 $^{o}C.min^{-1}$.

Dynamic mechanical analyzer DMA was employed to find out the storage modulus for the materials included in the study. Single cantilever bending was the deformation mode, the range of temperature was (30-130) ºC, and the heating rate was 3.0 ºC.min-1. Scattering type scanning near field optical microscopy s-SNOM was used to evaluate Young's modulus in nano-scale for GO nano-sheets via the cryogenically fractured surface of PS/GO nanocomposites. Extensometer (Hounsfield, UK) was used to investigate the mechanical properties of the neat polymers and their nanocomposites. The load cell was 1000 N, and the speed of the crosshead was 1.0 $mm.min^{-1}$.

## RESULTS AND DISCUSSION

**Table 1.** Some thermal properties of GO, neat polymers, and their nanocomposites.

| Material | $T_g$/ ºC | $T_d$/ºC | Storage modulus /MPa |
|---|---|---|---|
| GO | - | 225 | - |
| PS | 99.5 | 346 | 1.41 |
| PS/GO | 102 | 360 | 2.23 |
| SAN | 108 | 413 | 2.44 |
| SAN/GO | 111 | 431 | 3.90 |

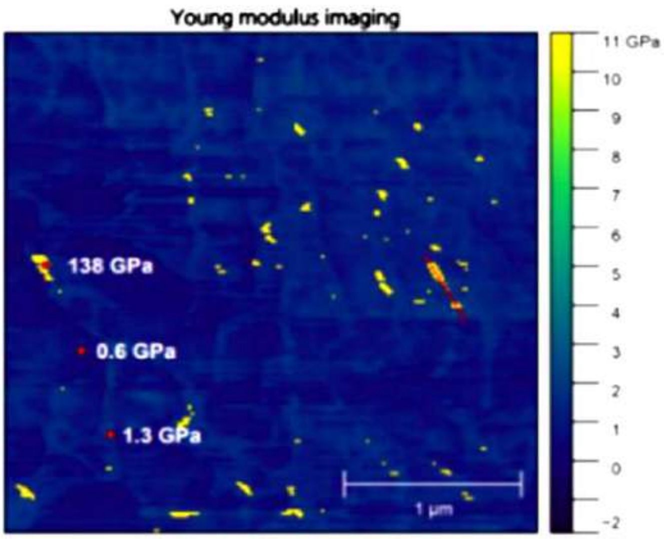


**Figure 1.** Nanomechanical properties for GO using s-SNOM [8].

## CONCLUSION

GO was prepared by Hummers' method. The neat styrenic polymers of PS, SAN and their nanocomposites 1.0 wt. % were successfully prepared by solution casting process using THF as a co-solvent. GO nano-sheets were homogeneously distributed within the styrenic matrices with few sites of nano-sheets agglomerations as shown by SEM. FTIR findings did not show a clear interaction between the styrenic polymers and GO as the load of GO used in the current study was apparently low. SAN and its GO nanocomposite showed superiority over PS and its nanocomposite in terms of thermal, thermo-mechanical, and mechanical properties. The measurement of Young's modulus in nano-scale for GO represented a milestone that could be employed to reveal the reasons behind the performance improvement for the polymer nanocomposites compared to the pure polymeric matrices.


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**CHAPTER 6**

# A REVIEW ON RECENT ADVANCEMENTS IN TEXTILE COMPOSITES FOR BIOMEDICAL APPLICATIONS


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**ABSTRACT**

Recent advancements in textile composites offer promising avenues for diverse biomedical applications, spanning wound healing, tissue regeneration, drug delivery, and protective biotextiles. This review amalgamates insights from cutting-edge research on textile composite development, characterization, and application, with a focus on PGF, PLA, and nanofiber-based textiles, including AgNP/rGO nanocomposite impregnated fabrics. It highlights innovative manufacturing techniques like the 50-nozzle bushing for PGF strands and manual bench-top Inkle-type looms for textile weaving, alongside advanced electrospinning methods for nanofiber yarns. The review delineates the mechanical properties, degradation behavior, and drug release capabilities of these composites, emphasizing the impact of fiber orientation, volume fraction, and matrix interactions. Notably, it underscores the antimicrobial efficacy of AgNP/rGO nanocomposite textiles against healthcare-associated infections and the potential of nanofibrous materials in enhancing biotextile performance through size and surface/interface effects. These findings underscore the pivotal role of processing conditions and material selection in shaping the mechanical properties, degradation rates, and functionalities of textile composites for biomedical applications. Future avenues and opportunities in clinical translation are outlined, stressing the need for further research to overcome existing limitations and explore novel applications in the dynamic realm of biomedical engineering.



*Keywords:* Textile Composites; Biomedical Applications; Electrospinning Techniques; Nanofibrous Materials; Antimicrobial Activity.


## INTRODUCTION

Recent advancements in textile composites have notably influenced the biomedical sector, especially in the development of more effective medical implants and devices. Traditional metal implants, while robust, often induce stress shielding and inflammatory responses due to their rigidity and bio-incompatibility. This has spurred interest in biodegradable composites that better mimic the mechanical properties of human tissues and offer improved biocompatibility. Phosphate glass fiber (PGF) composites, for example, closely match the mechanical characteristics of human cortical bone and degrade at a controlled rate, allowing for gradual load transfer to the underlying bone, thus minimizing osteopenia and stress shielding (1,2). This review explores the production techniques, including advancements in fiber production and textile processing, and highlights their applications in medical implants and drug delivery systems. The focus is also on the potential for these materials to reduce the need for secondary surgeries by degrading in synchrony with the healing process, providing a comprehensive look at the potential of textile composites to revolutionize biomedical applications.

## MATERIALS USED IN TEXTILE COMPOSITES FOR BIOMEDICAL APPLICATION

Recent studies on textile composites for biomedical applications focus on creating biodegradable and bioactive materials. Key techniques include the industrial production of phosphate glass fibers (PGFs) drawn into multifilament fibers and twisted into yarns, which are then woven or formed into unidirectional mats (2). These are combined with polylactic acid (PLA) through film stacking or solvent evaporation for structural integrity. Additionally, drug-loaded textiles are created by integrating antibiotics into hand-woven fabrics combined with PLA via solvent casting (3). In one study, silver nanoparticles (AgNP) and AgNP/reduced graphene oxide (rGO) nanocomposites were incorporated into medical-grade polyviscose textile pads through a simple, surface-oriented wet chemical solution-dipping method for antimicrobial application (4).Furthermore, nanotechnology is utilized to enhance microbial resistance, with methods like electrospinning used to produce nanofibers for advanced biomedical textiles (5).

## PERFORMANCE OF TEXTILE COMPOSITES FOR BIOMEDICAL APPLICATION

The studies presented a comprehensive overview of various textile composites tailored for biomedical applications. The first study focused on phosphate glass fiber (PGF) composites, highlighting their manufacturing process and mechanical characterization. Despite comparable fiber volume fractions, unidirectional (UD) composites exhibited superior flexural properties over textile composites due to yarn crimp, emphasizing the importance of processing conditions in composite fabrication. The second study introduced fully resorbable textile composites (T-C) woven from PGF textiles, showing higher flexural strength attributed to biased fabric formation. However, all composites demonstrated faster degradation rates than desired, indicating the need for further research to enhance durability and explore suitable coating agents. The third study developed woven cotton fabric PLA composite drug delivery devices, showcasing controlled drug release patterns influenced by composite degradation. These devices exhibited promise for wound dressing applications, offering water resistance and antimicrobial properties. The fourth study presented AgNP/rGO nanocomposite-impregnated textile pads with potent antimicrobial activity against E. coli, demonstrating high stability and efficacy even after laundering cycles. Finally, the fifth study highlighted the broad utility of biotextiles in biomedical applications, emphasizing the advantages of electrospun nanofibrous biotextiles over microfibers, with potential applications in wound healing, tissue regeneration, and drug delivery. Future research directions include optimizing composite properties, enhancing durability, and facilitating clinical translation to realize the full potential of textile composites in biomedical settings.

## BIOMEDICAL APPLICATIONS OF TEXTILE COMPOSITES

Textile composites are revolutionizing biomedical applications, providing solutions ranging from wound care to surgical enhancements. They are employed in creating drug-delivery wound dressings with controlled porosity, enhancing targeted therapy effectiveness. Additionally, they feature in antimicrobial textile pads impregnated with substances like silver nanoparticles, effective against bacteria such as Escherichia coli, crucial for preventing infections in healthcare settings. Moreover, their application extends to the manufacturing of surgical sutures and implants using nanofibrous materials produced via electrospinning, offering superior mechanical and biological properties ideal for tissue engineering. These composites also form protective gear like masks, pivotal during the COVID-19 pandemic, demonstrating their critical role in modern medicine.


## CONCLUSION

The studies in this review illustrate the evolving capabilities of textile composites in biomedical applications, particularly in enhancing drug delivery, wound care, and microbial resistance. Noteworthy is the utilization of electrospun nanofibrous materials and AgNP/rGO nanocomposite textiles, showing significant potential in healthcare. Future research should focus on optimizing these composites' properties and durability to fully harness their benefits in medical settings.


## ACKNOWLEDGEMENT

The authors would like to thank Universiti Putra Malaysia for the support that is given to carry out this conference.


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## CHAPTER 7

# A REVIEW OF WATER ABSORPTION BEHAVIOR ON NATURAL FIBER REINFORCED POLYLACTIC ACID COMPOSITES

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**ABSTRACT**
Researchers are now concentrating on developing biodegradable materials, specifically natural fiber-reinforced polymer composites, due to increasing environmental concerns around waste management. It is essential to determine the water-absorption behavior of these composites during their development. This review investigates the water absorption (WA) behavior of natural fiber-reinforced polylactic acid (PLA) composites. The review delves into the mechanisms and many elements associated with this behavior. This review examines the impact of many parameters, including natural fiber loading and manufacturing procedures, on the WA behavior of natural fiber-reinforced PLA composites. Furthermore, this paper discusses methods for enhancing the WA resistance of the composites. This review offers researchers insights into the WA behavior of composites, with the goal of assisting in the manufacturing of a versatile and sustainable material that can address waste disposal issues.
*Keywords:* Water Absorption; PLA; Biocomposites; Natural Fiber.

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## INTRODUCTION

Solving environmental issues related to waste disposal problems has become a significant priority. Between 1950 and 2010, the recycling rate of plastic waste was less than 10% [1]. To solve these issues, renewable and biodegradable materials are needed, and one of them is natural fiber-reinforced PLA. However, the incorporation of natural fiber in composites has several problems, one of them is the high WA value due to the hydrophilicity of natural fiber [2].

This review aimed to utilize knowledge of WA behavior in natural fiber-reinforced PLA composites, including parameters that impacted WA behavior and how to increase WA resistance, so researchers can explore the potential of these composites for other sustainable applications.

## WATER ABSORPTION BEHAVIOR OF NATURAL FIBER REINFORCED PLA COMPOSITES

Several parameters, including natural fiber loading and the manufacturing process, can impact the WA value of natural fiber-reinforced PLA composites. According to Gunti et al. [3] , the effect of fiber loading in elephant grass-reinforced PLA composites is increasing the WA rate of the composites due to the hydrophilic characteristics of elephant grass, which has a significant amount of hydroxyl groups. In terms of the manufacturing process, Ecker et al. [4] showed that the 3D-printed PLA composites exhibited higher WA rates compared to the composites produced using injection molding because the 3D-printed PLA composite samples have more porous structures. To enhance the WA resistance of the natural fiber-reinforced PLA composites, there are several methods can be used, such as chemical treatment and enzymatic treatment. According to Werchefani et al. [5], who conducted chemical and enzymatic treatments on tunisian alfa fiber-reinforced polylactic acid composites, the study demonstrates that the application of chemicals and enzymes can decrease the WA of the composites as shows in Figure 1.

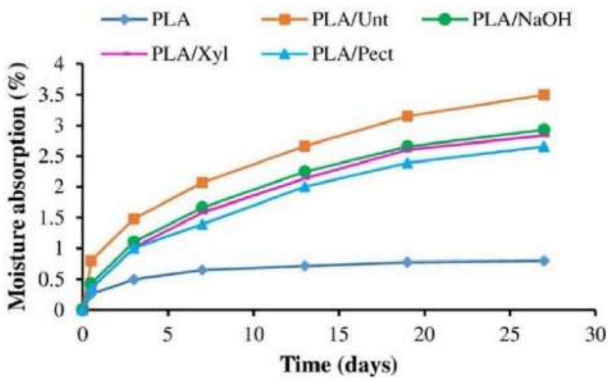


**Figure 1.** Evolution of the moisture uptake of virgin polylactic acid (PLA) and its composites at 23 °C temperature and 95 % relative humidity [6]

## CONCLUSION

This review paper covers several variables that impact the WA behavior on natural fiber/PLA composites, including the impact of natural fiber loading and manufacturing techniques on the WA of these composites. Additionally, it aimed to examine how to enhance the WA resistance of natural fiber/PLA with various treatment techniques for natural fiber to mitigate this issue.

## ACKNOWLEDGEMENT

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## CHAPTER 8

# LOW COST MIG BASED WIRE ARC ADDITIVE MANUFACTURING (WAAM) MACHINE – DEMANDS AND CHALLENGES

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**ABSTRACT**
Metal-based additive manufacturing has received a lot of attention in recent years. Unfortunately, the technology is very expensive, which limits its usage, especially as an early technology exposure. In this paper, the design and development of a low-cost WAAM machine are presented. The machine is developed using a modular approach with a DIY concept. The machine consists of five modules: the XY table, main body, CNC router, welding set, and programming software. Each of the modules has its own system and can be easily replaced or upgraded. The machine allows for the addition of new modules. The machine can achieve a maximum deposition rate of 19.31 g/min, with a deposition efficiency of up to 98.0%. Various 3D profiles have been successfully constructed, and the machine has proven to be able to print bi-metallic profiles with good inter-layer adhesion. On cost analysis, the overall cost involved in fabricating the machine is about RM2800.00, which is relatively cheaper than the competitor. Based on tests conducted, for a mild steel material, the average hardness value at the longitudinal and transverse surfaces could achieve up to 58.08 and 58.02 HRC. The UTS may achieve up to 948 MPa, and the yield stress can be met at approximately 460 MPa. While the highest value of fracture toughness can be achieved up to 113J, even though the properties are relatively low compared to the parent material, they show good potential for improvement in the future.
*Keywords:* Wire arc additive manufacturing (WAAM); Low cost; teaching; learning.

## INTRODUCTION

Metal additive manufacturing is now preferred as the application of the technology is spreading very quickly. This is because it offers many advantages. However, the technology is relatively expensive [1]. Cost increases due to enhancement of the technology by equipping with (a) lasers and optical scanning systems, (b) advanced optics to improve accuracy, and (c) degree of automation [2]. Due to the critical needs of technology in education and research, hands-on experience became invaluable [3]. Therefore, this paper will propose low-cost metal additive manufacturing as a solution.

## METHODOLOGY

The study begins with a survey to gain the perspective of public and industry people's opinion on this issue. Followed by the development of the machine. The process ends with evaluation of the machine capability.

## RESULTS AND DISCUSSION

Based on the survey, affordability to own the facility became the main barrier to respondents. Based on the design requirement listed by the respondent, two main elements of the machine are low-cost and user friendly. The prototype of the MIG-based wire arc additive manufacturing machine is as shown in Figure 1. The machine is developed based on modular approach to promote changeability [4].

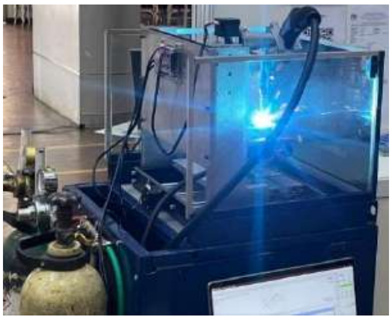

**Figure 1.** Prototype of the machine.

Furthermore, the machine performed excellently in terms of material utilization and deposition feed rate as summarized Table 1. In addition, the deposited material that has gone through various tests depicts an outstanding observation in terms of mechanical properties and tribological behavior [5-6].

**Table 1.** The machine capability.

| **Title** | **Description** | **Unit** | **Value** |
|---|---|---|---|
| Overall machine size. | Height x Length x Width | mm | 1140 x 1040 x 560 |
| Table size (Working area) | Height x Length x Width | mm | 45 x 300 x 180 |
| Material utilization | - | % | 98 |
| Deposition rate | - | g/min | 19.31 |

## CONCLUSION

As a conclusion, the machine shows great potential in exposing the metal additive manufacturing technology at affordable price. The machine is designed modularly and allows for upgrading in the future to improve its capabilities.

## ACKNOWLEDGEMENT

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## CHAPTER 9

# SELECTION OF NATURAL FIBRE IN HYBRID SYNTHETIC/NATURAL FIBRE REINFORCED POLYMER COMPOSITES FOR AUTOMOTIVE SIDE MIRROR HOUSING APPLICATIONS

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**ABSTRACT**

Concerns about the environment have been made about the use of synthetic fibres in composite materials because they release carbon dioxide during production and depend on resources that could not be replaced. Therefore, this study is the first step towards finding the right natural fibres to mix with glass fibres to make long-lasting, high-performance hybrid composites. These could be an alternative to traditional pultruded fibreglass composites for use in structural profile applications. An Analytical Hierarchy Process (AHP) was used to find the best natural fibre for strengthening hybrid natural/synthetic FRP composites that can be used for structural purposes. Seven different types of natural fibres were chosen as alternatives. The best one for hybrid composites was chosen based on six factors: density, thermal conductivity, tensile strength, Young's modulus, elongation at break, cost, government support, and fibre availability. Because it had the highest priority vector, kenaf was the best choice for strengthening out of the seven options. After that, a sensitivity analysis was done to confirm that kenaf was the best material for the study project.

*Keywords:* Analytical Hierarchy Process; Hybrid Polymer Composites; Natural Fibre; Synthetic Fibre.

## INTRODUCTION

Natural fibres can be combined with synthetic fibres to improve the mechanical performance and water resistance of composites. Extensive research has been conducted on natural fibre reinforced hybrid composites, focusing on long- and short-term qualities to identify viable application areas for the composites. For instance, Srinivas et al. [1] reported that the mechanical characteristics of natural/synthetic fibre reinforced hybrid composites increased with increasing volume percent of glass fibres until a point was reached where the negative hybrid effect occurred due to the production of agglomerates. While various studies have been conducted on natural/glass fibre reinforced composites, the practical use of natural/synthetic fibre hybrid composites is limited and remains in the research and development stage. The study aims to identify a natural fibre material from 7 options to be combined with glass fibres in creating eco-friendly hybrid FRP composites for automobile side mirror housing, in response to increasing environmental concerns. The study utilised the AHP approach to compare and identify the most appropriate natural fibre to be hybridised with glass fibre for automotive side mirror housing application. The proposed materials were ranked based on several factors and an overall ranking was determined by synthesising the PCM data. The consistency ratio was ensured to be below 0.10 (10%) to justify the judgements. The results were simulated by doing sensitivity analysis and adjusting the weight of each criterion.

**AHP METHODOLOGY**

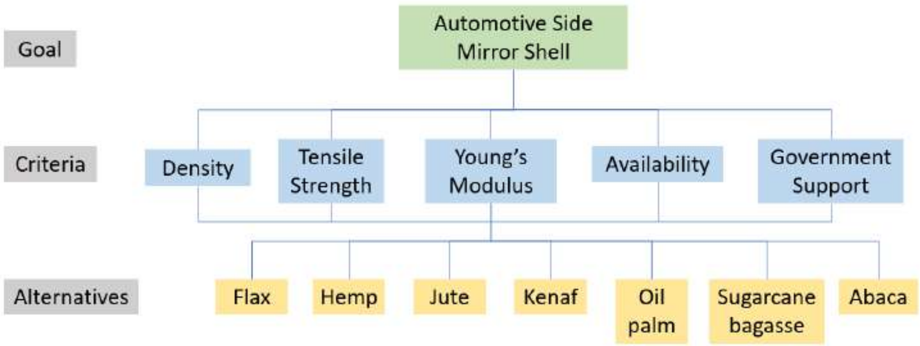


**Figure 1.** AHP of side mirror material selection

Most of the time, an analytical ranking process is broken down into several steps [2]. To set the goal, criteria, and possible solutions, a hierarchical framework was created. Figure 1 shows how the AHP approach is organised in a hierarchy. The first step of the analytical hierarchy process shows the main goal. As shown in the second level of the hierarchical structure, six factors were chosen as the selection parameters based on the needs to create FRP profiles for the side mirror housing. The third level shows the natural fibres (alternatives) that are being thought about as possible materials to mix with glass fibre to make outer car parts out of FRP composites based on Table 1. A pair-wise comparison matrix (PCM) was created for the criterion in relation to the goal using a relative intensity scale. The intensity scale ranged from 1 to 9 to represent the varying levels of importance for the criteria. The PCM data was utilised to establish the relative priority vector for each attribute. Once all values for each criterion, sub-criterion, and material alternatives have been inputted, the pairwise comparison can be represented.

**Table 1.** Mechanical and physical properties of natural fibers as compared to conventional reinforcing fiber retrieved from [3,4].

| Fibre | Density (g/cm3) | Young's Modulus (GPa) | Tensile Strength (MPa) |
|---|---|---|---|
| Flax | 1.4-1.5 | 27.6-80 | 345-1500 |
| Hemp | 1.48 | 70 | 550-900 |
| Jute | 1.3-1.46 | 10.0-30.0 | 393-800 |
| Kenaf | 1.45 | 53 | 215.4 |
| Abaca | 1.5 | 41 | 980 |
| Oil Palm | 1.55 | 3.2 | 248 |
| Sugarcane | 1.2 | 19.7-27.1 | 20-290 |

## RESULTS AND DISCUSSION

Sensitivity analysis is conducted to examine how the results are affected by changing the weight of the priority vector for each criterion. The analytical result is deemed robust when changes are not significant because of variations in underlying assumptions. AHP was conducted using "Expert Choice" v.11.5 software to determine the optimal natural fibre for reinforcing hybrid FRP composites in vehicle side mirror housing applications. The inconsistency in judging all criteria and alternatives is less than 0.1% [5]. The lesser the inconsistency, the more accurate the judgement is. Sensitivity analysis was used to get the verification and validation of the overall results of the AHP process. Figure 2 shows the performance chart demonstrating the priority vector yielded by the natural fibres with respect to the criteria. The most perfect option is kenaf fibre with an ideal value of 1, indicating that kenaf fibre is the most suited material for this project. The primary important variables are the availability in Malaysia and government backing, with kenaf scoring the highest in both aspects. Jute has the lowest index value of 0.523376 because the material is not available in Malaysia, despite its favourable material qualities. Kenaf fibre is identified as the top choice in two out of five criteria based on the sensitivity analysis: government backing and availability. Kenaf ranks fourth in density and second in Young's modulus and tensile strength compared to other options. Thus, the choice of kenaf as a viable alternative using the AHP has been demonstrated to be reliable, as consistent outcomes were achieved with changes in the priority vector weightage for each criterion. The sensitivity analysis confirms that kenaf fibre is the best appropriate fibre for use in hybrid FRP composites for automotive side mirror housing applications.

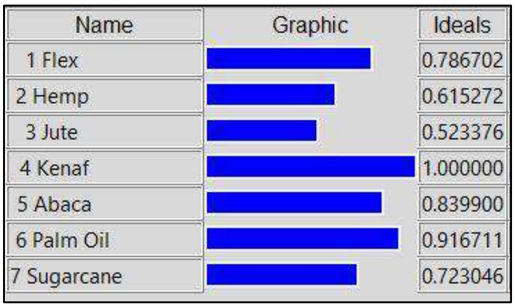


**Figure 2.** Ideals value for AHP method.

## CONCLUSION

Based on the research, it can be deduced that kenaf fibre is chosen as the appropriate option through AHP analysis, meeting the fundamental design objectives and criteria for the desired application. Moreover, a consistency study was conducted to verify the judgements made throughout the creation of PCM. The obtained inconsistency ratio for all criteria were below than 0.01, which has less than the maximum CR value of 0.1. Therefore, the judgements made throughout the AHP analysis have been demonstrated to be consistent and valid. The sensitivity analysis indicates that kenaf fibre is the most favourable option, as it received the greatest priority vector in four out of six criteria: tensile strength, density, cellulose, and availability. This further confirms the fibre selection procedure through the AHP. The AHP approach is a valuable multi-criteria decision-making tool for researchers and engineers to systematically undertake selection and problem-solving tasks across numerous applications. There is a significant opportunity to efficiently choose appropriate natural fibres for different technical applications using the AHP in several research fields. Furthermore, kenaf/glass reinforced hybrid composites can be analysed to assess their mechanical, physical, and structural performance in vehicle side mirror cover applications to confirm their integrity.

## ACKNOWLEDGEMENT

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## CHAPTER 10

# GRAPHENE BIOPOLYMER NANOCOMPOSITE FOR PIEZOELECTRIC SENSOR APPLICATION

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**ABSTRACT**
Researchers have been studying piezoelectric materials for almost a century. Piezoelectric materials are currently used in a wide range of applications, including energy harvesting, sensing and actuation, and have made their way into our daily life. Piezoelectric material characteristics are being improved in order to increase performance and enable new applications. The discovery of graphene has paved the way for several new material uses in a variety of disciplines. It has been utilised in conjunction with several biopolymers to create nanocomposites with superior mechanical, thermal, electrical, gas, and water vapour barrier qualities. This study gives an overview of graphene biopolymer nanocomposite in the field of piezoelectric sensors, including a material science and manufacturing viewpoint on the advancement of practical piezoelectric sensors. This paper also identifies numerous areas that may need more investigation and provides a thorough overview of the possible applications of graphene biopolymer nanocomposite in piezoelectric sensors. This paper also offers valuable insights and recommendations for researchers and specialists in the green composites sector, which may lead to the development of sustainable materials for a variety of piezoelectric sensor applications.
*Keywords:* Graphene; Biopolymer; Biocomposite; Piezoelectric.

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## INTRODUCTION

Piezoelectric materials are those that generate an electric charge in response to mechanical stress or strain. Graphene biopolymer nanocomposites have emerged as promising materials for piezoelectric sensor applications due to their unique combination of properties, including high mechanical strength, electrical conductivity, biocompatibility, and piezoelectric response [1]. When combined with biopolymers, such as proteins or DNA, it forms a nanocomposite with enhanced functionalities and potential applications in various fields including sensors, energy harvesting, and biomedical devices [2].

## METHODOLOGY

### *Solution Mixing*

In this method, graphene and biopolymer are dispersed in a solvent, followed by mixing to obtain a homogeneous solution or suspension. This mixture is then cast or dried to form the nanocomposite [3].

*Layer-by-Layer Assembly*

This method involves the alternate deposition of graphene and biopolymer layers on a substrate through processes such as spin-coating, dip-coating, or spray-coating [4].

## RESULTS AND DISCUSSION

Graphene biopolymer nanocomposites exhibit enhanced piezoelectric properties compared to pristine biopolymers due to the addition of graphene, which facilitates charge transfer and improves mechanical reinforcement [5].

*Piezoelectric Properties*

Different compression strengths were applied and the continuous voltage outputs were recorded; the results are shown in Figure 1.

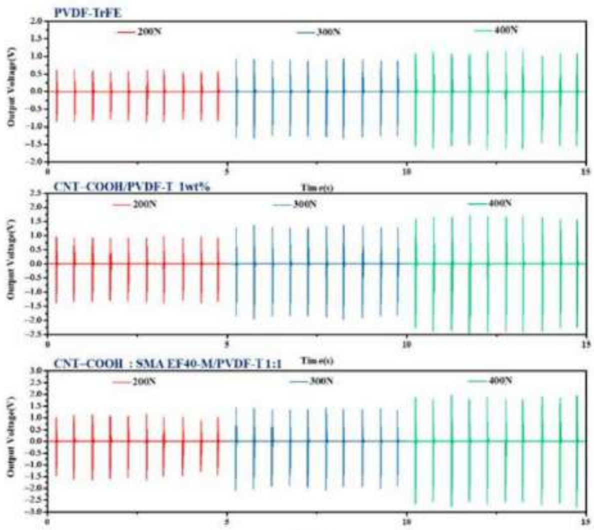


**Figure 1.** Different compression strengths on Graphene Biopolymer sample

The results demonstrated that pure PVDF-TrFE without additives had a poor piezoelectric effect; at 200 N of pressure, the maximum voltage of 1.57 V and the average voltage of 1.36 V were recorded for CNT–COOH:SMA EF40-M/PVDF-T. The CNT–COOH/PVDF–T film without a dispersant showed an average voltage of 2.16 V and a maximum voltage of 2.50 V. However, when the applied pressure was 400 N, these values increased by 9% to 2.36 V on average and 2.72 V on maximum. Consequently, a higher percentage of the PVDF-TrFE molecular chain was encouraged to transition from the α-phase to the β-phase by the improved dispersibility of the CNT–COOH solution and the enhanced intermolecular interactions between the –COOH groups on the surface of CNT–COOH and the fluorine atoms of PVDF-TrFE [6].

## CONCLUSION

In conclusion, graphene biopolymer nanocomposites hold great promise for piezoelectric sensor applications, offering a versatile platform for the development of sensitive, flexible, and biocompatible sensors. Further research and development in this field are expected to lead to the advancement of next-generation sensing technologies with enhanced performance and functionality.

**ACKNOWLEDGEMENT**

I would like to thank Advanced Engineering Materials and Composites Research Center (AEMC) of Universiti Putra Malaysia for the support that is given to carry out this conference and Fundamental Research Grant Scheme (FRGS) that made this research possible.

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## CHAPTER 11

# STUDY THE PROPERTIES OF LYSOZYME WITH MAGNETIC PARTICLE FOR DRUG DELIVERY APPLICATION

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**ABSTRACT**

This research was to investigate the stability of lysozyme in the presence of magnetic particles for drug delivery. Lysozyme can mostly be found in the hen egg albumin, and it also acts as an important agent, which is antibodies to fight bad bacteria or shield the human body. The problems in this research are magnetic particles that can cause toxicity and reduce the therapy's efficiency due to the degradation of carriers (drugs). To minimise this problem, the stability and activity of the lysozyme and Fe2O3 were investigated. The structure of lysozyme and $Fe_2O_3$ before and after adding acid or alkaline was defined, and the suitability of $Fe_2O_3$ as a drug delivery was determined. The stability of the lysozyme and $Fe_2O_3$was identified using an Ultraviolet-Visible (UV-Vis) Spectrophotometer, and the structure was investigated using a Field Emission Scanning Electron Microscope (FESEM) and Scanning Electron Microscope- Energy Dispersive X-Ray (SEM-EDX). Different concentrations become the parameters of this research as a comparison between the samples. This research found that the combination of the lysozyme alkaline material was suitable for the body at a pH of 12.2. It was also found that $Fe_2O_3$ is suitable for drug delivery in the body when the lysozyme can be carried by $Fe_2O_3$ and dissolved in the $Fe_2O_3$.

*Keywords:* Lysozyme; Stability; Magnetic Particle; Drug Delivery; Toxicity.

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## INTRODUCTION

Nowadays, the development of the technology affect in every field. It is including in health, environment and also in medication. According to my research on the stability of lysozyme in the magnetic particle for drug delivery, it is connected with the development of the technology which is on magnetic particle. Magnetic particle is important in the drug delivery because it is an agent or transports the delivery the medicine to the body.

## METHODOLOGY

In this experiment, the first thing is measure the weight of lysozyme, $Fe_2O_3$ and NaOH. For the dry sample, the Electronic weighing scale was used to measure weight of lysozyme, $Fe_2O_3$ and sodium hydroxide at different molarity.

## RESULTS AND DISCUSSION

### *Ultraviolet- visible (UV-Vis) Spectrophotometer*

Ultraviolet- Visible (UV-Vis) are to determine the absorbance of light spectrum. In this research, the wavelength for each sample was fixed at 200 nm until 1000 nm. Figure 1 shows the dilution of the lysozyme at different molarity. The lysozymes were classified with different molarity starting from 0.2 M, 0.4 M, 0.6 M, 0.8 M and 1.0 M. Since the unit of the molarity is mol/liter, which refer to the number of moles of solute per unit liter of solution it also can be defined as the concentration of the solution. So, graph below was referring to the analysis the activity of lysozyme at different concentration using ultraviolet-visible (UV-Vis) spectrophotometer.

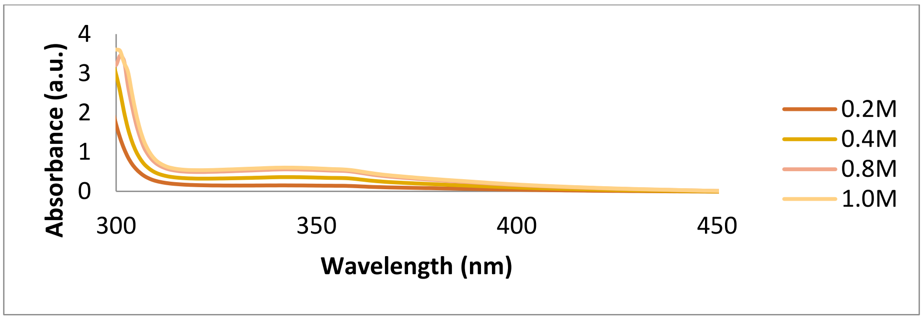


**Figure 1.** Lysozyme at different concentration**.**

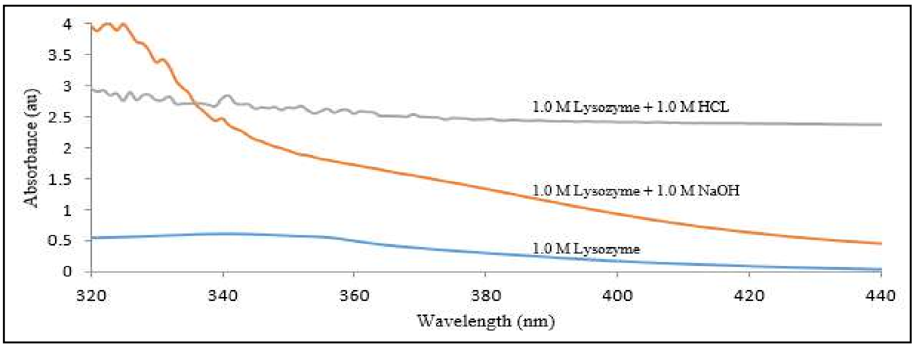


**Figure 2.** The graph for different type of lysozyme at fixed molarity.

Hydrochloric acid and sodium hydroxide were added in the 1.0 M concentration of lysozyme. It is to determine the activity of the lysozyme in the presence of acid and base. In this research, the suitable concentration of the acid and base was determined by the absorbance of light using ultraviolet-visible (UV-Vis) spectrophotometer. The highest peak of the absorbance at certain wavelength was chosen. 1.0 M of hydrochloric acid was added in the lysozyme solution. The result of the absorbance of light using UV-Vis spectrophotometer shows at 2.91 au and the wavelength at 320 nm to 380 nm.

Lysozyme solution that mix with 1.0 M concentration of NaOH shows that the highest peak while the lysozyme solution at the lowest peak and the acidic lysozyme solution was at the middle. The absorbance of light in the mixture of NaOH and lysozyme solution was at 4.0 au which the wavelength at 320 nm to 330 nm. So, we can conclude that the activity of the lysozyme is suitable in the alkaline state at pH 12.2 [1].

## CONCLUSION

In conclusion, the most stable of lysozyme was at the concentration 1.0 M and for the $Fe_2O_3$ was at 0.6 M. The stability of the sample depends on the transition of energy to produce highest peak absorbance and wavelength. Moreover, at alkaline state, the lysozyme shows the highest reading of absorbance compared to HCl which means that lysozyme can react faster in that state compared to the HCl.

## ACKNOWLEDGEMENT

The authors would like to thank the Faculty of Applied Sciences and Technology, Universiti Tun Hussein Onn Malaysia for facilities provided that make the research possible.

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## CHAPTER 12

# PHYSICAL AND MECHANICAL PROPERTIES OF SUGAR PALM FIBRE REINFORCED EPOXY/UNSATURATED POLYESTER BLEND COMPOSITES

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**ABSTRACT**

Sugar palm fibre/epoxy resin/unsaturated polyester (SPF/ER/UP) composites were successfully prepared by mixing the polymeric matrix of 1:1 weight ratio of epoxy resin/unsaturated polyester blend with 10% of SPF of 3mm or 5mm length and curing them at room temperature for at least 24 hours. The cured plain matrix which is a light brown hard flexible homogenous solid polymer produces black composites upon addition the SPFs suggesting there is a leachate of the lignin from the fibre into the matrix during the mixing. The almost identical of the matrix and composite FTIR spectra suggests that the formation of the composites does not involve chemical reaction or/and strong functional group interaction. The tensile test results reveal that the matrix are strong rigid solids which behave mainly as plastic materials. The presence of 10% fibres in the matrix, although slightly reduces tensile strength at break, modulus (Young's modulus) and tensile stress at yield, but their changes are not significant. SEM study of the composite fracture surface displays that, in addition of showing the matrix is a one phase rigid material, the fibres are well distributed in random direction. The existence of small gaps between the fibres and the matrix, and relatively clean of the fibre surface in the composites, support the earlier findings that their compatibility is poor. Furthermore, the water absorption of the composite of the 3mm is about the same as that of the matrix, which are 6.36% and 6.49%, respectively. However, this property increases of about 50% if the 3mm fibre is replaced with the longer (5mm) one.
*Keywords:* Sugar palm; Epoxy; Unsaturated polyester; Composites; Mechanical properties

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## INTRODUCTION

The environmental impact of non-biodegradable synthetic plastics prompts exploration of eco-friendly alternatives like sugar palm fiber (SPF), renowned for durability and resistance to degradation [1]. SPF, comparable in strength to bamboo and other fibers, has diverse applications and is increasingly studied for polymer reinforcement. However, its use with epoxy and unsaturated polyester blends remains unexplored [3]. This study investigates SPF composites with this blend as a matrix, offering insights for further applications in structural engineering and addressing environmental concerns over plastic waste [4].

## METHODOLOGY

Sugar palm fiber sourced locally underwent soaking, retting, drying, and cutting; materials including unsaturated polyester, epoxy resin, and hardener were supplied by Innovative Pultrusion Sdn Bhd., Malaysia. Epoxy resin, hardener, unsaturated polyester, and initiator were combined according to a 1:1 weight ratio, with methyl ethyl ketone peroxide added to the polyester before blending with epoxy components. Composite formulations ranging from 0% to 20% sugar palm fiber were prepared, cured, and molded into dumbbell shapes for testing, utilizing both 3mm and 5mm SPF samples.

For each sample of the composites, five specimens were tested to failure and the average value of tensile strength at break, modulus (Young's modulus) and tensile stress at yield were reported. The samples were coated with a thin layer of gold using the sputter in order to produce the contrast image on the SEM machine.

IR spectra of the specimen were recorded using a Perkin Elmer Fourier Transform Infrared (FTIR) Spectrometer. The presence of functional groups, formation of new bonding or/and interaction of functional groups was analysed from the spectra.

**RESULTS**

Tensile strength at break, modulus (Young's modulus) and tensile stress at yield of epoxy resin/ unsaturated polyester blend and, 3mm and 5mm of sugar palm fibre/epoxy resin/ unsaturated polyester (SPF/ ER/ UP) composites are presented in Figure 1. It shows that addition of 10% by weight of 3mm SPF or 5mm SPF decreases these properties with the effects by the 3mm fibres are bigger than those of the composites with 5mm. However, considering of their standard deviations, these changes are not significant.

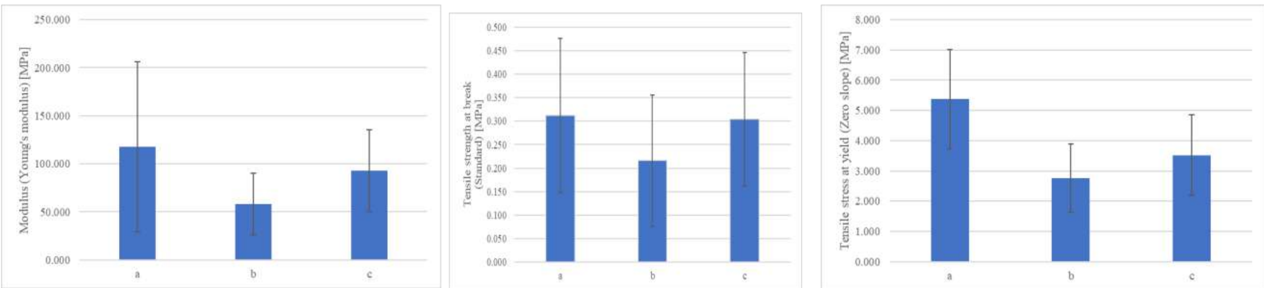


**Figure 1.** Tensile strength at break, modulus (Young's modulus) and tensile stress at yield of epoxy resin/unsaturated polyester blend (a), 3mm (b) and 5mm (c) of sugar palm fibre/epoxy resin/unsaturated polyester (SPF/ ER/ UP) composites.

Scanning Electron Microscopy (SEM) study was carried out for the fractured surface from the tensile tests of the composites reinforced by 5mm SPF. Figure 2 illustrates the fractured surface focusing on the matrix at 200 times magnifications. In addition to showing a characteristic of rigid material, it indicates also that blending of the unsaturated polyester and epoxy resin forms a single-phase solid indicating their good compatibility. The diameter sizes of the fibres were also estimated using the SEM micrograph as illustrated in Figure 2 are of in the range from 70 to 200µm.

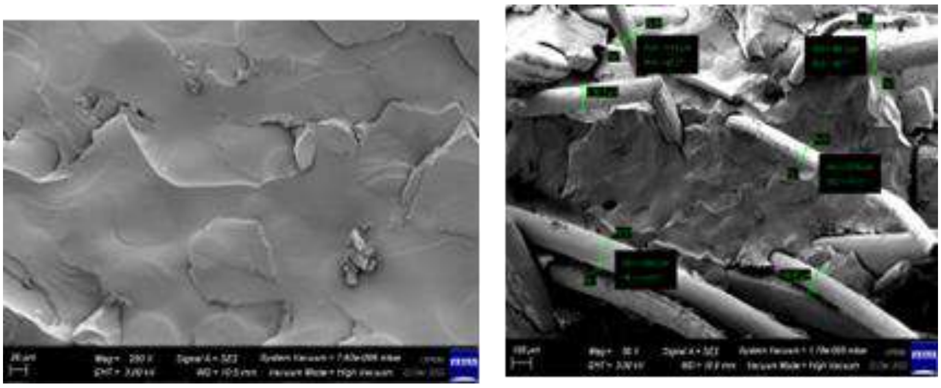

**Figure 1.** SEM Micrograph of the fractured surface at 200X magnification focusing the matrix. SEM micrograph showing the diameter sizes of the fibres.

Infrared spectra of plain matrix and composite with 5mm SPF exhibit almost identical profiles, indicating minimal fiber-polymer interaction or chemical bonding. Peaks suggest presence of OH, aliphatic chains, carbonyl groups, aromatic rings, and epoxy resin in the materials.

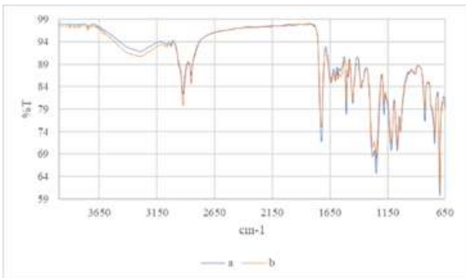


**Figure 3.** FTIR spectra of the matrix (a) and composite (b).

Samples with higher density than water sink and saturate with water over about seven days, reaching maximum absorption of 6.49%, 6.36%, and 9.40% for the matrix and composites. Addition of 5mm SPF to the matrix shows highest absorption, possibly due to more pores from longer fibers being less uniformly arranged.

## CONCLUSION

Sugar palm fiber/epoxy resin/unsaturated polyester (SPF/ER/UP) composites were fabricated successfully, revealing leaching of lignin from the fiber into the matrix, limited fiber embedding above 10%, negligible chemical interactions indicated by FTIR, minor impact on tensile properties, and relatively low compatibility between polymer and fiber.

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CHAPTER 13

# THE IMPACT OF VARYING CARBON NANOTUBE LOADINGS ON THE MECHANICAL PROPERTIES OF HYBRID CELLULOSE NANOFIBER AND ARROWROOT STARCH COMPOSITES

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**ABSTRACT**
This study is to investigate the impact of varying amounts of carbon nanotubes (CNTs) on the mechanical properties of hybrid composites made from arrowroot starch (ARS) and cellulose nanofibers (CNF). The purpose of integrating carbon nanotubes into natural polymers is to enhance the mechanical characteristics of biodegradable composites
These composites are highly sought after because of their beneficial effect on the environment. The hybrid matrix was altered by incorporating varying amounts of CNT, and the resulting composites were subjected to a series of mechanical evaluations, which included measuring tensile strength, elongation at break, and Young's modulus. The results showed that the mechanical properties were significantly improved by the addition of CNT, and the optimal concentration was found to maximize both strength and flexibility. The enhanced mechanical strengthening provided by CNT and their effective dispersion throughout the hybrid matrix are credited with the improvement.
This study shows the potential of cellulose nanofiber and arrowroot starch composites enhanced with carbon nanotube for applications requiring strong, lightweight, and biodegradable materials.
*Keywords:* Carbon Nanotubes; Arrowroot Starch; Cellulose nanofiber; Mechanical properties

## INTRODUCTION

Biodegradable films are used to reduce the environmental impact of non-biodegradable packaging made from petroleum. These films consist of biogenic compounds, including proteins, lipids, and polysaccharides [1]. Starch is highly useful as a polysaccharide due to its remarkable capacity to form a cohesive structure, its cost-effectiveness, its global accessibility, and its regenerative properties [2]. Arrowroot rhizomes, an unconventional source of starch, are currently under investigation as a crucial raw material [3].

Arrowroot, scientifically known as Maranta arundinacea, is a perennial herb that grows in tropical woods. It can be found in several regions including the West Indies, Indonesia, Malaysia, Philippines, India, and Sri Lanka [4]. Arrowroot starch is highly useful due to its rich fiber content, which is beneficial for the digestive system and serves as a filler in biocomposites [5]. Arrowroot tubers are an extremely concentrated reservoir of starch, with a starch concentration exceeding 85%. They are extensively employed in the culinary sector for the purpose of creating biscuits, as well as for manufacturing substances that increase viscosity. Furthermore, arrowroot tubers are also utilized for medicinal purposes [6].

The nanocellulose morphology encompasses many shapes such as rods, filaments, granular cellulose crystals, filaments, or whiskers. The material can be categorized into four types: cellulose nanocrystals (CNC), cellulose nanofibrils (CNF), spherical nanocellulose (SNC), and cellulose nanosheet (CNS) [7]. The preparation, structure, performance characteristics, and applications of nanocellulose and nanocellulose-based composites have been the subject of a multitude of studies conducted recently by specialists around the globe [8]–[10]. Nanocellulose based composites are well-known for enhancing the mechanical and barrier properties of biopolymers in food packaging. Moreover, they can serve as vehicles for bioactive compounds like antioxidants and antibacterial agents, thereby prolonging the durability of food items. Consequently, they hold considerable potential for future applications. [11].

Carbon nanotubes (CNTs), known for their remarkable strength, stiffness, and toughness, are being regarded as a highly promising material for achieving this objective [12]. Nevertheless, the clustering of carbon nanotubes (CNTs) caused by their powerful van der Waals forces restricts their ability to dissolve and disperse, resulting in a decrease in both the strength and toughness of the end product. The primary method now used to tackle this issue is modifying the surface of carbon nanotubes (CNT) through covalent or non-covalent means. This is achieved by introducing functional groups such carboxyl groups or polymers such as Poly(3-alkylthiophenes) [13].

Thus, the objective of this research work was to obtain and characterize CNT, CNF, and arrowroot starch biocomposites. The study the influence of its concentration on mechanical properties, thermal activity, and physical properties of the films.

## METHODOLOGY

CNT hybrid CNF composite films were produced by the process of solution casting. At first, all the necessary components and solutions, including sorbitol, glycerol, starch (10 g), CNF (3% w/w starch), CNT, and distilled water (170 mL), were prepared. The solutions were combined through the process of stirring and sonication. Sonication is essential for achieving a uniform nanocomposite film. A volume of 170 mL of distilled water was introduced into solutions containing various concentrations of CNT, CNF, and ARS. The mixture was then subjected to sonication for a duration of 30 minutes. Table 1 displays the meanings or definitions of CNT cinnamon EO integrated ARS/CNF nano-composite films. The proportions of sorbitol and glycerol indicated in Table 1 are calculated relative to the weight of ARS. Following the sonication procedure, a 10 g solution of ARS was agitated at a speed of 1000 rpm for a duration of 20 minutes at a temperature of 85 degrees Celsius using a disperser, until

the starch underwent gelatinization. The purpose of this technique was to guarantee the even distribution and consistent breakdown of starch granules.
The plasticizers were utilized in a 1:1 ratio, resulting in approximately 30% (weigh of starch) of each plasticizer in this experiment. The film-forming suspension was cooled to eliminate air bubbles. Subsequently, 60 grams of the suspension was introduced onto a Petri dish with a diameter of 13.5 centimeters in order to initiate the solution-casting process. The Petri dish was incubated in an oven at a constant temperature of 45 degrees Celsius for 18 hours. Once fully dried, the film was carefully removed from the Petri dish and placed in storage. It was kept at relative humidity of 53 ± 1% in a controlled room.

| No | Starch (g) | CNF (%) | CNT (%) | Sorbitol and Glycerol (1 : 1) (%) |
|---|---|---|---|---|
| 1 | 10 | 3 | 0 | 30 |
| 2 | 10 | 3 | 0.25 | 30 |
| 3 | 10 | 3 | 0.5 | 30 |
| 4 | 10 | 3 | 1 | 30 |

## CONCLUSION

To summarize, the study on CNF, CNT, and arrowroot starch composites provides encouraging findings for eco-friendly material. This study aims to tackle the environmental issues linked to traditional non-biodegradable packaging by using arrowroot, a renewable and underutilized source of starch. The results indicate that the addition of arrowroot starch to CNF/CNT improve the mechanical properties.
Nanocellulose inclusion has the ability to prolong the shelf life of food products by serving as a carrier for active chemicals such as antioxidants and antibacterial agents. This work makes a valuable contribution to the field of biodegradable packaging materials. It also investigates the efficient utilization of alternative starch sources, such as arrowroot, in order to meet the increasing need for environmentally friendly materials in industrial applications.

## ACKNOWLEDGEMENT

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**CHAPTER 14**

# MECHANICAL PROPERTIES OF A 3D WOVEN GLASS/POLYESTER COMPOSITE AFTER THE ADDITION OF ALUMINUM TRIHYDROXIDE

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**ABSTRACT**
A 3D composite's structure is based on a fabric comprising two parallel skin layers interconnected by vertical woven piles, a design known for enhancing delamination resistance. This study investigates the impact of incorporating aluminum trihydroxide (ATH) filler into a 3D woven glass/polyester composite, specifically focusing on its effect on compressive strength, and elastic modulus. The composite panel was constructed using unsaturated polyester resin as the matrix, with methyl ethyl ketone peroxide (MEKP) as the curing agent, and varying loads of ATH filler (30%, 40%, and 50%), and subjected to compression testing. Results demonstrate that the incorporation of up to 40% ATH filler enhances both compressive strength and elastic modulus. However, excessive loading beyond this threshold results in a decline in both properties. This research sheds light on the intricate interplay between filler content and composite characteristics, offering insights valuable for optimizing the design and performance of 3D woven sandwich composites.
*Keywords:* 3D woven sandwich composites; Aluminum trihydroxide; Compressive strength; Compressive modulus; Density.

## INTRODUCTION

Sandwich composites are lightweight materials with high bending stiffness and strength, making them ideal for applications in the aerospace, automotive, and railway industries. [1-5]. A 3D woven sandwich composite is a type of sandwich composite with improved delamination resistance due to the integrated pile yarn between the skin and core layers. Studies have shown that these composites offer excellent fatigue performance, increased flatwise and edgewise compression strength, and improved flexural strength and energy absorption [6-9].

Meanwhile, fire retardancy is an important consideration for polymeric materials used in transportation applications. Several approaches have been developed to enhance fire retardancy, including the use of fire-retardant fillers like Aluminum Trihydroxide (ATH) [6].

This study investigates the influence of ATH loading to the flatwise compressive strength and elastic modulus of the composites at 40% ATH loading.

## METHODOLOGY

Sandwich composite panel specimens were fabricated using unsaturated polyester resin as matrix, methyl ethyl ketone peroxide (MEKP) as  curing agent and aluminium trioxide filler (ATH) was used as fire retardant. While 3D woven core fabric used as core, and 2D woven roving used as facesheet. From the 3D fabric, the 3D woven sandwich composite panel was fabricated using the hand lay-up method. The samples were fabricated in the variation of ATH to polyhester weight ratio (30%, 40%, and 50%). All samples were subjected to a compression testing.

## RESULTS AND DISCUSSION

Figure 1 shows the result of compression test. It shows that the addition of ATH up to 40% increases both compressive strength and elastic modulus. However, another addition of ATH decreases both values.

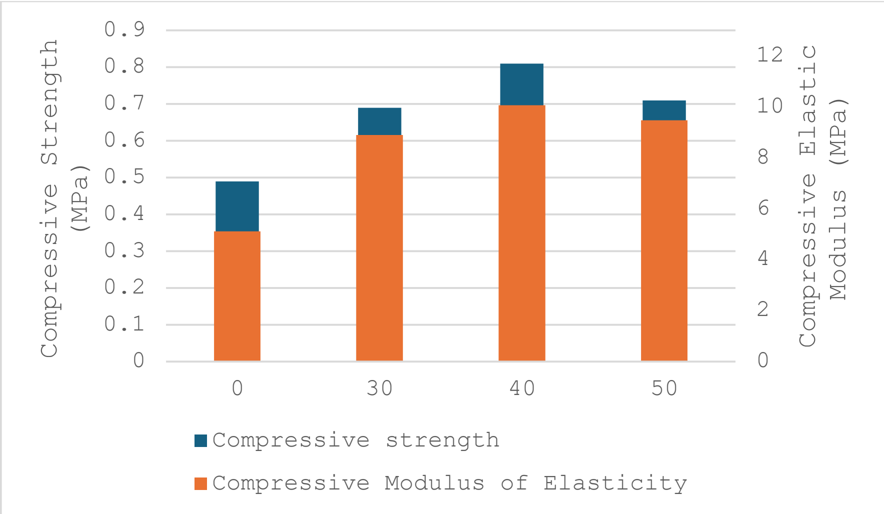


**Figure 1.** Compressive Test Result.

## CONCLUSION

While increasing the fire retardancy, the incorporation of ATH into polyester matrix up to 40% improves both compressive strength and elastic modulus.

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**CHAPTER 15**

# HYBRID POLYAMIDE BIOCOMPOSITES FOR HEAVY-DUTY RAILWAY SLEEPER APPLICATION

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**ABSTRACT**
Railway transportation safely connects people to different parts of a country at affordable cost. Although, the passing traffic, speed and load have significantly increased over time. The need and search for environmentally friendly, and higher service material for track component is on the increase. Hence, environmentally friendly composites are now an emerging material. To address those needs and due to environmental concerns, hybrid polyamide biocomposite has become of great importance. Therefore, this paper experimentally evaluates the performance of treated kenaf/glass fibre (TKF/GF) reinforced polyamide biocomposites for heavy-duty railway sleeper applications. Both TKF and GF incorporation influenced the biocomposite behaviour. The result further showed maximum increase in bearing capacity at 30 wt.% TKF/GF which is higher as compared to conventional wooden sleepers. although, water absorption decreased due to GF addition and the alkaline treatment to kenaf, but it was above the standard required threshold. Hybrid polyamide biocomposites have demonstrated their potential for heavy-duty railway sleeper applications as their load bearing capacity exceeds the minimum (> 28 MPa), recommended ISO 12856-1 and AREMA specifications; it also exceeds the reported Iranian Type-1 new plastic composite sleeper (NPCS) modulus of elasticity by 85%. While achieving these milestones, it is still imperative to address the water absorption nature of kenaf fibre. This study contributes valuable insight towards the development of sustainable and efficient materials for the evolving demands of modern railway infrastructure.
*Keywords:* Kenaf fibre; Hybrid polyamide biocomposites; Railway sleeper; Bearing capacity.

## INTRODUCTION

Rail seat deterioration is caused by chemical ingression and cracking occurrence on heavy-duty mono-block prestressed concrete sleepers. Consequently, increasing maintenance cost because of sudden sleeper failures. The environmental pollution due to emission of carbon dioxide across the world is in excess of 5% resulting from cement production for infrastructural development such as in for concrete sleeper [1]. Therefore, quest for alternative material such as hybrid biocomposites has become of great importance and is in focus by researchers and rail industry stakeholders. This is because of the numerous advantages they possess such as being environmentally friendly, resistance to chemical effect coupled with good strength.

## METHODOLOGY

The raw materials used for this research are polyamide six (PA6) as matrix, Kenaf fibre (KF) and Glass fibre (GF). The KF surface were modified via alkaline treatment in an attempt to reduce moisture intake and improve mechanical properties as in literature [2, 3]. Compounding was by internal blending followed by hydraulic compression moulding at a regulated/control. Subsequently, sample for tests were produced as per standards. Formulation for the hybridization is presented in Table 1.

**Table 1.** Formulation of Hybrid Polyamide biocomposite

| | Matrix | Reinforcement | | |
|---|---|---|---|---|
| | | | | Hybrid |
| Sample ref. | PA6 (wt. %) | TKF (wt. %) | GF (wt. %) | 50%TKF/50%GF (wt. %) |
| Control | 100 | 0 | 0 | 0 |
| 1 | 90 | 10 | 10 | 5TKF/5GF |
| 2 | 80 | 20 | 20 | 10TKF/10GF |
| 3 | 70 | 30 | 30 | 15TKF/15GF |
| 4 | 60 | 40 | 40 | 20TKF/20GF |
| 5 | 50 | 50 | 50 | 25TKF/25GF |

## RESULTS AND DISCUSSION

From Fig. 1, the initial tangent modulus of composite specimens tends to increase with increasing fibre loading. Increase in fibre loading up to 40 wt.%, results in large increase in modulus thereby indicating lesser damage of the biocomposite under loading. Consequently, it would result in longer sleeper fatigue life as also seen with [4].

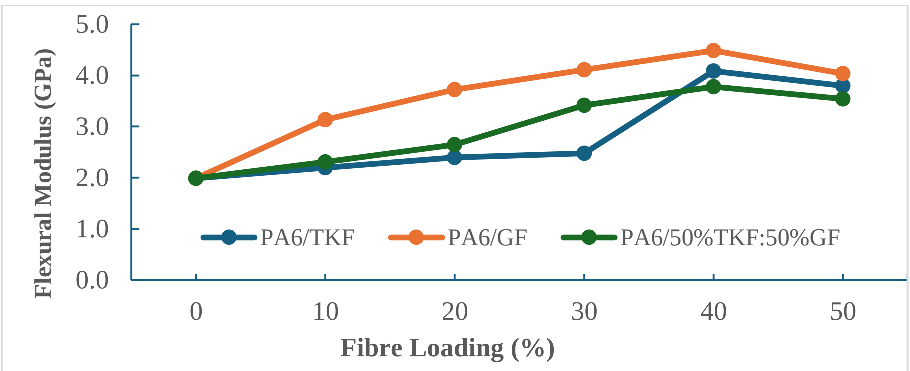


**Figure 1.** Flexural Modulus of Hybrid Polyamide Biocomposite

## CONCLUSION

Hybridized Treated Kenaf fibre/Glass fibre reinforced polyamide biocomposites have demonstrated their potential for railway sleeper applications as their modulus of elasticity exceeds some available heavy-duty plastic sleepers in use. This study contributes valuable insights toward the development of sustainable and efficient materials for the evolving demands of modern railway infrastructure.


## ACKNOWLEDGEMENT

The authors would like to thank Putra Grant Berimpak (GBP/2020/9691300) for funding this research and thank Tetfund/ The Federal Polytechnic Bauchi-Nigeria for the conference sponsorship.


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**CHAPTER 16**

# INVESTIGATION ON WEAR BEHAVIOR OF SUGAR PALM FIBER-BASED BRAKE PAD COMPOSITE FOR RAILWAY BRAKE PAD APPLICATIONS

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**ABSTRACT**

Green composites are crucial for mitigating environmental effects in rail brake materials. The purpose of this paper was to investigate the effects of sugar palm loading in a phenolic resin-based composite formulation under laboratory wear test conditions. The composition of the brake composite material formulation consists of alkaline-treated sugar palm fiber (30%), steel fiber (5%), wollastonite (5%), phenolic resin (35%), and nitrile butadiene rubber (25%) weight percentage respectively. A hot compression molding technique was used to prepare the formulated brake composites. The dry sliding wear tests were carried out in a Block-On-Ring test in accordance with ASTM G77 standard at a constant load of 1.2kg. The results obtained have been compared with conventional brake pad materials. The wear rate and volume loss were measured as $0.15859 cm^3$ and $2.2067039*10^{\wedge -2}$ $mm^3$/ Nm. Worn surface morphology supporting the findings.

*Keywords:* Dry sliding wear; Coefficient of friction; Sliding distance; Brake pad; Sugar palm.

## INTRODUCTION

Sugar palm is one of the most important crops in Malaysia because of its sugar. Lately, a growing consciousness of environmental issues has led to a paradigm change in favor of using renewable resources and creating eco-friendly materials. Because of their potential for several uses, natural fibers like those found in sugar palm, bananas, pineapple leaves, kenaf, cotton, and jute have drawn interest from both academics and business.[1]

## MATERIALS AND METHODOLOGY

Materials used in this work include Sugar palm, phenolic resin, NBR, wollastonite and steel fiber. The source of the wollastonite (KM25W) was KAOLIN (MALAYSIA) SDN.BHD, Puchong. The supplier of steel fibre was Dezhou Zhenbang Industrial Co. Ltd. The supplier of phenolic resin (PF-6801) was SHANDONG SHENGQUAN NEW MATERIALS CO., LTD. located in Jinan, China. ACN content of 30±2% rubber is used.

The commercial sugar palm, or Arenga pinnata, is native to Southeast Asia and is widely grown for its sugar. The fibres were harvested from the trunk of a matured plant located in Kedah. The gathered fibres were given four washings before being let to air dry for two days at room temperature and 30–40% relative humidity. For five hours, the dried fibres were submerged in a 0.5% NaOH solution to undergo an alkaline treatment.

The composites were prepared using the hot press moulding method. After weighing each powder, it is placed in a container and mixed for fifteen minutes. To facilitate extraction, the powder mixture was poured into an open steel mould and covered with Teflon sheet. The composite powder mixture-containing mould setup was heated to 160°C for 30 minutes before being squeezed. After that, the produced samples were post-cured in an oven for ten minutes at 5°C.

**Table 2.** Composite composition details.

| S. No | Sugar Palm | Phenolic resin | NBR | Wollastonite | Steel fiber |
|---|---|---|---|---|---|
| 1 | 30% | 35% | 25% | 5% | 5% |

**RESULTS AND DISCUSSION**

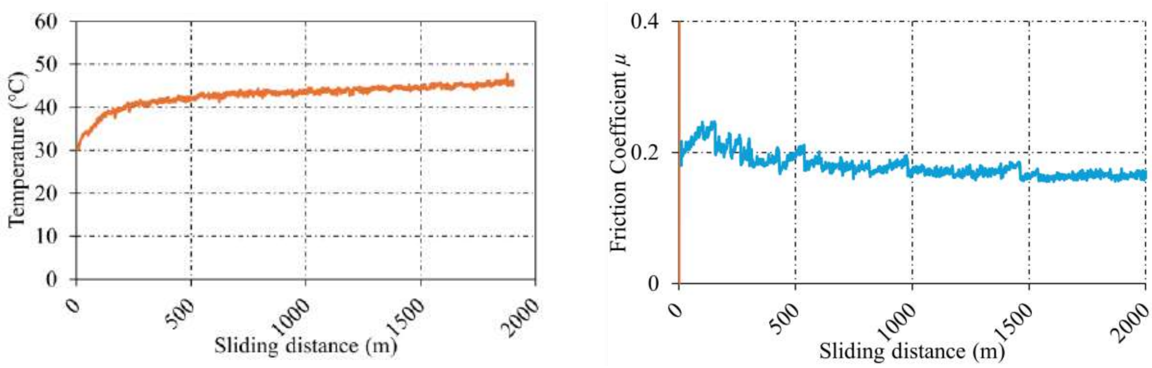


**Figure 1.** Temperature and coefficient of friction behavior with sliding distance.

Figure 1 Shows the temperature behavior of sugar palm fiber composite. The maximum temperature reached is 47°C. Decrease in coefficient of friction was observed with increase in temperature. A stable coefficient of friction is obtained after achieving the bedding in phase. The volume loss and specific wear rate were measured and compared with other conventional brake block materials. Good wear resistance is a result of natural fibres high resin adherence in composite materials. Microscopic image of worn-out surface is shown in Figure 3. From the scoring grooves that are apparent on the worn surfaces in the direction of sliding, abrasion wear is a significant wear mechanism. Given that the counter face has a harder hardness of 58 HRC than composite, it is reasonable that the counter face's roughness is what created the scored grooves.

| Brake pad material | Volume loss | Specific wear rate | COF |
|---|---|---|---|
| Sugar palm sample | $0.15859\ cm^3$ | $2.207 \times 10^{\wedge -2} mm^3$/ Nm | 0.18 |
| Commercial brake block sample[2] | $21.04\ mm^3$ | $2.8786 \times 10^{\wedge -2} mm^3$/ Nm | 0.31 |
| Steel ST 75 composite[3] | $0.002\ mm^3$ | $4.72 \times 10^{\wedge -9} mm^3$/ Nm | 0.24 |
| Banana Peels [4] | - | $1.38 \times 10^{-5}\ mm^3/Nm$ | 0.325 |
| Palm Kernels[5] | - | $2.4 \times 10^{-4}\ mm^3/Nm$ | 0.365 |
| Palm slag[4] | - | $0.89 \times 10^{-6}\ mm^3/mm$ | 0.33 |

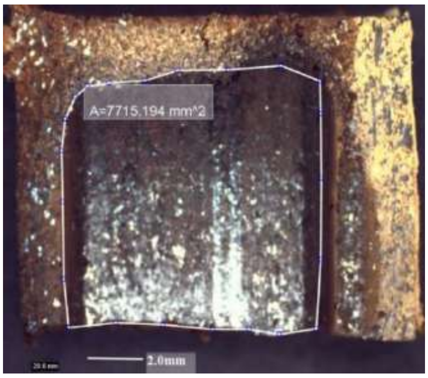


**Figure 3.** Microscopic image of worn-out surface.

## CONCLUSION

The versatile sugar palm (Arenga pinnata) tree has been used historically to make a wide range of regional goods. Sugar palm fibres can compete with the majority of natural fibres on the market, including jute, cotton, kenaf, coir, oil palm fibre, and many more, because of their exceptional mechanical qualities. The wear behaviour of phenolic resin-based sugar palm composite was determined. The use of sugar palm fibre in composites can aid in the following three areas: (1) establishing sugar palm as a new industrial crop for the future; (2) relieving pressure to rely less on petroleum products; and (1) lessening the harm synthetic polymers and fibres cause to the environment. Consequently, by raising incomes and generating additional employment opportunities, this can improve the socioeconomic empowerment of rural residents.

## ACKNOWLEDGEMENT

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**CHAPTER 17**

# REVERSE ENGINEERING OF ANEURYSM CLIP USING METAL FORMING

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**ABSTRACT**
Aneurysm clip is widely used as the primary treatment of complex brain aneurysm, primarily in a haemorrhage stroke due to cerebral blood vessel blockages or ruptures, leading to severe neurological deficits. In some developing countries, such as Indonesia, the open surgical clipping is sometimes unaffordable and causes a financial burden to the state. This study aims to reproduce the commercial aneurysm clip using a metal forming as a way to be more independent providing medical equipment throughout the country. The metal forming employed rolling and bending techniques, utilizing a base and a jig system to press the Ti6Al4V wire into the desired shape of an R-shaped contour. Our investigation confirmed their structural integrity, fine-grain structure, and mechanical properties. The density of the aneurysm clip shows 4.3 g/cm3 after the forming process. The chemical composition of the aneurysm clip tested with a scanning electron microscope equipped with an energy-dispersive X-ray spectrometer revealed the presence of Ti, Al, and V elements. The fabricated clip exhibited a closing force of 1.689 N and it is about doubled the closing force exerted by the commercial aneurysm clip, which is 0.791 N.
*Keywords:* Remanufacturing; Metallurgy, Neural Implant, Fenestrated Clips, Metal Machining, Stroke Haemorrhage.

## INTRODUCTION

An aneurysm clip is a metal surgery clip with a function to block the aneurysm, particularly in the brain [1]. The manufacture of the aneurysm clip has been developed and equipped with its applier or installation tools by many inventors [4]. There are also a lot of patents available under the theme of aneurysm clips as well as their surgical instruments. However, only a few patents declared the production phases of the aneurysm clip. To tackle the high dependency on imported medical devices, some middle-income countries, including Indonesia, attempt to provide and produce their medical equipment needs, such as aneurysm clips. This study aims to employ a metal-forming method to reproduce the commercial aneurysm clip in Siloam Hospital Karawaci, Tangerang, Indonesia. In previous studies, three-dimensional (3D) printing had been used to reverse engineer the aneurysm clip [19], [20]. However, the reverse engineering method using the additive manufacturing needs to improve the critical ability of the closing force as well as the ability to equalize the dimensions. Finally, this study tries to investigate the replication process of the commercial aneurysm clip, with no prior detailed information or any catalogue from the brand, that used broadly by neurosurgeons in Indonesia. This reverse engineering process is expected to provide medical equipment throughout the country. The investigation of the reverse-engineered aneurysm clip includes several factors the physical appearance, the closing force, and the material used.

**METHODOLOGY**

*3D model scanning and construction*

The available clip, a fenestrated Sugita aneurysm clip, was scanned using a Cairnhill 3D scanner. Figure 1 describes the aneurysm 3D model scanning and detailed drawing dimensions, viewed from above and from the side.

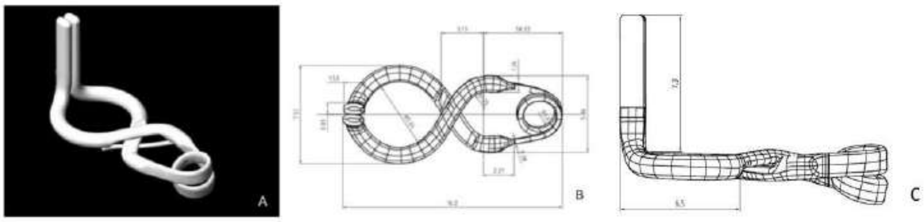


**Figure 1.** A fenestrated aneurysm clip model. (A) 3D model the aneurysm clip; (B) and (C) drawing dimensions of the scanned aneurysm clip.

*Manufacturing process*

The Ti6Al4V wire, upon reception, underwent a cold working process involving pressing and rollingThe received wire is subjected to compression using a mold of a combination of SKD-11 hardened steel and carbon steel S45C materials to create an R-shaped form. Subsequently, the compressed wire is rolled into a coil configuration with a pressing angle of 22 ° and a free angle of 34 °. Finally, the aneurysm clip is bent to obtain a 90 ° blade angle. The process was then followed by bending the blade part of the clip to create an L-shaped blade.

*Prototype characterization*

This evaluation consists of closing force measurement, the physical analysis, density test of aneurysm clips, the metallography test, the scanning electron microscope with energy dispersive spectroscopy (SEM EDS), and the Vickers hardness test to acquire information regarding material characteristics of the reverse engineered aneurysm clip.

**RESULTS AND DISCUSSION**

In the closing force measurement, the fabricated clip exhibited a closing force of 1.689 N and it is about doubled the closing force exerted by the commercial aneurysm clip, which is 0.791 N. In physical analysis, a reverse-engineered aneurysm clip is more prominent in size than the commercial aneurysm clip. Figure 2 describes the physical appearance of aneurysm clip.

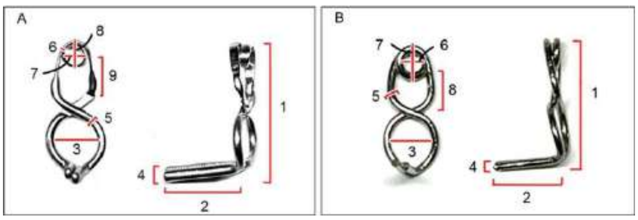


**Figure 2.** (A) The commercial Sugita; (B) the reverse engineered aneurysm clips.

In the material analysis, the metallography test that the Ti6Al4V aneurysm clip consists of α and β Ti phases with fine grain size. The fine grain structure observed in clip aneurysm manufacturing can be attributed to the utilization of rolling and bending processes. The SEM-EDS confirms that the wire consists of Ti (91.22 wt.%), Al (5.25 wt.%), and V (3.53 wt.%). Lastly, the Vickers hardness value of the reverse-engineered aneurysm is 330.64 HV ± 6.56. It is close to the theoretical value of Ti6Al4V hardness, 300 ± 2 HV. Overall, to the best of our knowledge, the attempts of remanufacturing or mastering the technology behind aneurysm clip production still need to be understood. The effort of remanufacturing aneurysm clip will significantly contribute to be a fundamental knowledge of how to produce the aneurysm clip with a slight modification, particularly on the blade side in a purpose to overcome the occurrence of the patient-specific aneurysm geometries

**CONCLUSION**

These findings contribute to advancements in clip design and installation techniques. Incorporating cold working and coining of the raw wire in the future is recommended.

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## CHAPTER 18

# A COMPREHENSIVE REVIEW OF PRECURSORS FOR ELECTRODEPOSITION OF CdS THIN FILMS

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**ABSTRACT**
This comprehensive review delves into the diverse array of precursors utilized in the electrodeposition process for the fabrication of cadmium sulfide (CdS) thin films. CdS thin films hold immense promise across a spectrum of applications such as solar cells, sensors, and optoelectronic devices due to their exceptional properties. Electrodeposition emerges as a versatile and cost-effective method for CdS thin film production, offering precise control over film characteristics. The review meticulously examines various categories of precursors encompassing inorganic, organic, and mixed compounds, shedding light on their distinctive roles and impacts on film properties. Through an extensive exploration of precursor selection, this review elucidates the profound influence of precursor chemistry on the morphology, crystallinity, optical, and electrical properties of CdS thin films. Furthermore, the review outlines future prospects and challenges in the field, highlighting emerging trends and opportunities for advancing the fabrication of CdS thin films via electrodeposition.
*Keywords:* Cadmium Sulfide; Electrodeposition; Precursors; Thin Films; Review.

## INTRODUCTION

In the realm of thin film technology, cadmium sulfide (CdS) stands as a pivotal material with a wide array of applications spanning from solar cells to optoelectronic devices [1] & [2]. The electrodeposition method has emerged as a promising technique for the fabrication of CdS thin films due to its cost-effectiveness [3], scalability [4], and controllability over film properties [5]. However, despite its potential, the successful electrodeposition of CdS thin films hinges significantly on the choice and utilization of suitable precursors [6].

## ELECTRODEPOSITION TECHNIQUE

The standard electrode potential for an electrochemical reaction is the potential where the rate of the reduction and the oxidation reactions are equal at standard conditions of concentrations, pressure and temperature. The Nernst equation relates the standard electrode potential E0 to the electrode potential E [8]

$$E = E^0 + \frac{RT}{nF} ln \frac{\{ox\}}{\{red\}} \qquad 1.0$$

where R denotes the standard gas constant ($8.314510 JK^{-1}.mol^{-1}$), T the absolute temperature in Kelvin, n the number of electrons transferred and F the Faraday's constant ($96485.309 C.mol^{-1}$). The potential also depends on the ratio of the natural logarithm of the activities of the oxidized and reduced species The time needed for this depletion of the species, the transition time $\tau$, is given by the Sand equation,

$$\tau^{1/2} = \frac{nF(\pi D)^{1/2}C^*}{2I} \qquad 2.0$$

where I is the current (in mA), C* is the bulk concentration (in mol·cm$^{-3}$), and D is the diffusion coefficient expressed in cm$^2$ ·s$^{-1}$ [9].

Electrodeposits are formed by the action of an electric current passing in an electrochemical cell, a device that consists of two conductive or semi-conducting electrodes immersed in an electrolyte [6]. CdS thin films have been effectively deposited onto glass/FTO substrates utilizing both acidic and aqueous solutions containing $CdCl_2.xH_2O$ and thiourea $(SC(NH_2))_2$. The electrodeposition process for CdS thin films was conducted potentiostatically, employing a 2-electrode system [10]. Cadmium Chloride ($CdCl_2$) has been extensively utilized as a precursor for CdS electrodeposition,$CdCl_2$ is favoured for its excellent solubility in aqueous solutions and convenient handling. Cadmium acetate dihydrate $Cd(CH_3COO)_2 2H_2O$ and ammonium thiosulphate $(NH_4)_2S_2O_3$ were employed as the cadmium (Cd) and Sulphur (S) sources, respectively[11]. The deposition of CdS layers on glass/FTO (fluorine-doped tin oxide) substrates was conducted at cathodic potentials ranging from 1300 to 1460 mV to optimize growth conditions. The resulting layers exhibited n-type conductivity, with bandgap values ranging approximately between 2.36 and 2.40 eV for as-deposited layers and 2.31 and 2.36 eV for air-annealed layers [12]. Cadmium sulphide (CdS) thin films were electrodeposited onto glass/FTO substrates using a two-electrode system, employing an acidic aqueous solution containing thiourea $CH_4N_2S$ and cadmium chloride hydrate $CdCl_2.xH_2O$ precursors [8]. These thin films underwent characterization through X-ray diffraction (XRD), scanning electron microscopy (SEM), photoelectrochemical (PEC) cell testing, and optical absorption analysis to investigate their structural, morphological, electrical, and optical properties [13]. XRD analysis revealed that the layers exhibited a polycrystalline nature with a hexagonal crystal structure, displaying preferred orientation along the (200) plane. Cadmium sulfide (CdS) layers for window applications have been applied onto indium tin oxide (ITO) coated glass surfaces through electrodeposition utilizing the galvanostatic method from a non-aqueous solution consisting of cadmium chloride ($CdCl_2$), sulfur (($S_8$)), and ammonium chloride ($NH_4Cl$) at a bath temperature of 90 °C. Favorable quality CdS-deposited layers are achieved at a cathodic current density of 0.25mA/cm$^2$ [14].

**SUMMARY**

The comprehensive review delves into the diverse range of precursors utilized in the electrodeposition process for producing cadmium sulfide (CdS) thin films.

**ACKNOWLEDGEMENT**

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CHAPTER 19

# EVALUATING COMFORT IN CONSTRUCTION EXOSKELETONS: A SYSTEMATIC REVIEW

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**ABSTRACT**
This research advocates for a holistic approach to evaluating the comfort of construction exoskeletons, emphasizing material selection, ergonomic design, and biomechanical fit. Using the PRISMA method, we distilled 74 key studies from an initial literature pool of 3,760 between 2013-2023, employing bibliometric analysis for deeper insight. Our findings, driven by both two automated tools and manual literature reviews, propose a novel comfort index and specific recommendations for structural and padding materials. We categorize exoskeletons into back, lower limb, and upper limb supports, addressing critical research voids and advancing exoskeleton technology for enhanced worker comfort and safety.
*Keywords:* Exoskeleton; PRISMA; Comfort material; Systematic review; Construction background.

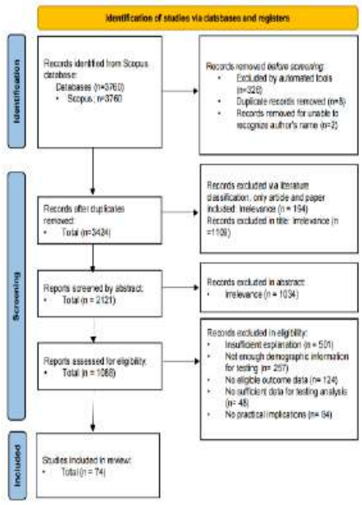
## INTRODUCTION

A preliminary review of existing literature reveals a notable gap in comprehensive studies focusing on the comfort of construction exoskeletons. While safety and efficacy have been the primary focus of previous research, the subjective and objective dimensions of comfort—ranging from material selection to design ergonomics—have received limited attention. Research on lower limb, back, and upper limb support exoskeletons has demonstrated the potential for selecting more suitable exoskeleton materials to enhance comfort and functionality. For lower limb support exoskeletons, the incorporation of polymer sheeting on existing interfaces has been shown to be most effective. Due to the greater rigidity of polymer sheeting compared to foam padding, forces are more efficiently distributed across the skin, reducing perceived pressure. This suggests that the stiffness of interface padding materials should be progressively decreased while their surface area is increased to optimize comfort. Studies on back support exoskeletons indicate that, although exoskeletons alleviate pressure on the lower back, they may introduce discomfort in the chest and thigh regions. Research involving upper limb support exoskeletons has shown a potential increase in lower body stress during testing experiments. These observation underscores the importance of holistic design considerations in exoskeleton development to ensure that enhancements in one area do not inadvertently introduce strain or discomfort in others. It highlights the need for an integrated approach in exoskeleton design, balancing support across different body regions to optimize user comfort and efficiency while minimizing adverse effects.

## METHODOLOGY

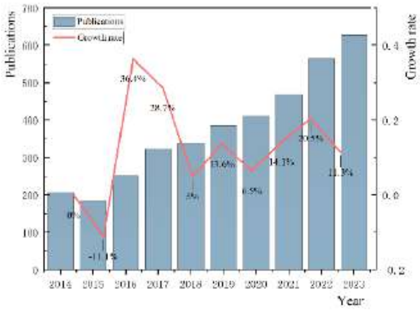
This systematic review was prepared following the preferred reporting items for systematic reviews and PRISMA guidelines (The PRISMA 2020 Statement Page, et al. [1]). As illustrated by Olukolajo, et al. [2], systematic literature review guidelines describe at least three types of inclusion criteria: academic databases, keywords to query and publication type to include. The Scopus database is renowned for its extensive coverage and is the favored academic resource for conducting reviews, due to the high quality of articles it encompasses. Consequently, publications were sourced from the Scopus search engine/academic database using the specified query code (as shown in **Error! Reference source not found.**), with the publication year limited to 2013-2023. This search yielded a total of 3760 publications. The search operation was carried out on March 16, 2024.

**Table 1.** Specified query code with its reference.

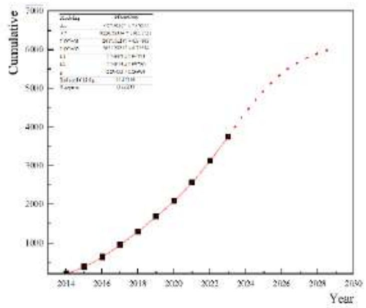
| Database | Reference | Query code | Study flow diagram |
|---|---|---|---|
| Scoups.com | Bär, et al. [3] | ( TITLE-ABS-KEY ( "exoskeleton" OR "exoskeletons" OR "exosuit" OR "exosuits" OR "wearable robotic" OR "wearable robotics" OR "wearable robot system" OR "wearable robot systems" OR "human power assistive system" OR "human power assistive systems" OR "human-robot cooperation system" OR "human-robot cooperation systems" OR "human-robot interaction" OR "human-robot interactions" OR "wearable assistive device" OR "wearable assistive devices" ) AND TITLE-ABS-KEY ( "construct*" OR "building" OR "architecture" ) ANDNOT TITLE-ABS-KEY ( "child*" OR "geology" OR "animal" OR "hotel" ) ) AND ( PUBYEAR > 2013 AND PUBYEAR < 2024 ) AND ( LIMIT-TO ( LANGUAGE , "English" ) ) |  |

## RESULTS AND DISCUSSION

The frequency of publication evolution by year is depicted in Figure 4a, which illustrates an upward trend in studies related to construction robotics, with the most significant growth observed in 2016. As shown in Figure 4b, despite a notable decline in publications since 2015, the volume of publications in this field has evolved exponentially.




(a) The frequency of publication evolution by year




(b) The volume of publications in this field has evolved exponentially

**Figure 4.** Overview of Publications

However, in the first round of bibliometric visualization clustering, we did not extract much information related to comfort, due to the limited research on the topic. Therefore, as a supplement and for comparative analysis, we employed Carrot2 software (github.com/carrot2/) to perform another round of literature visualization clustering on the filtered literature and manually increased the boosted fields weight for the keywords "comfort," "back," and "limbs" to significantly differentiate and retrieve key literature. See **Error! Reference source not found.**. Additionally, the primary function of filling materials is to ensure maximum comfort for the user by evenly distributing pressure across the contact points. Materials that can adapt to the wearer's movements while maintaining their cushioning properties are preferred. However, in our systematic review work, we found that there are very few previous studies in the literature related to architectural engineering and ergonomics related to the selection of filling materials for architectural exoskeletons. Given the rigorous conditions of construction sites, filling materials must withstand wear, tear, and deformation over time. See Table 2.

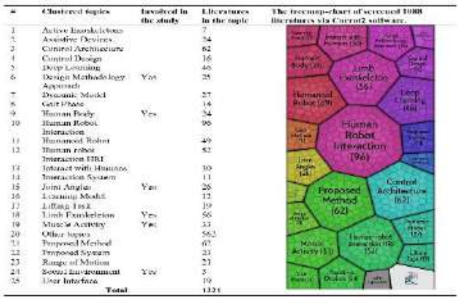



**Figure 5.** Clustered topics and involved literatures.

| Material | Reference | Thermal Insulation | Flexibility | Breathability | Moisture Management | Weight | Comfort For Extended Wear |
|---|---|---|---|---|---|---|---|
| Insulting Fabrics | Maldonado-Mejia et al. (2023) | High | Low | Low | Low | High | Low |
| Neoprene-based Composites | | High | Moderate | Moderate | Moderate | Moderate | Moderate |
| Synthetic Fleece | Lobo et al. (2016) | High | High | High | High | Moderate | High |
| Moisture Wicking Fabrics | Maldonado-Mejia et al. (2023) | High | Moderate | Low | Low | High | High |
| Breathable Mesh Materials | Kim et al. (2022) | Moderate | High | Low | Low | High | Moderate |
| Phase Change Materials (PCM) | Cabeza et al. (2014) | Moderate | Moderate | Moderate | Moderate | High | High |

**Table 2.** Potential filler with applications in exoskeleton equipment. (Maldonado-Mejía, et al. [4], Lobo, et al. [5], Kim, et al. [6], Cabeza, et al. [7], )

## CONCLUSION

Concluding this study, we underscore the essential need for a comprehensive framework to accurately assess comfort in construction exoskeletons. By harmonizing user feedback with physiological metrics, this research paves the way for innovations in exoskeleton design, prioritizing worker safety and comfort. Our meticulous review, employing PRISMA guidelines to distill significant findings from a vast literature base, sets the stage for future advancements.

Recommendations for materials and design improvements are poised to address gaps in current research, categorizing exoskeletons for targeted support areas and furthering their development and integration into construction practices.

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**CHAPTER 20**

# LOW VELOCITY IMPACT TEST OF 3/2 FIBRE METAL LAMINATE

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**ABSTRACT**
One of the best ways to reduce fuel consumption and harmful emissions is to develop lightweight vehicle bodies, especially in the automobile industry. Lightweighting a vehicle improves fuel efficiency without compromising safety. Fibre metal laminates (FMLs) are lightweight material consist of composite materials develop by overlapping layers of metal alloy and fibre-reinforced polymers. This research aims to develop the fibre metal laminate consist of aluminium layered with several type of selected composite material subject to low velocity impact test (LVI). These laminates were developed with the intention of combining the benefits of metal and composite materials, resulting in enhanced mechanical properties and resistance to damage include being lightweight, possessing great resistance to fatigue growth and exhibiting high strength and stiffness. The fibre metal laminate was fabricated by stacking the aluminium type 2024-T3 layered with Carbon Fiber Reinforced Polymer (CFRP), Glass Fiber Reinforced Polymer (GFRP), Self-Reinforced Polypropylene (SRPP) and hybrid sample combination of CFRP, GFRP and SRPP. Low-velocity impact tests are crucial for assessing the impact resilience of materials, particularly composites. These tests feature subjecting materials to impacts at selected velocities generally below 10 m/s with the objective to simulate impact situations. Analysis and comparison of load and displacement were conducted focus to impacted region resulting in the separation of the laminate's layers due to continuous loading. This research highlights the capacity of composite materials to serve as a durable and lightweight alternative material in automobile body structures particularly featuring interlayer hybrid compositions.
*Keywords:* Low velocity impact test; Fiber metal laminate; GFRP; CFRP; SRPP.

## INTRODUCTION

The car's body can use lightweight materials from several sources with the key idea is to strategically apply the appropriate multi-material adaptation in certain areas without compromising the intended function of the car. Fibre Metal Laminate (FML) is sandwiching process involves merging aluminium and composite materials to create a hybrid reinforced multi-layer material [1]. This material is designed with the goal of using fibre composites as its main structural components to enhance its capability resistance during the impact loading [2].

## METHODOLOGY

The fibre metal laminates were fabricated by using manual layup technique and compression moulding technique. During the fabrication, the type of metal use was aluminium alloy 2024-T3 to act as top, middle and bottom layer for all specimens. With the configuration of 3/2 (3 metal, 2 composite), The composition of layered are AL/GFRP/AL/GFRP/AL, AL/CFRP/AL/CFRP/AL, AL/SRPP/AL/SRPP/AL, AL/GFRP/AL/SRPP/AL (hybrid) and AL/GFRP/AL/CFRP/AL (hybrid)

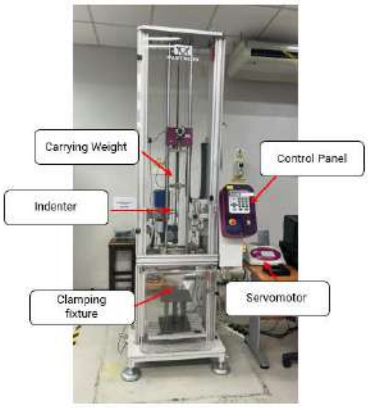


**Figure 1.** Machine CEAST 9350.

A thermoset epoxy was utilized to bond the dry fibres with the sheet metal for CFRP and GFRP. The laminates were subsequently cured at room temperature and subjected to a mild load for pressure application. For SRPP, a hot press machine used to melt the thin film to laminate the SRPP with metal and cured in the machine with stipulated time. Development of hybrid specimen use both methods to join them. The mechanical properties of the structures were examined by adjusting the changes in velocities and crosshead velocities using the drop tower impact machine Instron CEAST 9350 as in figure 1 above.

## RESULTS AND DISCUSSION

Five types of composite material were used under low-velocity impact tests. Figure 2 below illustrate the graph of impact response load (N) against central deflection (mm).

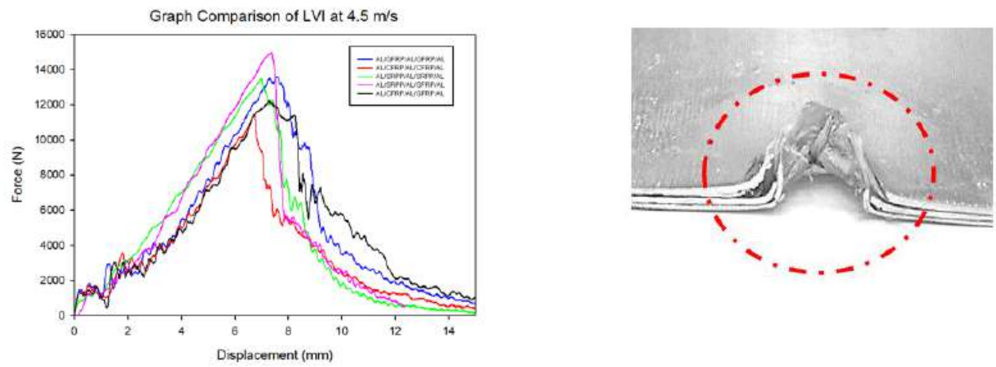


**Figure 2.** Graph of load against displacement of 3/2 FML at 4.5 m/s and impact failure on the specimen.

## CONCLUSION

This study delivers an investigation of the impact behaviour while discover the failure mechanism of the laminates between the different layers of fabricated Fibre Metal Laminates (FML) when subjected to low velocity impact testing.


## ACKNOWLEDGEMENT

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CHAPTER 21

# FLEXURAL ANALYSIS OF COMPOSITE B-PILLAR

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**ABSTRACT**

The automotive B-Pillars are purposefully engineered to absorb substantial energy while minimizing deformation, thereby limiting intrusion into the passenger compartment during any side collision. This study focuses on developing B-pillars using several types of composite materials to enhance structural strength and crashworthiness performance while contributing to the reduction of component's weight, as an alternative to conventional steel. Three combinations of fiber material were structured based on the interlayer and patch hybridization mode. These include a carbon-based pillar reinforced by two aramid interlayers, another reinforced by two glass interlayers, and lastly, one reinforced by patch consisting of a layer of carbon and a layer of glass. By using hand lay-up technique, the three samples of hybrid composite B-Pillar were fabricated at full size. The composite pillars underwent experimental three-point flexural tests, during which the mechanical and strain responses were examined. The results indicate that the composite pillars reinforced with interlayers exhibited the best flexural-resisting performance, whereas the patch-reinforced pillar showed weaker energy absorption. The strain measurements align with the load-displacement results observed in all samples. This study emphasizes the potential of composite materials, specifically those with interlayer hybrid compositions, to function as a sturdy, lightweight substitute for steel in the construction of automotive B-pillars.
*Keywords:* B-pillar; Hybrid composites; Carbon fibre; Aramid fibre; Glass fibre.

## INTRODUCTION

Composite materials, recognized for their specific strength and lightness, are widely used in defense and aerospace. Advancements have broadened their applications to industries such as automotive, rail, construction, and shipbuilding. Notably, fibre-reinforced plastic (FRP) composites like glass and carbon offer significant weight savings in transportation without compromising strength [1]. The B-pillar, positioned between the front and rear doors of a car, is precisely engineered to absorb a substantial amount of crash energy while minimizing deformation to prevent intrusion into the interior space [2]. This paper presents an analysis of the B-pillar constructed from hybrid composite materials, aiming to enhance structural strength and crashworthiness performance while reducing weight.

## MATERIALS AND METHODS

Three combinations of fiber materials were structured based on interlayer and patch hybridization. These configurations were employed in fabricating three full-sized samples of hybrid composite B-Pillar using the hand lay-up technique. The three lay-up schemes are:

i. CACAC: 3 layer carbon based pillar reinforced by hybrid of two aramid interlayer;

ii. CGCGC: 3 layer carbon based pillar reinforced by hybrid of two glass interlayer;

iii. CCC+CG: 3 layer carbon based pillar reinforced by a carbon and a glass layer patch.

To assess the mechanical performance of the composite B-Pillar in a quasi-static flexural test, the Shimadzu AG-X universal testing machine was utilized, with a crosshead speed of 10 mm/min. The experiment was set similar to three-point bending configuration with maximum displacement of 100 mm. The hybrid composite B-Pillar was positioned on a customized and fixed stands placed at both ends, as illustrated in Figure 1.

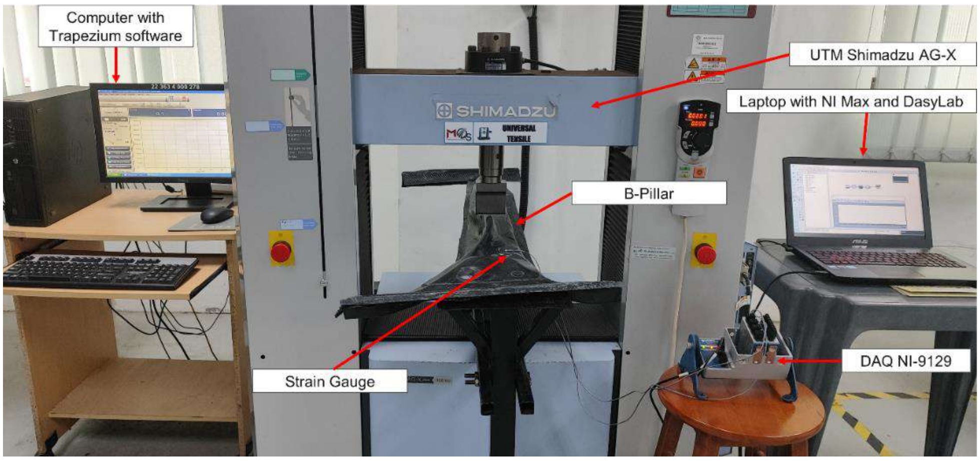


**Figure 1.** Experiment set up.

## RESULTS AND DISCUSSION

The flexural response was compared between all B-pillars, whereby the load-displacement and strain measurement curves are illustrated in Figure1.2.

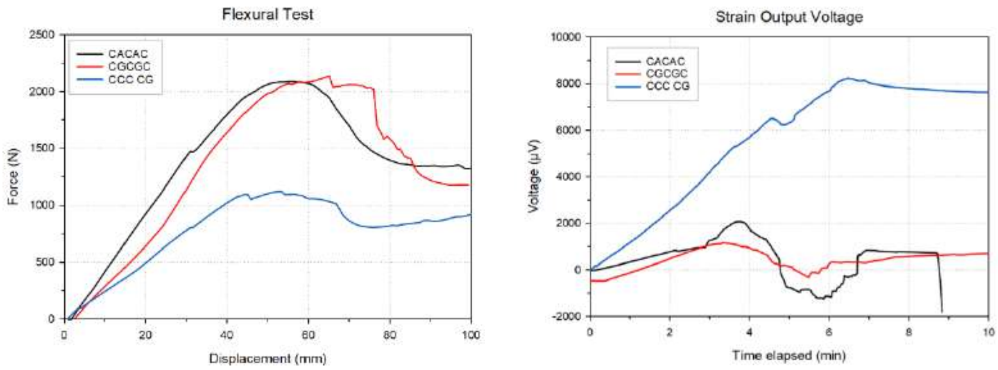


**Figure 2.** Experimental load–displacement response and strain gauge output.

## CONCLUSION

The study concludes that composite B-pillars reinforced with interlayers demonstrate superior flexural resistance compared to patch-reinforced pillar, which exhibit weaker energy absorption. Strain measurements support the observed load-displacement results across all samples, thus highlighting the potential of interlayer hybrid composite materials as excellent alternatives to steel for automotive B-pillar component.


## ACKNOWLEDGEMENT

The authors are grateful to DRB-HICOM University of Automotive Malaysia and Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA) for the support that is given to participate in this conference.


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## CHAPTER 22

# CRITICAL REVIEW OF THREE-POINT BENDING TEST AND STANDARD SIDE IMPACT TESTS OF ANTI-INTRUSION BEAM

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**ABSTRACT**
Anti-intrusion beam is a passive safety device installed in cars and is mounted on the door panels to protect the passengers during side collision. This paper summarized the standard side impact tests and practices in conducting simulations and experiments in compliance with the tests. Three-point bending and static side door crushing simulations and experiments are conducted to replace FMVSS 214 Static Door Strength if bending strength is of interest to researchers. Car-to-pole and car-to-car tests are conducted less commonly due to higher simulation costs and time, but more evaluating criteria can be obtained from these tests such as beltline and pelvis acceleration of a side impact dummy.
*Keywords:* Anti-intrusion beam; Crashworthiness; Side collision; Side impact beam; Side impact; FMVSS 214.

## INTRODUCTION

Side collision is the second most prevalent type of vehicle accident death (22%) after frontal collision (59%) [1]. Since there are fewer crash zones to absorb impact energy in the side door compared to the front and rear, side impact is more dangerous and requires more attention [2][3]. Anti-intrusion beam is one of the most important structures that is fitted into car doors at the lower section of the door frame to absorb impact energy and minimize deformation in the passenger compartment during a side crash accident [2].

## STANDARD SIDE-IMPACT TESTS

Side impacts can be classified into two types: car-to-broad-object and car-to-narrow-object [3], leading to the development of different types of side impact tests. Existing tests evaluate the side impacts of three types: static door strength, car-to-pole, and car-to-car. These standard tests differ in terms of the setup and evaluation criteria.

### *Static Door Strength (FMVSS 214 Static)*

The protocol FMVSS 214 is a quasi-static test developed by NHTSA to measure the crush resistance of a door by forcing a cylindrical punch with a diameter of 305mm (12 inches) until 450mm deflection is reached [4]. However, due to the high computational and experimental costs of a complete vehicle following the regulations of this test, most researchers are replacing it with a three-point bending test and drop impact test to door [5][6][7]. In the three-point bending test, the jigs and loading cylinders are prepared based on this FMVSS 214 Static test but there are no specific regulations on the jig span, beam length, and cross-sectional dimensions. Pawar et al. investigated the bending strength of a 945mm length beam made of AISI 4340 and glass fiber epoxy composite [5] whereas Lim & Lee [6] investigated a 540mm length beam made of AISI 4340 and composite UGN 150 & GEP 215. Seong Sik Kiran C. et al [7] simulated different combinations of thicknesses, shapes, and materials (AISI 1008, BH 220 & DP450) of a 900 mm beam and verified the resistance force using a three-point bending experiment on Universal Testing Machine (UTM).

*Car-to-Pole (FMVSS 214 Oblique Pole Test & EuroNCAP)*

In this test, the rigid pole is a stationary vertical metal structure with 254mm (10 inches) in diameter. The test vehicle is propelled sideways into the rigid pole at an angle of 75° at $32\ km\ h^{-1}$. The dummy is used to measure the acceleration in the chest and pelvis, representing the protection level of the chest and pelvis in a side impact. EuroNCAP Side Pole Impact Test has a similar set-up in terms of pole diameter, crashing angle, and speed, but they are different in terms of occupant seat position, test dummies, and injury criteria [8]. This test is mostly conducted in two ways: full vehicle simulations [7][9][10][11] and pole impactor on door frame simulations [9][12][13][14][15] and experiments [9][12]. The experiment is conducted by dropping a cylindrical pole impactor of a certain weight from a distance onto the trimmed door on a fixed base [10]. Similarly to the three-point bending test, the door models used for side pole impact simulation and experiment and full vehicle side pole impact simulation are different from each other.

*Car-to-Car (FMVSS 214 Moving Deformable Barrier, EuroNCAP Side Mobile Barrier Test & IIHS Moving Deformable Barrier)*

In Car-to-Car Side Impact Tests, Moving Deformable Barrier with weight of different weights (1368-1500kg) are propelled to strike the stationary vehicle at different speed (50-60km/h) at a right angle or 27° from the centerline in compliance with different test standards of FMVSS 214, EuroNCAP, and IIHS [16].

Compared to the previous two types of side impact tests, moving deformable barrier impact tests are more complex and require higher computational power. Complete vehicle impact simulations are conducted because the effectiveness of the beams developed could not be reflected merely from the bending strength in the three-point bending test and FMVSS 214 Static Door Strength Test.

## CONCLUSION

The simulations and experiments methods of standard side impact tests as well as their replacement tests in developing a side impact beam that improves the crashworthiness of the car in side impact collisions have been reviewed.

## ACKNOWLEDGEMENT

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## CHAPTER 23

### BISMUTH ADDITION IN SN-AG-CU LEAD-FREE SOLDER

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**ABSTRACT**
Sn-Ag-Cu solder is a form of solder to replace Sn-Pb solder in electronic device soldering. Sn-Ag-Cu however, consists of various weaknesses when compared to traditional Sn-Pb solder in terms of mechanical properties and reliability. Alloying with elements such as bismuth, can be one of the methods to improve the solder properties. Therefore, a short review is carried out to understand the improved performance with bismuth doping in the solder melting temperature and reliability testing.
*Keywords:* Sn-Ag-Cu; bismuth; alloying; reliability; mechanical cycling.

## INTRODUCTION

The advancement in technology has brought about an increase in demand for new alternatives to enhance the performance, functionality, and reliability of electronic devices. The soldering industry, along with the mandatory banning of tin-lead (Sn-Pb) solder, has urged the introduction of lead-free solder, including ternary tin-silver-copper (Sn-Ag-Cu) systems, which have since been one of the renowned solder types used in second-level interconnects of printed circuit board (PCB) assembly, thanks to their considerably low melting point and good wetting properties, making them one of the solder types with high compatibility with both traditional and modern board technologies. However, to produce Sn-Ag-Cu solders with ideal performance, different alternatives have been taken by scholars, including mechanical alloying of Sn-Ag-Cu solders. Alloying elements such as bismuth (Bi) serve as crucial factors in enhancing solder performance due to their capability of improving the solder's mechanical properties and reliability. Bi was found to be exceptional in enhancing the mechanical properties of lead-free solder due to its high solid solubility in the Sn matrix, where Bi tends to embed itself in Sn dendrites, thus hindering the movement of voids and preventing dislocation motion when exposed to mechanical or thermal stress. Since Bi only reacts with Sn to form the intermetallic compound (IMC) layer, the Bi atom helps to slow down the diffusion rate of the

Cu atom, thus assisting in controlling the growth of the IMC layer, which improves performance in aging and reliability testing.

## BISMUTH AS AN ALTERNATIVE IN Sn-Ag-Cu SOLDERS

*Melting temperature*

Melting temperature is extremely crucial in clarifying the applicability of a solder in an assembly process for either first-level or second-level interconnects, as it impacts the set reflow temperature for a PCB during reflowing. Therefore, with the consideration that manufacturers are still highly dependent on traditional board technologies with glass transition temperatures having high adaptability to the melting temperature of Sn-Pb solder at 183 °C, the creation of a Sn-Ag-Cu solder system with a temperature as close as possible to the respective temperature turns out to be an essential task pursued by researchers. Enhancement alloys such as Bi thus emerge as ideal dopants due to their ability to lower the eutectic temperature of Sn-Ag-Cu solder, which decreases inversely with increasing Bi composition until it reaches its saturation point at 3%. Above 3%, the brittleness of Bi dominates the overall mechanical property of alloyed solder and deteriorates its yield strength, fatigue life, and characteristic reliability [1]. Its brittle nature thus refrains scholars from utilizing 58Bi-Sn solder despite its low temperature of 138°C. Figure 1 shows the microstructure of Sn-Ag-Cu alloyed with 3% Bi.

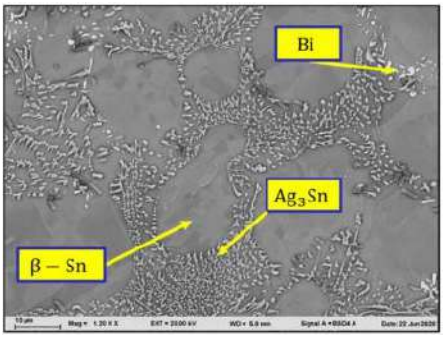


**Figure 1.** Microstructure of 92.5Sn-4.0Ag-0.5Cu-3.0Bi-0.02Ni [2].

*Reliability of Sn-Ag-Cu-Bi in mechanical cycling*

Assembled PCBs may be exposed to various forms of loading during actual service, either thermal or mechanical. Similar to thermal cycling, JEDEC standards define mechanical cycling as a form of load cycling under flexural instead of thermal stress to identify the product lifetime of a soldered PCB before product delivery to ensure robust mechanical and electrical connections between components and soldered boards. Mechanical cycling, however, does not restrict itself to only flexural bending but can be done through the introduction of force at different axes, either on a board or a reflowed solder bulk. For instance, with the aid of a universal six-axis load cell testing machine, cyclic stress in the form of tension, compression, and torsion can be exerted on a reflowed solder bulk specimen when placed within an aging chamber at 200°C [3]. Despite Bi's excellent performance in resisting the aging effect of Sn-Ag-Cu solders, in mechanical cycling, intergranular cracks can be observed along the grain boundaries, as shown in Figure 2 for either the case of pure or doped SAC305, but with a larger creep in pure solder, indicating the ability of Bi in enhancing mechanical cycling reliability [3]. The SEM image in Figure 2 further proves that instead of slip line steps that formed prior to intergranular cracking as observed in the case of SAC-Bi solder, transgranular cracks were observed beyond the grain boundaries of Sn dendrite in the case of pure SAC305 with continuous mechanical loading. At the level of PCB, however, a solder sphere can be mechanically cycled with the upper surface of a solder ball constantly exposed to shear stress in a micromechanical tester [4]. Mechanical cycling is also explored as an alternative approach to thermal cycling due to its shorter cycling period, which optimizes the duration for product delivery [5]. Nevertheless, the full performance of SAC-Bi in cyclic flexural testing is yet to be known.

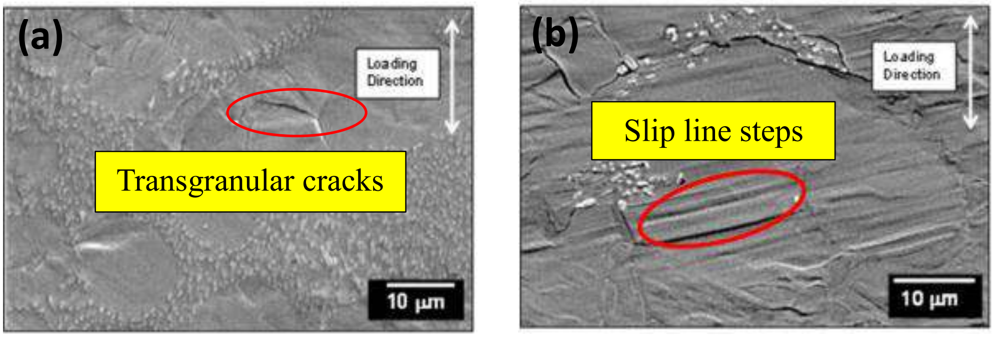


**Figure 2.** Microstructure of cracked samples for (a) pure SAC305 and (b) 3.0% bismuth doped SAC305 solders [3].

## CONCLUSION

In conclusion, bismuth (Bi) greatly enhances the performance of a Sn-Ag-Cu solder by improving its mechanical properties and performance. It is well known that Bi has a high resistance to aging effects, and it also performed better in reliability testing. Thus, it is a good option as a dopant to be further explored in this specific application.

## ACKNOWLEDGEMENT

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## CHAPTER 24

# INFLUENCE ON THERMAL AND CORROSION CHARACTERISTICS OF SOLAR THERMAL SYSTEMS BY ADDITION OF MXENE AS MICROSTRUCTURAL MODIFIER IN SOLAR THERMAL ABSORBER

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**ABSTRACT**
The efficiency of every solar thermal system largely depends on the quality of its absorbing medium. However, recent studies of solar thermal systems revealed structural failure and lower efficiency, prompting the needs for microstructural modification of absorbing medium of the systems. This chapter focuses on modifications of the solar thermal absorber with MXene as microstructural modifier as well as their influence on photo-thermal conversion, thermal conductivity, strength, and corrosion characteristics.
*Keywords:* MXene; Solar thermal absorber; Corrosion behaviour; Photo thermal; Microstructure

## INTRODUCTION

The synthesis and processing of materials have been responsible for the socio-economic development in the global arena. Advances in engineering materials and composites unlocked markets and potentials that are closed to industrial societies. This results in the development of 2D and 3D materials as well as the creation of huge opportunities for integration, synthesis, processing, and formation of a large and rapidly expanding family of solar thermal systems with improved characteristics and service reliability. MXene is a family of two-dimensional (2D) transition metal nitrides, carbides, and carbonatites, MAX phases, tetragonal carbides or nitrides [1]. Mxene has shown outstanding photothermal conversion characteristics and has demonstrated excellent stability in both strong alkaline and acidic solutions. This is because of their transparency, plasmonic behavior, and the nature of their high surface and tunable area due to their layered structure strong chemical bonding and tunable surface chemistry. Hence, such properties allow MXene to be used in solar thermal absorbers of various solar thermal systems [2]. Solar absorbers experience atmospheric attack, thermal fatigue, and structural failure, leading to low efficiency [3]. The study explores the latest microstructural modifications of solar thermal absorbers using MXene, focusing on their impact on photo-thermal conversion, thermal conductivity, strength, and corrosion characteristics.

## MXENE AND SOLAR THERMAL ABSORBER

A significant number of studies employed metallic materials as solar thermal absorbers [3]. MXene-reinforced nanofluids, phase change materials, and composites show good thermal conductivity, photothermal, thermo-physical, and corrosion qualities, making them widely used in solar thermal systems for enhanced performance as outlined in Table 1.

**Table 1.** Summary of the recent applications of MXene in enhancing the performance of solar thermal absorber.

| Materials | Treatment | Parameter/Application | Findings | Weakness |
|---|---|---|---|---|
| Copper Tube [4] | MXene particles | Thermo-physical properties/Solar Collector | Improved thermal performance | No thickness of the MXene-based coatings and weight % |
| Galvanized iron (G.I): [5] | MXene ($Ti_3C_2Tx$), 0.05% and 0.1%, was doped into black paint, | Heat transfer rate, water yield, and energy efficiency/ Solar still | The 0.1% MXene coating improved the heat transfer rate | The study lacks in-depth investigation on the optimal mass fraction of MXene doping |
| Aluminum [6] | MXene nanofluid | MXene nanofluids' optical properties photo thermal/ Direct Absorption Solar Collectors (DASCs) | MXene nanofluids enhanced photothermal conversion efficiency | The use of MXene nanofluids for (DASCs) has not been extensively studied, |
| Alumina ($Al_2O_3$) [7] | Two-dimensional $Ti_3C_2T_x$ MXene as reinforcement | Nanocomposite morphology and element distribution/ High Temperature environments | 2.4 times greater fracture toughness than pure $Al_2O_3$ at 1000°C. | The need for the application of $Ti_3C_2T_x$ MXene modification of microstructure |

## FABRICATION OF COMPOSITES

Nano and composites technologies enable microstructural alteration through heat, pressure, or both to distribute reinforcement uniformly and maintain particle homogeneity in the matrix. The fundamental processes are (i) solid techniques, (ii) fusion techniques and 3D manufacturing techniques.

## CHARACTERIZATION TECHNIQUES FOR SOLAR THERMAL ABSORBER

Solar thermal absorbers are characterized to ensure conformity with standards and reliability in service. Major qualities to access are (i) photo thermal conversion, (ii) microstructure and phase patterns, (iii) corrosion behavior, and (iv) mechanical properties. Photothermal can be investigated using: (a) Thermogravimetric Analysis (TGA) to determine the Thermal Stability of the composite by monitoring its weight loss or gain [5],(b) Differential Scanning Calorimetry (DSC). For measurement of heat flows associated with thermal transitions, (c) UV–Vis spectrophotometer for measurement of optical transmittance in the spectral range 300–1000 nm [5].

The composite's morphology and microstructural analysis can be access using Field Emission Scanning Electron Microscope (FESEM). Elemental, dispersion, and homogeneity, are determined using Energy-Dispersive X-ray Spectroscopy (EDX) [5]. X-ray diffraction analysis (XRD) is used for phase analysis with a scanning rate of 2°/min and 2θ range of 40–100° [9].

Mechanical parameters such as tensile strength and hardness of composites can be determined using universal tensile testing and micro-hardness testing under load, with Rockwell hardness. Corrosion behavior analysis can be accomplished using immersion weight lost or by measurement salt spray test.

## CONCLUSION

Thermal energy is focusing on MXene materials and composites, but the literature lacks information on stability, long-term performance, mass fraction, and best mass fraction for producing solar thermal absorbers.

## ACKNOWLEDGEMENT

The authors would like to acknowledge the support and opportunity given by the Faculty of Engineering, Universiti Putra Malaysia through Research Grant (9688700) and for providing the necessary resources and support.

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## CHAPTER 25

# MICROSTRUCTURE AND MECHANICAL PROPERTIES OF GRAPHENE REINFORCED A356 COMPOSITES PRODUCED BY SEMI-SOLID PROCESS

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**ABSTRACT**

The use of graphene-based materials to enhance the mechanical properties of metal matrix composites has attracted considerable interest in recent years. In this study, a stir casting process was proposed to fabricate graphene nanoplatelets (GNPs) reinforced aluminium matrix composites. Then the as-cast samples were subjected to thixoforming process. The microstructure and hardness properties of the composites with varying GNP content were analysed. The results of the microstructure analysis showed a transformation from a non-dendritic to a dendritic structure after the stir-casting process. All the microstructures of A356 alloy and composites after thixoforming process shows the uniform distribution of fine fibrous-like eutectic Si surrounding the irregular $\alpha$-Al grain. The optimum of GNPs at 0.3 wt.% led the fabricated composite to achieve an enhancement in hardness strength by 35.8 % and 51.4 % after stir casting and thixoforming process, respectively, compared to the A356 alloy.

*Keywords:* Aluminium matrix composites; Graphene; Thixoforming process; Hardness; Wear behaviour

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## INTRODUCTION

Carbon-based materials, such as graphene, are promising candidates for reinforcing aluminium metal matrices to improve their hardness strength and tribological properties [1–3]. Hence, the current study attempts to produce GNPs GNP-reinforced A356 matrix with the application of a stir casting and thixoforming process. The effects of the GNP content on the microstructure, hardness, and wear behaviour of the composites were studied.

## METHODOLOGY

An ingot of the A356 alloy was melted in a furnace before the GNP powders (0.3, 0.5 and 1.0 wt. %) and magnesium powder as wettability agents mixed in the molten metal. Stirring was immediately applied for 5 min at 500 rpm and the mixture was poured into a mould. Subsequently, the as-cast samples were subjected to thixoforming. Microstructural analysis was performed using an optical microstructure on the grind, polished, and etched samples. Vickers hardness equipment was used for the hardness testing.

## RESULTS AND DISCUSSION

Figure 1.1 displays OM images of the microstructure transformation of A356 and the composites. The application of stir-casting changed the $\alpha$ -Al to a globular and rosette-like structure. Furthermore, the application of thixoforming process transforms the $\alpha$ -Al to become coarser with an irregular globular structure while the eutectic Si transforms to a finer fibrous-like structure.

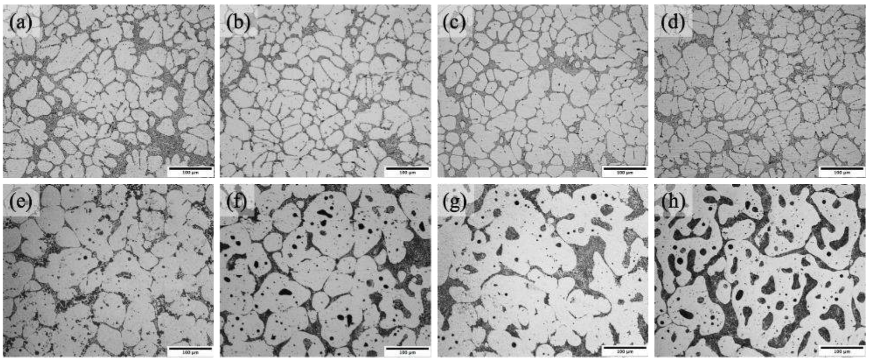


**Figure 1.** OM images of as-cast (a)A356 alloy, the composite of (b) 0.3 GNP/A356 (c) 0.5 GNP, (d) 1.0GNP/A356, and thixoformed (e)A356 alloy, and the composite of (f) 0.3 GNP/A356 (g) 0.5 GNP, (h) 1.0GNP/A356.

Figure 2 presents a comparison of the Vickers hardness graph of A356 and the composites after the stir-casting and thixoforming processes. The addition of GNPs and thixoforming process significantly increased the hardness of the composite. The decrease in hardness at high GNP contents may be attributed to the agglomeration of GNP in the composites.

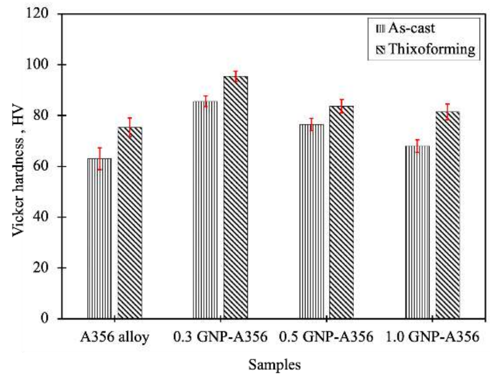


**Figure 2.** The comparison hardness of A356 alloy and composites after stir-casting and thixoforming process.

## CONCLUSION

GNP-reinforced A356 composites were successfully fabricated using stir-casting and thixoforming process. The fine fibrous-like structure of eutectic Si distributed uniformly surrounding the coarser globular $\alpha$ -Al phase after thixoforming process. The hardness of the composite was improved by 0.3 wt.% GNP by 35.8 % and 51.4 % after stir casting and thixoforming process, respectively, compared with base A356 alloy. The combination of the GNP addition and thixoforming contributed to the enhancement of the material.

## ACKNOWLEDGEMENT

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**CHAPTER 26**

# EFFECT OF SHORT HEAT TREATMENT ON WEAR CHARACTERISTICS OF GRAPHENE REINFORCED A356 ALUMINIUM COMPOSITES

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**ABSTRACT**
Recently, a study showed that a short heat treatment process improves aluminium alloy properties compared to conventional T6 heat treatment. This work investigates the impact of short T6 heat treatment on the microstructure, hardness characteristics, and wear behaviour of an A356-based composite material including 0.3 wt.% graphene nanoplatelets. The composite was manufactured using the thixoforming method and subjected to a short T6 heat-treatment process. A pin-on-disc tribometer was utilised to conduct wear tests under two different loads (10 and 50 N), fixed sliding speeds (1 m/s) and sliding distances (3 km). The eutectic Si structure transformed from a fibrous-like structure to a fine spheroidal structure after a short T6 heat treatment. The Vickers hardness of the short heat-treated composite sample exhibited a substantial increase of 94% compared to that of the A356 alloy. Furthermore, the composite sample displayed notable enhancements of 24% and 41% for loads of 10 and 50 N, respectively, after a short T6 heat treatment in comparison to the A356 alloy.
*Keywords:* A356 alloy; Graphene nanoplatelets; Thixoforming; Short T6 heat treatment; Wear behaviour.

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## INTRODUCTION

The utilisation of diverse techniques for introducing graphene into aluminium (Al) metal matrix composites has attracted considerable attention because of its capacity to enhance multiple properties [1]. In addition, short heat treatments have garnered interest because of their ability to minimise production costs and time [2,3]. Hence, the main objective of this study was to investigate the influence of short T6 heat treatment (ST6) on the microstructure, hardness characteristics, and wear resistance of A356 composites reinforced with graphene nanoplatelets (GNPs).

**METHODOLOGY**

A 400 g A356 alloy ingot was melted with 0.3 wt.% GNP powder as reinforcement material. The fabricated composites underwent thixoforming and were subjected to the ST6 process at 540 °C for 1 h of solution treatment, quenching, and 180 °C for 2 h of ageing treatment. The microstructure and hardness properties of the treated composite samples were analysed. Wear tests were performed using different loads (10 N and 50 N), a constant sliding speed, and a constant sliding distance (3000 m).

**RESULTS AND DISCUSSION**

Figure 1 illustrates the Vickers hardness properties and optical images of the microstructure of the samples. The hardness significantly increased after the addition of GNP and further increased after the short treatment process. After a short T6 heat treatment, eutectic Si transformed from a fine fibrous-like structure to a spheroid structure. The evidence provided by the improvement trends indicates that the period of solution treatment and artificial ageing was adequate to facilitate phase dissolution and homogenization.

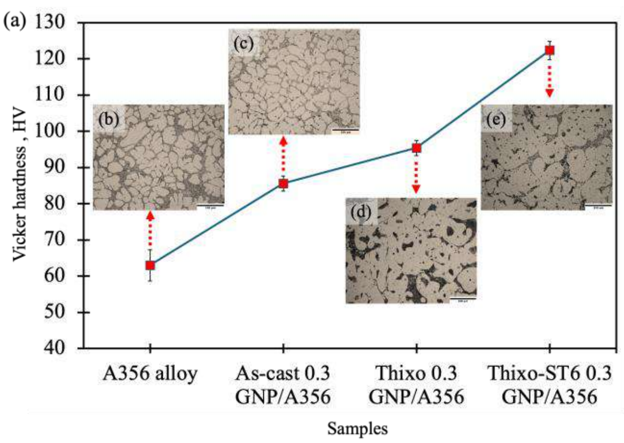


**Figure 1.** (a) Hardness properties of samples, and optical microstructure image of (b) A356 alloy, (c) as-cast composite, (d) thixoformed composite, (e) thixo-ST6 composite.

Figure 2 depicts the specific wear rate of the samples at loads of 10 and 50 N. The specific wear rates of the A356 alloy and composite decreased as the applied force increased.

Furthermore, the application of a short T6 heat treatment at both loads resulted in better wear resistance than that of the samples produced by the casting process.

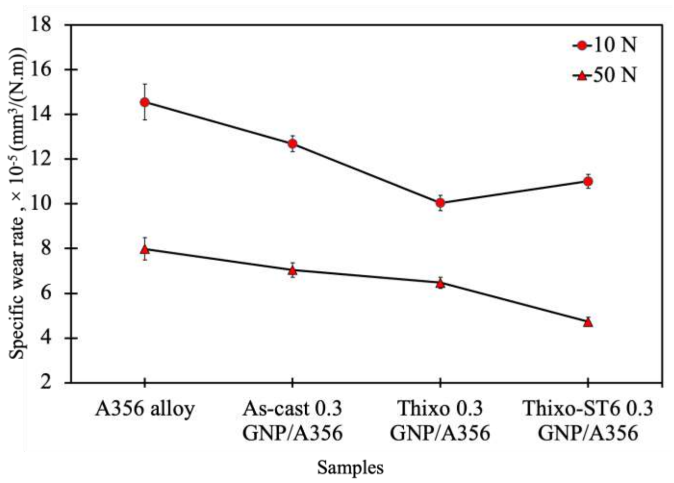


**Figure 2.** Specific wear rate as a function of applied load 10 N and 50. N.

## CONCLUSION

The employment of short T6 heat treatment on a thixoformed GNP-reinforced A356 composite successfully enhanced its hardness and wear behaviour. The hardness was enhanced by 94 % compared to that of the A356 alloy after a short T6 heat treatment. The specific wear rate was improved by 24 % for 10 N and 41 % for 50 N, compared to that of the A356 alloy.


## ACKNOWLEDGEMENT

The authors would like to thank Universiti Kebangsaan Malaysia and Universiti Teknikal Malaysia Melaka for their support with this study.


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## CHAPTER 27

# A COMPARATIVE STUDY BETWEEN DESIGN AND PARAMETER ADJUSTMENT FOR PROFIT MAXIMIZATION OF LOW-DENSITY POLYETHYLENE (LDPE) PRODUCTION IN HIGH-PRESSURE TUBULAR REACTOR

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**ABSTRACT**
The low-density polyethylene (LDPE) market is becoming increasingly competitive and profit margins are tightening, manufacturers must create solutions to optimize profit in LDPE high-pressure tubular reactors. Thus, in this study, the optimization of LDPE was proposed and conducted by improving the design and parameter adjustment of the LDPE tubular reactor. A mathematical model was developed and validated with industrial data using MATLAB R2023. Input parameter studies were carried out to investigate the effect of initiator concentration (CI), monomer concentration (CM), and solvent concentration (CS) on the ethylene conversion rate, reaction temperature rate, and final product grade, respectively. The CM was identified as the most significant parameter influencing the LDPE polymerization process. CM increment results in the highest reaction temperature peak, originating from 249.58 to 299.21°C. The highest MFI value was also obtained when the CM was increased from 0.01954 to 0.01979 mol/cm$^3$. Then, a comparative study between design and parameter adjustment for profit maximization in LDPE High-Pressure Tubular Reactor was conducted. With a profit of RM166.83 million/year, compared to RM106.83 million/year, double reaction zones demonstrate that it has a much better ethylene conversion rate compared to single reaction zones with optimization.
*Keywords:* LDPE, Polymer, Optimization, Modeling

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## INTRODUCTION

As the LDPE industry faces escalating competition and diminishing profit margins, manufacturers are increasingly driven to prioritize solutions that optimize profits within high-pressure tubular reactors to meet market demands. Researchers and engineers heavily rely on mathematical models as indispensable tools, enabling them to explore the effects of various design and operational variables on production and product quality in a safe and cost-effective manner. Asteasuain et al. [6] employed the steady-state assumption for parameter adjustment using a simplified mathematical model. Erdeghem et al. [7] concentrated on enhancing LDPE productivity while reducing investment costs. Buchelli et al. [8] and Fries et al. [9] delved into a fouling study within the reactor wall. Pladis et al. [10] proposed a computational model for predicting the viscoelastic behavior of LDPE generated in a high-pressure tubular reactor. These recent studies on LDPE cover various aspects; however, none of them include a comparison between design adjustment and parameter adjustment in their analyses. Hence, in this study, a mathematical model will be formulated and validated utilizing real industry data before proceeding to conduct the comparative analysis.

## METHODOLOGY

*Model Assumptions and Equation for Tubular Reactor*

The following equations were used in this study and shown in Table 1.

| Description | Equation | |
|---|---|---|
| Overall Mass Balance | $\frac{dv}{dz} = -\frac{v}{\rho}\frac{d\rho}{dz}$ | (1) |
| Initiator Balance | $V\frac{dC_{I_m}}{dz} = \left(-2fK_d C_{I_m} - C_{I_m}\frac{dv}{dz}\right)$ | (2) |
| Monomer Balance | $V\frac{dC_M}{dz} = \left(2K_{th}{C_M}^3 - K_{trm}C_M\lambda_0 - C_M\frac{dv}{dz}\right)$ | (3) |
| Solvent Balance | $V\frac{dC_S}{dz} = \left(-K_{trs}C_S\lambda_0 - C_S\frac{dv}{dz}\right)$ | (4) |

Where:
$C_{Im}$ = concentration of initiator, mol/l; $C_M$= monomer concentration, mol/l; $C_S$ = solvent concentration, mol/l; $C_p$ = specific heat of reactant mixture, cal/g·K; D = inside diameter of reactor, cm; I = initiator M monomer; $P_I$ = dead polymer with chain length l; $P_k$ = dead polymer with chain length k; $R_{in}$ = primary initiator radical; $R_1$ = radical of chain length l; $R_k$ = radical of chain length k; Re = Reynolds number; S = solvent

## RESULTS AND DISCUSSION

*Profit Maximization Calculation for Single Reaction Zone with Optimization and Double Reaction Zone*

The results proved that with the addition of reaction zones, it greatly improved the ethylene conversions rate, revenue, and profit of the LDPE high -pressure tubular reactor, as shown in Table 2.

| | **Single Reaction Zone with Optimization** | **Double Reaction Zones** |
|---|---|---|
| **Monomer Conversion, $X_M$ (%)** | 14.0513 | 22.3972 |
| **MFI (g/10min)** | 9.7709 | 5.3277 |
| **Revenue (million) RM/year** | 195.02 | 306.86 |
| **Material Cost (million RM/year)** | 80.37 | 126.47 |
| **Electric Cost (million RM/year)** | 8.57 | 13.56 |
| **Profit (million RM/year)** | 106.08 | 166.83 |

## CONCLUSION

With the profit of RM166.83 million/year, compared to RM106.83 million/year, double reaction zones demonstrates that it has much better ethylene conversion rate compared to single reaction zone with optimization. It was proven that adjusting the design of LDPE tubular reactor by adding extra reaction and cooling zone improved monomer conversion, thus increasing the annual profit, even though it requires much expensive raw materials and electricity costs.

## ACKNOWLEDGEMENT

The financial support from Universiti Teknologi MARA through Synergy 2021 Grant No. 600-

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## CHAPTER 28

# SYNTHESIS AND CHARACTERIZATION OF ELECTROSPUN FIBERS FROM PAN/CELLULOSE ACETATE: A SUITABLE APPROACH

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**ABSTRACT**

Electrospun nanofibers derived from Polyacrylonitrile (PAN) and Cellulose Acetate (CA) were successfully synthesized using the electrospinning technique. The morphology of these nanofibrous was examined through Field Emission Scanning Electron Microscopy (FESEM), providing invaluable insights into their structural characteristics and prospective applications. Elemental composition and chemical properties of the nanofibers were thoroughly investigated via energy-dispersive X-ray spectroscopy (EDX). Results demonstrated an elemental ratio of 67.03% carbon (C) and 32.97% nitrogen (N) in the PAN fibers, while the CA composite fibers exhibited elemental ratios of 63.20% C, 26.31% N, and 10.49% oxygen (O). These findings underscore the potential utility of cellulose nanofibers across a myriad of disciplines, encompassing environmental remediation, energy storage, and biomedical engineering.

*Keywords:* Nanofibers; Electrospun; Electrospinning; Cellulose; Nanofibrous.

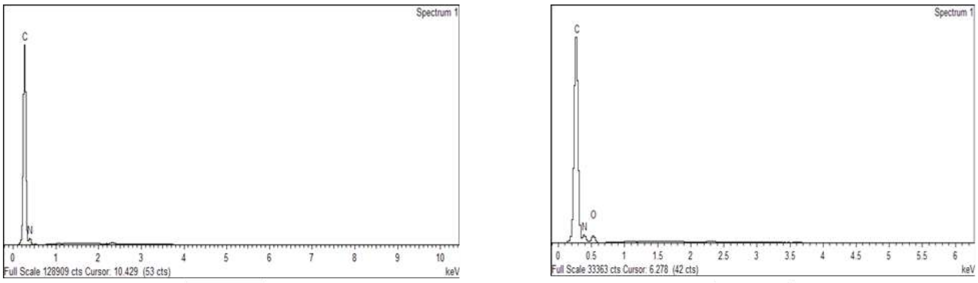
## INTRODUCTION

Electrospinning has emerged as a versatile technique for fabricating nanofibers with controllable properties, holding promise for various applications [1]. This study focuses on synthesizing and characterizing electrospun fibers from polyacrylonitrile (PAN) and cellulose acetate (CA), offering a unique combination of mechanical strength, thermal stability, and biocompatibility. By systematically investigating the synthesis process and employing characterization techniques such as X-ray diffraction (XRD) and energy-dispersive X-ray spectroscopy (EDX), insights into the structural, mechanical, and chemical properties of the fibers are gained. Understanding these properties is crucial for tailoring the fibers to meet specific application requirements in fields such as tissue engineering [2], filtration [3], and energy storage [4].

## METHODOLOGY

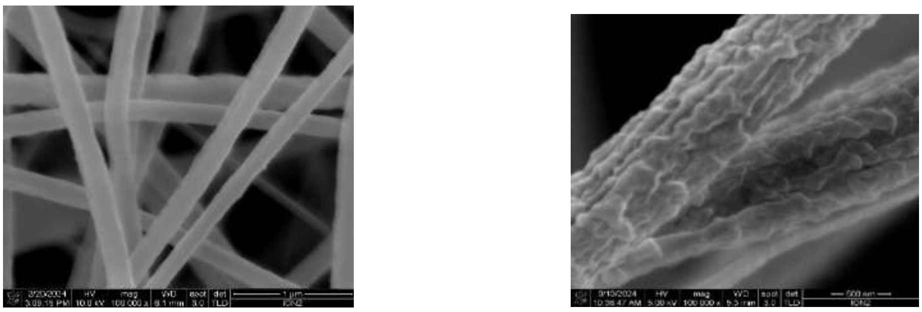
Polyacrylonitrile (PAN, Mw = 150,000) and cellulose acetate powder (with an acetyl content of 39.8 wt% and a molecular weight of 30,000) were utilized, along with N,N-dimethylformamide (DMF) without further purification. A mixture consisting of 0.7 g PAN blended with 0.1 g CA in DMF was stirred for 4 hours at room temperature to prepare the electrospinning solution. The prepared solution was loaded into a 10 mL syringe equipped with a 22-gauge needle. The flow rate was adjusted to 0.8 mL/h, and the syringe was positioned at 20 cm from the rotary collector, which was rotating at 229 rpm. A voltage of 18 kV was applied for the electrospinning process.

**RESULTS AND DISCUSSION**




(a) (b)

**Figure 1.** EDX analysis (a) PAN (b) PAN + CA



(a) (b)

**Figure 2.** FESEM Image (a) PAN (b) PAN + CA

**Table 1.** EDX element ratio

| Element | Weight% | | Atomic% | |
|---|---|---|---|---|
| | PAN | PAN +CA | PAN | PAN + CA |
| C | 67.03 | 63.20 | 70.33 | 67.50 |
| N | 32.97 | 26.31 | 29.67 | 24.10 |
| O | - | 10.49 | - | 8.41 |

The EDX of the CA composite fibers is shown in Fig. 1(b) to investigate the content elements of electrospun fibers. The elemental analysis as show as Table 1 reveals the presence of CA on the surface, the elemental ratio of C, N and O are 63.20, 26.31 and 10.49% respectively in the prepared CA composite fibers. The FESEM image of PAN-based electrospun fiber webs containing CA is shown in Fig.2(b). It can be seen from the figure that CA containing fibers appeared to have roughened and non-uniform surface at the CA containing places but otherwise the surfaces are smooth surfaces and diameters are uniform about 203 nm.

## CONCLUSION

In conclusion, electrospun nanofibers derived from polyacrylonitrile (PAN) and cellulose acetate (CA) through the process of electrospinning have been successfully synthesized. Utilizing characterization techniques such as Field Emission Scanning Electron Microscopy (FESEM) and energy-dispersive X-ray spectroscopy (EDX), invaluable insights into their morphology, elemental composition, and chemical properties have been obtained.

## ACKNOWLEDGEMENT

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CHAPTER 29

# EFFECT OF COMPATIBILIZER AND PLASTICIZER ON THE MECHANICAL PERFORMANCE OF PLA/TAPIOCA BIO-COMPOSITES

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**ABSTRACT**

The manufacturing and use of single-use plastic items have become a major issue in today's waste management and environmental sustainability movements. The substitution of polylactic acid (PLA) as a green matrix provides a solution for the development of biodegradable composites. However, the cost of PLA is known to be high and is brittle in nature. These disadvantages have hampered PLA's ability to be adopted into short-term applications. However, PLA can be integrated with low-cost natural fibers such as tapioca starch to form a green polymer matrix. This research investigates the influence of the addition of compatibilizer and plasticiser to improve the mechanical performance of PLA/Tapioca composites. Maleic Anhydride (MA) was first grafted with PLA to form grafted MA (MAgPLA) through a melt blending process and then added as a compatibilizer. Epoxidized Palm Oil (EPO) was added as a plasticiser. Eight compositions were mixed and compounded with varying levels of EPO & MAgPLA, and the results showed an overall positive impact indicating the opportunity to produce an optimized blend composition. Tensile tests of injection molded specimens showed that the addition of 5% by weight of grafted MAgPLA improved the tensile strength by 13% while EPO at a loading of 10% by weight, increased the percentage elongation by 7.5%. The Youngs Modulus shows a steady decrease as loading of EPO increases which supports the claim that EPO reduces brittleness. Overall, the PLA/Tapioca injection molded composites exhibited favorable properties, good surface quality, and cost- effectiveness indicating good potential in short-term applications.
*Keywords:* Natural fiber reinforced composite; PLA; Tapioca; Maleic anhydride; Epoxidized palm oil.

## INTRODUCTION

Biodegradable polymers are rapidly increasing in its demand across multiple industries & disciplines, especially the food packaging industry. Single-use plastics are particularly problematic as they do not naturally decompose but they can breakdown into microplastics and make their way into our food chain [1]. The substitution of polylactic acid (PLA) as a green matrix provides an alternative for the development of biodegradable composites [2]. However, PLA has been known to be a brittle polymeric material [3], [4], and costly in nature [2], [5]. To overcome this, natural fiber fillers such as starch can be combined to reduce cost and improve biopolymer properties [6]. PLA & tapioca starch (TS) are not wholly compatible due to PLA being hydrophobic in nature while starch is hydrophilic [7] resulting in an inadequate amount of interfacial bonding cohesion within the polymer fiber matrix [8]. This paper explores the use of maleic anhydride (MA) as a compatibilizer while to address the issues of brittleness the addition of epoxidized palm oil as a plasticiser is included to overcome this incompatibility issue and enhance the fiber-matrix adhesion.

## METHODOLOGY

Polylactide acid (PLA) was supplied by Shanghai Huiang Industrial Co. Ltd.. Tapioca starch (TS) in the form of fine powder was procured from AJ Infinite Sdn Bhd. Maleic anhydride (MA) and benzoyl peroxide (BPO) was supplied by Sigma Aldrich. Epoxidised palm oil (EPO) was supplied by Grunchem Tech Sdn Bhd. To remove moisture, PLA and TS were oven-dried for 6 hours at 50°C. MA was first grafted on PLA as per the procedure described by S.Chauhan [9] to synthesize the compatibilizer (MAgPLA). PLA, MA and BPO in the ratio of 96.4:3:0.6 (by weight) was used for the grafting reaction. PLA/TS/MAgPLA blend with a fixed proportion (70% PLA 30% TS + 5% MAgPLA) was melt blended in a Sigma Blade mixer at a starting temperature of 180. Eight different compositions were prepared; blend 1 ($S_{control}$) was made up of 70% PLA and 30% tapioca starch (TS) and the remaining blends were composed of blend 1 + 5% MagPLA and increasing loads of EPO from 0%-10%. All eight blends were mixed using the Sigma Blade Mixer model DBM-0.5L under controlled conditions. The mixer was preheated to 80°C, and the blend were added, and the mixing process occurred at a controlled temperature range of 180-190°C with speed of 30 rpm for 45 minutes until a homogeneous mixture was achieved. Subsequently, the resulting blend was removed from the mixer and crushed into pellet form using a crusher. Small batches of each composition were then injected into an Xplore IM-12CC Micro Moulder tabletop injection molding machine. Injection molding parameters include maintaining a mold temperature of 100°C, a melt temperature of 210°C, an injection pressure of 8 bar, and a holding time of 6 seconds to ensure the formation of standardized specimens as per ASTM D638 standards type IV. Tensile test adhering to ASTM D638 standards type IV, performed using the Shimadzu AGX-10kNVD universal testing machine at a crosshead speed of 5mm/min for each sample.

## RESULTS AND DISCUSSION

The mechanical properties were computed and is given in Table 1.

**Table 1.** Mechanical properties

| Sample | $S_{control}$ | $S_0$ | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ |
|---|---|---|---|---|---|---|---|---|
| Tensile Strength (MPa) | 27.65 | 17.92 | 31.19 | 26.39 | 24.02 | 21.16 | 21.05 | 20.31 |
| Elongation at break (%) | 3.0 | 2.4 | 3.6 | 5.9 | 6.0 | 8.1 | 8.6 | 10.5 |
| Youngs' Modulus (MPa) | 933.43 | 781.95 | 936.98 | 513.00 | 409.69 | 287.51 | 248.31 | 206.15 |

The presence of MAgPLA resulted in a 13% increase in tensile strength in comparison with the control confirming that there was an increase in interfacial bonding between the PLA and starch fibers within the green matrix. The improvement in the mechanical properties of blend with MAgPLA coupling agent is attributed to the improved compatibilization of PLA with TPS. $S_0$ utilized ungrafted MA and exhibited a reduced tensile strength which emphasizes that MA must be grafted to be used as a compatibilizer. The addition of EPO increased the % elongation and was observed to be more flexible during tensile testing. This increase denotes the increase in blend's ductility. This is due to the plasticizing effect of EPO dispersing into PLA matrix resulting in intermolecular interaction between EPO and PLA causing an increment in the chain mobility. However, the tensile strength observed a reduction with an increased loading of EPO which is further affirmed by the decreasing Youngs' modulus.

## CONCLUSION

Maleic anhydride grafted PLA was found to have a positive impact on improving the compatibility which was indicated by improvement in the tensile strength of the blend by 13%. The effect of concentration of EPO indicated that an increased loading of EPO was found to increase the ductility of the blends where at a loading of 10%, elongation at break improved by 7.5%.

## ACKNOWLEDGEMENT

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**CHAPTER 30**

# ADVANCEMENTS IN BAMBOO-KENAF FIBERS REINFORCED HYBRID POLYMER COMPOSITES RESEARCH

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**ABSTRACT**
This paper presents a review of recent research focused on the development and characterization of bamboo-kenaf fibers reinforced hybrid polymer composites, marking significant strides towards sustainable and eco-friendly material engineering. The investigation encompasses recent studies, contributing unique insights into the thermomechanical, dynamic mechanical, and enhanced mechanical properties achieved through strategic fiber hybridization and nanoclay incorporation. The review explores the dimensional stability and dynamic mechanical behavior of bamboo and kenaf hybrid composites, revealing the optimal 50:50 weight ratio for superior dimensional stability and mechanical properties, suitable for applications requiring high durability, such as automotive and building materials. The study also delves into polylactic acid (PLA)-based unidirectional green hybrid composites, employing high modulus and brittle (HMB) versus low modulus and ductile (LMD) fiber stacking sequences. This comparative analysis underscores the impact of fiber orientation on tensile, flexural, and impact strengths, highlighting the potential of these composites in applications demanding a balance of strength and ductility, such as sound absorption and vibration damping in transportation. Lastly, the study focuses on the enhancement of mechanical and dynamic mechanical properties through the introduction of nanoclay into bamboo-kenaf epoxy hybrid composites. The inclusion of organically-modified montmorillonite (OMMT) nanoclay significantly elevates tensile, flexural, and impact strength, advocating for its use in load-bearing structures where lightweight and high strength are crucial. Collectively, these studies illustrate the promising future of bamboo-kenaf reinforced hybrid polymer composites in various sectors.
*Keywords:* Hybrid biocomposites; Bamboo fiber; Kenaf fiber; Characterizations; Applications

## INTRODUCTION

The rising environmental awareness and advancements in materials science have driven significant interest in natural fiber-reinforced polymer composites. Particularly, bamboo and kenaf fibers, owing to their sustainability and mechanical robustness, have become prominent materials in creating hybrid composites. Recent studies have explored various configurations and enhancements to optimize their mechanical properties and environmental performance. This paper collates insights from the latest research into bamboo-kenaf fiber reinforced hybrid polymer composites, underscoring the void reduction, enhanced tensile strength, and superior acoustic properties achieved through innovative hybridization techniques and materials such as nanoclays and multi-walled carbon nanotubes. This research not only advances our understanding of material properties but also broadens the application spectrum of these eco-friendly composites in industries like automotive and construction.

## BAMBOO-KENAF HYBRID POLYMER COMPOSITES FABRICATION METHODOLOGY

The preparation of bamboo-kenaf fiber reinforced hybrid polymer composites, as described in the abstracts, involves meticulous methodologies to optimize the properties of the final materials. The primary technique used is the hand lay-up method, favored for its straightforward application and effectiveness in aligning fibers for optimal performance. This method was commonly employed across studies, ensuring a uniform dispersion of fibers within the resin matrix [1,2,3]. For instance, in the fabrication of composites incorporating natural fibers with nanoclay and multi-walled carbon nanotubes (MWCNTs), a high shear speed homogenizer was utilized to ensure the even distribution of nanoparticles within the matrix before the lay-up process. Additionally, the treatment of fibers with solutions like NaOH was reported to enhance fiber-matrix adhesion, contributing significantly to the mechanical strength and durability of the composites [4]. These preparation techniques are pivotal in achieving the desired structural and functional characteristics of the hybrid polymer composites.

## PERFORMANCE OF BAMBOO-KENAF HYBRID POLYMER COMPOSITES

The studies reviewed in the paper highlight significant advancements in the performance characteristics of bamboo-kenaf fiber reinforced hybrid polymer composites. These composites demonstrate improved mechanical and physical properties through innovative material combinations and structural optimizations. For example, hybrid composites with a balanced 50:50 kenaf/bamboo ratio exhibited the highest tensile strength at 55.18 MPa and modulus at 5.15 GPa. Similarly, composites enhanced with nanoclay and multi-walled carbon nanotubes (MWCNTs) showed remarkable gains in impact resistance, with an 80.6% improvement in energy absorption characteristics and increases in flexural strength up to 105 MPa. Additionally, sound absorption was notably enhanced in composites with air gaps, achieving coefficients greater than 0.5. The introduction of nanoclays also contributed to increased density and reduced void content, which suppressed water uptake and improved thermal expansion behavior, making these composites suitable for high-performance applications in the automotive and construction sectors. These numerical benchmarks underline the potential of these hybrid composites to meet diverse industrial needs with enhanced efficiency and sustainability.

## APPLICATION OF BAMBOO-KENAF HYBRID POLYMER COMPOSITES

The bamboo-kenaf fiber reinforced hybrid polymer composites discussed in the paper hold substantial potential for diverse industrial applications. Specifically, the enhanced mechanical properties and structural integrity make these composites ideal for load-bearing structures in automotive and construction industries. For example, the improved tensile strength and flexural properties suggest their suitability for automotive components like seatbacks and floor panels, as well as building materials where lightweight yet robust materials are advantageous. Additionally, their superior acoustic properties offer potential uses in sound insulation applications.

## CONCLUSION

This paper has highlighted significant advancements in bamboo-kenaf fiber reinforced hybrid polymer composites, showcasing improved mechanical and acoustic properties through innovative hybridization and material enhancements. These developments not only enhance the application potential in various industries but also underscore the composites' role in sustainable material science, promising for future environmental and engineering solutions.

## ACKNOWLEDGEMENT

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**CHAPTER 31**

# INNOVATIVE SOLUTIONS FOR SUSTAINABLE FOOD PACKAGING NANOCOMPOSITE: HARNESSING THE POTENTIAL OF NANOCELLULOSE

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**ABSTRACT**
Considering the environmental repercussions of petroleum-based packaging materials, there is a critical necessity to pioneer novel food packaging materials. Nanocellulose emerges as a promising candidate, offering a sustainable solution with its unique properties. This presentation aims to explore into the world of nanocellulose and its potential applications in revolutionizing food packaging. We will begin by understanding the fundamentals of nanocellulose, exploring its structure, properties, and methods of extraction. Subsequently, we will discuss how nanocellulose can be effectively utilized in the production of composite films tailored for food packaging. Emphasis will be placed on the remarkable mechanical strength, barrier properties, and thermal stability exhibited by nanocellulose-based packaging materials, crucial for ensuring food quality and safety. Furthermore, this presentation will highlight the versatility of nanocellulose in enhancing the shelf life and preservation of various food products. We will illustrate the practical applications and benefits of incorporating nanocellulose in food packaging. Ultimately, this presentation aims to foster a deeper understanding of nanocellulose as a sustainable alternative for food packaging, providing insights into its potential to mitigate environmental impact while meeting the demands of modern packaging requirements.
*Keywords:* Nanocellulose; Sustainable packaging; Food packaging; Alternative materials; Environmental impact

## INTRODUCTION

The ubiquitous use of petroleum-based packaging materials has raised significant concerns regarding environmental sustainability. These materials pose a myriad of challenges, including non-biodegradability and pollution. In response to these challenges, researchers have turned their attention to nanocellulose as a promising alternative [1]. Nanocellulose, derived from renewable sources such as plants and bacteria [2], offers a sustainable solution with its unique properties. This paper aims to provide a comprehensive review of nanocellulose and its applications in food packaging, highlighting its potential to mitigate environmental impact while meeting the demands of modern packaging requirements.

## NANOCELLULOSE

Nanocellulose, a nanomaterial derived from cellulose fibers, exhibits remarkable mechanical, chemical, and thermal properties. Its nanostructure imparts superior strength and flexibility, making it an ideal candidate for various applications [3]. Nanocellulose can be obtained through various methods, including mechanical disintegration, chemical treatment, and enzymatic hydrolysis [1]. Each method yields nanocellulose with distinct characteristics, influencing its suitability for specific applications.

## UTILIZATION OF NANOCELLULOSE IN FOOD PACKAGING

One of the most promising applications of nanocellulose lies in food packaging [4]. Nanocellulose-based composite films offer numerous advantages over traditional packaging materials, including enhanced mechanical strength, barrier properties, and biodegradability [5]. These composite films can effectively prevent oxygen and moisture permeation, thereby extending the shelf life of packaged food products. Additionally, nanocellulose-based packaging materials exhibit excellent thermal stability, making them suitable for a wide range of food processing and storage conditions.

## ENHANCING FOOD PRESERVATION WITH NANOCELLULOSE

Beyond its role in packaging, nanocellulose has shown great potential in enhancing food preservation. By incorporating antimicrobial agents into nanocellulose-based films, researchers have developed innovative packaging solutions capable of inhibiting microbial growth and extending the shelf life of perishable food products [6]. Furthermore, nanocellulose-based packaging materials offer opportunities for active packaging applications, such as controlled release of antioxidants and flavoring agents, further enhancing food quality and consumer satisfaction.

## CONCLUSION

In conclusion, nanocellulose stands as a sustainable revolution in the field of food packaging. Its unique properties make it an ideal candidate for addressing the environmental challenges associated with traditional packaging materials. Through continued research and innovation, nanocellulose-based packaging solutions have the potential to transform the food packaging industry, offering sustainable alternatives that meet the needs of both consumers and the environment. As we continue to explore the exciting possibilities offered by nanocellulose, it is evident that it holds the key to shaping the future of food packaging towards a more sustainable and environmentally friendly direction.

## ACKNOWLEDGEMENT

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CHAPTER 32

# STRUCTURAL AND MORPHOLOGICAL EVOLUTION OF ZnO NANOSTRUCTURES HYBRIDIZED WITH CARBON NANOTUBES COTTON UNDER THE INFLUENCE OF SYNTHESIS TEMPERATURE

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**ABSTRACT**
The study investigated the influence of synthesis temperature on zinc oxide nanostructure growth on a network of carbon nanotubes cotton (CNTC) using the chemical bath deposition method. The CNTC, derived from waste cooking palm oil, exhibited a soft, fluffy, and lightweight physical appearance. A ZnO seed layer, crucial for localized growth patterning, was deposited on the CNTC using a 99.9% ZnO target. It shows that the diameter and length of the ZnO nanorods increased proportionally with the thickness of the seed layer. The highest aspect ratio, reaching 9.21, was achieved with the thinnest seed layer of 107 nm. CNTC demonstrated superiority as a substrate due to its flexibility, easy accessibility, low cost, and ability to act as a carrier for charges compared to other substrates.
*Keywords:* Carbon nanotubes cotton; Zinc oxide nanostructures

## INTRODUCTION

The impact of synthesis temperature for the growth of zinc oxide nanostructures on carbon nanotubes cotton network growth via chemical bath deposition method was investigated. Carbon nanotubes cotton (CNTC) was derived from waste cooking palm oil as the carbon source via floating catalyst (FCCVD) chemical vapor deposition. ZnO nanorods were grown on CNTC using chemical bath deposition method for 3 hours. It was observed that the nanorods diameter and length increased proportionally to the increased seed layer thickness as observed by previous study [1].

## METHODOLOGY

Carbon nanotubes cotton (CNTC) from waste cooking palm oil (WCPO) was synthesized using chemical vapor deposition reactor. A seed layer \was deposited at a fixed current, duration, and gas pressure of a sputter coater. A solution of 0.05 M of zinc nitrate hexahydrate with hexamethlenetetramine (HMT) in 100 ml deionized water and stirred for 30 minutes. The sample was placed in the oven for 3 hours at 60°C, 90°C and 120°C temperature. Characterizations were carried out to determine the properties of the sample.

**RESULTS AND DISCUSSION**

The resulted buffer thickness layer was 81.6 nm after ZnO was deposited onto CNTC at sputter current of 150 mA for 4 minutes. It was observed from the FESEM image in Figure 1 that the nanorods diameter and length increased proportionally to the increased of synthesis temperature. The highest aspect ratio is 9.21 corresponds to the highest synthesis temperature of 120°C at seed layer thickness of 81.6 nm.

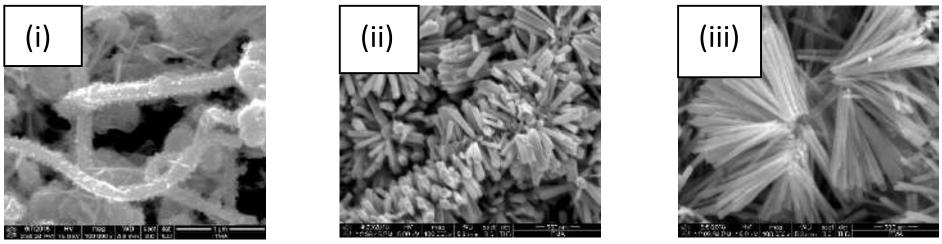


**Figure 1.** FESEM images of ZnO nanostructures growth on CNTC at :
(i) 60 °C, (ii) 90 °C and (iii) 120 °C.

The energy dispersive x-ray (EDX) analysis confirmed the presence of carbon atoms in the sample representing CNT and ZnO. All heteroatoms in the waste cooking palm oil such as S, N and O were removed during the high temperature synthesis via FCCVD [2].

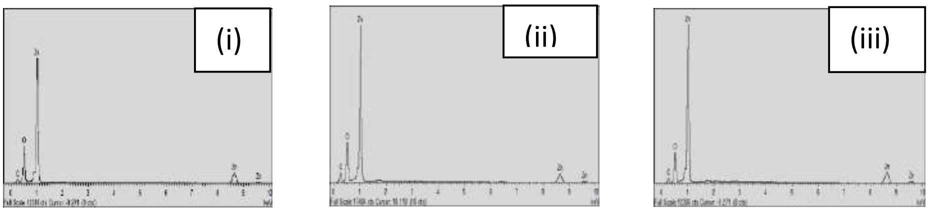


**Figure 2.** EDX spectrum of ZnO nanostructures growth on CNTC at :
(i) 60°C, (ii) 90 °C and (iii) 120 °C.

The high-resolution TEM image of the sample shows that the root of ZnO nanostructures are affixed on CNTs wall. The ZnO $d^{101}$ spacing is 0.25nm in accordance to JCPDS number 36-1451.

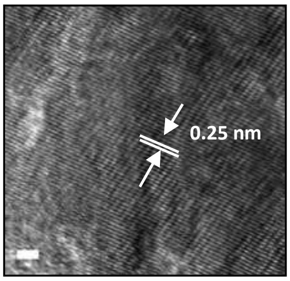


**Figure 3.** HRTEM of ZnO nanorods with d spacing of 0.25 nm.

## CONCLUSION

ZnO nanorods were successfully grown on the surface of CNTC. The nanorods diameter and length increased proportionally to the increased of buffer layer thickness. Results show that ZnO crystal size increased corresponded to the increased of temperature that showed high temperature influenced the morphology of ZnO nanostructures. CNTC is found a promising substrate as it is flexible, readily available, low cost and could act as charges carrier transport. The potential applications could be for small-scale electronics devices, sensors, and energy harvester.

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**CHAPTER 33**

# INVESTIGATION OF THERMAL BEHAVIOUR OF AEROGEL-INFUSED PAINT FOR BUILDING INSULATION

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**ABSTRACT**

Coatings are in high demand across various sectors due to their crucial roles in everyday life and industrial processes. With societal progress, the need for enhanced coating performance is escalating. Aerogel has gained prominence in building insulation owing to its unique characteristics such as low density, thermal insulation properties, flame retardancy, and high light transmittance. Despite the numerous advantages of aerogel paint, its fragility and rigidity pose significant limitations, constraining its widespread application. The primary objective of this study is to analyse the long-term thermal properties of painted surfaces. To accomplish this, a monitoring infrastructure was established, enabling real-time observation of temperature and humidity levels using LoRa technology. The research involves a comprehensive on-site assessment of the thermal efficiency of two houses-one coated with aerogel-infused paint and the other with regular paint. The analysis employed a monitoring and measuring system utilizing LoRa technology. Results indicate that the house coated with aerogel-infused paint exhibited higher thermal conductivity compared to the one with conventional paint. Specifically, the former had a thermal conductivity of 0.9 $W/m^2.K$, while the latter showed a significantly lower average of 0.2 $W/m^2.K$. The observed difference may be attributed to variations in relative humidity, wherein moisture content directly affects wall thermal resistance. Consequently, the increase in thermal conductivity of the aerogel-infused paint-coated wall can be linked to fluctuations in humidity levels within the wall structure.
*Keywords:* Coatings; Aerogel; Thermal conductivity; Insulation; LoRa technology

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## INTRODUCTION

The present study details continuing research into the potential of using aerogel-based paint. A case study was conducted where aerogel-based paint was used to coat the exterior wall of a building located in Pasir Mas, Kelantan, Malaysia. An experimental home model is utilized to conduct a case study evaluating the enhancement of thermal comfort by adding aerogel-infused coatings/paint on the outer surface of the building wall. The study also seeks to assess the potential of aerogel infused coatings and identify anticipated uses for this technology. These coatings, infused with aerogel, were developed through a partnership with a paint industry partner and a business specializing in Nano silica. They can be applied in the same way as regular construction paint, making them highly convenient for application in real-world conditions.

The main goal is to analyse the extended-term thermal characteristics of the painted surfaces. To achieve this goal, a monitoring system was established, allowing the direct observation of temperature and humidity levels using a wireless sensor system called LoRa technology. The purpose of these experiments is to provide a comparison between the thermal properties of a house building treated with aerogel-based paint and regular paint. In addition, a constant array of sensors monitors the indoor and exterior circumstances, as well as those in the neighbouring rooms. The findings of the initial comprehensive in-situ monitoring campaign, which aimed to compare the thermal performance of a house building treated with aerogel-based paint and regular paint, are presented, and analysed.

## METHODOLOGY

This study used two identical houses with the same orientation to evaluate the effectiveness of wall insulation technologies. One house had an external wall coated with aerogel-infused paint, whereas the other house had its exterior wall coated with the standard wall paint provided by the same manufacturer as the baseline scenario. The wall partitions were identical in their exposure to sunlight during the afternoon, as one side was entirely exposed without any obstructing structures. The paint was applied with a roller, with a same number of coats and nearly the same thickness in both cases.

In order to assess the thermal characteristics, sensors are placed on both the inner and outside surfaces of all relevant wall partitions in early October 2023. These sensors are positioned at the same heights and locations to monitor the temperature of the walls, the surrounding temperature, and the relative humidity. This experimental effort aims to gather significant data to comprehend the thermal dynamics within the structure across a 5-weeks period of data collection. Furthermore, in addition to utilizing HVAC systems indoors, the external conditions remain beyond our control. This will result in many scenarios and possibilities that have been encountered by the applied paint.

The case study is conducted in Pasir Mas, a town situated in Kelantan state, renowned for its tropical climate. The city is located at a latitude of 6.0424° N and a longitude of 102.1428° E. The weather dataset is sourced from the NASA Prediction of Worldwide Energy Resources, an internet portal with geographic information system (GIS) capabilities. The company provides customized data solutions for three primary user segments: Renewable Energy, Sustainable Buildings, and Agroclimatology. The solar radiation is increasing the temperature of the walls of the buildings.

## RESULTS AND DISCUSSION

An extensive analysis of the initial data was performed to ascertain the variations in the conductivity of the wall structures. To carry out this study, it was essential to monitor the temperature on both the inside and outside sides of the wall. The conductance $\Lambda$ was determined using the mean method outlined in the ISO standard 9869. To calculate $\Lambda$, one can use this method by dividing the average heat flow density by the average temperature difference from the wall (Equation 1).

$$\Lambda = \frac{\sum_{j=1}^{n} q_j}{\sum_{j=1}^{n}\left(T_{si,j} - T_{se,j}\right)} \qquad (Equation\ 1)$$

According to the data obtained, it was noticed that home 1, which was coated with paint infused with aerogel, showed higher thermal conductivity in comparison to the other residential buildings. The house, which was painted with aerogel-infused paint, had a thermal conductivity of 0.9 $W/m^2.K$. In contrast, the other structure, which was only covered with traditional paint, had a much lower average thermal conductivity of 0.2 $W/m^2.K$.

A possible explanation for this phenomena is that it is affected by the relative humidity of the house. According to the data obtained, house 1 has a greater relative humidity level than house 2. The construction of buildings with airtight architecture has resulted in a prevalent issue of walls becoming damp or moist. The moisture content within the wall directly impacts the thermal resistance of the wall. This phenomenon can be linked to the increase in the thermal conductivity value of the wall. The presence of a damp wall significantly impacts the energy usage of the heating system. The increased humidity is due to the absence of an air-conditioning system and adequate air circulation in home 1. This phenomenon arises from the confinement of hot air within the house, resulting in increased temperatures on the inner walls.

The situation may differ based on whether there is greater air circulation in the dwelling or not. It was found that the house coated with aerogel paint had a much lower outside wall temperature in comparison to the outdoor ambient temperature. This indicates that the insulating effectiveness of the wall will improve, and the influence of the aerogel can become more noticeable. This is because the paint could reduce the absorption of solar radiation. This outcome serves as an illustration of the paint's capacity to act as a thermal reflector for the wall.

**CONCLUSION**

In this article, a detail study of an elaborate in-situ assessment of the thermal performance of two houses that were applied with aerogel-infused paint and regular paint respectively has been reported. This analysis was carried out with the utilization of a monitoring and measuring system that implements the LoRa technology. It was discovered, on the basis of the data, that the house that had been painted with paint that contained aerogel had a higher thermal conductivity in comparison to the other residential constructions. The thermal conductivity of the house that was coated with aerogel-infused paint was 0.9 $W/m^2.K$, whereas the thermal conductivity of the other building, which was covered using traditional paint alone, was substantially lower, coming in at 0.2 $W/m^2.K$ on average. There is a possibility that this occurrence is influenced by the relative humidity of the house, which is a plausible explanation for the phenomenon. The amount of moisture that is contained within the wall has a direct impact on the thermal resistance capabilities of the wall. It is possible that the rise in the thermal conductivity rating of the wall is responsible for this occurrence.

**ACKNOWLEDGEMENT**

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## CHAPTER 34

# A REVIEW OF THE THERMAL INSULATION BOARD FROM NATURAL FIBER HYBRID COMPOSITES

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**ABSTRACT**
The thermal properties of composites made from natural fibers is crucial because the processing temperature significantly impacts the process of manufacturing of composites. At elevated temperatures, the natural fiber components cellulose, hemicellulose, and lignin begin to break down, causing alterations in their key features such as mechanical and thermal characteristics. Various techniques in the literature have been used to ascertain the thermal properties of natural fiber composites and assess how suitable they are for specific applications. Research has shown that thermal insulation undeniably one of the best methods in reducing energy consumption in tropical climate country and four season country. This paper provides an overview of thermal properties of an insulation board from natural fiber hybrid composites.
*Keywords:* Natural fiber; Fiber composites; Insulation board.

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## INTRODUCTION

Over the last decades, the construction sector has shown increasing interest in eco-friendly and energy efficient buildings. Research has shown that thermal insulation undeniably one of the best methods in reducing energy consumption in tropical climate country and four season country. The electricity demand in buildings can be significantly reduced by efficient thermal insulation. A recent thermal insulator review examined various types of insulators, including organic, inorganic, metallic, and waste material-based insulators, along with their thermal properties [1]. Several research studies have discovered that agricultural lignocellulosic wastes and natural fibers can serve as bioaggregates in the production of biobased insulating concretes [2,3]. For example, lignocellulosic from natural fiber hemp, flax, sunflower, and date palm have already been investigated and been used as insulating materials [4].

## FACTORS THAT AFFECT THE THERMAL PROPERTIES OF NATURAL AND HYBRID COMPOSITES

Natural fibers can be categorized into three primary classes based on their origin: mineral, animal, and cellulose/lignocellulose (see Figure 1). Mineral-based fibers were widely used in composite materials. Nevertheless, their utilization raised numerous human health concerns due to carcinogenic components that may be inhaled or ingested, leading to their prohibition in numerous countries globally. Animal fibers generally have inferior mechanical qualities than cellulose fibers, with the exception of silk which has excellent tensile strength [5]. Silk fibers are costly and mostly utilized in textile industries [5]. Cellulose and lignocellulose fibers are commonly used as natural fibers because of their cost-effectiveness as well as higher mechanical characteristics in comparison to other natural fibers. The natural fiber's components, such as hemicellulose, cellulose, and lignin, breakdown at different temperatures, ultimately resulting in the full destruction of the fiber [6].

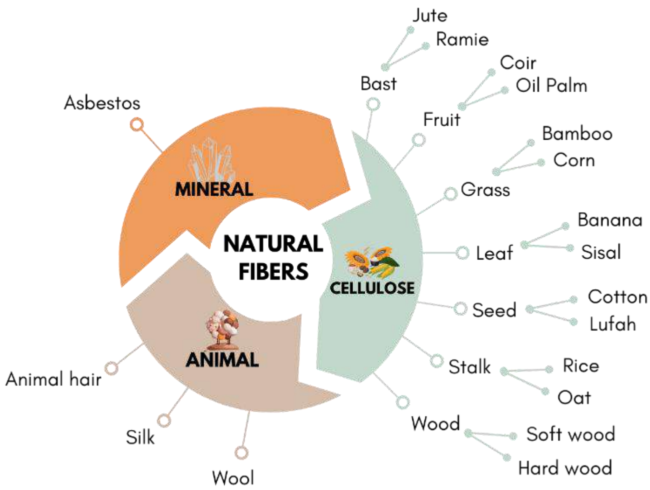


**Figure 1.** Diagram illustrating the categorization of natural fibers.

Research indicates that the thermal conductivity of insulating boards is mostly affected by their density, with lower densities often associated with lower thermal conductivities. The thermal conductivity value of insulation material from various natural fibre is shown in Table 1.

**Table 1.** Density and thermal conductivity of different natural fibers.

| Insulation board fiber/plant | Density (kg/m3 ) | Thermal conductivity, λ W/(m.K) | Reference |
|---|---|---|---|
| Coconut husk | 250 – 350 | 0.046 – 0.068 | [7] |
| Sugarcane fiber | 100 – 125 | 0.046 – 0.049 | [8] |
| Cotton stalk fiber | 450 | 0.082 | [9] |
| Hemp fiber | 369 – 475 | 0.090 – 0.108 | [10] |
| Date palm fiber | 754 | 0.150 | [11] |
| (Hybrid) Palm trees surface fibres/ Apple of Sodom fiber | 114 – 231 | 0.045 – 0.060 | [12] |
| Banana fiber | 70.4 | 0.04415 | [13] |

## CONCLUSION

To summarize, the thermal stability of natural fiber composites is a relevant aspect to be considered as the processing temperature plays a crucial role in the fabrication process of the composites. Natural fibers have a low environmental impact, biodegradable, cost-effective, sustainable, and possess favourable thermal-physical qualities.

## ACKNOWLEDGEMENT

The authors would like to thank the Malaysian Ministry of Higher Education (MoHE) for providing financial support through the Higher Education Centre of Excellence (HICoE).

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**CHAPTER 35**

# EFFECT OF GRADUAL THERMOFORMING PRESSURE ON THERMAL PROPERTIES OF A HYBRID COMPOSITE MADE OF BIOWASTES


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**ABSTRACT**

Thermal conductivity is a crucial thermal behavior of composite materials for various applications. Without characterization of thermal conductivity, the use of composite materials become extremely limited. This study builds a new approach to thermoforming process for a hybrid composite based on pressure control. The study investigates the effect of gradual pressure rise on thermal conductivity of composites produced from bio-wastes. Bio-wastes constituents are sawdust, groundnut shell, and chicken feather used as reinforcement and waste LDPE (Low Density Polyethylene) is used as matrix for making these composites using a compression molding machine. These wastes are mixed in equal proportion by weight, and fiber/matrix ratio (50:50) is used for fabricating composites. This work reports the thermal conductivity of these thermoplastic composites using simulation at a steady-state heat transfer with finite element analysis. Thermal conductivity was predicted and compared to experimental findings. It was tested with a hot disc and its range is 0.221 W/(mK) to 0.305 W/(mK). Results showed that thermal conductivity of the composites increases with increasing gradual thermoforming pressure.



*Keywords:* Bio-wastes; Hybrid composite; Thermoforming pressure; Thermal conductivity; Finite element simulation


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## INTRODUCTION

Materials which are available in nature and eco-friendly have spiked researchers towards composite materials [1]. Hybrid composite materials have currently received great attention from researchers due to their excellent potential when compared to the non-hybrid single fiber reinforced composites. Hybrid composites consist of different fillers integrated in a single polymer matrix [2]. Poultry feather waste, which the European Commission estimates that 8.5 billion tons are generated worldwide annually [3]. Currently, feather waste is either rendered into hydrolyzed feather meal as animal feed or sent to landfill or incinerated [4]. Besides this every year innumerable amounts of organic waste like saw dust, groundnut shell is thrown away due to lack of uses. It is crucial to transform our linear 'take – make dispose' economic model into a more sustainable, circular bio-economy model that utilizes wastes as a high value resource. Thermal properties are fundamental improvements required for these materials to enlarge the range of applications and to increase the competition with synthetic fibers [5]. Majority of the works consider thermal properties of composites which are produced with specific pressure. The aim of this work is to optimize pressure for thermal conductivity of composites with chicken feather, saw dust and groundnut shell.

**METHODOLOGY**

Polyethylene (LDPE) is used as matrix and chicken feather, groundnut shell powder, sawdust is used for reinforcement. Sawdust, ground nutshell treatment for making composite materials typically involves several steps, such as cleaning, alkali treatment, washing and drying before it can be integrated into a composite material. Compression moulding machine is used to produce this composite. The machine was run at 160°C for 10 minutes and 50 kN, 60 kN, 70 kN, 80 kN, 90 kN pressure was provided.

**RESULT AND DISCUSSION**

The modelling of composites has been done with ANSYS and also thermal conductivty of composites was estimated with this simulator which is shown in Figure 1 (a), (b), (c), (d), (e).

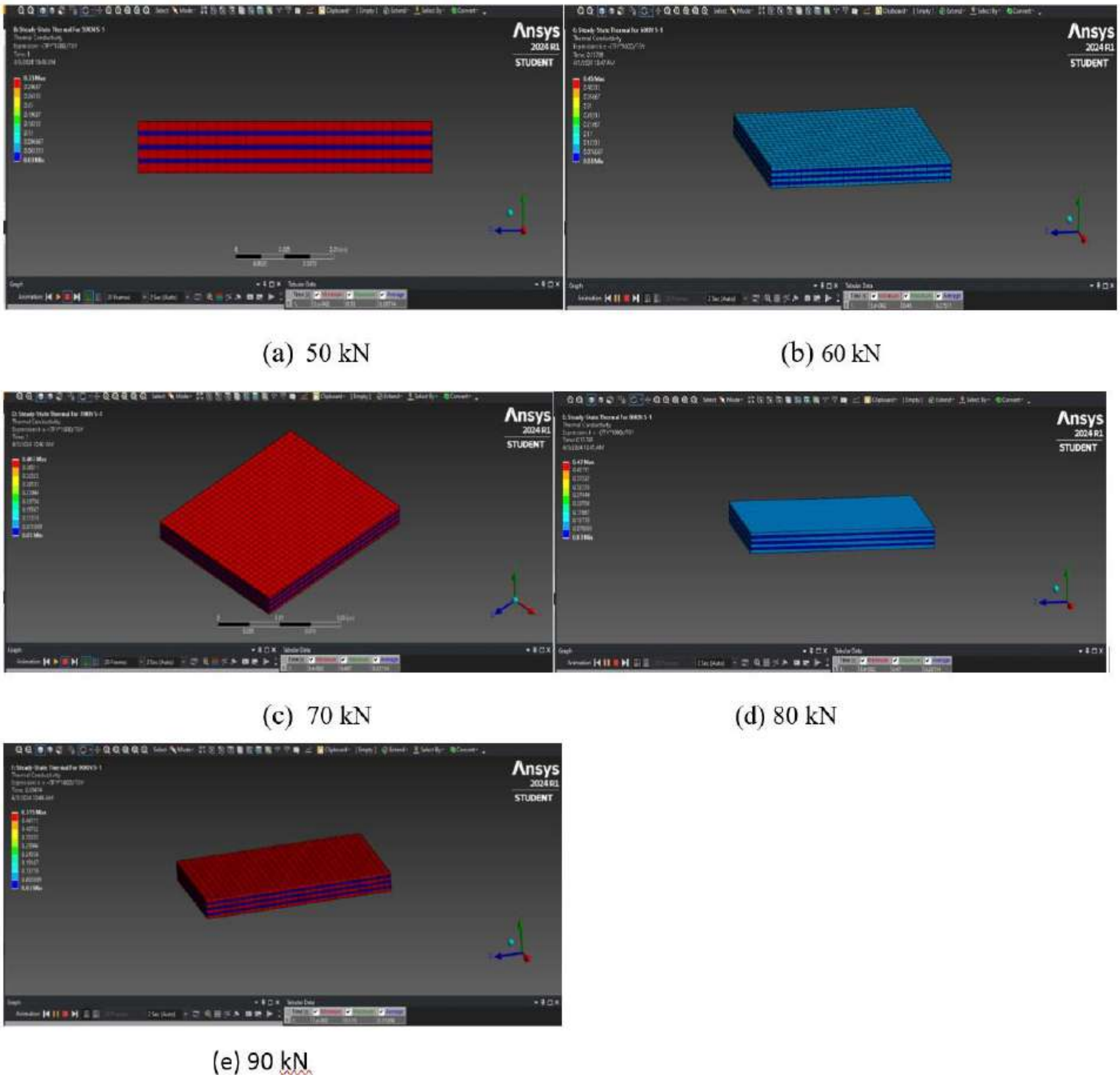


**Figure 1.** Prediction of thermal conductivity with ANSYS for composites made with (a), (b), (c), (d), (e).

**Table 1.** Thermal properties.

| Serial No | Pressure (kN) | Thermal conductivity (W/mK) | Specific Heat ($MJ/m^3K$) | Thermal Diffusivity ($mm^2/s$) |
|---|---|---|---|---|
| 1 | 50 | 0.221 | 0.8844 | 0.25 |
| 2 | 60 | 0.245 | 0.9209 | 0.27 |
| 3 | 70 | 0.269 | 1.0223 | 0.26 |
| 4 | 80 | 0.282 | 1.4292 | 0.20 |
| 5 | 90 | 0.305 | 1.1463 | 0.27 |

This data indicates a positive correlation between pressure and thermal conductivity. As the pressure increases from 50kN to 90kN, the thermal conductivity and specific heat show a consistent rise. This suggests that the material's ability to conduct heat improves under higher pressure conditions. The results align with the classical theory of thermal conductivity, which posits that denser materials, typically, have higher thermal conductivity due to reduced mean free paths of phonons. Thermal Diffusivity contrary to the previous trends, thermal diffusivity decreases with an increase in pressure. This suggests that the material's rate of heat spread slows down as the pressure is increased.

**Table 2.** Validation of simulated data with experimental data

| Sample | Simulated data | Experimental data | Difference = (Experimental data - Simulated data) | Error percentage |
|---|---|---|---|---|
| 50 kN | 0.20714 | 0.221 | 0.01386 | 6.27% |
| 60 kN | 0.27571 | 0.269 | 0.00614 | 2.237% |
| 70 kN | 0.25114 | 0.245 | 0.00669 | 2.444% |
| 80 kN | 0.28714 | 0.282 | 0.006710 | 2.4913% |
| 90 kN | 0.31286 | 0.305 | 0.00786 | 2.51% |

Table 2 shows the notable deviation between simulated and experimental thermal conductivity values. Possible reasons include inaccuracies in modeling composite behavior under lower mechanical stresses and uncertainties in experimental measurements.

## CONCLUSION

In this work, thermal properties of composites made of sawdust, chicken feather, groundnut shell and LDPE was predicted with ANSYS, experimented, and validated. It can be concluded that:

- Thermal conductivity values show a consistent rise, that means the material's ability to conduct heat improves under higher pressure conditions.
- The specific heat capacity of the samples also exhibits an increasing trend with the rise in pressure. This indicates that the material requires more energy to raise its temperature as the pressure increases.
- Thermal diffusivity contrary to the previous trends, thermal diffusivity decreases with an increase in pressure. This suggests that the material's rate of heat spread slows down as the pressure is increased.

## ACKNOWLEDGEMENT

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CHAPTER 36

# IMPACT OF SURFACE TREATED HALLOYSITE NANOTUBES ON THE SELF-HEALING EFFICIENCY OF NATURAL RUBBER COMPOSITES

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**ABSTRACT**
Acrylic acid was utilized for surface improvement of halloysite nanotubes to be used as reinforcement in self-healing natural rubber based on reversible metal thiolate ionic crosslinks. The amount of acrylic acid varied at 2, 4, 6 and 8 wt% of halloysite content and the optimized acid grafting was used to investigate the self-healing NR/HNTs composites. The graft polymerization of acrylic acid on halloysite was confirmed using FTIR spectroscopy. Intermolecular diffusion occurred at the fractured surfaces was detected using a scanning electron microscope. The self-healing rubber composites incorporating 6% AA treated HNTs exhibited improved properties in terms of tensile strength and elongation at break with healing efficiencies of 98.5% and 86%, respectively.
*Keywords:* Self-healing; Acrylic acid; Surface modification; Halloysite nanotubes; Rubber composites.

## INTRODUCTION

Halloysite Nanotubes (HNTs) are clay minerals that possess unique chemical composition and a tubular structure due to which, they have recently emerged as a potential nanomaterial for umpteen applications [1]. Over the years, the myriad applications of HNT have been realized through the surface modification of HNT, which involves the modification of nanotube's inner lumen and the outer surface with different functional compounds [2]. Different research works have been done in the last years, focused on HNTs modification using different acids like sulfuric acid [3], hydrochloric acid [4], and acetic acid [5]. Nevertheless, to our knowledge, an in-depth study of the effect of acrylic acid treated HNT on self-healing efficiency of NR has not been carried out.

Previously, it was demonstrated that integrating 8 phr of halloysite into the self-healing NR compound based on metal thiolate ionic networks has a pronounced intrinsic healing capability, with 85% recovery of damage in just ten minutes at room temperature [6, 7]. In the present work, we investigated the impact of acrylic acid treated HNTs reinforcement on the self-healing efficiency and mechanical performance of NR based on reversible metal thiolate ionic crosslinks.

## METHODOLOGY

### *Materials*

Natural rubber (SMR L), zinc oxide (ZnO) and stearic acid were purchased from Zarm Scientific & Supplies, Sdn. Bhd. Malaysia. Halloysite nanotubes (HNTs), acrylic acid (AA), zinc thiolate (ZT) and dicumyl peroxide (DCP) and ethanol were procured from Sigma Aldrich (M) Sdn. Bhd, Malaysia.

### *Surface Treatment of HNTs*

Halloysite nanotubes were chemically treated through a reaction with a solution mixture of acrylic acid having different concentrations in ethanol. Halloysite was gradually added to the acrylic acid solution and stirred for 2 h. The solution was left for 24 h, then filtered and dried at 80 °C for 24 h.

### *Preparation of Self-healing Rubber Composites*

NR was pre-masticated and further mixed with zinc thiolate using an internal mixer (HaakeTM) at 135°C and 60 rpm for 15 minutes as per formulations mentioned in Table 1. The masterbatch was then compounded with halloysite nanotubes, zinc oxide, stearic acid and dicumyl peroxide using the two-roll mill (XK-150). The prepared compounds were then subsequently vulcanized using compression molding at 150°C and 1000 psi, according to the optimum cure time (tc90) measured using moving die rheometer (Monsanto 2000, USA).

### *Self-healing composites characterization*

*FTIR Spectroscopy*: A PerkinElmer spectrometer was used to determine the functional groups of self-healing NR/HNTs composites recorded in the range of 500 cm−1 to 4000 cm−1 under ATR mode and with a resolution of 4 cm-1.

*Tensile Test*: Mechanical performance was evaluated twice, before and after the healing process using a Universal Testing Machine (UTM, Instron 3366, USA) at a strain rate of 50 mm/min according to ASTM D412.

*Morphology Analysis*: The healed fractured surfaces of self-healing rubber composites were characterized using a tabletop scanning electron microscope (SEM, Hitachi TM3000, USA) at an accelerating voltage of 15 kV.

**Table 1.** Composition of untreated and treated HNTs filled Self-healing NR.

| Materials | SHNR/HNT (Untreated) | SHNR/HNT (Treated) |
|---|---|---|
| NR (SMR L) | 100 | 100 |
| HNTs | 8 | 8 |
| ZT | 30 | 30 |
| ZnO | 5 | 5 |
| St. Acid | 1 | 1 |
| DCP | 1 | 1 |
| AA (%) | - | 2, 4, 6, 8 |

[a]AA: Acrylic Acid, wt% based on weight of HNTs.

## RESULTS AND DISCUSSION

Fig. 1 (a) shows the FTIR analysis of untreated and treated HNTs at various concentrations of AA. The absorption bands at around 3500–3600 $cm^{-1}$ and 908–910 $cm^{-1}$, indicate towards the presence of –OH group attached to the silica and alumina groups in the inner lumen and outer surface of HNT. The Si-O stretching and bending vibrations of HNT are also revealed through the presence of absorption band at around 1050–1070 $cm^{-1}$. Compared to raw HNTs, some sharp peaks were observed in 6% AA treated HNTs at 2938 $cm^{-1}$ and 1718 $cm^{-1}$ which are assigned to $CH_2$ symmetric stretching and C=O stretching vibrations due to carboxylic rich groups.

The tensile strength and elongation at break of self-healing rubber composites were displayed in Fig 1 (b and c). The tensile strength and its healing efficiency gradually increased with increasing the AA treated HNT loading from 2-6% and further decreased with 8%. The elongation at break and corresponding self-healing recovery were found to decrease gradually as the HNTs content increased.

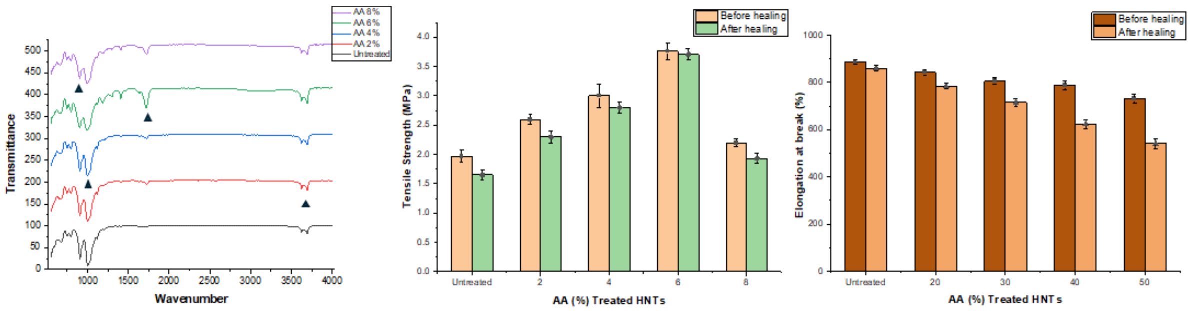


**Figure 1.** (a) FTIR of HNTs, (b) Tensile strength and (c) Elongation at break of SH-NR composites.

The morphologies of the healed fractured surfaces of untreated and AA treated HNTs filled SH-NR composites were observed after the broken surfaces were brought together for 10 mins [Fig. 2 (a-e)]. The results revealed that the healed area of the fractured surface adhered well with minor scar on the contact surface, suggesting that intermolecular diffusion occurred at the fractured surface.

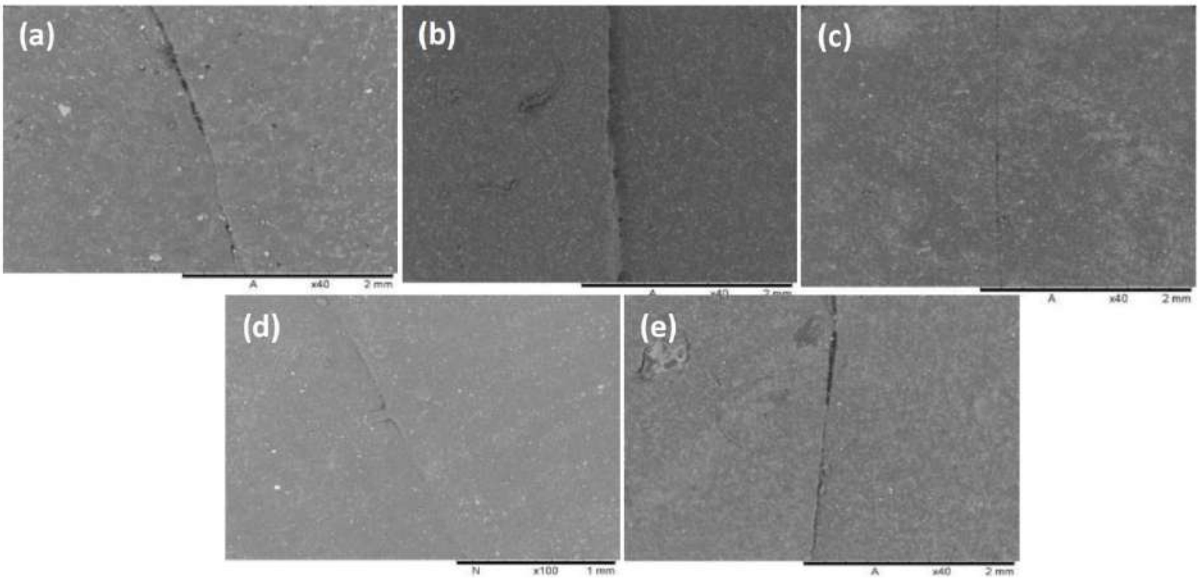


**Figure 2.** SEM of SH-NR filled with HNT (a) untreated, (b) 2% AA, (c) 4% AA, (d) 6% AA, and (e) 8% AA.

## CONCLUSION

The developed self-healing rubber composites can repair and recover their properties intrinsically, reflecting the reversible metal thiolate ionic components. The FTIR results confirmed the acrylic acid grafting on HNT. The 6% AA grafted HNT filled composites showed the highest tensile properties and healing efficiency (98.5%). SEM results revealed that thin trace lines at healed fractured surfaces indicates effecting healing.

## ACKNOWLEDGEMENT

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**CHAPTER 37**

# ASSESSMENT OF CARBONIZED CASSAVA PEEL AND SAWDUST BLEND BRIQUETTES AS SOLID BIOFUEL

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**ABSTRACT**
This study was carried out to assess the energy value of briquettes produced from carbonized cassava peel (CP) sawdust (SD) feedstock blend with cassava starch as a binder. The feedstocks were carbonized in a drum carbonizer at temperature of 400°C and 350°C, respectively. The CP-SD and binder mixtures were manually pressed at 2.4 MPa compaction pressure and 30-minute resident time with 5-ton hydraulic jack briquette machine. The quality of the briquettes was examined in terms of moisture content, calorific value, and carbon content. Results showed that the CP-SD briquettes have excellent moisture content (4.37% - 6.76%), carbon content (55.67 - 56.58%), and calorific value (20.34 MJ/kg – 30.98 MJ/kg).
*Keywords:* Cassava peel; sawdust; briquettes, moisture content, calorific value, carbon.

## INTRODUCTION

West African countries particularly Nigeria grapple with widespread forest degradation primarily driven by heavy reliance on fuelwood for cooking. Fuelwood obtained from forests remains the primary source of energy for approximately 80% of Nigerians living in rural or semi-urban areas [1]. Sajjakulnukit and Verapong argue that reducing the demand for fuelwood lies in the increased utilization of renewable sources of energy such as biomass briquettes [2]. Akogun et al., successfully demonstrated that the quality of CP-SD blend briquettes significantly improved with torrefaction of raw feedstock materials at 300°C [3]. Following this finding, this research seeks to investigate the quality of CP-SD blend briquettes carbonized at temperature above 300°C.

## METHODOLOGY

Feedstock materials were sourced from Oyo city in Nigeria. Raw CPs were air-dried for two weeks followed by milling and sieving through a 2mm particle-size mesh screen following the ASAE S424.1 specification. The CPs was heated at a temperature of 400°C for 3 hours while the SD was heated at 350°C for three (3) hours, both in a drum carbonizer. The binder, in a form of gelatinous starch pastes, was prepared by mixing 100 ml of boiled water (98°C) with 10g of cassava starch. Five (5) different CP-SD ratios were considered in this study – 100:0, 25:75, 50:50, 75:25, 0:100.

The CP/SD blend and binders were manually fed into a 5-ton hydraulic jack briquetting machine. A compaction pressure of 2.4 MPa was applied to form the briquettes. The briquettes were allowed to rest for three days to harden the samples before they were oven-dried at 93°C for four (4) hours [4]. Moisture content was determined according to the ASTM Standard D2444-16, carbon content was examined with CHNSO elemental analyzer (LECO CHN628, Saint Joseph, MO, USA) and the calorific value was obtained from a bomb calorimeter (Model IKA C2000).

## RESULTS AND DISCUSSION

Results from laboratory tests are shown in Table 1. Samples S1 and S2 recorded the lowest moisture content (4.37±6.63%, 4.74±7.22%) over other samples with higher SD ratio. On the other hand, sample S4 was found to obtain the highest carbon content (57.07 ± 0.49%) while sample S2 and S5 obtained the highest calorific value (30.19 ± 0.85 MJ/kg , 30.99 ± 0.19 MJ/kg).

**Table 1** The quality of the CP/SD briquettes

| Sample number - CP/SD ratio | Moisture content (%) | Carbon content (%) | Calorific value (MJ/kg) |
|---|---|---|---|
| S1- 100:0 | 4.37 ± 6.63 | 55.71 ± 0.25 | 20.35 ± 0.25 |
| S2 - 25:75 | 4.74 ± 7.22 | 56.79 ± 0.51 | 30.19 ± 0.85 |
| S3 - 50:50 | 5.29 ± 5.66 | 56.58 ± 0.10 | 27.15 ± 0.16 |
| S4 - 75:25 | 5.93 ± 1.28 | 57.07 ± 0.49 | 29.85 ± 0.96 |
| S5 - 0:100 | 6.76 ± 5.95 | 55.67 ± 0.19 | 30.99 ± 0.19 |

## CONCLUSION

Carbonization of biomass materials produces high quality of biomass briquettes with low moisture content, high carbon content and high calorific value. Briquettes with a blend of two or more biomass materials will result in favorable quality over briquettes produced with only one biomass materials. In this study, we demonstrated that sample S2 with 25:75 CP/SD ratio is the most favorable briquettes over other samples. Sample S2 recorded the second lowest moisture content, second highest carbon content, and second highest calorific value.

## ACKNOWLEDGEMENT

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## CHAPTER 38

# FABRICATION OF CHITOSAN COLLAGEN GLYCERINE SCAFFOLD FOR ORAL WOUND TREATMENT

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**ABSTRACT**
The current study aimed to fabricate and evaluate chitosan collagen glycerine (CCG) scaffold for suitability for usage for oral wound treatment. The scaffolds were developed in three different ratios of chitosan: collagen; 30:70, 50:50, and 70:30. Parameters tested were morphology, mechanical strength, and cytocompatibility. The morphology of the scaffold was evaluated using scanning electron microscopy imaging (SEM). The biostability of the scaffold was tested by measuring its degradation rate over four weeks of being immersed in phosphate-buffered saline (PBS). The cytocompatibility of the CCG scaffold is evaluated after 3 days of seeding HTERT TIGKs cells obtained from ATCC onto the scaffold via 2,5-diphenyl-2H-tetrazolum bromide (MTT) assay. The mean pore size of the scaffolds obtained through measurement using SEM for each ratio is 141.76 ± 27.03um (30:70), 166.76 ± 41.88um (50:50), and 174.43 ± 34.78um (70:30). The biostability test found the degradation rate was the highest in the first week (70-87.5% weight loss) but declined drastically and had insignificant weight loss over the three remaining weeks. In terms of cytocompatibility, the CCG scaffold (30:70) has the highest cell count followed by the other ratios respectively; 50:50, and 70:30. In conclusion, the CCG scaffold has the potential for oral wound treatment.
*Keywords:* Collage, Chitosan, Scaffold, Oral, Wound, Tissue Engineering.

## INTRODUCTION

The aim of this research is to perform an in-vivo evaluation on the CCG scaffolds suitability for oral wound treatment as according to the principals of tissue engineering. There are three different ratios of chitosan to collagen used in this evaluation; 30:70, 50:50 and 70:30. The purpose of the different ratios is to find the ratio that has the best potential to assist tissue regeneration. The scaffolds are evaluated as well in terms of porosity and biodegradability. To evaluate the scaffolds suitability for oral wound treatment, hTERT TIGKs cells which are epithelial gingiva cells are seeded on the scaffolds over three time points and measured for cell proliferation.

## METHODOLOGY

*Porosity*

The three scaffolds were sent for SEM imaging and had their pores measured to acquire their average pore sizes

*Biodegradability*

The initial dry weight of the scaffolds was recorded and the scaffolds were immersed in Phosphate Buffered Saline over a period of 4 weeks. Every week the scaffolds are dried and the weight loss of each scaffold is recorded

*MTT Assay*

The hTERT TIGKs cells were seeded onto the scaffolds at a density of 10 x $10^4$ cells / scaffold in a 24 well plate. The culture media is changed every 3 days, and the MTT assay is measured at day 3, 7 and 14. The MTT assay is done by adding 100 ul of MTT solution into each well of seeded scaffold. The plate is incubated at 35°C temperature for four hours. After the incubation period DMSO is added to dissolve the formazan crystals formed during the incubation with the MTT solution. The readings are taken using a microplate reader at 570Nm absorbance.

**RESULTS AND DISCUSSION**

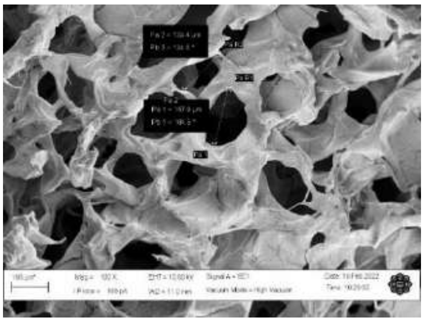

**Figure 1.** Porosity of the scaffold taken using SEM imaging

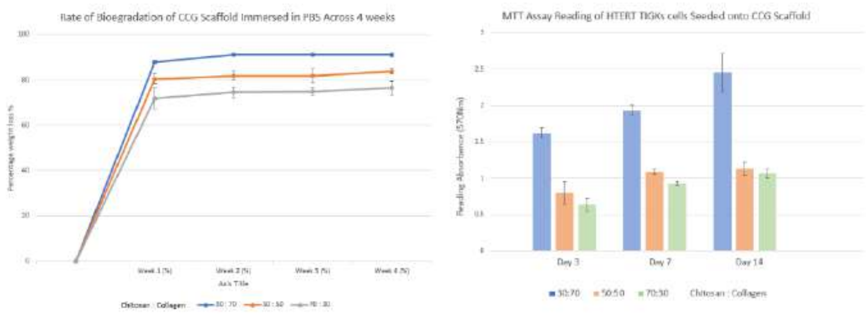


**Figure 2**. Results of the biodegradation assay (left) and MTT Assay (right)

**CONCLUSION**

The Chitosan Collagen Glycerine Scaffold was successfully fabricated, evaluated, and suited for oral wound treatment.

**ACKNOWLEDGEMENT**

The committee members would like to thank International Islamic University Malaysia and Ministry of Higher Education for the support through FRGS grant (project ID 14938-FRGS/1/2019/SKK14/UIAM/03/3) given to carry out this study.

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**CHAPTER 39**

# ENHANCING THE PERFORMANCE OF GRADE 91 STEEL WELDS: A REVIEW OF HEAT TREATMENT AND REPAIR TECHNIQUES

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**ABSTRACT**

This review examines various heat treatment and repair processes employed to enhance the mechanical properties of P91 steel welded joints. Literature on heat treatment explores its influence on the microstructure and mechanical behavior of P91 welds. The paper discusses different heating methods used in post-weld heat treatment (PWHT), such as furnace heating and induction heating. Furthermore, the review analyzes weld joint repair procedures, including excavation methods and considerations for the final excavated region geometry. It details crucial aspects like bevel angle, radius, depth of material removal, and bead overlap critical for structural integrity. Finally, the paper reviews various mechanical testing methods used to assess the effectiveness of heat treatment and weld repair on P91 steel. These methods include tensile testing, hardness testing, impact testing, and creep rupture testing.

*Keywords:* Welding; Repair; Creep; Grade 91; Post Weld Heat Treatment.

## INTRODUCTION

Elevated temperature service environments induce microstructural alterations in steel, consequently affecting its mechanical performance. This phenomenon, known as thermal aging, presents a significant challenge for various steel components [1]. Over time, thermal aging leads to a degradation in steel's ductility and toughness, ultimately reducing the design life of materials exposed for extended periods [2]. Accurate assessments of structural integrity require material properties that reflect real-world service conditions caused by thermal aging. Unfortunately, replicating these conditions in experiments is challenging. Therefore, researchers often use controlled environments to predict material behavior under actual service conditions. [3].

Another critical failure mode at elevated temperatures is creep, characterized by time-dependent deformation under constant loads. The interaction of creep with fatigue further compromises structural integrity, prompting extensive research on predicting the lifetime due to creep-fatigue damage [4]. High thermal stress necessitates excellent heat resistance in materials where notably, Modified 9Cr-1Mo steel (ASME Grade 91, Gr. 91) fulfills these requirements. However, the absence of data for aged materials limits the applicability of evaluation procedures to virgin materials only.

To account for the influence of thermal aging on creep damage assessments, both elastic and creep properties for aged materials are necessary. Some studies have investigated the tensile properties (yield stress, tensile stress, and elastic modulus) of aged Gr. 91 steel [3].

**HEAT TREATMENT ON GRADE 91 STEEL WELD JOINTS**

Several studies have explored optimizing heat treatment conditions for P91 steel welded joints using Gas Tungsten Arc Welding (GTAW) and filler metals with similar composition [5]. These studies aimed to develop faster and more environmentally friendly procedures while maintaining satisfactory results. Additionally, research has investigated the influence of heat treatment on the mechanical properties of P91 weldments. For instance, one study examined the softening mechanism at specific temperatures [6] Another study found that post-weld heat treatment at 665°C and 690°C reduced the hardness of the material [7]

Research also examines ferritic steel, a widely used steel type with a specific crystal structure (body-centered cubic). Studies show that heat treatment can strengthen these steels [8]. While carburizing, a different heat treatment, which is typically used for low-carbon, low-alloy steels. For post-weld heat treatment, there are several heating methods like furnace heating, internal firing, resistance heating, and induction heating. The choice of method and treatment time depending on the joint thickness and stress distribution. [9][10]

**WELD JOINT REPAIR**

There are several approaches for the excavation of damage in weldments, depending on the assumptions that are made [11]. For instance, a scenario where a weld damage is found in the HAZ of the weld joint, where both sides of a weldment share the same parent material (Figure 1), performing a partial repair instead of a minor repair might be more cost-effective. While factors like geometry, design, and stress all influence damage accumulation, assuming similar damage on both sides is often reasonable. This makes removing the heat-affected zone (HAZ) on both sides offers a safer and more efficient approach.

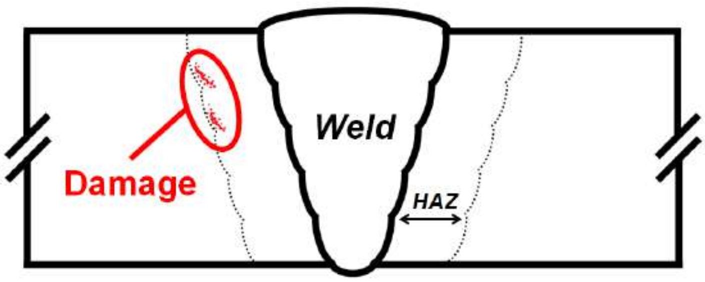


**Figure 1.** A scenario where damage is found in the HAZ, then “Partial” Excavation of Damage is recommended [11]

Sharp corners in the excavated region of a weld repair act as stress concentrators, initiating crack propagation and jeopardizing the integrity of the repaired joint. To mitigate this risk, a mandatory design principle is the implementation of smooth transitions or contours. These rounded geometries promote uniform stress distribution, thereby enhancing the repair's effectiveness and longevity. Several key aspects influence the optimal geometry, including bevel angle, radius, depth of material removal, and bead overlap.

## CONCLUSION

In conclusion, this review underlines the importance of considering thermal aging effects and proper weld repair techniques to ensure the safety and longevity of grade 91 steel components operating in high-temperature environments.

## ACKNOWLEDGEMENT

The committee members would like to thank Universiti Putra Malaysia for the support that is given to carry out this conference.

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CHAPTER 40

# A COMPREHENSIVE STUDY ON THE MECHANICAL PROPERTIES OF HIGH-DENSITY POLYETHYLENE (HDPE) PLASTICIZED WITH HYDROXYLATED PALM STEARIN (HPS)

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**ABSTRACT**
High-density polyethylene (HDPE) is a highly utilised polymer in a variety of resin applications due to its exceptional tensile properties. However, it has come to light that the industrialization of polymers derived from petroleum is a significant factor in the worldwide buildup of plastic waste. Several studies involving the combination of HDPE and biodegradable material have been identified to address this issue. This research developed a novel biohybrid resin combining HDPE with hydroxylated palm stearin (HPS), an innovative plasticizer. Assessing the mechanical properties of a novel biohybrid resin formulation in terms of HPS's capacity to plasticize HDPE and impart new, distinctive qualities was the objective of this research. HPS (10–30%), commercial compatibilizer (3–9%), and fillers (10–30%) were utilized in the production of the resins. The incorporation of additives into the blending process of HDPE and HPS led to a 25% increase in elongation at break. Consequently, the ultimate product exhibited improved flexibility, durability, and toughness. The expected mechanical properties of the ideal HDPE/HPS formulation containing additives were to be exceptional, given the global usage of existing polymer resins.
*Keywords:* Hydroxylated Palm Stearin (HPS); Polyethylene; Polymer Blend; Mechanical Properties; Biohybrid Resin

## INTRODUCTION

Plastic demand has increased globally due to its lightweight and durable characteristics. However, it also caused landfill demands for plastic decomposition [1]. A few current alternatives, such as polymer recycling and polymer blends, can solve these non-renewable resin decomposition issues. Polymer recycling, on the other hand, is less effective because recycled polymers exhibit mechanical strength deterioration [2]. As a result, this study expanded the polymer blend of HDPE with renewable materials. The application of hydroxylated palm stearin (HPS) has been discovered to be used as the plasticizer in HDPE blends based on the previous work of some authors who have applied the modified palm oil structure as a plasticizer to blend with various polymers [3–9].

## METHODOLOGY

*Resin Preparation*

The HDPE was manually mixed with the commercial compatibilizer in a beaker. Then, the mixture was poured into the internal mixer at a temperature of 180 °C and the mixer's screw speed at 50 rpm. Then, the commercial filler was added to the mixer, followed by the HPS plasticizer to plasticize the HDPE. The mixing process was continued for 2 minutes before the collection.

*Hot press Procedure*

The hot press processes consisted of 7 minutes of preheating and 10 minutes of heating at the temperature of 150 ℃ and cooling temperature of 50 ℃ for 10 minutes with the pressure applied at 25 kg/cm$^2$.

*Tensile Test Procedure*

The sample was prepared according to the chosen standard, ASTM D638-Type I. 10 mm /min and 10kN were the chosen crosshead speed and load cell, respectively [10]. The analyzed properties are tensile strength, Young's modulus, and elongation at break.

## RESULTS AND DISCUSSION

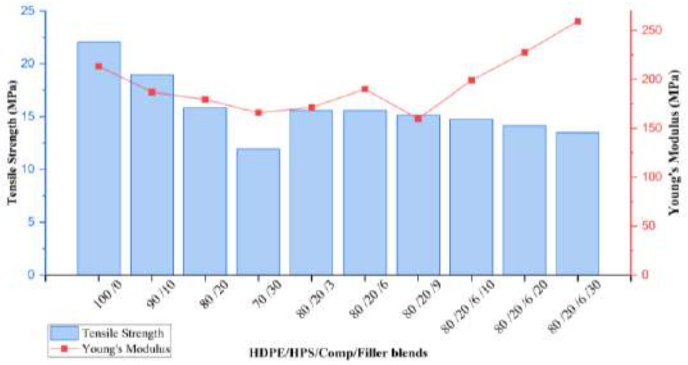


**Figure 1.** Tensile Strength and Young's Modulus of HDPE/HPS with additives resin blends with various formulations

From Figure 1, within the blend of HPS and HDPE, a minor decrement of around 28.16% was identified. However, the added compatibilizer was able to sustain the final strength. Meanwhile, the filler assisted gave a large increment of Young's modulus by 19.74%, which indicates that this resin is suitable for any application with elasticity properties.

## CONCLUSION

In conclusion, the blend with HPS demonstrated its plasticizing properties. However, the addition of HPS was limited to below 20% to avoid a major reduction in the ultimate tensile strength properties of the blend. With the aid of the additives, it was sufficient to increase the elasticity limit of the blend up to 259.50 MPa.


## ACKNOWLEDGEMENT

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**CHAPTER 41**

# DLC COATED TOOLS FOR BLANKING AND PUNCHING PROCESS

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**ABSTRACT**
Tool wear is a common occurrence in the blanking process of metal forming. To increase tool life and reduce wear and tear, protecting tool surfaces with Diamond-Like Carbon (DLC) coating is one of the methods. This study evaluates the performance of DLC coated tools against commonly used industrial coatings such as Titanium Nitride (TiN) and Aluminum Titanium Nitride (TiAlN). DLC-coated tools exhibit fewer wear scars and require around 32% less force than uncoated tools, making them more efficient and cost-effective. The wear rate of DLC-coated tools is much lower than tools coated with other materials, making DLC the preferred choice in metal forming processes. This research shows the importance of coating technology, especially DLC, in improving the durability and performance of blanking tools. The use of DLC coatings can lead to increased efficiency and longevity of metal forming processes in the manufacturing industry.
*Keywords:* Blanking; Coating; DLC; Wear.

## INTRODUCTION

Blanking is a basic metalworking process used to create flat shaped pieces (blanks) from sheet metal. It uses a set of punches and dies in a mechanical or hydraulic press to cut the desired shape from the sheet [1]. The punched piece becomes the desired blank or product, while the remaining piece of metal is scrap [2]. This process is known for its efficiency in high volume production of the same part [1].

Tool coatings are often used to increase the hardness, strength, wear resistance, and heat resistance of tools and increase their life, tool coatings are often used [3]. Coated tools have a longer lifespan because they experience reduced wear [4].

This paper investigates the effect of force to the life-time tool intern of wear performance during the blanking process on the single-layer coating on the top surface of the blanking tool.

## METHODOLOGY

Three types of single-layer coatings were applied to the tool during the blanking process, as detailed in Table 1. A 1 mm thick aluminum 1060 workpiece was used, with its mechanical properties outlined in Table 2 and setup proces as Figure 1. Each type of coating underwent 50 strokes on the workpiece in dry condition.

**Table 1.** The properties of the TiN, TiAlN and DLC coating.

| Coatings Tool | Thickness (µm) | Hardness (HV) |
|---|---|---|
| TiN | 5 ±0.3 | ~2240 |
| TiAlN | 6 ±0.2 | ~3250 |
| DLC | 5 ±0.4 | ~2500 |

**Table 2.** The mechanical properties of aluminum 1060 [5].

| Properties | Value |
|---|---|
| Tensile Strength, Ultimate | 82.7 MPa |
| Tensile Strength, Yield | 75.8 MPa |
| Modulus of Elasticity | 68.9 GPa |
| Shear Modulus | 26 GPa |
| Poisson's Ratio | 0.33 |

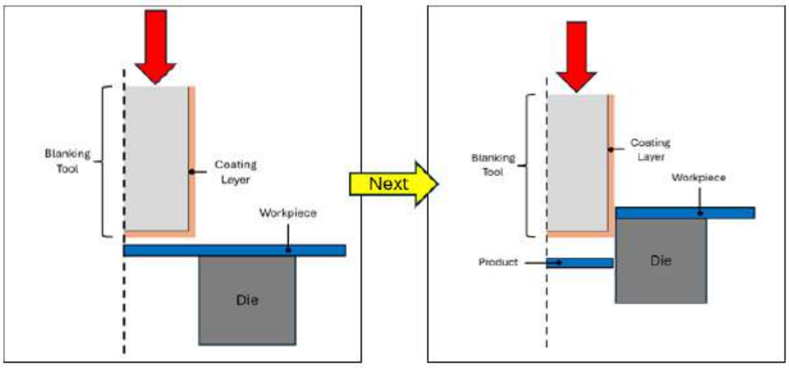



**Figure 1.** The blanking process of workpiece to product.

## RESULTS AND DISCUSSION

*Maximum force of blanking*

All coating tools exhibit a similar trend, with an increase in blanking force as the number of strokes increases. The TiN coating tool started with an average blanking force of 155.76 N for the first 10 strokes, increasing by around 31% to 50 strokes in the blanking process. Similarly, the AlTiN coating tool showed a 19% increase, from 146.72 N for the first 10 strokes to 180.62 N at 50 strokes for the average blanking force. The DLC coating tool demonstrated a small increment in blanking force, around 8% from 107.27 N in the first strokes, which is the lowest blanking force among the three coating tools. At 50 strokes, the average blanking force was 116.78 N, also the lowest among all coating tools. DLC coating shows the lowest blanking force followed by AlTiN and TiN.

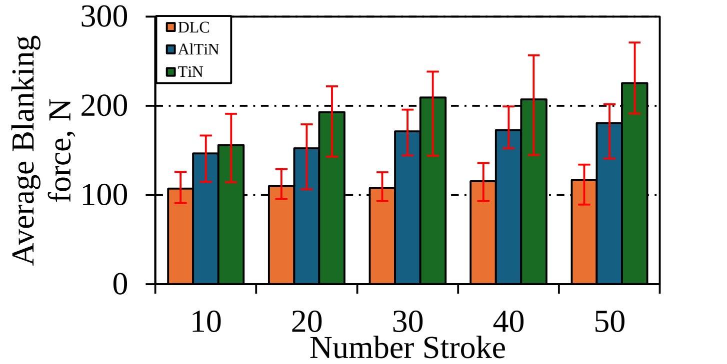



**Figure 1.** The average blanking force for every 10 strokes.

*Effect blanking force to wear*

Based on the average maximum force data in Figure 1, DLC coating exhibits the lowest force, followed by AlTiN and TiN. This trend is consistent with the wear patterns observed in Figure 2. The DLC coating shows minimal wear, as indicated by the small area of wear observed in square (1) after 50 strokes, which corresponds to the low force acting on the tool. In contrast, the AlTiN coating shows significant wear across most of the surface of the punching tool. Similarly, the TiN coating also exhibits wear across most areas, with some areas showing deformation, as seen in square (2).

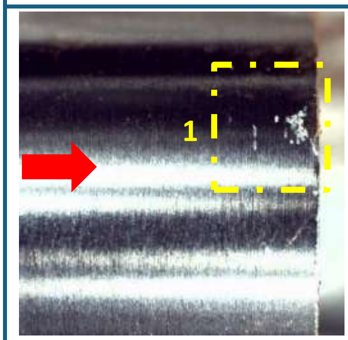
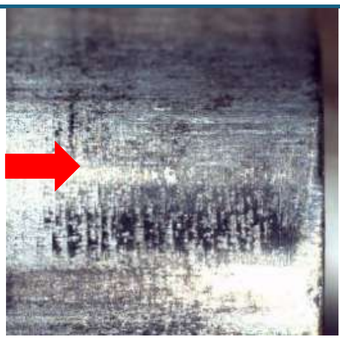
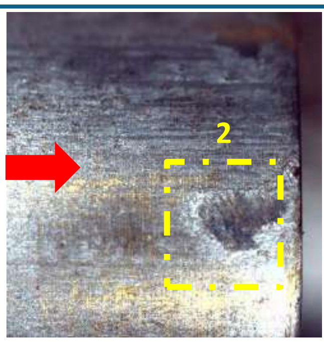
| **DLC** | **AlTiN** | **TiN** |
|---|---|---|
|  |  |  |

**Figure 2.** The wear

## CONCLUSION

From the experiment:

- As the blanking force increases, wear on the tool surface becomes more noticeable over time.
- DLC coating exhibits lower wear on the tool surface compared to AlTiN and TiN coatings after 50 uses.
- The lifetime of tools with DLC coating is longer due to reduced wear on the tool surface.

## ACKNOWLEDGEMENT

The committee members would like to thank Universiti Putra Malaysia for the support that is given to carry out this conference.

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CHAPTER 42

# PHYSICAL PROPERTIES OF OIL PALM EMPTY FRUIT BUNCH/BANANA HYBRID COMPOSITES

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**ABSTRACT**
This study delves into the characterization of physical and mechanical properties of hybrid phenol formaldehyde composites comprising Oil Palm Empty Fruit Bunch (OPEFB) and Banana(B) fibres. As sustainability and environmental concerns grow, the exploration of natural fibre-reinforced composites gains prominence due to their potential to replace conventional synthetic materials. The research aims to analyze the effects of incorporating OPEFB fibre and B fibre as reinforcements in phenol formaldehyde as matrices, examining the physical properties of the composites. The fibre was treated with 2% silane (2% Triethoxy(ethyl) silane) and composites were fabricated with different ratios of OPEFB/B which is 100/0, 75/25, 50/50. 25/75 and 0/100. The fibre loading was maintained at 60 wt%. Through experimental testing and analysis, insights are gained into the feasibility and potential applications of OPEFB/B hybrid phenol formaldehyde composites in diverse industries, including automotive, construction, and packaging. The finding reveals the water absorption and thickness swelling increase as B fibre increases. In addition, the density and void content of the composite was reported ranging from 0.31-0.35 g/cm3 and 72.80-77.13% respectively. The based on the finding the fabricated composites is suitable for indoor applications.
*Keywords:* Physical properties; Oil Palm Fibre; Banana Fibre; Phenol Formaldehyde; Water Absorption; Thickness Swelling.

## INTRODUCTION

The need of green composites due to the environmental awareness and government policy has become driving forced for the researcher to study of natural fibre-based polymer composites.

In this study banana/oil palm empty fruit bunch fibre reinforced phenol formaldehyde was fabricated to explore it potential for insulation board applications.

## MATERIALS AND METHODS

*Materials*

Fibre used is Banana and oil palm empty fruit bunch fibre while resin is phenol formaldehyde. Triethoxy(ethyl) silane) was use for treatment. Teflon sheet was used for fabrication.

*Fibre Preparation*

Fibre was cut to size 1-2cm and treated with 2% Triethoxy(ethyl) silane)

*Fabrication Method*

The composite was prepared using hand-lay up method and cured using hot-press. The formulation shown in Table 1.

**Table 1.** Fabrication formulation, density and voids content.

| Composite | Fibre ratio (OPEFB/ B) | Density ($g/cm^3$) | Voids (%) |
|---|---|---|---|
| EFB | 100/0 | 0.34 | 75.18 |
| H1 | 75/25 | 0.31 | 77.13 |
| H2 | 50/50 | 0.34 | 73.92 |
| H3 | 25/75 | 0.35 | 72.92 |
| BF | 0/100 | 0.34 | 72.80 |

*Characterizations*

The water absorption and thickness swelling of the composite was carried out as per ASTM D-1037 with sample dimensions of 152 mm × 152 mm × 13 mm. In addition, the void content of the composites was calculated based on formular in ASTM D-2734.

## RESULTS AND DISCUSSION

Density and void content were presented in Table 1 while water absorption and thickness swelling were shown in Figure 1.

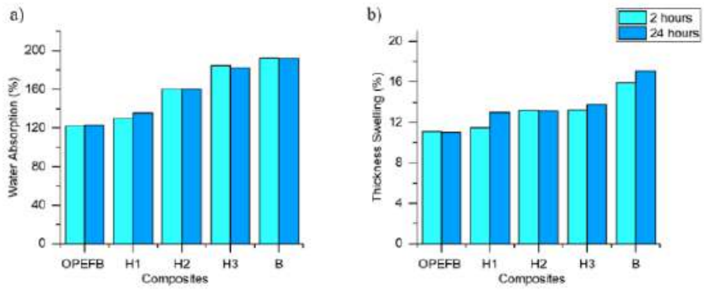


**Figure 1.** (a) Water absorption of composite, (b) Thickness Swelling of composites.

## CONCLUSION

Based the findings the composite was suitable for indoor applications.


## ACKNOWLEDGEMENT

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## CHAPTER 43

# EFFECT OF PALM STEARIN ON THE CRYSTALLIZATION AND PHYSICOCHEMICAL PROPERTIES OF POLY (LACTIC ACID) (PLA)

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**ABSTRACT**
This research aimed to produce a biodegradable polymer mix resin of poly (lactic acid) (PLA) modified with palm stearin (PS). The effect of the addition of PS as a plasticizer on the crystallization and physicochemical properties of PLA was studied. A melt blending technique has been employed to effectively generate a PLA/PS mix with PS at 5 wt%, 10 wt%, 15 wt%, 20 wt%, and 30 wt%, and this study focuses on torque analysis, rheological properties, thermal properties, PLA crystallization, and tensile properties in various compositions of PLA/PS with different PS loadings. Due to PS's low melt viscosity, adding PS to PLA reduced the overall blends' torque while mixing. The PLA matrix improved significantly in terms of ductility and elasticity when blended with 15 wt% of PS (85PLA/15PS). Added PS in PLA has insignificant effect on thermal stability of the PLA, as evidenced by the thermal degradation temperature. Overall, the incorporation of PS into the PLA composite has given some significant improvement to the mechanical and thermal properties of PLA at 15 wt% of PS incorporation.
*Keywords:* Poly(lactic acid); Biopolymer; Palm Stearin; Melt Blending.

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## INTRODUCTION

Despite its advantages, poly(lactic acid) PLA also has several drawbacks, such as brittleness and limited temperature stability [1], which limit its processing using injection moulding. According to a previous study conducted by [2], several parameters should be considered in choosing the material for injection moulding, such as its flowability during the injection and its thermal properties, such as the melting temperature ($T_m$), glass transition temperature ($T_g$), and crystallization temperature ($T_c$), as these properties determine the injection moulding procedure and the properties of the formed articles. Therefore, in this study, the effect of palm stearin (PS) addition to PLA with various PLA/PS mix ratios as a greener plasticization approach for injection moulding application and the crystallization and physicochemical characteristics of the blend were investigated.

## METHODOLOGY

### *Materials and Melt Blending*

Poly (lactic acid) (PLA) of injection molding grade (3001D) and RBD Hydrogenated Palm Stearin (PS) were used in this research. Both substances were employed in the preparation of the composites without chemical treatment. PLA granules underwent vacuum drying at 60°C for 5 hours to eliminate moisture. PLA granules and PS powder were premixed and melt-blended using an internal mixer at 170°C and 60 rpm for 10 minutes. Various PLA/PS ratios (wt%) were utilized. The blends were crushed into pellets.

### *Torque Analysis*

A torque study was performed on each blend sample using an internal mixer to determine the mixing torque as a function of mixing duration at 170 °C and 60 rpm.

### *Rheological Analysis*

The capillary rheometer was used for rheology analysis. The process for operating the capillary rheometer equipment must take the temperature of the material into account [3]. PLA/PS samples were examined at temperatures of 170 - 190°C. The viscosity was tested throughout a shear rate range of 1000 1/s to 5000 1/s.

### *Mechanical Analysis*

The mechanical parameters were determined using a tensile machine and was outfitted with a 2 kN load cell with 0.5 percent accuracy, the tensile specimens was constructed following ASTM D882-10 standards for thin. The crosshead speed is set to 25 mm/min.

### *Thermal Analysis*

Thermal characteristics were measured using a differential scanning calorimeter, where the samples were heated first from 25°C to 200°C, cooled down from 200°C to -50°C, and heated again from -50°C to 200°C, all at the same heating rate of 10°C/min. Then, a thermogravimetric analyzer (TGA, Mettler Toledo) was used to assess the degradation temperatures of the mixture. They were heated from 30°C to 600°C at a heating rate of 10°C/min.

## RESULTS AND DISCUSSION

### *Torque and Rheological Analysis of PLA/PS Using Melt Blending Technique*

Figure 1 depicts the torque curves of pure PLA as well as blends of PLA and PS as a function of mixing time at 60 rpm and 170 °C. The torque is reduced whenever there is a rise in the PS composition. The first step is significantly increased because of the addition of polylactic acid (PLA) and palm stearin (PS) to the mixing chamber. In the beginning, the lines are shifted about as the PLA/PS mixes are gradually introduced into the mixing chamber to prevent the chamber from being overfilled. After the 8th minute, the curve becomes stable as the PLA and PS get homogenized.

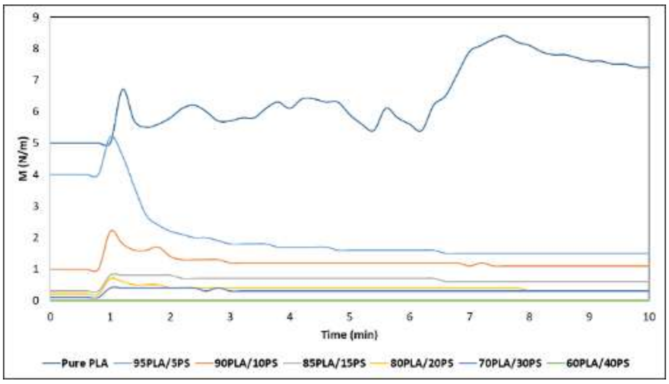


**Figure 6.** Mixing torque as a function of mixing time at 60 pm and 170 °C.

## CONCLUSION

PLA/PS mix resin with different weight percentages of PS at 5%, 10%, 15%, 20%, and 30% had been successfully created by using the melt blending technique. The results show that the incorporation of PS into the PLA matrix had a significant impact on PLA's mechanical properties. PLA incorporated with 15 wt% of PS (85PLA/15PS) demonstrated a significant improvement in PLA ductility and elasticity. The addition of PS also resulted in a slight improvement in PLA's melting point.


## ACKNOWLEDGEMENT

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## CHAPTER 44

# REINFORCING ALUMINUM MATRIX WITH CHROMIUM AND IRON FOR OPTIMUM CORROSION CHARACTERISTICS AND IMPROVED STRENGTH IN SOLAR-STILL ABSORBER

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**ABSTRACT**

The growing global population and industrial expansion have escalated the demand for freshwater, straining traditional sources. Consequently, research emphasis has shifted towards enhancing the efficiency of solar thermal systems for energy harvesting, storage, and conversion. Despite advancements, challenges persist, particularly regarding corrosion and low strength in solar radiation absorbers. This study aimed to address these challenges by reinforcing aluminum matrix with chromium and iron absorbers to optimize corrosion resistance and strengthen solar-still absorbers. Various analytical techniques were employed to characterize the composites, revealing a cubic structure and corrosion-resistant phases via X-ray diffraction. Increasing mixing time, ball mill speed, compaction pressure, and sintering temperature resulted in larger average crystallite sizes, uniform distribution, and homogeneity, as confirmed by FESEM and EDX analyses. Additionally, the influence of chromium on aluminum matrix corrosion behavior was investigated, with immersion tests confirming product stability in acidic and basic solutions. Hardness tests indicated a significant 140% increase in hardness values, demonstrating improved mechanical and corrosion properties, qualifying the material as an optimal candidate for solar still absorber applications.

*Keywords:* Aluminium matrix; Corrosion behaviour; Tensile strength; Hardness; Microstructure.

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## INTRODUCTION

Recent studies highlight the need to enhance the performance of solar thermal absorbers, as they convert concentrated solar irradiation into thermal energy, but deterioration and structural failure can lead to low distillate and heat loss [1]. Therefore, there are still a lot of unknowns regarding the intricate relationship between those materials and the aggressive, high-temperature environment that causes their corrosion [2]. As a result, corrosion and its prevention present significant challenges for thermal energy harnessing, storage, utilization, and optimization. For its non-toxicity, thermal conductivity and lightness aluminum is chosen as matrix in this study and has been reinforced with chromium due to its freedom from atmospheric attack. Owing to its, elastic and plastic qualities, iron was also selected as secondary reinforcement to improve the performance of solar still by employing powder metallurgy technique to developed a composite material as the solar thermal absorber.

## METHODOLOGY

The selection of matrix and reinforcements for the composite was based on material requirements analysis, candidate material screening, and design data development. Commercially procured materials included pure aluminum powder, pure chromium, and iron powder obtained from magnetite ore. Powder morphology of both matrix and reinforcements is illustrated in Figure 1b. Iron was added in a constant ratio of 2 wt%, while chromium was added in ratios of 1%, 2%, 3%, and 4% by weight. The materials were mixed using a planetary ball milling machine with powdered graphite as a lubricant/binder. The mixture was compacted under various conditions, including different speeds and durations, using a die and tooling machine. Compaction pressures ranged from 60 to 75 kN at a rate

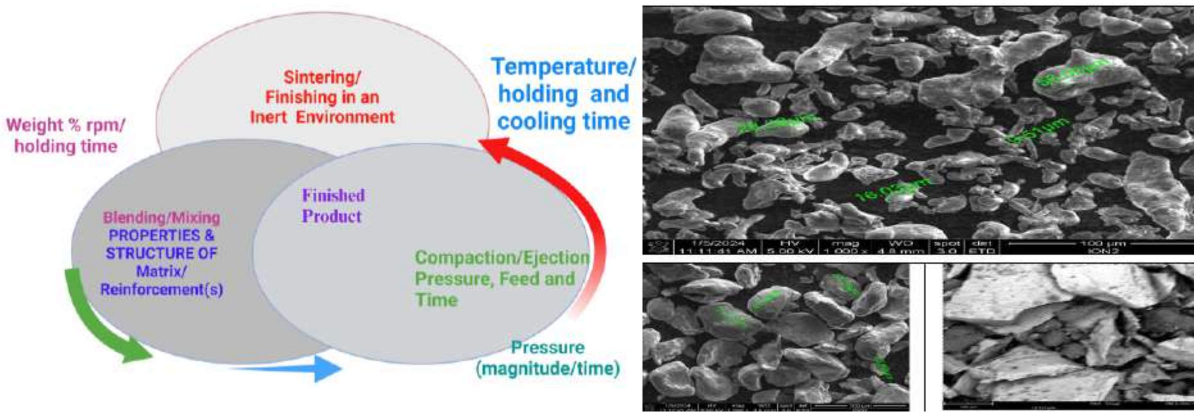


**Figure 1.** (a) basic steps in powder metallurgy processes (b) microstructure of pure i) aluminum ii) chromium iii) iron

The average hardness of the composites is measured using the Rockwell hardness test at B scale. The 1/16-inch tungsten carbide indenter is used and 100 Kgf load was exerted on the composite for dwell period of 20 secs [3]. The samples were thoroughly cleaned and immersed in a beaker containing 3.5%. Sodium chloride (NaCl) solution. The beakers is sealed with a pH value of 0.6, and incubated at a constant temperature of 25 °C for 25 days duration. Afterwards, the specimens is rinsed with acetone, deionized water, and removed corrosion products prior to weight measurement. The corrosion rate was calculated using $CR = 87.6\ (\Delta W/\rho a t)$ mm/yr……………………………… (1)

Where CR is the corrosion rate in mm/yr, K = 87.6, ΔW is the weight loss in g, ρ represents the density values of the base materials (in g/cm$^3$), a is the area of the specimen in cm$^2$, and t represents the specimen submersion time in hours. 5% HCL was used for acidic solution This process is repeated with Potassium Hydroxide (KOH), and Sodium Hydroxide (NaOH) solutions for level 2 and level 3 respectively [3] [4]

## RESULTS

Morphological and microstructure changes

a b c

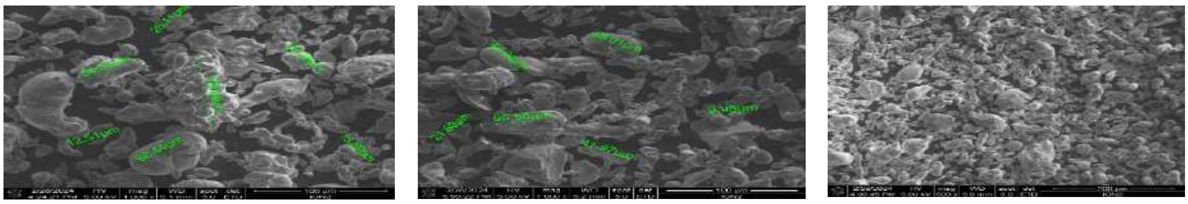

**Figure 2.** a) morphology of aluminum, chromium, and iron blended for 2hrs at 300rpm with same reinforcements loading, Figure 2 b) morphology of aluminum, chromium, and iron blended for 2hrs at 500rpm with same reinforcements loading and Figure 2 c) morphology of aluminum, chromium, and iron blended for 3hrs at 500rpm with same reinforcements loading

It can be deduced from Figure 2 that reinforcement loading and milling speed significantly influence matrix microstructure, affecting composite properties. Optimal dispersion and homogeneity achieved with 4% chromium and 2% iron loading at 3hrs and 500rpm milling time.

Mechanical and Corrosion Characteristics

a b

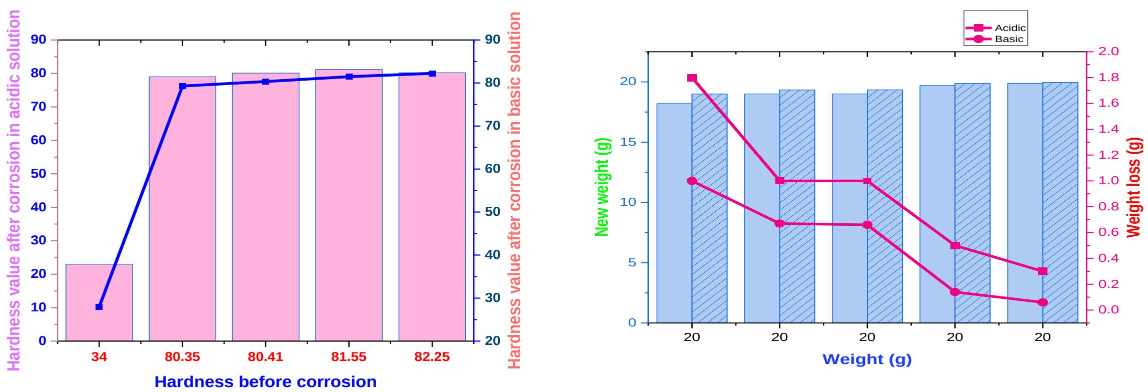


**Figure 3.** a) at constant weight % of iron, the hardness is proportional to chromium percentage up to 4w% chromium, b) corrosion characteristics of chromium-iron reinforced aluminum matrix composite

It is revealed that provided all relevant parameters are maintained at optimum level, and with constant 2w% iron, both mechanical and corrosion qualities in a chromium-iron reinforced aluminum matrix composite are directly proportional to the chromium percentage up to 4w% of chromium as illustrated in Figure 3. More so, the composite is stable in both acidic and basic solutions. This may be attributed to new phases formed by chromium and other metal including phases found in stainless steels [5].

## CONCLUSION

The composite material demonstrated stability in both acidic and basic solutions, as confirmed by immersion tests. Additionally, hardness levels increased by approximately 140%. These improved mechanical and corrosion properties make the material an excellent choice for a solar still absorber.

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## CHAPTER 45

# DEVELOPMENT OF AN ERGONOMICALLY - DESIGNED LEIQIN LEG REST USING ADDITIVE MANUFACTURING

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**ABSTRACT**
To address the discomfort associated with extended use of the *leiqin* leg rest and the instability during playing, this study employed additive manufacturing (AM) to redesign the leg rest according to ergonomic standards. The remodeled *leiqin* leg rest following semi-structured interviews with 10 experts and receiving approval from 8 experts, who confirmed that the remodeled leg rest can enhance comfort and stability. Subsequently, an acoustic test was conducted in a semi-anechoic room following the ISO3744:2010 standard. The study concluded that the resuts of the remodeled leg rest did not change much from the original leg rest. Overall, the use of AM proved effective in creating ergonomic leg rests for the *leiqin*, enhancing stability without compromising the instrument's timbre. This innovation may potentially replace traditional wooden leg rests.
*Keywords:* Additive manufacturing, Ergonomy, Musical instrument.

## INTRODUCTION

The compatibility of the instrument with human physical abilities and characteristics is one of the principles in ergonomics. Inadequate instrument set-ups and sizes that mismatch the performer's physical attributes is frequently cited as one of the factors that contribute to the development of PRMD [1]. The *leiqin,* a traditional Chinese musical instrument, was created by Wang Dianyu. It has a history of only 100 years. It is played while the player is seated in a chair or stool, with the instrument's body resting in his or her lap and held in a vertical or near-vertical position. The leg rest is a tool specifically designed to assist players in maintaining stability, balance and proper posture [2]. However, the smooth and flat bottom of the leg rest is designed reduced friction between the instrument and the player's legs, which can cause beginners to slip due to poor force control, leading to performance accidents. Additionally, the flat design of the leg rest can lead to discomfort in the legs of players who practice for extended periods.

Among the many technologies, additive manufacturing (AM) can address some of the limitations of musical instruments by offering the ability to create personalizion and customization to cater to individual requirements [3]. Several studies have focused on creating lightweight instruments through AM, including a titanium flute by Kolomiets et al. [4], a solid body guitar by RedEye RPM [5]. Barinque et al. has also made a lightweight and cost-effective violin chinrest, and also noted that AM can enable the creation of instruments with unique shapes and features, musicians can have unparalleled customization options for their instruments that would not be possible with traditional manufacturing techniques [6].

Currently, there is a lack of literature exploring the use of AM in studying the design development of the *leiqin* from both physical and musical perspectives. Therefore, this study aims to investigate the following questions: 1) Can AM be used to remodeling the ergonomic leg rest and improve the performance of the *leiqin*? 2) Are the acoustic requirements for remodelled the leg rest of the *leiqin* suitable for mass production?

## METHODOLOGY

This study is involved four stages: (1) Finding the defects and designing the leg rest. (2) Designing the remodeled leg rest. (3) Manufacturing the remodeled leg rest. (4) Acoustical testing of the remodeled leg rest. In this leg rest design, process management, and design engineering used the theory of inventive problem solving (TIPS).

Taking into account the varying heights and sizes of players, the bottom curvature of the leg rest was specifically designed to accommodate the majority of individuals. In this study, researchers utilized a handheld three-dimensional laser scanner to scan the legs of the players and collect initial data on their leg dimensions. Following the leg rest scanning, Rhino 7.3 was utilized for model creation and export to STL format. Subsequently, Magics 26.1 was employed for prepping the model for off-machine printing. The printing process took a total of 20 hours, after which the form was tested and refined to achieve the final product. The sound power level (SWL) of the remodeled leg rest and the original leg rest was tested after the successful remodeling of the *leiqin*, under conditions approximating a free field on a reflective surface. Additionally, ten *leiqin* players were interviewed using a semi-structured method to assess the comfort between the original and remodeled leg rest.

## RESULTS AND DISCUSSION

In this research, the SWLs of the *leiqin* have been thoroughly determined. As a result, the material and design scheme proposed in this research can potentially replace the original wooden leg rest, allowing for mass production while maintaining the desired sound quality.

The data gathered from interviews with *leiqin* players indicated that the remodeled leg rest has significantly enhanced comfort, and can increase the stability of the players when playing, particularly benefiting players with slender legs. This improvement can be considered a significant advantage.

## CONCLUSION

The acoustic characteristic data obtained from remodeling the leg rest of the *leiqin*, along with test data comparing the remodeled leg rest to the original leg rest, served as a foundational resource for acoustic research in folk music halls. Additionally, they offered valuable insights for the remodeling of other *huqin* musical instruments. Furthermore, the study highlighted the importance of sound source directivity in enhancing and producing musical instruments, as well as in the pickup and harmonic reproduction of instruments and the compilation of national musical pieces. Lastly, the study suggested the potential use of AM for customizing musical instruments.

**ACKNOWLEDGEMENT**

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## ABSTRACT ENTRIES

### ABSTRACT 1

# INFLUENCE OF LAYER THICKNESS OF 3D PRINTED POLYAMIDE AGAINST TEMPERATURE

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**ABSTRACT**

Polyamide is one of the materials in 3D printing that can produce valuable products to meet the needs of the industry. Previous studies have proven that the layer thickness of the 3D printed material and the increase in temperature affect the mechanical and physical properties. However, only a few studies involve polyamide material as a test material, especially in analyzing the influence of the layer thickness of the printed material and the increase in temperature on the mechanical and physical properties of polyamide. Therefore, the bending properties of polyamide with different layer thicknesses at 0.1 mm, 0.2 mm and 0.3 mm and the tensile properties of the material at different temperatures at room temperature, 75˚C and 110˚C will be studied. This study will involve polyamide (PA) materials printed at three different layer heights using the FDM process. Bending and tensile tests at different temperatures from 27˚C to 110˚C are conducted using the Instron Universal Testing Machine. The study results show that the layer height of 0.3 mm exhibits the highest flexural strength at an average rate of 11.05 MPa compared to 0.1 mm (6.739 MPa) and 0.2 mm (9.636 MPa). The tensile strength decreases when the temperature elevates, making the temperature of 110˚C have the lowest tensile value (1.591 MPa) compared to the temperature of 75˚C (1.668 MPa) and 27˚C (2.159 MPa). Several material characterizations such as SEM, TGA, DMA, DSC and density have been performed to study the microstructure and influence of tensile test temperature on the mechanical properties of polyamide.

*Keywords:* Polyamide; 3D printing; Layer height; Mechanical strength; Temperature

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## ABSTRACT 2

# BASALT POWDER AS A REINFORCEMENT IN THERMOSET AND THERMOPLASTIC BASED POLYMER COMPOSITES FOR LIGHTWEIGHT APPLICATIONS

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**ABSTRACT**

The continuous raise of environmental issues by the polymer products has led to the use of eco-friendly basalt as a reinforcement for the composites fabrication. Basalt reinforcement has attractive qualities such as non-toxicity, ease of processing steps, economical, less harmful, excellent thermal and mechanical properties. Basalt loading into different polymer matrices is indeed a comparably novel concept that may offer some very intriguing views, which have not yet been fully explored. The ability of mineral filler such as basalt powder to reduce the polymer portion in polymer goods by retaining their original characteristics contributes to the creation of a pollution-free ecosystem and the balancing of ecological issues. In this context, the current research aims to manufacture and characterize thermoset (i.e., synthetic epoxy, bio-epoxy, polyester and vinyl ester) and thermoplastic (i.e., polylactic acid, polypropylene, high density polyethylene) based composites reinforced with the same weight content (i.e., 30%) of basalt powder. These composites were employed to physical, mechanical, wettability (contact angle analysis), morphological and water absorption investigations. Moreover, basalt powder was subjected to elemental analysis (Energy dispersive X-Ray), particle size distribution, and morphological (Scanning Electron Microscopy) observations. The experimental results revealed that the tensile, flexural, and impact strengths properties of composites were slightly reduced in comparison to neat polymers because of higher reinforcement. Besides, the tensile modulus, flexural modulus, and hardness values were gradually improved due to filler effect. The increased water absorption is mainly caused by the voids inside of the composites, which create the perfect environment for moisture to seep into the interface. However, the obtained findings can be considered satisfactory for prospective applications in concern with lightness and environmental friendliness.

*Keywords:* Basalt; Polymer composites; Mechanical properties; Contact angle; Water absorption; Morphology.

## ABSTRACT 3

# MARINE WASTE AS A RESOURCE: DEVELOPING BIO-EPOXY COMPOSITES FOR A SUSTAINABLE FUTURE

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**ABSTRACT**

Biowastes from discarded fish scales and seashells are rich sources of natural polymers, such as collagen, keratin, and calcium carbonate, that can be used to produce eco-friendly and biodegradable polymer composites. Therefore, utilizing the biowastes for manufacturing polymer composite can offer economic, environmental, and social benefits. This experimental study explores the use of SR33 Biopoxy as a matrix and fish scale and seashell powders derived from biowastes as filler reinforcements while the composites were manufactured through open mold stir casting technique. Thereafter, the fillers were extracted and processed from raw waste sources, and were characterized using XRD and FTIR analyses. Mechanical and physical properties, including density, water absorption, fracture morphology, flexural, tensile, impact strength, and hardness, was also evaluated to assess the composite's performance. Additionally, thermal properties were investigated through DSC and TGA analyses. The results revealed that green composites with fish scale fillers at 2.5 wt.% and seashell fillers at 7.5 wt.% exhibited superior performance. These compositions demonstrated enhanced mechanical and thermal properties, suggesting their efficacy in reinforcing the SR33 Biopoxy matrix. The study underscores the potential of utilizing biowaste derived fillers for sustainable and eco-friendly composite materials. The combination of SR33 Biopoxy with these specific filler concentrations presents a promising avenue for developing green composites with favorable mechanical and thermal characteristics, contributing to the ongoing efforts for sustainable material development.

*Keywords:* Fish scale, Seashell, Bio Epoxy, Bio wastes, Waste to Wealth, Natural Composites.

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**ABSTRACT 4**

## CRITICAL ASSESSMENT OF THE THERMAL STABILITY AND DEGRADATION OF CHEMICALLY FUNCTIONALIZED NANOCELLULOSE-BASED POLYMER NANOCOMPOSITES

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**ABSTRACT**

In the last century, global awareness of the environmental repercussions associated with petroleum-based polymer composites has surged. This realization urged extensive scientific research directed towards plant-based biomass, particularly nanocellulose, as a reinforcing element in polymer matrices. Markets and Markets project the nanocellulose market to reach USD 783 million by 2025. Despite nanocellulose's performance benefits, its poor compatibility with hydrophobic polymer matrices poses challenges, limiting thermal stability and impeding widespread commercialization at higher processing temperatures. To overcome these issues, chemical modification or functionalization emerges as a promising solution to enhance nanocellulose-based polymer nanocomposites' thermal stability. The abundance of hydroxyl groups on nanocellulose enables specific chemical modifications, such as grafting functional molecules or forming covalent/ionic bonds with the polymer matrix. This study aims to validate that integrating chemically functionalized nanocellulose into various polymer matrices, including thermoset, thermoplastic, and bio-polymer, enhances the thermal stability of resulting polymer nanocomposites, supported by thermogravimetric analysis (TGA). The paper also explores six additional factors influencing TGA in nanocomposites, providing a comprehensive understanding of elements impacting the thermal properties of these materials.

## ABSTRACT 5

# TENSILE AND THERMAL PROPERTIES OF POLYURETHANE FOAM/COCONUT HUSK COMPOSITE FOR AIR CONDITIONING INSULATION

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**ABSTRACT**

Over the last decades, natural fiber-reinforced polymer composite has been of interest to scientists and researchers for their favorable mechanical and thermal characteristics, offering a potential alternative to synthetic materials. This study aims to investigate the capability of natural fiber-reinforced polymer composite that can be used as air conditioning insulation systems. Here, polyurethane foam is blended with coconut husk at a weight percentage of 5–25%. The results indicate that the thermal conductivity coefficient falls within the acceptable range values, which is between 0.041 and 0.046 W/m.K. On other hand, the tensile strength increases as the weight percentage of the natural fiber increased, ranging from 0.2 to 0.744 MPa. Additionally, the analytical hierarchy process (AHP) method is used to identify the suitable weight percentage of fibre based on the selected parameters. It is showed that the 25% wt is the most suitable percentage selection of the fibre for the composite fabrication.

*Keywords:* Analytic hierarchy process (AHP), Coconut husk, Polyurethane foam ,Thermal conductivity.

## ABSTRACT 6

# HYBRID GLASS/JUTE FIBER EPOXY COMPOSITES: THERMAL CYCLING EFFECTS ON FLEXURAL BEHAVIOR

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**ABSTRACT**

This research focuses on the development and characterization of a hybrid glass/jute fiber reinforced epoxy composite intended for use as tooling materials subjected to elevated temperatures during service. The study investigates the influence of processing parameters and thermal degradation on the flexural properties of the hybrid laminated composites. Fabrication of the hybrid laminated composites was conducted using optimized parameters derived from vacuum infusion processes. Subsequently, the fabricated composites underwent exposure to thermal cycles at room temperature, 120°C, and 200°C to assess their flexural and physical properties. Results from flexural testing were complemented by evaluation of physical properties such as density and water absorption, as well as thermal analysis. The findings reveal that hybridization between glass and jute fibers resulted in a weight reduction of approximately 25% in the samples. Moreover, the hybrid glass/jute fiber reinforced epoxy laminated composite exhibited a water absorption of less than 10%, with a decreasing trend observed with an increase in the number of thermal cycles. Composites exposed to higher temperatures (200°C) demonstrated slightly elevated water absorption (14%) compared to those exposed to 120°C. Thermal cycling at various temperatures and durations significantly influenced the stability of both physical and mechanical properties of the hybrid laminated composites. Composites subjected to thermal cycles at 120°C maintained their flexural properties even after multiple cycles, indicating notable thermal stability and structural integrity. Conversely, composites exposed to higher temperatures (200°C) initially experienced substantial decrements but exhibited marginal deformation once full curing was achieved. This research highlights the potential of the hybrid composite as a viable candidate for replacing entirely synthetic fiber-based composites, offering advantages in terms of strength-to-weight ratio, cost-effectiveness, and sustainability.

## ABSTRACT 7

# HEAT TREATMENT ON MULTI-MATERIAL ADDITIVE MANUFACTURING FABRICATED BY LASER POWDER BED FUSION

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**ABSTRACT**
Multi-material additive manufacturing (MMAM) is a 3D printing operation that prints a single part consists of different materials. For metals, laser powder bed fusion (LPBF) may be suitable for such approach. To date, there is very limited reports on MMAM of metals with LPBF. However, such approach seems viable with other powder metallurgy techniques such as powder injection molding (PIM). It is said that MMAM part is possible to have the combination of advantages properties of a single material. Therefore, driven by its feasible and novelty value, two different metals; SS316L and SS630 are used to fabricate the MMAM part via LPBF. Such materials pairing is due to not too distinct thermal properties differences and unique combination of non-magnetic (SS316L) and magnetic (SS630) materials. A printing strategy with similar processing parameters is applied to achieve the SS316L/SS630 MMAM parts. Residual stresses are commonly reported on LPBF parts where such stresses can be reduced by a heat treatment process called annealing. In this work, annealing heat treatment was applied on the SS316L/SS630 MMAM parts. Analysis on hardness and microstructure was conducted on non-treated and heat treated SS316L/SS630 MMAM parts. It was found that the hardness of SS316L/SS630 MMAM parts were reduced after the heat treatment. For microstructure analysis, no delamination or cracks were observed on the joining region of the SS316L/SS630 MMAM parts. This means that the printing strategy was successfully implemented and able to produce intact MMAM parts. An intermetallic layer between the SS316L and SS630 was also observed that shows a good fusion of bonding occurred during the printing of SS316L/SS630 MMAM parts. For SS316L, it was observed that the amount of austenite reduced after the heat treatment while for SS630, the martensite was changed partially to austenite after heat treatment.
*Keywords:* Laser powder bed fusion; Multi-material additive manufacturing; Stainless Steel, Heat Treatment; Hardness; Microstructure

## ABSTRACT 8

# TI6AL4V-LPBF MICROSTRUCTURAL CHANGES THROUGH ALTERATION OF HEAT TREATMENT PARAMETERS

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**ABSTRACT**
Residual stress is frequently reported in LPBF products due to the high thermal gradient between laser beam and powder bed during processing. High residual stress in final parts can lead to detrimental defects like pores, cracks and delamination. Heat treatment has been commonly applied as a method for stress relief. Four main heat treatment parameters include heating temperature, heating rate, cooling rate, and holding time. However, past studies rarely focused on all four parameters. Thus, this work aims to investigate the effect of heat treatment parameters on the microstructure of Ti6Al4V-LPBF samples. Ti6Al4V cubic samples were LPBF printed using parameters of laser power = 200 W, scanning speed = 1200 mm/s, layer thickness = 40 μm, and hatching distance = 60 μm. Annealing heat treatment were then applied at nine sets of varied parameters based on the DOE Taguchi L9 method. The heat treatment parameters used were (i) heating temperature: 835 °C - 1035 °C, (ii) heating rate of 2 °C /min - 10 °C/min, (iii) holding time: 4 hours - 8 hours and (iv) cooling rate controlled at 0.6 °C/min. The heat-treated cubic samples were evaluated on their microstructure properties. Heating temperature was found to be the most significant parameters in influencing the microstructure performance of Ti6Al4V-LPBF samples. Microstructure analysis revealed changes from acicular α' martensite to α + β phases.
*Keywords:* Laser powder bed fusion; Ti6Al4V; Heat Treatment; Hardness; Microstructure

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## ABSTRACT 9

# CHARACTERISTICS OF THERMOPLASTIC CASSAVA STARCH/NATURAL FIBRE COMPOSITES: A REVIEW

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**ABSTRACT**
Starch is a versatile substance with a wide range of applications. It is widely used in the food business to encapsulate flavours, as a thickening or filling ingredient, in bread items, syrup manufacture, and others. Apart from the commonly known application, starch can be converted into biopolymer with the presence of heat and plasticizer, namely, thermoplastic starch. However, neat thermoplastic starch possesses poor physical properties which limits the potential application. Hence modification of this material is necessary to improve its functionality. In this review, various modifications of thermoplastic starch via incorporation of natural fiber will be discussed and the characteristics of the fully bio-based composites will be presented as well. Overall, thermoplastic starch with appropriate modifications shows promising characteristics as alternative polymer materials. Comprehensive study on the performance of the material upon exposure to humid environments is an interesting study to be further explored.
*Keywords:* Cassava starch; Coconut husk fibre; Fibre size; Thermoplastic starch.

## ABSTRACT 10

# MECHANICAL PROPERTIES OF PLA BIOCOMPOSITE REINFORCED WITH SUGARCANE BAGASSE FIBER USING 3D PRINTING METHOD: EFFECT OF ALKALIZATION ON FIBER SURFACE

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**ABSTRACT**

The use of natural fibers is becoming increasingly diverse nowadays. This is evident from the numerous studies discussing natural fibers as biocomposite blend materials. This study examines biocomposites based on PLA and sugarcane bagasse fiber produced using the 3D printing method. The effect of alkalization on the fiber surface was studied on the mechanical properties of the biocomposite. Sugarcane bagasse fibers were subjected to alkalization treatment with NaOH solutions of 4%, 6%, and 8% by weight. The percentage of fiber in the matrix was kept at 2%. The 3D printing method was employed for fabricating tensile test specimens. Fracture morphology was observed by scanning electron microscope (SEM). The results show that the tensile strength increases with higher NaOH concentration. The highest tensile strength was at 6% for 34.59 MPa. This result is very different from the biocomposite without treatment, namely 19.10 MPa. SEM displays that this biocomposite sample (6% alkalization) has strong bonding between the PLA matrix and fibers. This phenomenon of increasing mechanical properties shows that NaOH treatment has been successful as a treatment to improve the bond between matrix and fiber.

*Keywords:* Sugarcane bagasse fiber; Polylactic acid; Alkali treatment; Tensile strength; Morphological structure.

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ABSTRACT 11

# INVESTIGATION ON EFFECTIVE STIFFNESS OF FUSED DEPOSITION MODELLING INFILL LATTICE PATTERN MADE FROM POLYLACTIC ACID-SUGAR PALM FIBER COMPOSITES

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**ABSTRACT**
Fused Deposition Modeling (FDM) uses a wide variety of materials in additive manufacturing, including the developing use of bio-composite filaments, which offer sustainable alternatives to synthetic filaments harmful to the environment. This project focused on determining the effective stiffness of SPF-PLA filament, a bio-composite, in lattice structures with varying infill densities and patterns using the FDM method. The SPF-PLA filament, consisting of 7.5% SPF and 92.5% PLA, underwent alkaline and silane treatments to enhance its mechanical properties. It was then extruded into 1.75 mm diameter filament and used to 3D print samples according to ASTM D790 standards, with infill densities of 20%, 30%, 40%, and 50%, and triangle or tri-hexagon patterns. These samples were tested for flexural strength using a 3-point bending test to calculate their effective stiffness. Statistical analysis, including simple linear regression, was conducted to predict Young's Modulus and Shear Modulus based on infill density and pattern. Micro-characterization was also performed to identify any defects affecting mechanical properties. Results showed that samples with triangle patterns were more ductile and withstood higher flexural loads than those with tri-hexagon patterns, which were less ductile. Increasing infill density also improved mechanical properties. However, different mechanical properties were observed under different parameters that can be applied for specific situations by using the bio composite filament.

## ABSTRACT 12

# HONEYCOMB PAPER FOR CUSHIONING PACKAGING MATERIAL: A MINI REVIEW

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**ABSTRACT**
Honeycomb paperboard is a type of environmentally friendly cushioning packaging material that applied natural fibre as a based material which can be structured via various designs. Recently, the demand of such paperboard is increasing in many industrial sectors regarding fanciful characteristics, eco-friendly, recyclability, cost, exceptional protection, versatility, strength, compact storage, efficient packaging, pleasant unboxing experience and countless factors. The objective of this study is to share information about the application of honeycomb paperboard which is becoming more popular. From the literature review carried out, honeycomb paperboard has high potential to expand in the market depending on many reasons mainly the sustainability of raw material.
*Keywords:* Honeycomb; Paper; Board; Medical Purpose; Papermaking.

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## ABSTRACT 13

### IMPACT OF THE CARBON AND NITROGEN CONCENTRATIONS ON THE PRODUCTION OF POLYHYDROXYALKONATES (PHA) USING *PRIESTA MEGATERIUM* AND ITS STATISTICAL ANALYSIS

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**ABSTRACT**

Demand for biodegradable plastics has increased in recent years as a result of environmental concerns related to traditional plastics. Polyhydroxyalkanoates (PHA) produced through microbial fermentation is an appropriate solution to this problem. This study evaluates the development of PHA using *Priestia megaterium* bacteria, a novel species with a high potential for biopolymer production. The specificity of this strain lies in shift in the production of scl-PHA to mcl-PHA as well as lcl-PHA and even a innovative combination of both types of monomers having improved features and versatility in applications. Gas chromatography (GC-MS and GC-FID) investigations revealed the presence of a mixture of scl and mcl-PHA, as well as the monomer composition. The highest amount of PHA produced at a C/N ratio of 25 was 4.73 g. $L^{-1}$ (60%) of dry cell weight. Transmission electron microscopy (TEM) has been used to study the structure and nature of bacterial cells. It is determined that *Bacillus megaterium* can produce both scl-PHA and mcl-PHA while feeding on a nitrogen-deficient mineral medium.

## ABSTRACT 14

# IMPROVING THE DIELECTRIC AND THERMAL PROPERTIES OF NATURAL ESTER OIL WITH NANOPARTICLE INFUSION FOR ELECTRICAL AND HEAT TRANSFER APPLICATIONS.

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**ABSTRACT**

Natural ester oils are a biodegradable and environmentally friendly alternative to traditional mineral oils in a wide range of industrial applications. However, their suitability for electrical insulation and heat transfer tasks is frequently limited by poor dielectric and thermal properties. This study proposes a method for addressing this issue by incorporating nanoparticles into natural ester oils, with the goal of significantly improving performance. Systematic experimentation and characterization to determine the effects of nanoparticle infusion on key properties such as dielectric breakdown strength and thermal conductivity. Using advanced techniques such as dielectric and thermal conductivity measurements, gain insight into the mechanisms underlying the improvement of dielectric and thermal properties. Furthermore, morphological analysis sheds light on the dispersion and interaction of nanoparticles in the ester oil matrix. The findings not only demonstrate significant improvements in dielectric breakdown strength and thermal conductivity, but also shed light on the optimal nanoparticle concentrations and dispersion methods. These findings have significant implications for the development of high-performance dielectric fluids and heat transfer media based on nanoparticle-infused natural ester oils. This research advances the field of sustainable dielectric and thermal fluids, creating new opportunities for their use in electrical transformers, capacitors, and other heat-intensive manufacturing processes. By leveraging nanoparticles' unique properties can develop more efficient and environmentally friendly options for electrical and heat transfer applications.

## ABSTRACT 15

### A PROMISING OF BACTERIAL CELLULOSE BIOMATERIAL FOR ADVANCED WOUND DRESSINGS: FROM SYNTHESIS AND MODIFICATION TO SCALE-UP INDUSTRY

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**ABSTRACT**
Bacterial cellulose (BC) emerges as a promising wound dressing material due to its flexibility, high water content, and hydrophilicity. Notably, BC combined with biocides shows potential as an antibacterial dressing. Beyond wound care, BC boasts applications in food, cosmetics, and biomedicine. This review explores BC's applications in skin regeneration, wound healing, and biomedicine, highlighting its biocompatibility and unique structure. We delve into BC synthesis methods, modifications for enhanced performance, and promising antibacterial composites like chitosan and silver. Additionally, the review explores the exciting potential of 3D-printed BC. This review serves as a valuable resource on BC's potential, particularly in biomedicine as an antibacterial wound dressing component.
*Keywords:* Bacterial cellulose; Antibacterial BC; Promising of wound dressing BC; *Acetobacter xylinum*

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