International Research Journal of Education and TechnologyPeer Reviewed Journal
ISSN 2581-7795

PROCESSING AND TESTING OF BANANA FIBER NATURAL COMPOSITE

Premkumar G[1], Rukiren Analsee GK[2], Sridhar B[3]

[1]*Premkumar G B.E Mechanical Engineering, Bannari Amman institute of technology, Erode.*
[2]*Rukiren Analsee GK, B.E Mechanical Engineering, Bannari Amman institute of technology, Erode.*
[3]*Sridhar B*, B.E Mechanical Engineering, Bannari Amman institute of technology, Erode.

---***---

Abstract - *The demand for sustainable and lightweight materials in the automotive industry has led to increased interest in natural fiber composites as alternatives to synthetic, petroleum-based materials. This study explores the development and evaluation of a banana fiber composite, reinforced with 30% cotton fiber and bonded with polyester resin, for potential use in automotive components. Banana fiber, sourced from the pseudo stem of banana plants, is an abundant, biodegradable material with high tensile strength and flexibility, making it suitable for eco-friendly applications. Blending banana fiber with cotton enhances its toughness, flexibility, and impact resistance, while polyester resin provides structural support and effective fiber-matrix adhesion.*

The composite was fabricated using the compression molding technique to ensure a uniform fiber distribution and a good surface finish. Key mechanical properties, including tensile strength, flexural strength, and impact resistance, were tested to assess the composite's loadbearing capacity and resilience under bending and impact forces. Additionally, thermal analysis was conducted to evaluate the composite's stability under high temperatures, which is essential for automotive applications that require durability in varying temperature conditions. Water absorption tests were performed to determine the material's resistance to moisture, a crucial factor for longevity in humid environments.

Results indicate that the banana fiber-cotton blend composite exhibits satisfactory mechanical properties, particularly in terms of strength-to-weight ratio, impact resistance, and thermal stability. Comparisons with conventional glass fiber composites suggest that banana fiber composites offer comparable performance with the added benefit of being lightweight and biodegradable. This study supports the potential of banana fiber composites as a viable alternative in the automotive industry, contributing to reduced environmental impact by minimizing the reliance on non-renewable resources. Further research into large-scale production and material optimization is recommended to facilitate the integration of natural fiber composites in automotive manufacturing.

***Key Words*: Sustainable materials, Natural fiber composites, Banana fiber, Cotton fiber, Polyester resin, Compression molding, Mechanical properties, Tensile strength, Flexural strength, Impact resistance, Biodegradability.**

1. INTRODUCTION

Banana fiber, derived from the pseudo stem of banana plants (Musa spp.), is an emerging natural fiber known for its strength, flexibility, and biodegradability. With a high cellulose content, banana fiber offers desirable mechanical properties, making it suitable for eco-friendly composite applications. Blending banana fiber with other natural fibers, such as cotton, enhances its toughness and flexibility, allowing for improved load distribution and durability. Polyester resin, selected as the matrix material, provides structural support and good adhesion with natural fibers, creating a strong fiber-matrix bond. This study focuses on developing a composite material comprising banana fiber reinforced with 30% cotton and bonded with polyester resin, specifically tailored for use in automotive components. Testing will include tensile, flexural, and impact strength assessments, along with thermal and water resistance analysis, to determine the composite's suitability for demanding applications. By optimizing the composition and evaluating its performance, this research aims to introduce a sustainable alternative to synthetic fibers, promoting reduced plastic usage and environmental impact in the automotive industry.

2. BACKGROUND OF THE WORK

The increasing demand for sustainable materials in the automotive and other industries has driven research into natural fiber composites as a potential substitute for traditional synthetic fibers. Among natural fibers, banana fiber has garnered attention due to its abundance, biodegradability, low cost, and favorable mechanical properties, making it an eco-friendly alternative. In the quest to further reduce the environmental footprint, banana fiber composites can be blended with other natural fibers and resins to enhance specific properties, such as strength, durability, and thermal stability, thereby creating a viable option for load-bearing applications, including automotive components.

3. MATERIAL SELECTION

In this study, banana fiber is used as the primary reinforcement due to its lightweight, high tensile strength, and environmental benefits. Polyester resin was chosen as the matrix material because of its ease of processing, good adhesion to natural fibers, and satisfactory mechanical properties. To improve the composite's toughness and flexibility, cotton fiber, blended at 30% with banana fiber, was incorporated into the design. Cotton not only improves the elasticity and tensile strength of the composite but also reduces its brittleness, providing a better load distribution within the material.

4. COMPOSITE FABRICATION

The composite was manufactured using the compression molding technique, a widely used process for fabricating fiber-reinforced plastics. This method offers advantages such as good surface finish, efficient fiber-matrix bonding, and uniform fiber distribution. The composite sample was prepared with an optimal layering structure to balance strength, weight, and durability, with each layer contributing to the load-bearing capability of the composite.

5. TESTING OF THE COMPOSITE

To assess the mechanical performance and durability of the banana fiber-cotton blended composite, a series of tests were conducted, including:

1. Tensile Strength Test: This test measures the material's resistance to breaking under tension. It provides insights into the composite's load-bearing capacity, which is critical for applications in automotive components.

2. Flexural Strength Test: This test evaluates the composite's ability to withstand bending forces. It helps in assessing the material's rigidity and suitability for structural parts that may undergo bending stresses.

3. Impact Strength Test: This test determines the energy absorbed by the composite during impact, simulating real-world conditions where components face sudden forces or shocks.

4. Thermal Analysis: To ensure the composite's thermal stability, thermal analysis was conducted to observe its behaviour at elevated temperatures, which is essential for automotive applications exposed to high temperatures.

5. Water Absorption Test: This test evaluates the composite's water resistance, essential for durability in varying environmental conditions.

The combination of banana Fiber with polyester resin and 30% cotton blending provides an innovative approach toward developing a sustainable material with improved mechanical properties, suitable for applications in the automobile industry. The conducted tests aim to validate the composite's effectiveness and suitability as a lightweight, high-strength, and ecofriendly alternative to synthetic Fibers traditionally used in automotive parts.

6. SCOPE OF THE WORK

The scope of this work focuses on the development, characterization, and evaluation of a banana fiber composite reinforced with 30% cotton and polyester resin for potential application in the automotive industry. This project aims to explore the feasibility of using natural fiber composites as a replacement for synthetic fiber materials to create environmentally sustainable, lightweight, and durable automotive components, with an emphasis on front bumpers and other impact-resistant parts. The specific areas covered in this study include:

1. Material Development: The study involves the fabrication of a composite using banana fiber as the primary reinforcement, blended with cotton at a 30% ratio and bonded with polyester resin. The aim is to optimize the composition and structure of the composite to achieve a balance between weight reduction and mechanical strength.

2. Characterization of Mechanical Properties: Comprehensive testing will be conducted to assess the mechanical properties of the composite, including tensile strength, flexural strength, impact resistance, and water absorption. These tests are critical for evaluating the composite's performance under various loading and environmental conditions, particularly those relevant to automotive applications.

3. Thermal Stability Analysis: This includes evaluating the thermal properties of the composite to ensure stability under high temperatures, as automotive components often operate in environments that experience significant temperature fluctuations. The goal is to verify that the material can maintain its properties and durability over a range of temperatures.

4. Comparative Analysis with Conventional Materials: The study will compare the results of the banana fiber composite with traditional synthetic materials such as glass fiber composites. This comparison is necessary to evaluate if the banana fiber composite can meet or exceed the performance standards required in the automotive industry, while also offering the advantages of being lighter and more eco-friendly.

5. Evaluation of Environmental Impact: Beyond performance, the study assesses the environmental benefits of using banana and cotton fibers over synthetic fibers. This includes considerations of the material's biodegradability, carbon footprint, and end-of-life disposal options. The goal is to demonstrate the sustainability advantage of natural fiber composites as a step toward reducing plastic usage in automotive manufacturing.

6. Feasibility for Large-Scale Production: The research will also examine the practicality of scaling up the manufacturing process for potential commercialization. This includes the cost effectiveness, availability of raw materials, and any challenges that may arise in transitioning to large-scale production of banana fiber composites for automotive components.

7. Prototype Development and Testing: As a part of applied research, the scope includes developing a prototype of a front bumper or similar automotive component using the fabricated banana fiber composite. The prototype will undergo testing to validate its performance and durability in simulated real-world conditions, ensuring it meets the required safety and regulatory standards for automotive parts.

The outcome of this work is expected to establish a framework for implementing banana fiber composites in automotive design, reducing dependency on non-renewable, petroleum-based materials. Through the successful completion of this study, the groundwork will be laid for further research and development of natural fiber composites, with potential applications not only in the automotive industry but also in consumer goods, construction, and other fields that require lightweight, sustainable materials.

7. OBJECTIVE AND METHODOLOGY

This chapter presents the objectives and methodology of the study, concentrating on optimizing techniques to enhance the performance of composites with banana fiber as the matrix and polyester as the composite. It outlines the key research goals, such as identifying the most effective methods for improving composite properties, and provides a detailed description of the experimental approaches used. This chapter serves as a guide for understanding the systematic processes undertaken to enhance the performance and properties of banana fiber-polyester composites and establishes a foundation for analyzing the outcomes.

8. OBJECTIVES OF THE PROPOSED WORK

• To study different mechanical and chemical properties of the composite material that reduces reliance on synthetic fibers

• Optimization of material by combining the different volumes of fiber and matrix which is reliable, durable and sustainable.

• To replace this composite as a valuable fiber which can replace plastic parts in automotive sectors.

9. METHODOLOGY

9.1 MATERIAL REQUIREMENTS

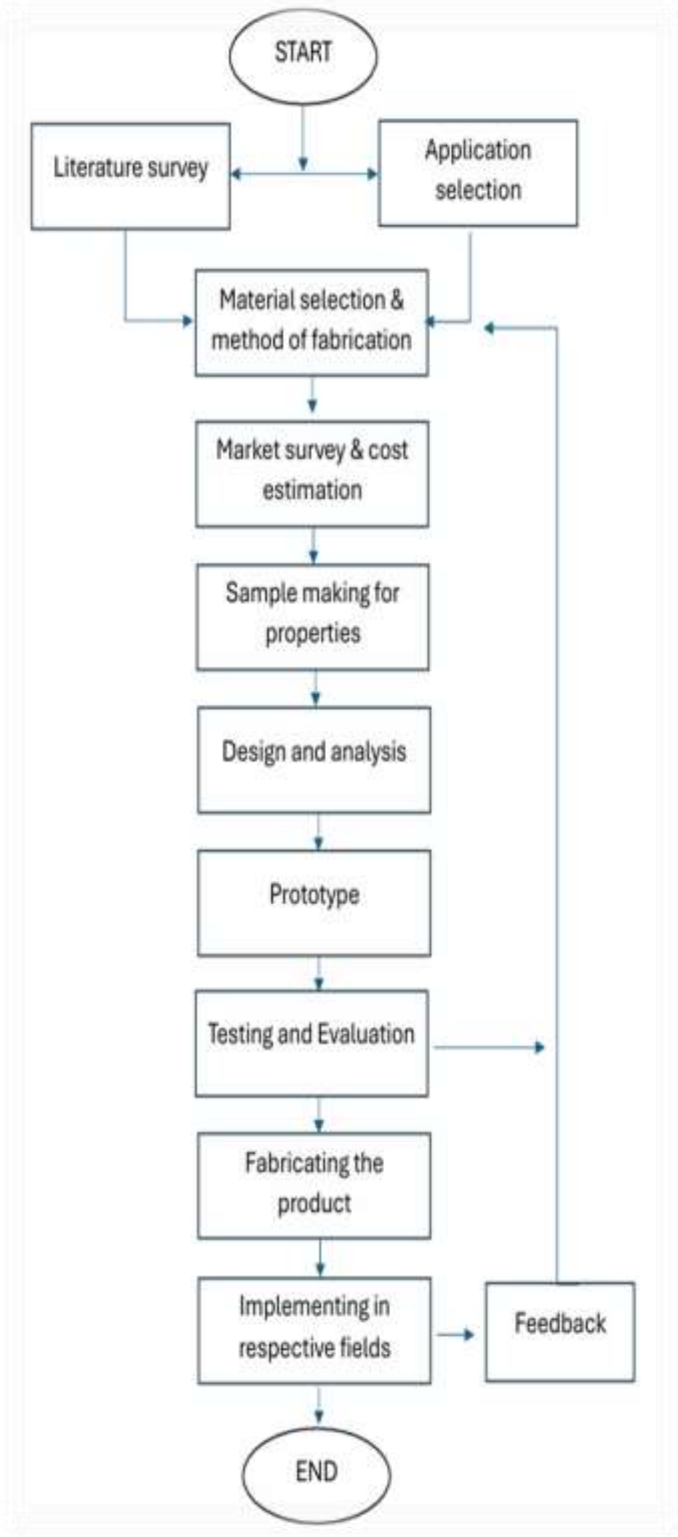
9.1.1 RAW MATERIAL

- BANANA FIBRE
- COTTON FIBER
- CATALYST
- HARDENER
- LIQUID PARAFFIN WAX
- POLYESTER RESIN

9.1.2 EQUIPMENTS

- UNIVERSAL TESTING MACHINE
  - TENSILE
  - FLEXURAL
  - HARDNESS
  - IMPACT TEST
- WATER ABSORBTION
- THERMOGRAVITY ANALYSER
- SCANNING ELECTRON MICROSCOPE
  COMPRESSION MOULDING MACHINE

International Research Journal of Education and TechnologyPeer Reviewed Journal
ISSN 2581-7795



Flow chart-1: proposed flow chart

10. RAW MATERIAL SELECTION

The selection of raw materials for preparing banana stem is critical to optimizing the yield and quality of the product. First, the variety of banana stems must be carefully chosen, with emphasis on using fresh, healthy stems that are free from pests or diseases to prevent contamination. The core and outer layers of the stem are preferred due to their high fiber content and other beneficial compounds. Harvesting should occur at the optimal growth stage, typically when the plant is mature but before the fruiting process, when nutrient content is at its peak.

Moisture content also plays a significant role, as fresh banana stems contain more water and may require drying or direct aqueous processing, while dried banana stems are ideal for extractions using organic solvents. For quality assurance, organically grown banana stems are preferred to avoid pesticide residue, and locally sourced materials ensure freshness and minimize the degradation of beneficial components during transportation. The size of the plant material is also important; chopping or grinding banana stems into uniform pieces enhances the processing efficiency by increasing the surface area for solvent interaction. Finally, seasonal factors and post-harvest handling influence the chemical composition and preservation of the beneficial compounds. Harvesting during the peak season and immediate processing or proper storage in cool, dry conditions ensure maximum retention of beneficial properties, contributing to the overall success of the preparation process.

11. DRYING

Drying is a crucial step in the preparation of banana fibers for various applications, particularly in preserving the quality of the fibers and preventing microbial growth. It involves removing moisture from the raw material to ensure the fibers are stable and maintain their integrity during storage and further processing. One effective method for drying banana fibers is using a fluidized bed dryer. This technique offers several advantages, including uniform drying, controlled temperature conditions, and efficient moisture removal, all contributing to maintaining the quality of the banana fibers.

In a fluidized bed dryer, hot air flows through a bed of suspended banana fibers, creating a fluid-like movement that increases the exposed surface area, leading to faster and more efficient drying compared to methods like air or sun drying. The continuous airflow ensures uniform drying, preventing issues like over-drying or under-drying. This consistency is crucial for preserving the structural integrity of the banana fibers, which can be sensitive to heat and prolonged air exposure. The drying process is conducted at

International Research Journal of Education and TechnologyPeer Reviewed Journal
ISSN 2581-7795

55°C for 60 minutes, effectively removing moisture without reaching temperatures that could degrade the fibers.

By reducing the moisture content to an optimal level, typically around 8-10% for most fibers, drying minimizes the risk of microbial growth, mold formation, and enzymatic reactions that can degrade the quality of the banana fibers. Properly dried fibers are more stable for long-term storage and can be easily processed for further applications. Maintaining the integrity of the fibers during drying is paramount, as they can be lost or altered if exposed to excessive temperatures or improper drying conditions.

Moreover, the efficiency of drying also impacts the overall processing of banana fibers. Fibers with inconsistent moisture content can lead to uneven processing, affecting the yield and quality of the final product. Over-dried fibers may become too brittle, making them difficult to handle, while under-dried fibers may retain too much moisture, promoting microbial growth and reducing the shelf life of the final product. Fluidized bed drying addresses these issues by providing a controlled environment that ensures precise moisture reduction, enhancing the quality and safety of the banana fibers for various applications. Moisture content analysis is an essential part of the drying process, ensuring that moisture levels in the banana fibers are reduced to the optimal range for long-term storage and efficient processing.

$$= \frac{\text{Initial weight of the sample} - \text{Final weight of the sample}}{\text{Initial weight of the sample}} \times 100$$

This formula calculates the percentage of water removed from the plant material during drying. The initial weight refers to the fresh, undried weight of the material, while the final weight is the dried weight after the moisture has been removed.

12. FABRICATION OF COMPOSITE

The film stacking process was used to create the PP/AS composites, which were then cured in a hot compression molding machine. Using this technique, Banana fibers and polyester sheets were alternately inserted into the aluminum mold and heated to 180 °C for 15 minutes while under constant pressure (25 bar). A little higher pressure of 0.5 bar was used during curing under compression when the To increase the laminae's capacity to stack, the melting point of PP was raised. After the entire mold had cooled to room temperature, the PP/AS composite laminate was taken out of the aluminum mold and cut to the precise size needed for more research.

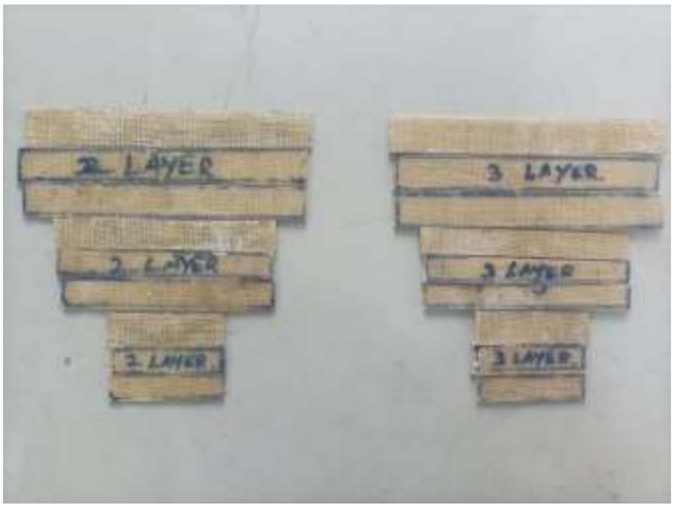


Image-1: Finished composite product

13. RESULT AND DISCUSSION

13.1 TENSILE TEST

The variation in tensile strength and tensile modulus of pure polyester and banana fiber/polyester (BF/P) composites at different fiber loadings (40, and 50 vol%) has been studied. The findings show that both tensile strength and tensile modulus of BF/P composites increase as fiber content increases, compared to pure polyester. However, beyond 40% fiber loading, these properties start to decrease. This drop is likely due to fiber agglomeration and inadequate bonding between the fibers and the matrix. The tensile strength of a composite is very sensitive to the interactions between the reinforcement and the matrix. Good bonding between the fiber and the polymer matrix enables effective stress transfer, significantly boosting tensile strength. Conversely, poor fiber–matrix bonding can cause early fractures, as stress concentrations can develop at the fiber–matrix interface.

Increasing fiber content beyond the optimal level (40 vol%) leads to weak interfacial areas and micro gaps between the fiber and the matrix, causing a drop in tensile strength. Higher fiber content also makes it harder for the polyester to fully saturate the fibers, resulting in poor bonding and reduced mechanical properties. Poor wetting further lowers the efficiency of stress transfer across the fiber–matrix interface, leading to agglomeration and obstructed stress transfer. Thus, there is a decreasing trend in tensile strength and tensile modulus with increasing fiber content in the BF50P composites. Among all the BF/P composites, BF40P composites showed significantly higher tensile strength and tensile modulus, with values of

31.48±2.5 MPa and 2.88 ±0.50 GPa, respectively. The percentage improvements in tensile strength and tensile modulus of BF40P composites are 20.14% and 58.41%, respectively, compared to pure polyester. Notably, a tensile modulus value exceeding 2 GPa indicates strong fiber–matrix interactions within the BF40P composites.

FESEM images of BF40P composite samples fractured during tensile testing. These failure modes directly reflect the bonding strength between the fiber and matrix, a well-established critical factor influencing the tensile properties of banana fiber reinforced polyester composites. Additionally, the bonding characteristics at the fiber–matrix interface in composite materials are significantly influenced by the surface characteristics or roughness of the fibers.

13.2. FLEXURAL TEST

The flexural strength and flexural modulus of neat polyester and banana fiber/polyester (BF/P) composites at various fiber loadings (40, and 50 vol%) were studied. The results show that the flexural properties of BF/P composites improve with increased fiber content compared to neat polyester. However, both flexural strength and modulus decline beyond the optimal fiber loading of 40 vol%. This trend is likely due to the laminate structure of the BF/P composites during flexural testing, where the inner layers experience compressive forces and the outer layers are subjected to tensile forces, creating tensile and compressive stresses within the composites. During flexural loading, the banana fibers may compress, leading to defects or kinks and creating stress concentration points at their ends. When fiber loading exceeds 40 vol%, the number of crack initiation points rises due to higher stress concentration at the fiber ends, weakening the adhesion between polyester and banana fibers and resulting in reduced flexural strength.

The analysis reveals that the BF40P composites exhibited higher flexural strength and modulus, measuring 41.93±1.50 MPa and 1.88±0.50 GPa, respectively. The improvements in flexural strength for BF40P, and BF50P composites compared to neat polyester are 274.02%, and 238.59%, respectively. Similarly, the improvements in flexural modulus for these composites are 431.53%, and 308.27%. FESEM images of the fractured specimens of BF40P composites after flexural testing show failure phenomena such as fiber breakage, pores, crack propagation, and matrix damage. These observations highlight the critical influence of fiber-matrix bonding strength on the flexural properties of banana fiber reinforced polyester composites.

13.3. IMPACT TEST

The impact strength of neat polyester and banana fiber/polyester (BF/P) composites with different fiber loadings has been depicted. It is observed that the impact strength follows a similar trend to flexural strength. Impact strength refers to the material's ability to resist fracture failure under high-speed loads, making it a crucial property for composites. This property is influenced by the interaction between the banana fibers and polyester during crack formation and stress transfer, with fiber loading playing a significant role. As fiber loading increases, the impact strength of the BF/P composites also increases, compared to that of neat polyester. The percentage improvements in impact strength for BF/P composites, compared to neat polyester, are as follows: 314.42% for BF40P, and 285.58% for BF50P, respectively.

BF40P composites exhibit the highest impact strength among all the BF/P composites, with a value of 134±3 J/m^2. This highest impact strength at the optimal fiber loading (40 vol%) is attributed to the improved bonding between the matrix and fibers because banana fibers are uniformly dispersed in the polyester matrix, serving as an efficient stress transfer medium. However, as the fiber loading exceeds 40 vol%, the impact strength begins to decrease.

This decreasing trend can be influenced by the emergence of voids and stress concentration points at higher fiber concentrations. These voids and stress concentration points become initiation points for cracks during impact, leading to reduced impact resistance. The impact strength of natural fibers primarily relies on their composition, which includes factors like fiber structure, cellulose content, angle of fibrils, and cross-section. Natural fibers also contain pectin and lignin, and are abundant in hydroxyl groups, making them polar and hydrophilic materials. In contrast, polymer materials are polar but display considerable hydrophobicity. Fractured specimens of BF40P composites after impact testing have been subjected to FESEM analysis to observe the failure mechanisms, as depicted. It is evident from the micrographs that the predominant failure modes on the fractured surfaces are matrix breakage, crack formation, hole formation, and fiber breakage.

14. CONCLUSIONS

In this study, banana fiber/polyester (BF/P) composites at various fiber loadings were fabricated using a hot compression molding machine through the film stacking technique. The physico-mechanical properties of BF/P composites increased with increasing banana fiber loadings up to 40%, then decreased. The BF40P composites demonstrated superior physico-mechanical properties over those of neat polyester and other BF/P composites. The percentage improvements in tensile strength, tensile modulus, flexural strength, flexural modulus, impact strength, and hardness of the BF40P composites are 20.14%, 58.41%, 274.02%, 431.53%, 314.42%, and 32.73%, respectively, in contrast with neat polyester. Additionally, The failure phenomena occurring to the fractured mechanical test samples were matrix damage, fiber fracture, fiber debonding, crack propagation, and hole formation. Water absorption study results revealed that the water absorption rate increased in BF/P composites compared to neat polyester, due to the banana fiber loadings and inherent properties of the fiber. Hence, it is concluded that the BF40P composite can be used for manufacturing automotive interior components, such as door panels, seat backs, and dashboards. The lightweight and eco-friendly nature of this composite makes it an attractive choice for reducing vehicle weight and improving fuel efficiency.

REFERENCES

[1.] "Study on the mechanical behavior of banana fiber reinforced epoxy composites".

[2.] "Characterization of Flexural Strength of Developed Hybrid Hemp and Banana Natural Fiber Composite Material" ,Ravi Y V, Sacheth, Ruman S U, Vinayak Veerayya Kavalur.

[3.] "Research Article Banana Fiber-Reinforced Epoxy Composites: Mechanical Properties and Fire Retardancy" Tuan Anh Nguyen and Thi Huong Nguyen.(International Journal of Chemical Engineering Volume 2021, Article ID 1973644)

[4.] "Effect of Composite Composition on Mechanical Properties of Banana Fiber Composites with Epoxy Matrix for Functional Materials" , Yoga Ahdiat Fakhrudia, Kholis Nur Faidzina, Rahayu Mekar Bisonoa.(Volume 06, Issue 02, July 2022)

[5.] "Experimental Investigation on Banana Fiber Reinforced Phenol Formaldehyde Composite for Automotive Application" G Subbiah Jeeva, S Prem Kennedy, S.Nishanth, P Shanjai, V Ajith Tisho.(Volume 02 Issue 08 August 2020 e-SSN:2582-4376)

[6.] "Potential of lignocellulosic fiber reinforced polymer composites for automobile parts production" Current knowledge, research needs, and future direction Abdulrahman Adeiza Musa, Azikiwe Peter Onwualu.

[7.] "Innovative Banana Fiber Nonwoven Reinforced Polymer Composites: Pre- and Post-Treatment Effects on Physical and Mechanical Properties", K. Z. M. AbdulMotaleb , Abdul Ahad, Ginta Laureckiene and Rimvydas Milasius.

[8.] "Development of Eco-Sustainable Silica-Reinforced Natural Hybrid Polymer Composites for Automotive Applications" ,M. Senthil Kumar ,G. Sakthivel ,R. Jagadeeshwaran,J. Lakshmipathi,M. Vanmathi, T. Mohanraj, and Yesgat Admassu .(Volume 2022, Article ID 5924457)

[9.] "Study on Mechanical Properties of Banana Fiber-Reinforced Materials Poly (Lactic Acid) Composites". Tuan Anh Nguyen and Thi Huong Nguyen Faculty of Chemical Technology, Hanoi University of Industry (HaUI), No. 298 Cau Dien, North District Tu Liem, Hanoi, Vietnam.

[10.] "Study on Preparation and Application of Banana Fiber-Based Composites Yuxin Fan, College of Chemical Engineering and Materials" .Science, Tianjin University of Science, and Technology, Tianjin, China.

[11.] Matrix materials used in composites": A comprehensive study Arun Kumar Sharma , Rakesh Bhandari , Amit Aherwar, Ruta Rimasauskiene.

[12.] "Determination of material properties for ANSYS progressive damage analysis of laminated composites" . Ever J. Barbero , Mehdi Shahbazi.

[13.] "Modeling elastic properties of unidirectional composite materials using Ansys" . Material Designer Saiaf Bin Rayhana , Md Mazedur Rahman.

[14.] "Effect Of Various Orientation Of Banana Fiber Woven Mat On Fracture Behaviors Of Laminated Epoxy Composites" N.Rajini, T.P.Sathishkumar, M M. Jegan, PON.Maheshkumar, P.Navaneethakrishnan, S.Kalirasu.

[15.]]"A Review on Natural Fiber Composite Materials in Automotive Applications" Venkatesh Naik,Mohan Kumar and Vijayananda Kaup.