Plant Archives **Vol. 25, Special Issue (ICTPAIRS-JAU, Junagadh) Jan. 2025 pp. 527-531**
e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.SP.ICTPAIRS-074

COMPARATIVE STUDY OF WOOD POLYMER COMPOSITES AND FRP IN FARM MACHINERY FOR SUSTAINABLE AGRICULTURE

Sourav Patel[1], S.K. Badjena[1]* and P.C. Padhi[2]

[1]Department of Metallurgical and Materials Engineering, Veer Surendra Sai University of Technology (VSSUT), Burla, Odisha, India
[2]Department of Manufacturing Engineering, Institute of Petrochemicals Technology (IPT),
Central Institute of Petrochemicals Engineering and Technology (CIPET), Bhubaneswar, Odisha, India.
*Corresponding author E-mail : skbadjena@gmail.com

ABSTRACT

The growing demand for sustainable agricultural practices has led to the exploration of advanced materials in farm machinery, with the aim of improving efficiency, reducing environmental impact and enhancing durability. This study presents a comparative analysis of two promising materials: Wood Polymer Composites (WPC) and Fiber-Reinforced Polymers (FRP), focusing on their applications in farm machinery. WPC, a combination of wood fibers and polymer resins, offers advantages in terms of renewable sourcing, biodegradability and cost-effectiveness. In contrast, FRP, composed of fibers such as glass, carbon or aramid embedded in a polymer matrix, provides superior strength-to-weight ratio, corrosion resistance and durability under harsh agricultural conditions. The study evaluates the mechanical properties, environmental impact, manufacturing processes and performance of both materials when applied to key components of farm machinery, including structural parts, implements, tanks, and ergonomic features. Both materials contribute to enhanced sustainability, FRP outperforms WPC in terms of durability and resistance to chemical degradation, making it more suitable for long-term applications in farm machinery. However, WPC offers a more cost-effective and eco-friendlier alternative for certain non-load-bearing components. The findings suggest that a hybrid approach, incorporating both WPC and FRP in farm machinery design, may offer the optimal balance of performance, sustainability, and cost-effectiveness for the future of sustainable agriculture. This mainly described the processing method of WPC and FRP fabrication.

Key words : Agricultural implements, Fiber-Reinforced Polymers (FRP), Farm machinery, Manufacturing processes, Wood Polymer Composites (WPC).

Introduction

Wood Polymer Composites (WPCs) are materials made by combining wood fibers or wood flour with thermoplastic polymers, resulting in a versatile and durable material that combines the best attributes of wood and plastic. The composition typically includes wood fibers derived from waste or processed wood, thermoplastic polymers like polyethylene (PE), polypropylene (PP), or polyvinyl chloride (PVC) and various additives such as fire retardants, UV stabilizers and colorants to enhance performance. WPCs offer benefits such as enhanced durability, reduced maintenance and environmental sustainability, making them suitable for a wide range of applications including construction and consumer products. Historically, the concept of combining wood with other materials dates back to the early 20th century, with early examples like Bakelite, a composite of phenol formaldehyde and wood flour. WPCs began to gain commercial traction in the 1970s and 1980s, with significant advances in processing techniques. The 1990s saw increased demand for environmentally friendly materials, further boosting WPC popularity. By the 2000s, improved formulations and efficient manufacturing processes propelled the industry forward. Today, WPCs are widely used in North America for outdoor decking, railings, siding and other applications. Thermoplastic polymers, which are easily moldable upon heating, are commonly used in WPCs. Polyethylene is frequently used in exterior components, while polyvinyl chloride (PVC) is common in window and decking materials. Wood fillers, such as sawdust or wood flour, reinforce the polymer matrix, enhancing mechanical properties and reducing costs. The use of natural fibers like hemp, flax and sisal is also increasing, particularly in the automotive sector. However, several challenges exist when combining polymers with wood fillers. Issues include poor adhesion between the two materials due to their differing properties, moisture absorption leading to degradation, and processing difficulties such as temperature control and flow behavior. These challenges can result in inconsistent mechanical properties and surface quality. Strategies to address these issues include surface treatments, optimizing processing conditions, and incorporating moisture-resistant additives.

Glass Fiber Reinforced Polymer Composites (GFRPs) are advanced materials made by combining glass fibers with a polymer matrix, typically epoxy, polyester, or vinyl ester. This combination results in a composite material that exhibits enhanced mechanical properties such as high strength, stiffness and durability, along with a relatively low weight. Glass fibers provide reinforcement to the polymer, improving the composite's resistance to impacts, fatigue and environmental degradation, while the polymer matrix binds the fibers together and offers additional protection. GFRPs are widely used in various industries due to their versatility and cost-effectiveness. Applications include construction, automotive, aerospace, marine, and sports equipment, where their high strength-to-weight ratio and corrosion resistance are particularly beneficial. The composite materials also exhibit good thermal and electrical insulating properties, making them suitable for a wide range of demanding environments. Despite their many advantages, GFRPs do present some challenges, such as their relatively low fracture toughness and difficulty in recycling. Research continues to focus on improving the properties of GFRPs, including enhancing their impact resistance, sustainability and ease of processing.

Hasanin *et al.* (2022) studied focuses on producing natural fiber plastic composites (NFPCs) from waste polyethylene and modified sunflower fibers to address environmental pollution. Sunflower fibers were treated with the fungus *Rhizopus oryzae* under different fermentation conditions (submerged and solid-state) to enhance their compatibility with polyethylene. The treated fibers improved the mechanical properties, biodegradability and water vapor transmission rate (WVTR) of the NFPCs. The results showed better tensile strength, modulus and biodegradation with fibers treated under solid-state fermentation (SSF). The findings suggest that these NFPCs, with enhanced biodegradability and WVTR, are suitable for various applications like packaging and household items. Ghoneim *et al.* (2024) described agricultural and plastic waste pollution is a significant environmental issue in Egypt, where millions of tons of waste are either burned or dumped, causing harm to both air quality and aquatic ecosystems. Egypt imports substantial amounts of wood, including wood plastic composites (WPC), which combine wood fibers and plastics. To address this, research has focused on using post-harvest agricultural residues, like orange tree trimmings, cotton stems, and casuarina tree trimmings, as sustainable sources for WPC production. These residues, when combined with recycled High-Density Polyethylene (rHDPE) and coupling agents like Maleic Anhydride Grafted Polyethylene (MAPE), can create high-quality WPCs with improved mechanical properties. A successful formulation includes 50% orange wood, 50% rHDPE, and 5% MAPE, offering an eco-friendly alternative to traditional wood products while managing waste effectively. This approach helps reduce environmental pollution and the demand for imported wood. Rahmatian *et al.* (2022) studied the comparison of the performance of a Fiber Reinforced Polymer (FRP) composite blade with a conventional steel blade in tillage operations. The study considered factors such as draft force, soil disturbance area, soil cone index and fuel consumption, while also examining the effects of rake angle, forward speed and soil moisture content. The results show that the FRP composite blade outperformed the steel blade, reducing draft force, fuel consumption, and soil cone index by 14.97%, 16.63% and 35.08%, respectively. Additionally, the FRP blade increased soil disturbance area by 4.93%. The FRP composite is also more cost-effective than steel, offering economic benefits for both farmers and manufacturers, especially in chisel and combined tillage tools. Iwatani *et al.* (2021) explores the potential benefits of using Fiber Reinforced Polymer (FRP) pipes instead of galvanized steel for agricultural greenhouses. Steel greenhouses face challenges such as rigidity, corrosion and high installation costs, especially when increasing the size of the structure. FRP pipes, being corrosion-resistant, lighter (1/5 the weight of steel), and stronger (twice the strength of steel), offer a solution to these problems. Al-Haddad *et al*. (2022) found that an FRP-based greenhouse could support heavy machinery with a 20-meter frontage and 8-meter height, while costing half the price of a traditional steel greenhouse. The Re-Wind Team at Georgia Tech, in collaboration with Queen's University Belfast and University College Cork, has developed a patented solution for reusing end-of-life Fiber

Reinforced Composite (FRC) wind turbine blades. Instead of landfilling the blades, they propose using them as vertical tower structures in future high-voltage electrical transmission lines. This innovative approach not only helps avoid the disposal of millions of tons of composite material but also reduces the carbon footprint of expanding and improving the US electrical grid, which will require trillions of dollars in investment over the next two decades.

Current research focuses on enhancing the performance of WPCs, including improving strength, flexibility, and lifespan. The development of bio-based polymers and the integration of nanomaterials, such as metal oxide nanoparticles and carbon-based nanoparticles is also an area of interest for improving fire resistance and mechanical properties. Overall, WPCs represent a successful blend of traditional materials and modern technology, offering sustainable, durable and versatile alternatives for various industries. GFRPs represent a significant innovation in material science, offering a combination of strength, durability and lightweight characteristics that make them valuable in numerous applications.

Materials and Methods

Wood dust was sourced from various wood mills, ensuring a diverse range of wood types for composite preparation. Sodium hydroxide (NaOH) pellets, resin, glass fiber, dimethyl aniline and methyl ethyl ketone peroxide were procured from IndiaMART.

All materials were handled and prepared according to standard protocols for composite fabrication.

Alkaline Wood Treatment Process

Initially, a sodium hydroxide (NaOH) solution was prepared. Fine wood dust particles were gradually added to the solution while stirring continuously with a glass rod for 2 hours to ensure uniform mixing. The pH of the mixture was then measured. The treated wood dust was washed thoroughly with distilled water until the pH of the material approached neutral (approximately 7). Finally, the wood dust was dried in an oven to remove any residual moisture in 60^0 C for 24 hrs.

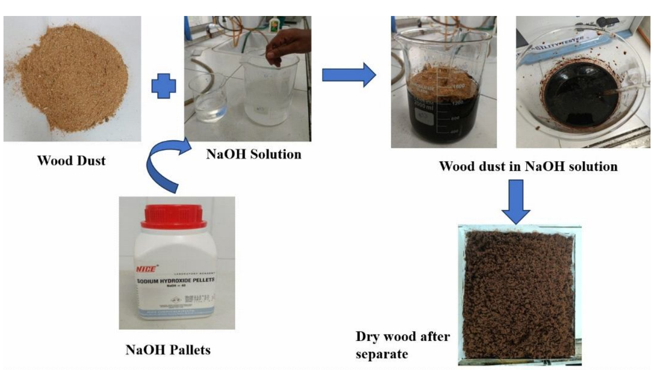

Fig. 1 : Wood Treatment Process.

Hand Lay up Process of FRP fabrication

The fiberglass laminate production process begins with applying a gel coat of resin mixed with color pigments, accelerator (Dimethyel Aniline) and catalyst (MEK peroxide). The gel coat is brushed onto the mould surface, creating a thick, polished layer that cures before adding other materials. Next, a resin mixture, containing accelerator and catalyst is applied to secure the glass material and prevent air bubbles. The glass fiber is then laid over the mould, ensuring it is placed smoothly to avoid air pockets. Additional layers of glass material, are applied similarly, increasing the laminate's strength with each layer. After curing, a final resin coat with color is added for a smooth finish. The laminate is allowed to cure for 16-24 hours, depending on catalyst concentration. Once fully cured, or slightly flexible for easier removal, the laminate is carefully detached from the mould using a putty knife or thin wooden pieces. The edges are then trimmed and smoothed using hand tools, with optional resin coating for a polished finish. The strength of the laminate is determined by the balance of glass and resin, with greater glass volume enhancing the product's strength.

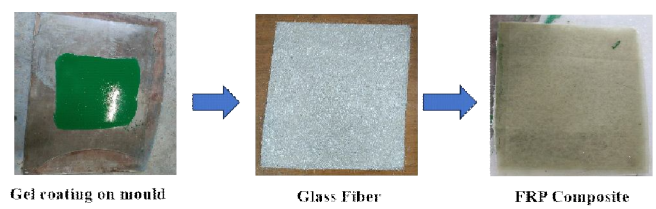

Fig. 2 : FRP Fabrication.

Experimental Discussion

The wood treatment process removes some of the lignin and cellulose content in the wood. The incorporation of wood polymer composites (WPCs) in farm machinery demonstrates significant improvements in performance and sustainability. WPCs exhibit high durability and resistance to environmental factors such as moisture, UV radiation, and chemicals, ensuring longevity and reduced maintenance. Additionally, WPCs offer corrosion resistance, making them ideal for components exposed to water and chemicals. Their noise-dampening properties enhance operator comfort by reducing vibration and noise levels. The versatility in customization allows manufacturers to meet aesthetic and functional requirements, while the use of renewable wood fibers promotes sustainability. Applications such as panels, irrigation systems and tool handles illustrate the adaptability of WPCs, highlighting their potential to replace traditional materials in agricultural machinery effectively.

The hand lay-up process for fabricating fiber-reinforced polymer (FRP) composites offers several advantages, making it a popular choice for various applications. It is cost-effective, requiring minimal equipment and ideal for small to medium production runs. The process is highly flexible, allowing for the creation of complex shapes and customization to suit different mold types. Hand lay-up is particularly well-suited for large parts, such as boat hulls or automotive components. The method also provides operators with control over fiber orientation, ensuring that mechanical properties can be tailored. Additionally, the process can achieve good surface finishes, especially with the use of gel coats and is relatively simple to implement, requiring only basic training. It is also scalable and can be adapted for both small and large production volumes, with minimal waste, making it an environmentally friendly choice. Overall, the hand lay-up process combines cost-efficiency, flexibility, and ease of use, making it an excellent option for custom and prototype FRP parts. The application of fiber-reinforced polymer (FRP) in farm machinery reveals significant advantages in performance, durability, and efficiency. FRP's high strength-to-weight ratio allows the development of lighter yet robust structural components, such as body panels and hoods, enhancing machinery performance. In tractors and harvesters, FRP materials resist corrosion in harsh agricultural environments, protecting parts like fenders and engine covers from moisture and chemicals. FRP is also extensively used in pumps, tanks, and pipelines, where its corrosion resistance ensures a longer lifespan compared to traditional metals. Agricultural implements, including plows, seeders, and sprayers, benefit from FRP's lightweight and durable properties, which reduce wear and improve handling. Additionally, ergonomic components like seats leverage FRP's customizable nature to enhance operator comfort during prolonged operations. Overall, the integration of FRP in farm machinery provides durable, low-maintenance solutions that withstand challenging agricultural conditions, reduce machinery weight and improve operational efficiency.

Both wood polymer composites (WPC) and fiber-reinforced polymers (FRP) are advanced materials increasingly utilized in farm machinery to enhance performance, sustainability, and durability. While both materials offer unique benefits, their applications and properties differ, making them suitable for distinct uses within agricultural machinery.

Material Composition and Strength

WPC: Combines wood fibers and plastics, offering a balance of natural aesthetics, moderate strength, and moisture resistance. Its strength-to-weight ratio is adequate for non-critical components like panels, handles, and storage structures.

FRP: Composed of fibers (e.g., glass or carbon) embedded in a polymer matrix, FRP provides a superior strength-to-weight ratio, making it ideal for critical structural components and high-stress applications such as body panels, fenders and tanks.

Durability and Environmental Resistance

WPC: Highly resistant to environmental factors like moisture, UV radiation, and chemicals, though its durability is generally lower than FRP for extreme conditions.

FRP: Offers exceptional durability and corrosion resistance, particularly against water, fertilizers and chemicals, making it highly suitable for parts exposed to harsh agricultural environments.

Weight and Efficiency

WPC: Lightweight, though not as light as FRP. It improves fuel efficiency and ease of handling but is better suited for less weight-sensitive applications.

FRP: Significantly reduces the overall weight of machinery while maintaining strength, resulting in enhanced fuel efficiency and performance for heavy-duty machinery like tractors and harvesters.

Sustainability

WPC: Incorporates renewable wood fibers, making it an eco-friendly option aligned with sustainability goals.

FRP: Lacks the renewable component of WPC but compensates with longer lifespan and lower maintenance needs, indirectly contributing to sustainability by reducing material waste and replacements.

WPC and FRP are both valuable in agricultural machinery but cater to different needs. WPC excels in sustainability, cost-effectiveness and comfort-focused applications, while FRP outperforms in high-strength, lightweight and corrosion-resistant roles. A combined use of these materials can optimize the performance, durability, and eco-friendliness of farm machinery. Commonly WPC used for non-structural components such as panels, covers, tool handles and storage structures. Its noise-dampening properties also enhance operator comfort. FRP widely applied in structural components, ergonomic seats, and fluid-handling systems like tanks and pipelines, where superior strength, corrosion resistance, and lightweight properties are essential.

Conclusion

WPCs and GFRPs offer sustainable, durable and versatile solutions, enhancing performance, strength and environmental resistance across various industries. Overally both wood polymer composites (WPC) and fiber-reinforced polymers (FRP) offer significant benefits in the context of farm machinery in different areas, contributing to enhanced performance, durability and sustainability. WPC, with its renewable wood fiber content, is well-suited for non-critical, aesthetic and comfort-focused applications, offering moisture resistance, moderate strength and noise-dampening properties. It is an eco-friendly option that aligns with sustainability goals. On the other hand, FRP stands out for its superior strength-to-weight ratio, exceptional durability, and resistance to harsh environmental factors, making it ideal for critical structural components exposed to wear, corrosion and extreme conditions. The combination of these materials in agricultural machinery provides a balanced solution, optimizing both functionality and sustainability. By leveraging the unique properties of WPC and FRP, manufacturers can improve the efficiency, performance and longevity of farm machinery, while also meeting modern demands for reduced maintenance and environmental responsibility. The integration of these advanced materials into various components of agricultural equipment can lead to more durable, lightweight and cost-effective solutions for the industry.

Acknowledgement

This study was conducted using laboratory facilities designed and developed at the Central Institute of Petrochemical Engineering and Technology, Institute of Plastic Technology, Bhubaneswar.

References

Al-Haddad, T., Alshannaq A., Bank L., Bermek M., Gentry R., Henao-Barragan Y. and Woodham C. (2022, March). Strategies for redesigning high performance FRP wind blades as future electrical infrastructure. In: *Proceedings of the ARCC-EAAE 2022 International Conference-Resilient City: Physical, Social, and Economic Perspectives, Miami, FL, USA* (pp. 2-5).

Basalp, D., Tihminlioglu F., Sofuoglu S.C., Inal F. and Sofuoglu A. (2020). Utilization of municipal plastic and wood waste in industrial manufacturing of wood plastic composites. *Waste and Biomass Valorization*, **11**, 5419-5430.

Ghoneim, A., Youssef Y. and Hassan M.K. (2024). Production of wood plastic composites as a sustainable solution for the post-harvest agriculture waste and plastic waste. *The Amer. J. Engg Technol.*, **6(08)**, 7-21.

Hasanin, M.S., Abd El-Aziz M.E., El-Nagar I., Hassan Y.R. and Youssef A.M. (2022). Green enhancement of wood plastic composite based on agriculture wastes compatibility via fungal enzymes. *Scientific Reports*, **12(1)**, 19197.

Hossain, M.F., Islam M.K. and Islam M.A. (2014). Effect of chemical treatment on the mechanical and physical properties of wood saw dust particles reinforced polymer matrix composites. *Procedia Engg.*, **90**, 39-45.

Iwatani, T. and Nishino Y. (2021). Research and development of large FRP arched greenhouse. *GPI J.*, **7(2)**, 75-82.

Nukala, S.G., Kong I., Kakarla A.B., Tshai K.Y. and Kong W. (2022). Preparation and characterisation of wood polymer composites using sustainable raw materials. *Polymers*, **14(15)**, 3183.

Rahmatian, M., Karparvarfard S.H., Nematollahi M.A. and Malvajerdi A.S. (2022). Comparison of Fiber Reinforced Polymer (FRP) composite blade with steel blade performance used in chisel plow.

Rosenstock Völtz, L., Di Guiseppe I., Geng S. and Oksman K. (2020). The effect of recycling on wood-Fibre thermoplastic composites. *Polymers*, **12(8)**, 1750.