International Journal of Scientific Research & Engineering Trends
Volume 12, Issue 3, May-Jun-2026, ISSN (Online): 2395-566X

A Study On Properties And Reinforcing Potential Of Rice Husk Polymer Composites

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Abstract: The increasing demand for sustainable and environmentally friendly engineering materials has promoted the utilization of agricultural waste as reinforcement in polymer composites. Among various agro-based materials, rice husk (RH), a by-product obtained during rice milling, has emerged as a promising reinforcing material due to its low density, abundant availability, renewable nature, and unique silica-rich composition. Rice husk contains cellulose, hemicellulose, lignin, and a considerable amount of silica, which contribute to its stiffness and thermal resistance. However, the hydrophilic nature of rice husk and the hydrophobic nature of most polymer matrices often lead to weak interfacial adhesion, limiting the mechanical performance of composites.This review paper presents a comprehensive analysis of the reinforcing potential of rice husk in thermoplastic and thermosetting polymer matrices. The influence of rice husk content, particle size, chemical treatment, and processing techniques on the mechanical, thermal, morphological, and water absorption characteristics of composites is critically reviewed. The effects of coupling agents such as maleic anhydride grafted polypropylene (MAPP) and silane treatments in improving fiber–matrix compatibility are discussed. The recent advancements in hybrid rice husk composites and bio-based polymer systems are also highlighted. The review concludes that rice husk has significant potential as a low-cost and eco-friendly reinforcement for manufacturing lightweight materials for automotive, construction, packaging, and consumer product applications.

Keywords—Rice husk, natural fiber composites, polymer composites, mechanical properties, thermal properties, surface treatment, sustainable materials.

I. INTRODUCTION

Polymer composites reinforced with natural fibers have gained considerable attention in recent decades because of the increasing need for sustainable materials with reduced environmental impact. Conventional synthetic reinforcements such as glass and carbon fibers provide excellent mechanical performance; however, they are associated with high energy consumption, non-biodegradability, and difficulties in disposal. Therefore, agricultural residues and natural fibers have become attractive alternatives for developing environmentally responsible composite materials [1].

Rice husk is one of the most abundantly available agricultural residues worldwide. It constitutes nearly 20% of the total weight of harvested rice and is generated in enormous quantities during rice processing. Traditionally, rice husk has been disposed of through open burning or landfilling, leading to environmental issues. The incorporation of rice husk into polymer matrices offers an effective strategy for converting agricultural waste into value-added engineering materials [2].

The chemical composition of rice husk generally includes approximately 35–45% cellulose, 20–25% hemicellulose, 15–30% lignin, and 15–20% silica. The presence of silica differentiates rice husk from many other natural fibers and contributes to improved hardness, rigidity, and thermal resistance. Due to these characteristics, rice husk has been explored as a reinforcement in polymers such as polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC), polylactic acid (PLA), epoxy, and polyester resins [3].

The reinforcement mechanism in rice husk polymer composites is governed by stress transfer between the polymer matrix and rice husk particles. Efficient stress transfer requires strong interfacial bonding. However, because rice husk possesses numerous hydroxyl groups, it absorbs moisture and exhibits poor compatibility with non-polar polymers. Surface modifications such as alkali treatment, acetylation, silane treatment, and the use of compatibilizers like MAPP have been extensively investigated to improve adhesion between the reinforcement and polymer matrix [4].

Recent studies have demonstrated that optimized rice husk loading can improve tensile modulus, flexural modulus, hardness, and thermal stability of polymer composites. The incorporation of suitable coupling agents further enhances the mechanical strength by reducing interfacial defects and promoting better dispersion of rice husk particles within the polymer matrix [5].

The increasing focus on circular economy principles and sustainable manufacturing has further accelerated research on rice husk polymer composites. These materials have found potential applications in automotive interior components, building panels, furniture, packaging materials, electrical insulation components, and consumer goods due to their lightweight nature, acceptable mechanical performance, and reduced environmental footprint [6].

II. RICE HUSK AS A REINFORCING MATERIAL

Rice husk is the protective outer layer of rice grains and possesses a complex lignocellulosic structure. The main constituents of rice husk are cellulose microfibrils embedded within a matrix of hemicellulose and lignin. Cellulose provides tensile strength and stiffness, while lignin contributes to rigidity and resistance against microbial degradation.

A distinguishing feature of rice husk is its high silica content, which is generally present as amorphous silica distributed on the outer surface. This silica-rich layer provides improved hardness, wear resistance, and thermal insulation characteristics compared with several other agricultural fibers. These properties make rice husk particularly suitable for developing low-density polymer composites with enhanced rigidity.

The physical characteristics of rice husk, including low density, low cost, renewability, and wide availability, make it an attractive filler for large-scale composite production. However, the presence of hydroxyl groups causes moisture absorption and dimensional instability. Therefore, surface modification is often necessary to achieve improved compatibility with polymer matrices.

Advantages and Limitations of Rice Husk Reinforcement

The major advantages of rice husk as reinforcement include:

1. Low density and lightweight characteristics.
2. Low manufacturing cost due to agricultural waste utilization.
3. High silica content resulting in improved hardness and thermal resistance.
4. Renewable and environmentally friendly nature.
5. Reduced dependence on synthetic fibers.

Despite these advantages, certain limitations affect its performance. The hydrophilic nature of rice husk results in high moisture absorption, poor dispersion in hydrophobic polymers, and weak interfacial bonding. Additionally, excessive rice husk loading can lead to particle agglomeration and reduced impact strength. Consequently, optimization of filler concentration and surface treatment is essential for obtaining superior composite properties [7].

III. POLYMER MATRICES USED IN RICE HUSK REINFORCED COMPOSITES

The properties of rice husk polymer composites are strongly influenced by the matrix material, which provides structural support, facilitates stress transfer, and protects the reinforcement. Both thermoplastic and thermosetting polymers are widely employed in rice husk-based composites [8]. Thermoplastics such as polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC), and polylactic acid (PLA) are preferred because of their ease of processing and recyclability. PP composites often require compatibilizers like maleic anhydride grafted polypropylene (MAPP) to improve interfacial bonding and mechanical performance [9]. PE-based composites exhibit enhanced stiffness and hardness, although excessive rice husk loading may reduce tensile strength due to poor dispersion [10]. PVC matrices offer improved rigidity and dimensional stability, making them suitable for construction applications [11], while PLA–rice husk composites provide a sustainable biodegradable alternative, though improvements in toughness and moisture resistance are still required [12].

Thermosetting matrices such as epoxy and unsaturated polyester are used where higher thermal stability and chemical resistance are needed. Rice husk reinforced epoxy composites demonstrate improved hardness, stiffness, and wear characteristics, with properties strongly dependent on filler content and surface treatment [13]. Similarly, polyester-based composites offer low cost and acceptable mechanical performance for lightweight applications [14]. However, the non-recyclable nature of thermosets has encouraged research toward bio-based and recyclable polymer matrices for sustainable rice husk composite development [15].

IV. FABRICATION METHODS OF RICE HUSK POLYMER COMPOSITES

The fabrication technique plays a crucial role in determining the dispersion of rice husk, interfacial adhesion, porosity, and overall composite performance. Compression molding is widely used due to its simplicity, low cost, and ability to produce composites with controlled thickness and uniform reinforcement distribution, especially for thermosetting and thermoplastic sheet composites [16]. Injection molding is suitable for large-scale production of thermoplastic rice husk composites, providing high productivity and dimensional accuracy; however, excessive shear during processing may damage the natural reinforcement and affect mechanical properties [17].

Extrusion, particularly twin-screw extrusion, ensures effective mixing and homogeneous dispersion of rice husk particles and is commonly used for producing profiles, sheets, and construction materials such as decking and window frames [18]. Other techniques, including hand lay-up, resin transfer molding, and hot pressing, are also employed to minimize voids and enhance fiber–matrix interactions, particularly in thermosetting composite systems [19].

V. SURFACE MODIFICATION AND INTERFACIAL IMPROVEMENT OF RICE HUSK

The hydrophilic nature of rice husk and the hydrophobic characteristics of most polymer matrices lead to poor interfacial adhesion, limiting mechanical performance and increasing moisture absorption. Therefore, various surface modification techniques have been developed to enhance compatibility and improve composite properties.

Alkali treatment using NaOH is widely employed to remove impurities, waxes, hemicellulose, and partial lignin, thereby increasing surface roughness and improving mechanical interlocking between rice husk and the polymer matrix [20]. Silane treatment forms chemical bridges between the hydroxyl groups of rice husk and polymer chains, resulting in improved dispersion, reduced water absorption, and enhanced mechanical properties [21]. Coupling agents such as maleic anhydride grafted polypropylene (MAPP) and maleic anhydride grafted polyethylene (MAPE) further improve the compatibility of rice husk with non-polar thermoplastic matrices, leading to efficient stress transfer and reduced interfacial defects [22].

Advanced modification methods, including acetylation, enzymatic treatment, plasma treatment, and nanocoating, have recently gained attention due to their ability to improve hydrophobicity, thermal stability, and durability of rice husk composites, thereby expanding their potential for advanced engineering applications [23].

VI. MECHANICAL PROPERTIES OF RICE HUSK POLYMER COMPOSITES

Mechanical properties are key indicators of the reinforcing potential of rice husk in polymer composites and are influenced by factors such as filler content, particle size, surface treatment, processing conditions, and matrix compatibility. The incorporation of rice husk generally enhances the tensile modulus due to its rigid lignocellulosic structure; however, excessive filler loading can reduce tensile strength because of poor dispersion, inadequate wetting, and void formation. Surface treatments and coupling agents improve interfacial bonding and promote efficient stress transfer, resulting in better tensile performance [24].

The flexural behaviour of rice husk composites is largely improved by the increased stiffness imparted by cellulose and silica constituents. Optimum rice husk loading, commonly around 20–40 wt.%, enhances flexural strength and modulus, whereas higher filler concentrations may cause agglomeration and reduced mechanical performance. Chemical modifications such as alkali and silane treatments improve fiber–matrix adhesion and contribute to superior flexural properties [25], [26].

Impact resistance depends on reinforcement concentration, particle dispersion, and interfacial interaction. Moderate rice husk loading may improve impact behavior, while excessive amounts often decrease toughness due to stress concentration and crack propagation. The use of compatibilizers such as MAPP and MAPE, along with hybrid reinforcement strategies, can improve impact performance [27]. The silica-rich nature of rice husk also contributes to enhanced hardness and wear resistance, although poor adhesion may lead to particle pull-out and increased wear under severe operating conditions [28].

VII. THERMAL PROPERTIES OF RICE HUSK POLYMER COMPOSITES

Thermal stability is a critical parameter for engineering applications involving elevated temperatures. Rice husk reinforcement influences the thermal behavior of polymers through its cellulose, lignin, and silica components.

Thermogravimetric analysis (TGA) studies indicate that rice husk composites generally exhibit improved thermal stability compared with unfilled polymers due to the formation of a protective char layer and the presence of silica-rich ash. However, degradation of cellulose and hemicellulose at elevated temperatures may limit the processing window of natural fiber composites [29].

Differential scanning calorimetry (DSC) studies reveal that rice husk can affect the crystallization behavior and melting characteristics of thermoplastic matrices. Rice husk particles may act as nucleating agents, increasing crystallinity and improving stiffness and dimensional stability. The extent of these improvements depends on particle size, filler concentration, and compatibility with the polymer matrix [30].

VIII. MORPHOLOGICAL CHARACTERIZATION

Morphological analysis is essential for understanding the interfacial interaction between rice husk and polymer matrices. Scanning electron microscopy (SEM) is commonly used to evaluate filler dispersion, interfacial adhesion, crack propagation, and failure mechanisms.

SEM micrographs of untreated rice husk composites often show gaps, voids, and fiber pull-out, indicating poor adhesion between the reinforcement and polymer matrix. In contrast, chemically treated rice husk composites demonstrate improved surface contact and reduced interfacial defects due to better compatibility and stronger bonding [31].

The morphology of fracture surfaces provides valuable information regarding stress transfer mechanisms. A rough fracture surface with limited particle pull-out generally indicates strong interfacial adhesion and improved mechanical performance [32].

IX. WATER ABSORPTION AND ENVIRONMENTAL RESISTANCE

One of the major limitations of rice husk polymer composites is their susceptibility to moisture absorption due to the presence of hydrophilic hydroxyl groups in cellulose and hemicellulose.

Water absorption can cause swelling of the rice husk particles, microcrack formation, reduction in dimensional stability, and deterioration of mechanical properties. The amount of moisture absorbed depends on factors such as rice husk content, particle size, environmental conditions, and exposure duration [33].

Chemical modifications such as alkali treatment, silane treatment, acetylation, and the use of compatibilizers effectively reduce moisture uptake by decreasing the number of accessible hydroxyl groups and improving the barrier properties of the composite [34].

The environmental benefits of rice husk polymer composites include reduced dependence on petroleum-based fillers, lower carbon emissions, utilization of agricultural waste, and improved sustainability. When combined with biodegradable polymers such as PLA, these composites offer a potential route toward fully bio-based engineering materials [35].

X. APPLICATIONS OF RICE HUSK POLYMER COMPOSITES

The combination of low density, cost-effectiveness, satisfactory mechanical properties, and environmental sustainability has promoted the use of rice husk polymer composites in diverse industrial applications. In the automotive sector, they are utilized for lightweight non-structural components such as interior panels, door trims, and dashboards, contributing to improved fuel efficiency [36]. In construction, rice husk composites are employed in decking, wall panels, window profiles, insulation materials, and furniture due to their improved stiffness and durability [37]. The development of biodegradable rice husk composites has expanded their application in sustainable packaging and consumer products by reducing dependence on conventional plastics [38]. Additionally, their good insulating properties and low cost make them suitable for electrical housings and low-load industrial components, with further potential enhancement through hybridization and nanotechnology [39].

XI. CHALLENGES AND FUTURE RESEARCH DIRECTIONS

Although rice husk polymer composites demonstrate considerable potential as sustainable engineering materials, several challenges remain before their widespread industrial adoption.

The major challenges include moisture sensitivity, variability in the chemical composition of rice husk, poor compatibility with hydrophobic polymers, and limitations in impact strength. Future research should focus on advanced surface treatments, novel coupling agents, nano-modification, and hybridization with synthetic or natural fibers to achieve superior multifunctional properties [40].

The integration of rice husk with nanofillers such as nanoclay, graphene, carbon nanotubes, and silica nanoparticles offers promising opportunities for developing advanced lightweight composites with improved mechanical, thermal, and barrier properties. Furthermore, the use of biodegradable polymer matrices and environmentally friendly processing techniques will support the development of fully sustainable composite materials.

XII. CONCLUSION

Rice husk has emerged as an effective and sustainable reinforcement material for polymer composites due to its low density, abundant availability, renewable nature, and significant silica content. The incorporation of rice husk generally improves the stiffness, hardness, thermal stability, and cost-effectiveness of polymer composites. However, challenges such as moisture absorption and weak interfacial bonding require suitable surface modifications and compatibilization techniques.

Chemical treatments including alkali and silane modification, as well as coupling agents such as MAPP and MAPE, significantly enhance fiber–matrix adhesion and improve mechanical performance. The properties of rice husk composites depend strongly on filler loading, particle size, processing method, and matrix selection.

Recent advancements in hybrid composites, nanotechnology, and biodegradable polymers have expanded the scope of rice husk-based materials for applications in automotive, construction, packaging, and consumer products. With continued research focused on improving durability, environmental resistance, and processability, rice husk polymer composites are expected to become an important class of sustainable materials for future engineering applications.

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