Development and Performance Evaluation of Eco-Sustainable Walnut–Hemp Reinforced Friction Composites for Automotive Brake Applications

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Abstract

The growing need for eco-sustainable friction materials in automotive braking systems has accelerated research into natural fiber–reinforced composites that offer high performance with minimal environmental impact. This study develops and evaluates Walnut–Hemp Reinforced Friction Composites (WHRCs) across three formulations and compares them with a standard Walnut–Hemp composite. Physical Properties including density, ash content & water absorption were experimentally characterized using ASTM standards. The results reveal significant performance shifts based on walnut–hemp ratios. This study demonstrates the potential of walnut–hemp hybrid reinforcements as environmentally responsible alternatives to synthetic friction materials, supporting safer, more sustainable automotive systems.

Keywords: Natural fiber composites, walnut shell, hemp fiber, friction materials, brake applications, Physical characterization

1. Introduction

Growing environmental concerns and the need to reduce dependency on non-renewable, metal-based friction materials have accelerated the search for eco-sustainable alternatives in automotive brake systems. Conventional brake composites often contain harmful constituents such as metals, synthetic fibers, and high-temperature resins that contribute to particulate emissions, ecological degradation, and occupational health risks. In response, natural bio-fillers have emerged as promising reinforcements due to their biodegradability, low density, renewability, and favorable mechanical characteristics. Among these, walnut shell powder and hemp fibers offer a unique balance of hardness, thermal stability, and structural reinforcement, making them suitable candidates for high-performance friction composites. Walnut shell possesses excellent abrasion resistance and moderate ash content, while hemp fiber exhibits high tensile strength and good interfacial bonding with polymer matrices. This research focuses on formulating and analyzing walnut–hemp reinforced composites across varying compositions to identify an optimal eco-friendly alternative for automotive brake applications.

2. Materials and Methods

Eco-sustainable friction composites were developed using walnut shell powder and hemp fibers as primary natural reinforcements. Phenol Formaldehyde resin was selected as the binding matrix, while graphite powder, vermiculite, and barium sulphate were incorporated as friction-modifying fillers. Two formulation groups were prepared: (baseline composite) and WHRC-1, WHRC-2, WHRC-3, where the walnut/hemp ratio was varied to study its effect on performance.

Table 1: Composite Formulations

Material	Baseline (%)	WHRC-1 (%)	WHRC-2 (%)	WHRC-3 (%)
Hemp	25	20	15	10
Walnut Shell Powder	5	10	15	20
Phenol Formaldehyde	20	20	20	20
Graphite Powder	5	5	5	5
Vermiculite	5	5	5	5
Barium Sulphate	40	40	40	40

All raw materials were dried at 70°C for 24 hours and then uniformly blended. The mixtures were compression-molded at 160–170°C, 5–10 MPa, and cured for 20–30 minutes to obtain test specimens.All tests were conducted at 23–24°C, as per ASTM Standards and results were compared to determine the optimal walnut–hemp ratio for eco-friendly brake applications.

3. Results and Discussion

Experimental data were obtained from certified laboratory testing (Dutech India Pvt. Ltd.), using ASTM and ISO standards. Compositions were compared: Standard Walnut–Hemp composite WFRC-1, WFRC-2, WFRC-3 (with varying walnut/hemp ratios)

3.1 Physical Testing Results

Table 2 presents the density, ash content, and water absorption of the developed composite.

Table 2: Physical Properties of Developed Composites

Composition	Density (g/cc)	Ash Content (%)	Water Absorption (%)
Walnut + Hemp	1.16	26.64	37.59
WFRC-1 (Walnut/Hemp 10%)	0.85	49.58	21.51
WFRC-2 (Walnut/Hemp 15%)	1.2	46.24	31.39
WFRC-3 (Walnut/Hemp 20%)	1.11	45.69	33.42

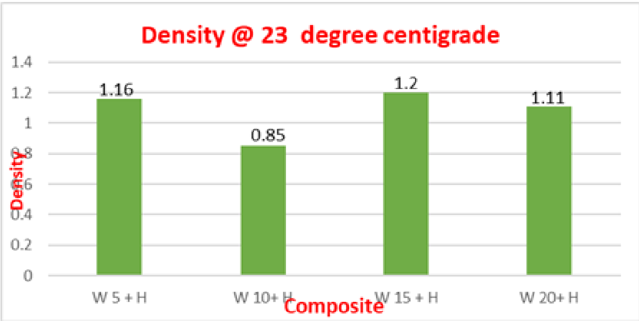

Figure 1. Density Comparison of Walnut–Hemp and WFRC Composites

The standard Walnut–Hemp composite exhibits the highest density, indicating a more consolidated and filler-rich structure. WFRC-1 demonstrates the lowest density primarily due to its higher hemp fiber content, which naturally reduces composite mass because of hemp's hollow, lightweight cellular morphology. WFRC-2 records the highest density since its balanced 15–15 walnut–hemp ratio promotes stronger particle packing and reduced internal voids. WFRC-3 maintains an intermediate density, influenced by increased walnut content, which is harder and heavier than hemp.

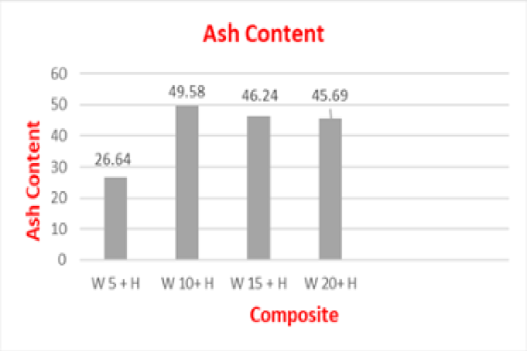

Figure 2. Ash content Comparison of Composites

Baseline composite shows the lowest ash content, it shows higher proportion of combustible organic content. WFRC-1 marked increase in ash content followed by sustained high value in WFRC-2 & WFRC-3. Higher ash content in hybrid composites reflects increased inorganic filler contribution, which enhances thermal stability and supports stable friction layer formation during braking.

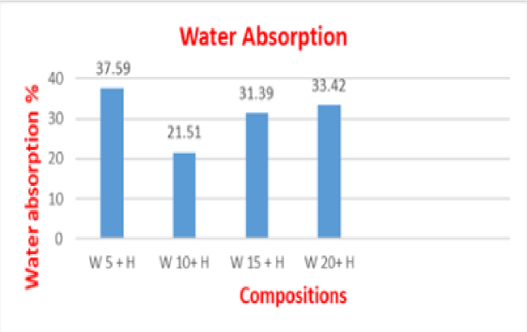

Figure 3. Water absorption Comparison of Composites

Baseline composite exhibits the highest water absorption, shows greater moisture pathways. Water absorption increases again at higher walnut shell contents (W 15 + H and W 20 + H) due to enhanced porosity and hygroscopic behavior.

4. Conclusion

Three eco-friendly friction composites—WFRC-1 (10% walnut + 20% hemp), WFRC-2 (15% walnut + 15% hemp), WFRC-3 (20% walnut + 10% hemp)—were developed and experimentally evaluated for brake pad applications. The key technical findings are summarized below:

1. An optimized walnut–hemp hybrid composition provides controlled density through improved particle packing, ensuring structural stability of the brake pad.
2. Higher ash content in hybrid composites increase thermal stability & supports stable friction layer formation.
3. Moderate hybrid filler ratios reduce moisture uptake, improving durability and reliability under service conditions.

5. References

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