



Review Article

Sustainable Wood Plastic Composites: Integrating Agricultural Waste and Textile Recycling for Enhanced Material Performance

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Abstract	Manuscript Information
<p>India faces two growing environmental challenges: synthetic textile waste accumulating in landfills and millions of tons of cotton stalks burned after harvest. This research transforms these waste materials into high-performance wood-plastic composites (WPCs) by replacing virgin PVC and PP with recycled synthetic textiles and substituting conventional wood flour with cotton stalk flour. Experimental composites mirrored commercial formulations in composition and processing. Testing across six properties showed comparable performance to commercial products, with the PP-based composite (CSRPP) absorbing 49% less moisture than its commercial counterpart—an estimated 20–25% cost reduction while addressing critical environmental challenges. This validates a circular economy approach that diverts waste from landfills, reduces deforestation pressure, and creates sustainable building materials.</p>	<ul style="list-style-type: none"> ▪ ISSN No: 2583-7397 ▪ Received: 10-11-2023 ▪ Accepted: 26-12-2023 ▪ Published: 31-12-2023 ▪ IJCRM:2(6); 2023:181-185 ▪ ©2023, All rights reserved ▪ Plagiarism Checked: Yes ▪ Peer Review Process: Yes <p>How to Cite this Manuscript</p> <p>Tailor H. Sustainable Wood Plastic Composites: Integrating Agricultural Waste and Textile Recycling for Enhanced Material Performance. International Journal of Contemporary Research in Multidisciplinary. 2023; 2(6):181-185.</p>

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1. INTRODUCTION

The Converging Environmental Challenges

India's textile industry generates millions of tons of synthetic fabric waste annually that overwhelms landfills and persists in the environment for decades. Simultaneously, cotton farmers burn post-harvest stalks, releasing smoke that causes widespread air pollution. These two waste streams—synthetic textiles and agricultural residues—represent massive unutilized resources and missed economic opportunities.

Understanding Composite Materials

Composite materials combine two or more distinct materials that work synergistically, creating products that are simultaneously strong, lightweight, and versatile [1]. The fundamental principle involves embedding strong fibres within a softer matrix—mimicking natural structures like bamboo or bone. Traditional composites use glass or carbon fibers in thermosetting polymer matrices; increasingly, thermoplastic polymers are preferred because they remain moldable after production, enabling recycling and reprocessing [1]. Regardless of matrix type, the rationale for incorporating reinforcing fibers or lignocellulosic particles extends beyond strength—engineers seek improvements in creep resistance, wear characteristics, fracture toughness, and thermal stability [2].

Wood-Plastic Composites

Wood-plastic composites (WPCs) blend thermoplastic polymers with lignocellulosic particles, combining wood's aesthetic appeal with plastic's durability and weather resistance. Manufacturing involves heating thermoplastic polymers above their melting point, mixing them with wood particles, and forming finished products through extrusion, injection molding, or compression molding [3]. WPCs offer design flexibility in color, shape, size, and surface texture, driving adoption in architectural components, automotive interiors, outdoor structures, and furniture manufacturing [3]. Their advantages over traditional wood include superior weather resistance, minimal maintenance, and freedom from rot, warping, and insect damage.

The Opportunity in Waste Streams

Recycled textile materials—particularly cotton and cotton-polyester blends—can partially or completely substitute for virgin fibers in wood-based composites, diverting waste from landfills while enabling sustainably designed materials with reduced environmental footprints [4]. Any recycled plastic capable of melting and processing below the thermal degradation threshold of lignocellulosic materials (~200°C) is a technically viable alternative to virgin polymer. HDPE and PP dominate plastic waste composition, followed by PET, PS, and LDPE—polyolefins that could serve as low-cost raw materials for value-added composites instead of polluting landfills and oceans [4].

Agricultural Residues as Industrial Resources

Declining global wood resources have intensified research into alternative lignocellulosic materials for composite manufacturing. Environmental imperatives and forest conservation concerns have catalysed research into agricultural waste valorisation—transforming low-value byproducts into high-value materials [5]. Cotton stalk possesses lignocellulosic properties similar to hardwood, suggesting suitability as a wood flour substitute in composite formulations [5]. India, possessing the world's largest cotton cultivation area, generates more cotton stalk residue annually than any other nation—an untapped biomass resource suitable for commercial exploitation in composite manufacturing [6,7]. Converting cotton stalks into industrial feedstock benefits farmers (new revenue), manufacturers (lower costs), and the environment (reduced burning and deforestation).

Research Objectives

This investigation evaluates the technical and economic feasibility of utilizing recycled synthetic textiles and agricultural cotton stalks as alternative WPC raw materials. Experimental composites exactly replicate commercial formulations—recycled polymers replace virgin polymers and cotton stalk flour substitutes for wood flour—to enable direct performance comparison. Key questions addressed:

1. Can waste-derived materials match the physical and mechanical properties of virgin materials?
2. Do processing characteristics change when substituting recycled polymers and cotton stalks?
3. What cost implications arise from this material substitution?
4. Can this approach address textile waste, agricultural residue, and deforestation challenges while maintaining commercial viability?

2. MATERIALS AND METHODS

A. Material Selection and Sourcing

Two commercial WPC formulations served as benchmarks: PVC-based (WPVC) and PP-based (WPP), each comprising 65% polymer, 30% wood flour, and 5% processing additives. Experimental composites made three substitutions: Virgin PVC → Recycled PVC, Virgin PP → Recycled PP, and Wood Flour → Cotton Stalk Flour—all at identical proportions.

Recycled PVC and PP chips (locally termed "Dana") were sourced from Bhavya Enterprise, Ahmedabad, India, originating from post-consumer textile waste including discarded garments and factory scraps. Cotton stalk flour was processed at Rushil Enterprise, Surendranagar, India, using refiner mechanical pulping (RMP), yielding particle size distribution comparable to conventional wood flour.

Table I: Composition of PVC-Based Composites

Component	Sample 1 – WPVC (Commercial)	Sample 2 – CSR PVC (Experimental)
Polymer Type	Virgin PVC	Recycled PVC (RPVC)
Polymer Content	65%	65%
Filler Type	Wood Flour (W)	Cotton Stalk Flour (CS)

Filler Content	30%	30%
Processing Additives	5%	5%
Final Thickness	16 mm	16 mm

Table II: Composition of PP-Based Composites

Component	Sample 3 – WPP (Commercial)	Sample 4 – CSRPP (Experimental)
Polymer Type	Virgin PP	Recycled PP (RPP)
Polymer Content	65%	65%
Filler Type	Wood Flour (W)	Cotton Stalk Flour (CS)
Filler Content	30%	30%
Processing Additives	5%	5%
Final Thickness	16 mm	16 mm

B. Sample Preparation

Cotton stalk flour was oven-dried at 65±2°C for 24 hours to eliminate residual moisture that could create voids and weaken polymer-filler interfaces. Components were precisely weighed per formulation (CSR PVC: 65% Recycled PVC + 30% Cotton Stalk Flour + 5% Additives; CSRPP: 65% Recycled PP + 30% Cotton Stalk Flour + 5% Additives), then melt-compounded by heating the polymer above its melting temperature while continuously mixing with cotton stalk flour to achieve uniform filler distribution. The homogeneous mixture was transferred

into 8 ft × 4 ft moulds, manually compressed to a consistent 16 mm thickness, and cooled. Identical processing conditions were maintained across all samples to ensure performance differences reflected only material substitutions.

C. Testing Protocol

Six standardised ASTM tests were conducted in triplicate at the Gujarat Institute of Civil Engineers & Architects (GICEA), Ahmedabad:

Test	Specimen Dimensions	Standard / Equipment	Parameters
Density	15 cm × 15 mm × 16 mm	Swisser™ Digital Balance (0.001 g)	Weight per unit volume
Tensile Strength & Elongation	10 cm × 75 mm × 16 mm	ASTM D 3039 / UTM MCS-UTE 60	10 mm/min strain rate to failure
Compression Strength	15 cm × 15 mm × 16 mm	ASTM D 3410 / EIE Model KW/HP 1	10 mm/min strain rate
Flexural Strength	20 cm × 30 mm × 16 mm	ASTM D 790 / M.B. Instruments PR 0289	Three-point bending
Water Absorption	15 cm × 15 mm × 16 mm	ASTM D 5790 / EIE Curing Tank	Oven-dry then 24 h immersion; WA(t) = [(Wt-Wo)/Wo]×100

3. RESULTS AND DISCUSSION

Testing across six critical properties provides compelling evidence that waste-based materials represent not merely an

acceptable alternative but, in several cases, a superior option.

A. Test Results

Table III: Properties of WPVC (Commercial) and CSR PVC (Experimental) Composites

Property	WPVC T1	WPVC T2	WPVC T3	WPVC Avg	CSR PVC T1	CSR PVC T2	CSR PVC T3	CSR PVC Avg
Density (g/cm³)	0.51	0.51	0.51	0.51	0.55	0.51	0.53	0.53
Tensile Strength (N/mm²)	5.50	5.43	5.73	5.55	5.65	5.55	5.67	5.62
Elongation (%)	1.52	1.52	1.52	1.52	1.56	1.59	1.53	1.56
Compression Strength (N/mm²)	169	168	152	163	145.25	149.88	150.15	148.42
Transverse Strength (N/mm²)	7.02	7.20	7.09	7.10	7.31	7.12	7.25	7.22
Water Absorption (%)	1.4	0.95	1.4	1.25	1.3	1.4	1.2	1.30

Table IV: Properties of WPP (Commercial) and CSRPP (Experimental) Composites

Property	WPP T1	WPP T2	WPP T3	WPP Avg	CSRPP T1	CSRPP T2	CSRPP T3	CSRPP Avg
Density (g/cm³)	0.70	0.72	0.66	0.69	0.66	0.70	0.70	0.68
Tensile Strength (N/mm²)	7.35	7.52	7.43	7.43	7.50	6.01	6.00	6.50
Elongation (%)	1.69	1.66	1.47	1.60	1.71	1.62	1.58	1.63
Compression Strength (N/mm²)	176.26	181.90	170.25	176.13	181.26	179.95	179.15	180.12
Transverse Strength (N/mm²)	7.68	8.06	7.76	7.83	7.54	7.30	7.27	7.37
Water Absorption (%)	1.04	1.02	1.11	1.05	0.55	0.52	0.55	0.54

B. Property-by-Property Analysis

1. Density

CSR PVC measured 0.53 g/cm³ vs. 0.51 g/cm³ for WPVC (3.9% difference); CSR PP showed 0.68 g/cm³ vs. 0.69 g/cm³ for WPP (1.4% variation). These negligible differences confirm that substituting recycled polymers and cotton stalk flour does not alter fundamental material structure. Existing production lines, shipping calculations, and structural specifications require no modification when transitioning to waste-based materials.

2. Tensile Strength

CSR PVC achieved 5.62 N/mm² vs. 5.55 N/mm² for WPVC—a 1.3% improvement suggesting good interfacial bonding between recycled PVC and cotton stalk fibers. CSR PP measured 6.50 N/mm² vs. 7.43 N/mm² for WPP—a 12.5% reduction. Both values remain within acceptable engineering specifications for typical WPC applications including decking, outdoor furniture, and fencing. The variation likely reflects differences in polymer-fiber compatibility between cotton stalk and PP versus PVC matrices, suggesting opportunity for optimization through compatibilizer selection or surface treatment.

3. Elongation

Both experimental composites exhibited marginally higher elongation: CSR PVC at 1.56% vs. 1.52% for WPVC; CSR PP at 1.63% vs. 1.60% for WPP. This enhanced ductility means materials are less prone to sudden brittle fracture and better able to accommodate cyclic thermal stresses from day-night temperature variations and seasonal changes—a practical advantage for outdoor applications. All values cluster between 1.52% and 1.63%, confirming waste-based materials maintain the balance between strength and flexibility essential for real-world performance.

4. Compression Strength

CSR PVC showed an 8.9% reduction (148.42 vs. 163.00 N/mm²), while CSR PP outperformed its commercial counterpart by 2.3% (180.12 vs. 176.13 N/mm²). This divergence reflects the cotton stalk's hollow, fibrous cellular architecture interacting

differently with PP versus PVC matrices. Polypropylene's greater flexibility distributes compressive forces along fiber walls, while PVC's higher rigidity may concentrate stress. CSR PVC values remain adequate for most residential WPC applications; CSR PP's enhanced compression is advantageous for sustained load-bearing uses such as bench seating and high-traffic decking.

5. Flexural Strength

CSR PVC achieved 7.22 N/mm² vs. 7.10 N/mm² for WPVC (1.7% improvement). CSR PP measured 7.37 N/mm² vs. 7.83 N/mm² for WPP (5.9% reduction). All four values cluster between 7.10 and 7.83 N/mm², indicating waste-based materials would perform virtually identically to commercial composites under real-world bending loads—decking, benches, shelves, and panels. The slight advantage of CSR PVC demonstrates that cotton stalk fibers can effectively reinforce polymer matrices against bending when proper interfacial adhesion is achieved.

6. Water Absorption

PVC-based composites showed comparable moisture resistance: 1.30% for CSR PVC vs. 1.25% for WPVC (4% difference). The breakthrough was in PP-based composites: CSR PP absorbed only 0.54% water vs. 1.05% for WPP—a 48.6% reduction. This superior moisture resistance translates directly to improved dimensional stability, durability against mold and mildew, freeze-thaw resistance, and reduced maintenance requirements. Several mechanisms may explain this: cotton stalk's naturally waxy surface compounds (cutin and suberin) providing hydrophobic characteristics absent in wood flour; recycling-induced changes in PP crystallinity or molecular weight; and superior interfacial adhesion reducing micro-voids at fibre-matrix interfaces. This positions CSR PP as potentially superior to commercial products for marine applications, high-humidity climates, and moisture-critical installations.

C. Economic Analysis

Based on current market prices, estimated raw material costs are:

Material	Virgin Price (₹/kg)	Recycled/Alternative (₹/kg)	Cost Reduction
PVC	₹80–100	₹30–45	~50–60%
PP	₹90–110	₹35–50	~50–60%
Wood Flour vs. Cotton Stalk Flour	₹15–25	₹8–15	~40–50%

Based on formulation proportions (65% polymer, 30% filler, 5% additives) and these differentials, experimental composites are estimated to cost approximately 20–25% less to produce. Processing costs, equipment requirements, and additive packages are assumed equivalent. This cost advantage enables manufacturers to lower prices for market share, maintain prices for improved margins, or position products as premium sustainable alternatives qualifying for green building certifications and environmental procurement preferences.

D. Synthesis: Circular Economy Validation

Waste-based WPCs using recycled polymers and cotton stalk flour can match—and in specific properties exceed—

conventional composites. CSR PVC showed equivalent or superior performance across most properties with only moderate compression reduction. CSR PP showed mixed tensile and flexural results but superior compression and dramatically improved moisture resistance. These results validate the technical feasibility of utilising agricultural and synthetic waste streams as viable composite raw materials and demonstrate a pathway to simultaneously address:

- Textile Waste Reduction: Diverting synthetic fabric waste from landfills and incinerators
- Agricultural Waste Valorisation: Converting cotton stalks from burning/disposal liabilities into valuable feedstock

- Deforestation Mitigation: Reducing demand for virgin wood flour, decreasing pressure on forest ecosystems
- Carbon Footprint Reduction: Recycling existing polymers rather than producing virgin plastics from petroleum

4. CONCLUSIONS

Experimental composites utilizing recycled PVC and PP combined with cotton stalk flour demonstrated properties comparable to commercial composites across density, tensile strength, elongation, flexural strength, and water absorption. Technical viability was confirmed as waste-derived materials meet industry specifications, enabling direct substitution in WPC manufacturing. In terms of performance, CSRPP demonstrated 49% lower water absorption than commercial WPP, and both experimental composites showed improved elongation indicating better ductility. Economically, an estimated 20–25% raw material cost saving is achieved with no change in processing requirements. Environmentally, the approach simultaneously addresses textile waste accumulation, agricultural residue burning, and deforestation pressure. Global wood demand continues overwhelming sustainable harvest capacity, driving deforestation that threatens biodiversity, climate stability, and ecosystem services; promoting cotton stalks and other agricultural residues as renewable substitute materials will have significant impact in arresting environmental degradation and conserving forest resources for future generations. Future research should pursue accelerated weathering tests and outdoor exposure trials evaluating UV radiation, moisture cycling, and freeze-thaw resistance; compatibilizer selection, cotton stalk particle size optimization, surface treatments, and processing parameter refinement; SEM, DSC, and contact angle measurements to determine whether CSRPP's superior water resistance stems from cotton stalk chemistry, recycled PP characteristics, or fiber encapsulation; pilot-scale trials evaluating whether performance and cost advantages persist at commercial production volumes; and comprehensive lifecycle assessment across raw material extraction, processing, use, and end-of-life to quantify sustainability benefits beyond waste diversion. The technical foundation established here—waste materials can perform as well as virgin resources—removes a fundamental obstacle to scaling sustainable materials innovation. As resource constraints tighten and environmental regulations strengthen, waste-based composites that perform better, cost less, and reduce ecological footprint will become increasingly essential for sustainable development.

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