Blending and injection molded wood polymer composites using morus alba fibers and hdpe: a study on physical, mechanical, and termite resistance properties and morphology

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Abstract. The growing impact of global warming and deforestation has increased the demand for sustainable alternatives to traditional wood based materials. This study examines *Morus alba* (silk mulberry) wood particles as a renewable reinforcement in high density polyethylene (HDPE) composites. Composites were produced through melt blending and injection molding with varying particle loadings. Mechanical, physical, termite-resistance, and morphological properties were evaluated. Results showed that incorporating silk mulberry particles enhanced tensile and flexural strength, density, and durability up to an optimal reinforcement level. Morphological analysis confirmed good particle dispersion and interfacial bonding. These findings demonstrate the potential of silk mulberry agricultural waste for developing eco-friendly polymer composites and supporting sustainable material innovation.[1]

1. Introduction

The rapid growth in environmental awareness and the global changes towards sustainable materials have significantly influenced in research and industrial innovations in polymer composites. Traditional polymers like non-renewable fossil resources create environmental challenges due to their non-biodegradable nature and high carbon footprint, so this motivating the development of eco friendly composite materials to balance performance, cost, and ecological impact has become a focal point of materials science research in recent [1].

Wood polymer composites (WPCs) are combine thermoplastic polymer materials with lignocellulosic fibers to attain enhanced performance and sustainability. High density polyethylene is commonly used as a matrix because of its good mechanical properties, chemical resistance, and recyclability. Natural fibers enhance stiffness and strength while reducing dependence on fully synthetic polymers [2].

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Lignocellulosic fibers derived from plant sources gives numerous benefits such as low density, renewability, and competitive specific mechanical properties. Among them, Morus alba (silk mulberry) fiber has gained attention as a promising reinforcement candidate due to its favorable fiber morphology, availability as an agricultural byproduct, and potential inherent resistance to biological degradation. While many studies have investigated on wood fibers such as pine, oak, and bamboo in WPCs, but investigations are limited to related morus alba fibers. In particular, its influence on termite resistance, which is a critical factor for many structural and outdoor applications, has not been ivestigated thoroughly.
Wood polymer composite materials performance is mainly governed by material parameters such as fiber type, fiber content, matrix properties, and processing conditions including blending and injection molding. Blending of natural fibers with thermoplastic matrices is a major challenge due to the intrinsic hydrophilicity of fibers and hydrophobicity of polymers like high density polyethylene (HDPE). This contrast, leads to poor interfacial adhesion and decreased mechanical performance. To avoide this, surface modifications, compatibility, and optimized processing techniques such as injection molding are commonly employed to enhance fiber matrix interaction and improve overall composite properties.
This study investigates Morus alba fiber reinforced high density polyethylene composites prepared by blending and injection molding, focusing on physical, mechanical, morphological, and termite resistance properties to support sustainable material development for the indoor, construction, decking, and other load bearing outdoor applications [4].

2. Materials and methods

2.1 Materials

Morus alba (silk mulberry) wood fibers were used as the reinforcing material. High-density polyethylene (HDPE) grade HD50MA180 (Relience made) was used as the polymer matrix in this study. Commercial grade HDPE granules with a density of 0.95 g/cm³ and melt flow index 20 g/10min suitable for injection molding were procured from a local polymer supplier, coupling agent MAPE (malic anhydried grafted polyethylene) SKF made Orevac 18507 grade, paraffin wax and colour granules.
Morus alba (silk mulberry) wood fibers were used as the reinforcing material. The fibers were obtained from agriculture biproduct mulberry wood [6]. The raw material was cleaned to remove impurities, air dried, and subsequently processed into fibers of controlled size. The selection of Morus alba fibers was based on their availability, lignocellulosic composition, and potential resistance to biological degradation [5].
The polymer matrix, filler, and MAPE coupling agent were weighed according to the desired formulation [3]. The MAPE content was varied (0 to 5 wt%) relative to the total composite weight to evaluate its effect on composite properties. Prior to compounding, the filler was oven dried at 80-105 °C for 24 hours to reduce moisture content.

2.2 Preparation of morus alba fibers

The collected Morus alba wood was initially cut into small pieces and dried in an oven at 80 to 90 °C to reduce moisture content. The dried wood was then mechanically grind into small pieces made to chipper by the chipping machine then pulvarization using a pulverizer to obtain fibers. The fibers were sieved size 0-80 mesh size to achieve a uniform particle size distribution, typically in the range of 100-300 μm. Prior to composite fabrication, the fibers were oven dried at 105 °C for 24 hours to minimize moisture absorption, which can adversely affect processing and interfacial bonding with the polymer matrix.

2.3 Composite formulation

Wood polymer composites were prepared with varying weight percentages of Morus alba fibers in the HDPE matrix. Typical fiber loadings investigated in this study were 20 wt%, 30 wt%, 40 wt% and 50 wt% of silk mulberry wood fibers as ashowed in **Table 1**. In continuation the similar batches were synthesized with 5% MAPE as coupling agent. The compositions were selected to evaluate the influence of fiber content on the physical, mechanical, termite resistance, and morphological properties of the composites.
Wood fiber (flour), high density polyethylene (HDPE), MAPE as coupling agent and wax were first dry mixed using a highspeed mixer. The resulting blends, either with and without the coupling agent, were then compounded using a co-rotating twinscrew extruder equipped with six segmented barrels [3]. The barrel temperature in the feed zone was maintained at 168 °C, while the subsequent barrel zones were set to 175 °C. The extruder die temperature was fixed at 185 °C, and the screw speed was maintained at 100 rpm. The molten composite exited the extruder in the form of strands with a diameter of approximately 3 mm.
These strands were cooled using water cooling tank and subsequently pelletized into granules by using pelletizer. During water cooling, the composite strands tended to absorb moisture; therefore, the pellets were oven dried at 85 °C for 24 hours to remove residual moisture before further processing or testing.

Table 1. Formulation for Preparation of WPC

Wood(g)	**Polymer(g)**	**Coupling agent(g)**	**Wax(g)**
200	780	--	20
300	680	--	20
400	580	--	20
500	480	--	20

2.4 Blending process

The dried HDPE granules and Morus alba fibers were melt blended using a twinscrew extruder (internal mixer, as applicable). The blending process was carried out at a temperature range of 170-190°C, with screw speed adjusted to ensure uniform mixing without thermal degradation of the fibers. The extrudate obtained from the blending process was cooled in ambient conditions and pelletized into granules suitable for injection molding.

2.5 Injection molding of test specimens

The compounded composite granules were molded into standard test specimens using an injection molding machine. The barrel temperature was maintained between 170–200 °C, and the mold temperature was controlled at approximately 30-40 °C. Injection pressure and holding time were optimized to ensure complete molded and defect free specimens. Standard specimens as per ASTM D790-15 (2015) D638-14 physical and mechanical testing were prepared ASTM standards according to wpc specimen.

2.5.1 Specification of testing samples

Composite granuels were injection moulded into test specimens as per ASTM D790-15(2015) for flexural properties (127 mm x 12.6 mm x 6.6 mm; rectangular bar shape) and ASTM D638-14(2014) for tensile properties (165 mm x 13 mm x 3.35 mm; dumbelle shape) (**Fig. 1.**) using a 60 tonne L&T Demag microprocessor controlled, closed loop injection moulding machine. The moulded specimens were kept in desiccators over silica for 24 hours before mechanical testing.

Fig. 1. Fabricated WPC samples

3. Result and discussion

3.1 Physical property testing

3.1.1 Density measurement

The density of the prepaed wood ploymer composites was measured at room temperature using water displacement method (equation (1)) in accordance with ASTM D792 at room temperature.

$$\rho = \frac{m}{V_2 - V_1} \quad (1)$$

Where, m is mass of WPC specimen (g), V_1 is initial volume of water (cm^3), V_2 is final volume of water after immersion (cm^3), ρ is density of WPC (kg/cm^3)

Table 2. shows that, SMHD 1 (20%) having morus alba (silk mulberry) wood fiber low quantity hence it has lesser moisture content and lower density than SMHD 4 having 50% morus alba (silk mulberry) fibers having more density and moisture content and with MAPE coupling agent, SMHDCA 1 (20%) having morus alba (silk mulberry) wood fiber less quantity hence it has lesser moisture content and lower density than SMHDCA 4 having 50% morus alba (silk mulberry) fibers having more density and moisture content , along with the control sample without fibre having lesser moisture content and density[3, 7, 8].

Table 2. Moisture contentant and density

Sample ID	Sl. No	Length (mm)	Width (mm)	Thickness (mm)	Initial weight (g)	Oven Dry weight (g)	Density (kg/m³)	MC (%)	MC (avg)	Density (avg) (kg/m³)
SMHD1 (20%)	1	63.11	12.56	6.66	4.78	4.76	902	0.42	0.31	895
	2	62.48	12.72	6.76	4.78	4.77	888	0.21		
SMHD2 (30%)	1	63.37	12.55	6.85	5.07	5.02	921	1.00	0.99	921
	2	63.73	12.56	6.88	5.12	5.07	921	0.99		
SMHD3 (40%)	1	63.43	12.60	6.85	5.33	5.26	961	1.33	1.13	960
	2	63.96	12.62	6.89	5.38	5.33	958	0.94		
SMHD4 (50%)	1	65.46	12.60	6.97	5.93	5.83	1014	1.72	1.59	1003
	2	61.99	12.67	7.02	5.55	5.47	992	1.46		
Control	1	61.09	12.22	6.59	4.32	4.31	877	0.23	0.23	863
	2	62.28	12.25	6.64	4.31	4.30	849	0.23		
SMHDCA1 (20%)	1	62.87	12.57	6.65	4.73	4.71	896	0.42	0.32	886
	2	63.28	12.85	6.74	4.81	4.80	876	0.21		
SMHDCA2 (30%)	1	63.31	12.67	6.59	4.96	4.92	931	0.81	0.81	926
	2	63.29	12.62	6.67	4.95	4.91	922	0.81		
SMHDCA3 (40%)	1	63.46	12.56	6.67	5.18	5.15	969	0.58	1.07	956
	2	63.53	12.89	6.62	5.19	5.11	943	1.57		
SMHDCA4 (50%)	1	63.41	12.62	6.72	5.34	5.30	986	0.75	0.84	998
	2	64.02	12.61	6.68	5.5	5.45	1011	0.92		

3.1.3 Moisture content of WPC specimens

Testing specimen samples initially mass (W_w)is taken by using balance and then keep it in hot air oven for 24 hours, after oven dried, the mass (W_d) is measured by using equation (2), the moisture content of respective specimen is calculeted, the moisture content is expressed in percentag (%) as shown in **Fig. 2**. Moisture content (MC) of WPC is the amount of water present in the material. Even though plastics are hydrophobic, the wood fibers in WPC absorb moisture.

$$MC(\%) = \frac{W_w - W_d}{W_d} \times 100 \qquad (2)$$

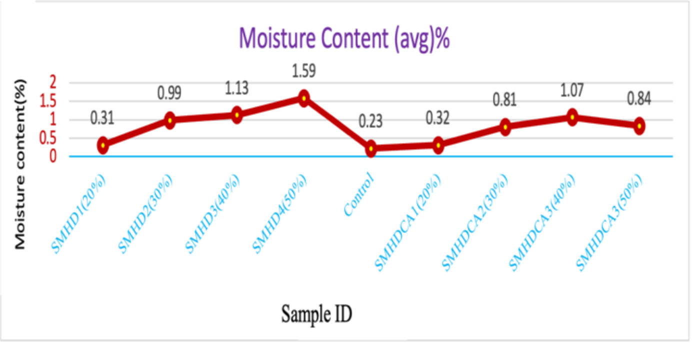


Fig. 2. Moisture content (%)

Fig. 3. illustrates density of the WPC materials, the SMHD4 (50%) sample showed the highest density (1003 kg/m³), while the control sample had the lowest density (863 kg/m³). Overall, WPC density increased with filler content due to improved packing and higher solid content

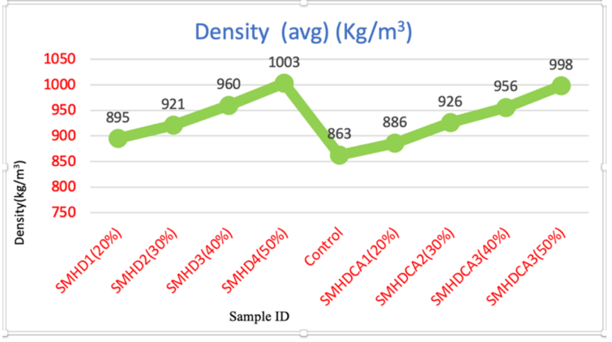


Fig. 3. Density (Kg/m^3)

3.2 Mechanical property testing

The mechanical properties of the composites were evaluated using a universal testing machine, with tensile properties measured according to ASTM D638 and flexural properties determined by a three point bending test in accordance with ASTM D790. For each composition, five specimens were tested, and the average values were reported.

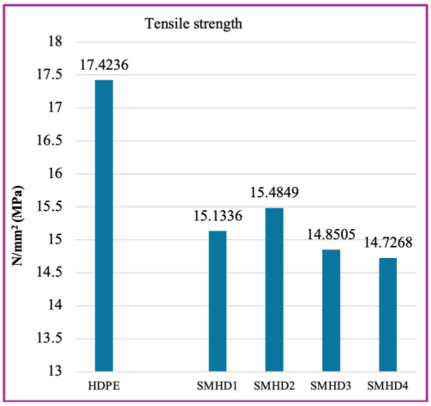


Fig. 4. Tensile strength.

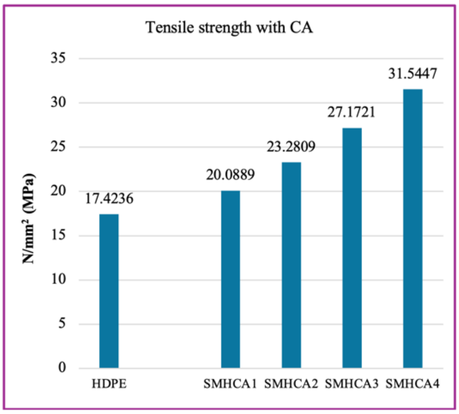


Fig. 5. Tensile strength (Mpa).

The tensile property (**Fig.4, Fig.5**) results shows that HDPE exhibits the highest tensile strength (17.42 MPa), indicating superior resistance to applied tensile forces with the modified samples. Where as, the morus alba fibers+HDPE polymer, composite samples exibits lower tensile strength values (15.48, 15.13, 14.85, and 14.73 MPa), with a gradual decrease the HDPE, fiber content increases. This reduction in tensile strength is because of weaker in bonding and possible stress concentration effects caused by the filler. Overall, HDPE express better tensile stength, while the HDPE polymer combined with the morus alba(silk mulbery) fibers leads to a decline in tensile strength.The flexural test results indicated that pure HDPE exhibits the lowest strength (17.42 N/mm²), while the composition of HDPE polymer + Morus alba fibers + MAPE as coupling agent made to a progressive increase in tensile strength (20.09, 23.28, 27.17, and 31.54 N/mm²(Mpa))[11]. This reults the increased and improved Tensile strength demonstrates couling agent effectively enhances the improves the internal bonding between the Silk mulbery filler and the HDPE matrix, resulting in improved stress transfer and higher flexural strength. It conclude, significantly improves the mechanical performance of SMHDPE composites compared to pure HDPE.

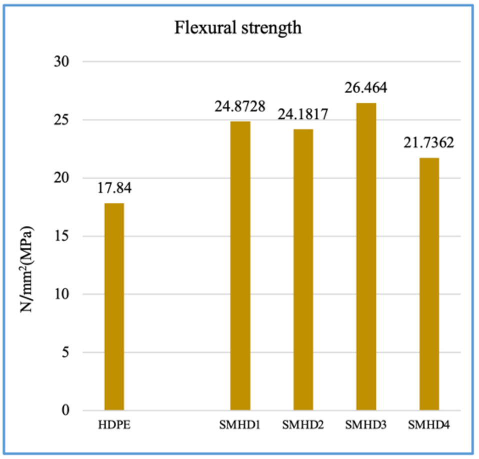


Fig. 6. Flexural strength

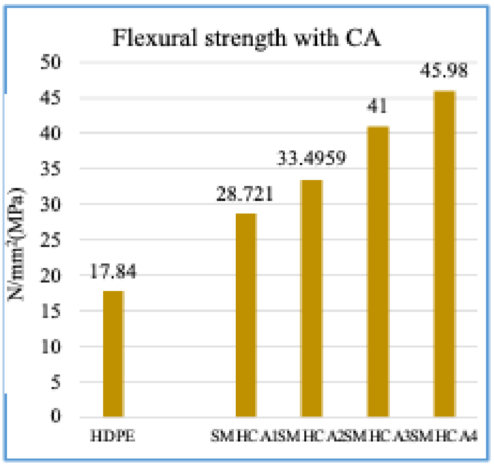


Fig. 7. Flexural strength with CA

The flexural test (**Fig.6, Fig.7**) results shows that pure HDPE has the lowest strength (17.84 N/mm²), while the HDPE + Morus alba (Silkmulbery) + MAPE as coupling agent (CA) leads to effective increase in flexural strength from 28.72 to 45.98 N/mm². This demonstrates that fiber and coupling agent (CA) improves the interfacial bonding between the Silkmulbery filler and the HDPE matrix, enabling more stress transfer within composite loads to more stength. Overall, filler and matrix and coupling agent significantly improves the flexural strength of SMHDPE composites compared to pure HDPE.The flexural strength results shows that pure HDPE exhibits the lowest value (17.84 N/mm²), while the composition of Silkmulbery with coupling agent (CA) leads to a significant and continuous improvement in flexural strength [12]. As the SMHDCA content increases, the strength rises effectively from 28.72 N/mm² to a maximum of 45.98 N/mm²(Mpa), demonstrating the positive effect of CA treatment. This enhancement is showed to improved interfacial adhesion of morus alba (silk mulberry) and the HDPE matrix, which proves more efficient stress transfer under bending, totally the mechanical property of SMHDCA i.e., tensile strength and flexural strength progresive increase results the strength of composite material.

3.3 Termite resistance test (outdoor test yard method)

The termite resistance test in an outdoor test yard is carried out to evaluate the natural durability of WPC under real environmental conditions. In this method, test specimens with morus alba (silk mulberry) wood are installed in soil where termite activity is naturally present. WPC samples of standard size and morus alba (silk mulberry) control samples are placed vertically in an outdoor termite test yard. Each specimen is positioned such that half of its length is buried in the soil (in contact with earth) and the remaining half is exposed above the ground surface (**Fig. 8(a)**). This arrangement simulates actual service conditions, where materials experience both soil contact and atmospheric exposure. The samples are left in the field for a fixed exposure period commonly 3-12 months. Every month contineous observation, after 3 months we observed that inside soil the morus alba (silk mulberry) samples attacked by the termite with weight loss from 200gram to 172 grams (**Fig. 8(b)**) and (**Fig. 8(c)**) total change in its original shape size and 28 grams lost by termite. where as our wpc smaples still there is no change and there is no termite attack and no changes in shape and size. this regular testing carried out every month, the result we observed our WPC samples are completely termite resistance (**Fig. 8(d)**) and free from termite attack, there is no change in size and shape.

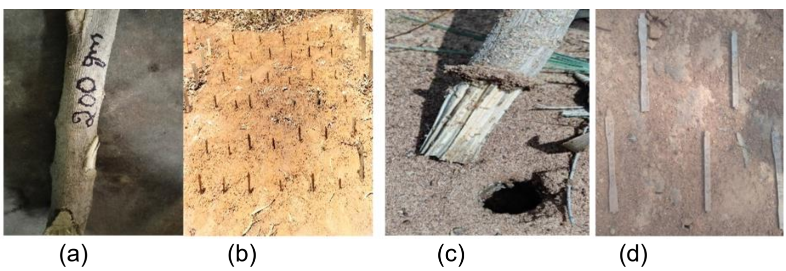
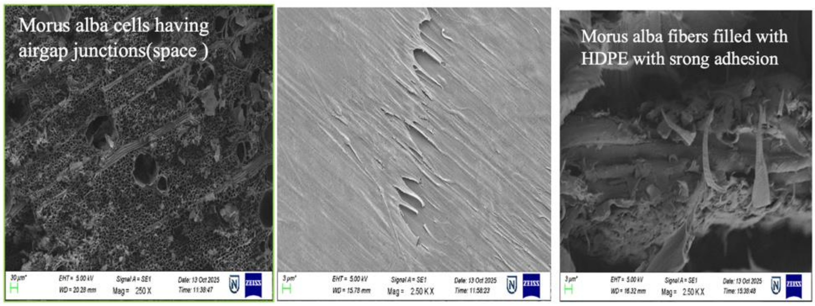


Fig. 8. (a) Silkmulberry wood, (b) Samples Planted in filed, (c) Termite attacked, (d) wpc samples free from termite attack

3.4 Morphological analysis

The morphological analysis of WPC made from silk mulberry fiber and HDPE at 20%, 30%, and 40% fiber loadings shows clear changes in fiber matrix interaction. At 20% fiber, the HDPE matrix is continuous with well dispersed fibers and good interfacial bonding, resulting in minimal voids. At 30% fiber, fiber distribution becomes denser with slight voids and limited fiber pull out, indicating acceptable but reduced matrix coverage. At 40% fiber, insufficient HDPE leads to fiber agglomeration, increased voids, and noticeable fiber pull out, reflecting weaker interfacial adhesion [10, 15]. Overall, 20–30% fiber loading provides better morphological integrity, while higher fiber content reduces composite uniformity. where as with coupling agent MAPE, the morphological analysis (**Fig. 9(a)**), (**Fig. 9(c)**) of WPC prepared from silk mulberry fiber and HDPE with MAPE coupling agent at 20%, 30%, and 40% fiber loadings (HDPE balanced to 1 kg) shows improved fiber–matrix interaction compared to uncoupled composites. At 20% fiber, SEM images (**Fig. 9(c)**) typically reveal a uniform HDPE matrix with well embedded fibers, strong interfacial adhesion, and negligible voids, indicating effective coupling by MAPE. Resulting in better fiber wetting and bonding than untreated composites [16].



(a) (b) (c)

Fig. 9. (a) Morus alba (silkmulberry fiber), (b) Pure HDPE, (c) Composite specimen

Morous alba(silkmulberry)flour (fibers) are with vacume air space filled with HDPE (**Fig. 9(b))** shown in figures having adhesion along the HDPE the CA (mapp) is also improve the bonding strength (**Fig. 9(c)**), in wpc which improves close impact in strong morphological features.

4. Conclusion

The overall study the blending of Morus alba (silk mulberry) fibers with HDPE, particularly in the presence of coupling agents, significantly improves the overall performance of the composites. The blending and injuction moulded combination of fibers anf polymer enhance the physical and mechanical properties, as well termite resistance with the coupling agents promotes strong intenal bonding between the morus alba as hydrophilic fibers and the HDPE as hydrophobic matrix and coupling agent. This formulation leads to improved effectiveness adhesion resulting in higher strength and stiffness. the treated fiber HDPE composites exhibit enhanced termite resistance, making them more durable for practical applications. where as the internal structure of composite material is studied by SEM explains the Morphological feature with strong adhesion, it confirms uniform Morus alba fibers dispersion and strong fiber matrix adhesion, indicating strong and uniform distribution and bonded composite structure. Overall, the use of Morus alba fibers with HDPE and MAPE as coupling agent produces environmentally friendly wood polymer composites with improved mechanical integrity, durability, and termite resistance characteristic.

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