

Original Research Paper

## Effects of Ultraviolet Radiation on the Properties of Wood Plastic Composite with Recycled Polypropylene Matrix

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**Abstract:** Indonesia has an abundance of wood sawdust waste and polypropylene (PP) plastic waste, which remain underutilized. This study aims to investigate the effects of ultraviolet (UV) radiation on the mechanical and physical properties of wood plastic composite (WPC) made from recycled polypropylene. WPC specimens were fabricated using injection molding with 40-mesh pine and teak wood particles at 10% weight fraction. The samples were exposed to UV radiation for 0, 240, and 750 hours, respectively. Mechanical properties were assessed through impact toughness using the Izod test, while physical properties were evaluated based on density and thickness swelling. The results indicated that prolonged UV exposure significantly reduced the impact strength and density of WPC while increasing its thickness swelling. Notably, teak-based WPC exhibited greater resistance to UV degradation compared to pine-based WPC. These findings highlight the importance of UV stability in WPC applications for outdoor environments and suggest potential improvements through material modifications or protective coatings.

**Keywords:** Impact Strength, Recycled Polypropylene, Thickness Swelling, UV Degradation, Wood Plastic Composite.



## 1. Introduction

Indonesia faces major environmental challenges, particularly in managing plastic waste, which continues to accumulate at an alarming rate. Plastic is widely used due to its strength, flexibility, durability, and affordability, making it an essential material in daily life [1]. In 2020, Indonesia generated 65.2 million tons of waste, ranking as the fifth-largest global producer. Without proper management, this figure is expected to double in the coming years. Besides plastic waste, the country also produces significant amounts of wood waste, including sawdust and wood powders from species such as sengon, teak, pine, and coconut fibers [2]. Sawdust, a byproduct of wood processing industries, is often discarded as waste, contributing to environmental issues due to inefficient recycling.

In addition to the challenges of waste management, waste-based materials such as WPC also face environmental challenges, especially due to exposure to UV radiation which can accelerate material degradation. WPC combines the natural strength and aesthetic appeal of wood fibers, such as teak and pine, with the technical benefits of plastic polymers. Teak is valued for its high density and strength, while pine is known for its workability and cost-effectiveness. When blended with polypropylene—a polymer recognized for its water and corrosion resistance—these materials form durable composites suitable for outdoor applications like decking, fencing, and furniture, where longevity and low maintenance are crucial.

One of the primary challenges affecting WPC performance is UV degradation, which can cause embrittlement, surface cracking, and discoloration. These effects occur due to polymer chain scission and oxidation, leading to reduced mechanical integrity. Accelerated weathering tests have demonstrated the impact of UV exposure and heat treatment on WPC's suitability for outdoor use. For instance, testing at 50°C with 500-hour UV radiation cycles has revealed visible surface damage, including cracks and color changes, primarily due to polymer photodegradation and lignin oxidation in the wood filler [3] [4]. This degradation directly affects the mechanical and physical properties of WPC. UV irradiation reduces impact strength by promoting microcracks and increasing brittleness, while density decreases as polymer breakdown leads to material loss. Conversely, thickness swelling increases due to greater moisture absorption through surface cracks and degraded polymer regions [5]. Similarly, Kajaks et al. [6] conducted accelerated aging tests on WPCs made from polypropylene and birch plywood powder, following ASTM G154 for 814 hours. Their findings confirmed that artificial weathering leads to progressive material degradation, with aging rates strongly influenced by composite composition. These studies emphasize the importance of selecting suitable polymer matrices and wood fillers to enhance WPC durability in outdoor environments.

Hirsch et al. [7] further emphasized that the physicomechanical properties and UV weathering resistance of WPCs are significantly affected by the type of plastic and wood powder used in the formulation. The interaction between the polymer matrix and the wood filler plays a critical role in determining WPC's overall performance, particularly under environmental stresses like UV radiation. Another key factor is thickness swelling, which measures the material's resistance to water absorption and dimensional stability. When WPC absorbs moisture, it expands, leading to swelling that can compromise its structural integrity, especially in outdoor environments. The type of wood powder mainly influences swelling behavior, as thermoplastics exhibit low water absorption capacity, which helps limit board swelling and enhance resistance to moisture [8].

Polypropylene (PP) is widely used as a matrix in Wood Plastic Composite (WPC) due to its favorable mechanical properties, chemical resistance, and recyclability [9]. Compared to other thermoplastics such as polyethylene (PE) and polyvinyl chloride (PVC), PP offers several advantages that enhance WPC performance in both structural and environmental applications. PP has lower water absorption compared to both PE and PVC, which enhances the moisture resistance of WPC. Studies have shown that WPC with PP as a matrix absorbs less water and exhibits better dimensional stability than those made with PE [10]. Moreover, PP has superior chemical and UV resistance, reducing the likelihood of microbial growth and photodegradation, both of which are critical for ensuring the long-term durability of WPC in outdoor conditions [4].

This study aims to examine the effects of UV exposure on the impact strength, density, and thickness swelling of Wood Plastic Composite (WPC) made with a waste polypropylene (PP) matrix. The research hypothesizes that prolonged UV exposure will degrade WPC's mechanical and physical properties, leading to a reduction in impact strength and density, while increasing thickness swelling. By analyzing these effects, this study seeks to determine the extent of material degradation over time and compare the findings with existing literature on UV aging in polymer-based composites. The

results are expected to provide valuable insights into the long-term durability of WPC using recycled PP, particularly for outdoor applications where UV exposure is inevitable. Furthermore, this study aims to contribute to the development of more UV-resistant WPC formulations, potentially through the incorporation of stabilizers or material modifications to enhance weathering resistance and structural longevity.

## **2. Literature Review**

### **2.1. Wood Plastic Composite**

Wood Plastic Composite (WPC) is an engineered material that combines wood fibers or sawdust with thermoplastic matrices, offering an eco-friendly alternative to conventional wood and plastic products. WPCs are widely used in construction, automotive, and outdoor applications due to their improved durability, moisture resistance, and recyclability [10]. However, their performance is highly dependent on the type of polymer matrix, wood filler properties, and environmental exposure conditions. The choice of polymer plays a crucial role in determining the mechanical strength, weather resistance, and long-term stability of WPC materials [11].

### **2.2. Effect of Wood Type on WPC Properties**

The type of wood powder used in WPC affects its mechanical strength, moisture resistance, and aging performance. Studies have shown that hardwood-based WPCs generally exhibit better dimensional stability than softwood-based composites due to higher lignin content and lower water absorption [12]. However, lignin, which provides rigidity to wood fibers, is also susceptible to UV degradation, leading to color fading, surface roughness, and embrittlement [13]. This makes UV resistance a critical factor in determining the outdoor durability of WPCs.

Pine and teak are commonly used as wood fillers in WPCs due to their abundance, cost-effectiveness, and mechanical reinforcement properties. Pine-based WPCs contain relatively high lignin content, making them more prone to UV-induced discoloration and embrittlement, whereas teak-based WPCs have a higher natural oil content, which enhances moisture resistance and UV stability [5] [14] [15].

### **2.3. Effect of Polypropylene as WPC Matrix**

Polypropylene (PP) is one of the most commonly used polymer matrices in WPC due to its high mechanical strength, thermal stability, and resistance to moisture absorption. Compared to polyethylene (PE) and polyvinyl chloride (PVC), PP provides superior rigidity, impact resistance, and better recyclability, making it an ideal choice for structural and outdoor applications [16]. Several studies have demonstrated that PP-based WPCs exhibit lower water absorption and better UV resistance compared to PE-based WPCs, which tend to degrade more rapidly due to their lower crystallinity and weaker intermolecular forces [17]. Additionally, compared to PVC-based WPCs, which often require plasticizers for flexibility, PP provides a chlorine-free and environmentally friendly alternative while maintaining long-term mechanical integrity. The selection of PP as a matrix for WPC is thus driven by its balance of processability, strength, and weather resistance, making it a preferred choice for outdoor and structural applications.

### **2.4. Effect of UV Radiation on WPC**

Exposure to ultraviolet (UV) radiation is a major factor contributing to the degradation of WPCs, particularly in outdoor environments. UV-induced aging in polymer composites occurs due to photo-oxidative reactions, leading to chain scission, embrittlement, and discoloration [18]. The degradation of WPCs under UV exposure is influenced by both the polymer matrix and the type of wood filler used.

Kajaks et al. [6] conducted an accelerated weathering study following ASTM G154, exposing WPC samples to UV radiation for 814 hours. Their results showed significant reductions in impact strength and increased surface roughness, particularly in composites with higher wood filler content. Similarly, Vasiljevs et al. [12] found that UV exposure led to surface cracking and microstructural damage, which subsequently increased water permeability and thickness swelling in WPC materials [19]. PP-based WPCs generally show better UV stability compared to PE-based WPCs, but still experience degradation over extended exposure periods. The extent of degradation depends on composite composition, polymer crystallinity, and the presence of stabilizers.

## 2.5. Research Gap

Despite extensive research on WPCs, comparative studies on the UV resistance of WPCs with different wood fillers, particularly pine and teak, remain limited. Most previous studies have focused on single-wood filler composites, without systematically analyzing how different wood species influence UV degradation rates in WPCs.

## 3. Methodology

### 3.1. Materials

This study utilizes wood powders from pine (*Pinus* spp.) and teak (*Tectona grandis*), along with waste polypropylene (PP) as the polymer matrix. The wood powders are derived from industrial wood waste, with pinewood powder chosen for its ease of processing, lighter color, and relatively low density. In contrast, teak wood powder is selected for its high density, natural strength, and resistance to moisture and decay. To ensure uniformity in composite production, both wood powders are sieved to a particle size of 40 mesh.

The polypropylene used in this research is sourced from post-consumer plastic waste, including packaging and household products. Before processing, the material is cleaned, shredded, and then melted before combining the wood powders. Polypropylene is selected due to its durability, chemical resistance, and recyclability, making it an ideal matrix material for WPC production.

### 3.2. Method

Wood plastic composite (WPC) samples are produced by blending wood powder with waste polypropylene. Before incorporation into WPC production, the wood powder undergoes an alkali treatment to enhance mechanical properties and improve adhesion between the wood powder and the polymer matrix. This process, known as alkalization, removes impurities such as lignin, hemicellulose, and natural oils that could hinder bonding between the wood powder and polypropylene, thereby improving material compatibility [20].

Figure 1 and Figure 2 illustrate the WPC fabrication process and the resulting test specimens, respectively.

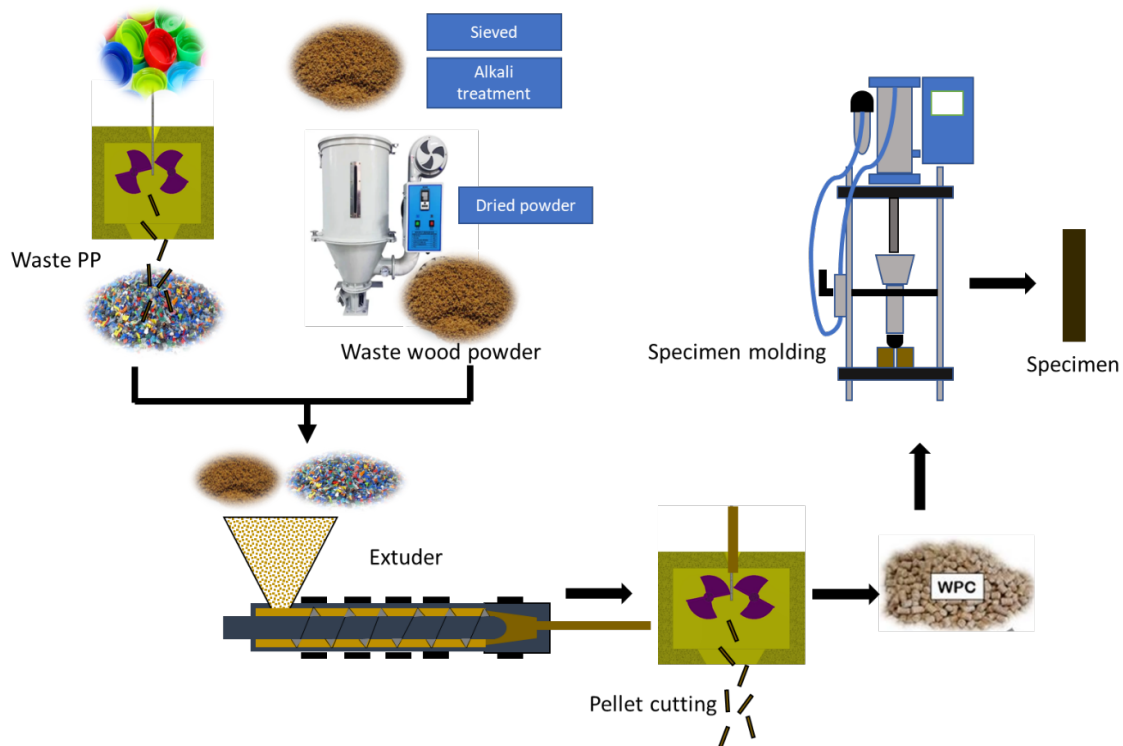


Figure 1. Fabricating WPC Specimen

Both pine and teak wood powders are treated with a 5 wt.% sodium hydroxide (NaOH) solution. The wood powder is immersed in the solution for 2–4 hours at room temperature. After soaking, it is thoroughly rinsed multiple times with clean water until the washing water reaches a neutral pH (pH 7). This step is essential to eliminate any residual alkali, which could negatively affect the composite’s mechanical properties [21] [22]. The cleaned wood powders are then dried at 105°C for 24 hours, reducing the moisture content to below 2%, which helps prevent moisture-related defects during composite processing.

The dried wood powders are mixed with shredded polypropylene at a weight fraction of 20% wood powder using an internal mixer. The wood fraction was set at 20% by weight, based on previous studies indicating that this ratio provides an optimal balance between mechanical strength, processability, and dimensional stability[23]. A maleic anhydride-grafted polypropylene (MAPP) coupling agent is added to enhance compatibility between the wood powder and polypropylene matrix [24]. The mixture is processed through an extrusion machine, where it is heated, melted, and thoroughly mixed to ensure uniform distribution of the wood powder within the polymer. The extruded material is then cooled and cut into pellets, which are subsequently molded into test specimens using an injection molding machine. The molding temperature is maintained between 180°C and 200°C to achieve optimal specimen formation [25].



Figure 2. WPC Specimen

To replicate the effects of prolonged outdoor exposure, the WPC samples undergo accelerated weathering tests. The samples are subjected to UV radiation in a controlled UV chamber, following ASTM G154 standards [26]. The test was conducted using a weathering chamber, with the following parameters:

- UV Light Source: UVA-40 lamps
- UV Intensity: 0.89 W/m<sup>2</sup>
- Temperature: 50°C
- Relative Humidity: 50%

To simulate long-term outdoor conditions, the UV exposure duration is set at three intervals: 0 hours, 250 hours, and 750 hours. All tests were conducted with a minimum of five replications per condition (n = 5) to ensure statistical validity.

The experimental design is outlined in Table 1.

Table 1. Experimental Design

Experiment Nr.	Factor		
	Matrix	Wood Powder	UV exposure
1	PP	Pine	0
2			250
3			750
4		Teak	0
5			250
6			750

Post-weathering evaluations included impact testing, density measurement, and thickness swelling assessment.

The Impact Test was conducted to determine the impact strength of WPC specimens after UV exposure, following the ASTM D256 standard [27]. This standard outline the Izod impact test method, which is widely used to assess the impact resistance of plastics and composite materials.

The Density Measurement was performed using the buoyancy method, adhering to the ASTM D792 standard [28]. This method is commonly applied to determine the density of polymer-based materials, including wood-plastic composites.

The Thickness Swelling Test was carried out according to the ASTM D570 standard [29], which provides guidelines for evaluating the water absorption and dimensional stability of composite materials. In this test, WPC specimens were immersed in water for 24 hours at room temperature, after which the increase in thickness was measured to assess their moisture resistance and dimensional stability. The percentage of thickness swelling was determined using the following Equation (1).

$$T_s = \left( \frac{T_i - T_o}{T_o} \right) \times 100 \quad (1)$$

- $T_s$  = Thickness swelling (%)
- $T_o$  = Panel thickness (mm) before
- $T_i$  = Panel thickness after 24 hours of water immersion

## 4. Finding and Discussion

### 4.1. Impact Strength

After undergoing different durations of UV exposure (0, 250, and 750 hours), the impact testing results showed notable changes in the impact strength of the Wood Plastic Composite (WPC) specimens. Table 2 and Figure 2 present the impact test findings.

Table 2. Average Impact Strength of WPC

Experiment Nr.	Factor			Average Impact Strength (kJ/m <sup>2</sup> )
	Matrix	Wood Powder	UV exposure	
1	PP	Pine	0	19.93
2			250	16.35
3			750	13.3
4		Teak	0	23.46
5			250	20.65
6			750	19.56

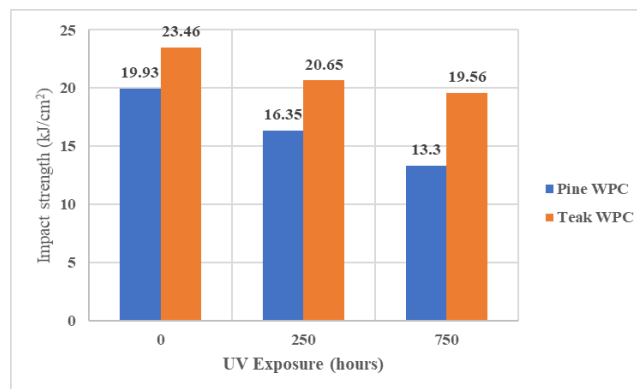


Figure 2. Effect of UV Exposure on Impact Strength

UV exposure significantly influences the impact strength of WPC specimens, regardless of the type of wood powder used. For both pine and teak wood powder, the results indicate a consistent decline in impact strength as UV exposure duration increases.

For WPC specimens made with pine wood powder, the impact strength starts at 19.93 kJ/m<sup>2</sup> at 0 hours of UV exposure. After 250 hours, it decreases to 16.35 kJ/m<sup>2</sup>, reflecting an 18% reduction. With 750 hours of exposure, the impact strength further declines to 13.3 kJ/m<sup>2</sup>, marking a total reduction of 33% from the initial value.

In contrast, WPC specimens with teak wood powder exhibit a higher initial impact strength than those with pine. At 0 hours, the impact strength is 23.46 kJ/m<sup>2</sup>. After 250 hours, it drops to 20.65 kJ/m<sup>2</sup>, a 12% reduction. After 750 hours, the impact strength further declines to 19.56 kJ/m<sup>2</sup>, resulting in a total reduction of 17% from the initial value.

These results suggest that WPC specimens containing teak wood powder demonstrate greater resistance to UV-induced degradation in terms of impact strength. This makes teak a more suitable material for applications requiring higher durability and toughness after prolonged UV exposure. The degradation rate in impact strength is significantly more pronounced for WPCs with pine wood powder, which lose 33% of their initial impact strength after 750 hours of exposure, whereas WPCs with teak lose only 17%.

#### 4.2. Density

The density test results of the Wood Plastic Composite (WPC) specimens after UV exposure illustrate the impact of prolonged UV radiation on the material's compactness and structural integrity. These measurements offer valuable insights into potential changes in material composition, porosity, and degradation caused by UV exposure.

Table 3 presents the average density values of WPC specimens subjected to different UV exposure durations.

Table 3. The Average Density of WPC

Experiment Nr.	Factor		Density (g/cm <sup>3</sup> )
	Wood Powder	UV exposure	
1	Pine	0	0.93
2	Pine	250	0.7
3	Pine	750	0.63
4	Teak	0	0.92
5	Teak	250	0.75
6	Teak	750	0.66

At 0 hours of UV exposure, both WPC specimens exhibit higher density values, indicating a compact and well-bonded material with minimal voids or internal degradation. However, as UV exposure increases, the density of WPC specimens gradually decreases, suggesting a breakdown of the composite's internal structure. This degradation is likely caused by UV-induced micro-cracking, loss of cohesion, and polymer deterioration [30].

For pine-based WPC, the density starts high but decreases progressively after 250 hours and further at 750 hours. The density reduction in pine-based WPC (29%) is more pronounced than in teak-based WPC (26%). Similarly, teak-based WPC follows the same decreasing trend but maintains better density stability, indicating slightly higher resistance to UV-induced structural degradation.

This reduction in density suggests that UV radiation weakens the polymer matrix, affecting the bonding between polypropylene and wood powder [31]. This leads to the formation of micro-cracks, voids, and overall deterioration in compactness and mechanical integrity. Given the greater density loss in pine-based WPC, the corresponding decline in impact strength further confirms its reduced suitability for long-term outdoor applications compared to teak-based WPC.

### 4.3. Thickness Swelling

The thickness swelling results of Wood Plastic Composite (WPC) after UV exposure provide critical insights into the material's resistance to moisture absorption and dimensional stability, particularly following prolonged UV exposure. Table 4 presents the thick swelling percentages of WPC after 24 hours of water immersion.

The increase in swelling percentage over the three UV exposure durations suggests that pine-based WPC becomes more susceptible to water absorption as UV exposure intensifies. This trend indicates that UV radiation degrades the composite's structure, making it more prone to moisture infiltration.

In contrast, teak-based WPC exhibits more stable swelling behavior, demonstrating better dimensional stability even after extended UV exposure. This suggests that teak wood powder provides stronger resistance to UV-induced degradation and moisture absorption, making it a more durable choice for outdoor applications where exposure to both UV radiation and moisture is a concern.

Table 4. Thickness Swelling After 24 Hours of Water Immersion

Experiment Nr.	Factor		Initial Thickness (To, in mm)	Thickness at Time t (Tt, in mm)	Thickness Swelling (%)
	Wood Powder	UV exposure			
1	Pine	0	3.76	3.79	0.798
2	Pine	250	3.65	3.68	0.822
3	Pine	750	3.6	3.63	0.833
4	Teak	0	3.62	3.64	0.552
5	Teak	250	3.61	3.63	0.554
6	Teak	750	3.6	3.62	0.556

Pine-based WPC exhibits a greater increase in swelling compared to teak-based WPC, likely due to its lower resistance to UV radiation. The higher degree of surface degradation in pine WPC allows for increased water absorption, leading to more pronounced swelling.

On the other hand, teak-based WPC demonstrates superior dimensional stability, with minimal changes in swelling across all UV exposure durations. This suggests that teak WPC is more resistant to UV-induced surface degradation and moisture absorption, making it a better choice for outdoor applications where exposure to weathering and humidity is a concern.

### 5. Conclusion

This study examined the impact of UV exposure on the mechanical and physical properties of WPC using recycled PP matrix with pine and teak wood powder. The results indicate that teak-based WPC has better UV resistance compared to pine-based WPC.

- Impact Strength: After 750 hours of UV exposure, pine-based WPC lost 18.6% of its impact strength, while teak-based WPC only decreased by 5.3%, showing teak's superior UV durability.
- Density: Both materials experienced density reduction, but pine-based WPC lost 32.3%, while teak-based WPC lost 28.3%, indicating greater degradation in pine-based composites.
- Thickness Swelling: Pine-based WPC showed higher swelling (0.798% to 0.833%) than teak-based WPC (0.552% to 0.556%), suggesting better dimensional stability in teak-based WPC.

These findings highlight the importance of wood species selection in WPC durability. Teak-based WPC is more suitable for outdoor applications due to its higher UV resistance and stability. Future studies should focus on UV stabilizers, long-term weathering tests, and advanced material modifications to enhance WPC performance.

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