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ORIGINAL PAPER

The effect of nanoclay (NC) on mechanical, thermal, and morphological properties of wood plastic composite (WPC) based on recycled polyethylene (rPE) and kenaf fiber

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Abstract

This development contributes to the effects of nanoclay (NC) on mechanical, thermal, and morphological properties of wood plastic composites (WPC). The WPC was formulated with recycled polyethylene (rPE), kenaf fiber, polyethylene-*graft*-maleic anhydride (PE-*g*-MA), both with and without nanoclay (NC). The results showed that the addition of NC into WPC slightly decreased tensile strength due to low surface interactions. However, tensile modulus had increased from 1471 to 2001 MPa due to rigid structures of NC. The impact strength of WPC increased from 6.1 to 8.2 kJ/m^2 due to exfoliation of NC had improved fiber/nanoclay-matrix interfacial. DSC results showed that only one peak of T_g had observed in both WPC due to miscible blending. The WPC decomposition had slightly affected with NC addition. The cross-section of WPC observed no holes in kenaf/rPE/nanoclay.

Introduction

Wood plastic composite (WPC) is a composite material that consists of plant fibers and a thermoplastic or thermoset. The ability of thermoplastics to melt allows wood fibers to be mixed with them to produce composites [1]. Currently, WPC market has grown significantly across various applications including door frames, docks, furniture, and wall panels. Therefore, environmental friendly wood resources are crucial for WPC production because conventional woods are costly [2]. Furthermore, with the expanding application of thermoplastics, many industries have shifted to use recycled thermoplastics that are both eco-friendly and cost-effective. Moreover, the manufacturing of WPC has shifted from using virgin thermoplastics to recycled thermoplastics due to the high cost and limited availability of virgin plastics. The combination of recycled thermoplastics such as recycled polyethylene (rPE) and recycled polypropylene (rPP) with wood fiber is an environmentally way to produce WPC [3].

Thermoplastic polyethylene (PE) is well-suited for recycling as its properties are well-preserved across multiple cycles of aging and processing. Recycled thermoplastics and wood fibers composites have risen the attention of researchers because it can offer outstanding mechanical properties. WPC typically comprises four key components: wood flour, thermoplastic, a coupling agent, and a lubricant [4]. The mechanical and physical properties of WPC heavily rely on material formulations. Commonly, wood flour comprises about 50 to 70 percent of WPC formulation. Kenaf is a commonly used natural fiber that can replace wood. This fiber is readily available and cost-effective. Numerous studies have shown that kenaf fiber exhibits outstanding mechanical and thermal properties in contrast to other natural fibers [5, 6].

Recycled plastics alone cannot overcome the mechanical and thermal properties of WPC. Therefore, mineral fillers such as NC, talc, graphite, mica, can be used to improve their properties. Nanocomposites have become a key development for plastic industries, for example layered silicate NC is used as in situ reinforcement. The properties of nanocomposite, such as high aspect ratio and surface area, offer excellent product quality. Currently, nanocomposite have been validated to improve various thermoset and thermoplastic properties such as flexural strength, tensile strength, thermal degradation, and barrier resistance [3].

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This research investigated the influence of NC on mechanical, thermal, and morphological properties of WPC based on rPE and kenaf fiber. NC was used to improve the properties of WPC. Furthermore, to improve bonding and compatibility between rPE and wood flour, PE-g-MA was used as a coupling agent. The utilization of NC and kenaf fiber to make WPC is the novelty of this project.

Material and method

Material

Kenaf core, sized at 250 µm as disperse phase and recycled polyethylene (rPE) as matrix phase were supplied by Innovative Pultrusion Sdn. Bhd. Polyethylene-*graft*-maleic anhydride (PE-*g*-MA), $(C_4H_2O_3{\cdot}C_2H_4)_n$ as coupling agent. Nanoclay (NC) surface modification by 35 to 45 wt% of dimethyl dialkyl (C_{14}–C_{18}) amine as reinforcing filler. All chemicals were purchased from Merck, Germany.

Composites preparation

WPC formulations were prepared with 38.8 wt% of kenaf fiber, 58.2 wt% of rPE, and 3 wt% of PE-*g*-MA. Additionally, 3 phr of NC was included in the kenaf/rPE/nanoclay sample. The materials were weighed and manually premixed in a container for 15 min before being fed into a single-screw extruder (Labtech Engineering, model LBE20-30/C). The barrel temperature profile for the compounding process was set to 210 °C at solid conveying zone, 220 °C at melting zone and 210 °C at melt conveying zone. The screw speed was set to 60 rpm. After extruded, the samples were compression molded at 5.17 MPa and temperature 215 °C using 250 mm × 350 mm × 100 mm stainless steel frame for 20 min. All sample were kept in desiccators for 24 h before testing.

Characterization

Mechanical analysis

Tensile strength test was conducted using a universal testing machine (UTM), Instron model 8112, according to ASTM D3039 with an extension rate of 2 mm/min. Izod impact test was conducted using advanced equipment impact testing machine, AE-ICITFC, according to ASTM D256 on notched impact samples. Five samples of each formulation were tested, and the average values were determined.

Thermal analysis

Thermal degradation test was conducted using thermogravimetric analysis (TGA), TGA/DSC/1600, Mettler Toledo according to ASTM E 1131. The WPC samples were scanned from 24 to 1000 °C at a heating rate 10 °C/ min. Each sample was placed in a platinum pan with a nitrogen inlet flow rate of 20 mL/min function as purge gas. Onset temperatures of 10% and 50% weight loss were used as an indicator for thermal stability. Furthermore, glass transition temperature (T_g) and melting temperature (T_m) of the WPC samples were determined using differential scanning calorimetry (DSC), Netzsch Polyma214 according to ASTM D 3418. Initially, the WPC sample weighing between 10 and 15 mg was placed in an aluminum pan. Subsequently, the sample was scanned from 30 to 500 °C at a heating rate of 10 °C/min.

Morphological analysis

Morphological properties of WPC samples were examined by Scanning electron microscope (SEM), Carl Zeiss EVO 50. The fractured sample from impact test was cut into a small piece and observed under SEM with an acceleration voltage of 10 kV.

Results and discussion

Mechanical analysis

Table 1 shows the tensile strength, tensile modulus, and impact strength of kenaf/rPE and kenaf/rPE/nanoclay WPC. The addition of NC into kenaf/rPE has slightly decrease the tensile strength from 14.67 to 14.07 MPa. Wang et al. reported that a higher content of NC (> 3phr) leads to a reduction in tensile strength. This is due to the agglomeration of NC, poor exfoliation of NC, and limited surface interaction between NC and the composites [7]. Furthermore, the addition of NC to kenaf/rPE increased tensile modulus from 1471 to 2001 MPa. The modulus of composite relies on ratio of filler modulus to polymer matrix. NC has higher modulus and rigidity than the polymer matrix. Therefore, the addition

Table 1 Tensile strength, tensile modulus and impact strength of kenaf/rPE and kenaf/rPE/nanoclay samples

Sample	Tensile (MPa)		Impact (kJ/m^2)
	Strength	Modulus	Strength
Kenaf/rPE	14.67	1471	6.1
Kenaf/rPE/Nanoclay	14.07	2001	8.2

of NC increases the composite's modulus and make it stiffer [8]. Furthermore, the impact strength of kenaf/rPE enhanced from 6.1 to 8.2 kJ/m^2 in the presence of NC. This result suggests that the exfoliation of NC enhanced the performance of the fiber/NC-matrix interface [9]. Moreover, NC effectively distributed the applied stress across a significant volume at the notch base, helping to prevent crack propagation and absorb excessive energy, thereby preventing brittle fractures [9, 10].

Thermal analysis

Figure 1 shows thermogravimetric analysis (TGA) curves of kenaf/rPE and kenaf/rPE/Nanoclay. The presence of NC caused the initial decomposition temperature, $T_{10\%,}$ to decrease from 290 to 279 °C. According to Olewnik et al., a catalytic effect on degradation of polymer matrix was not detected under nitrogen flow [11]. Furthermore, the decomposition temperature, $T_{50\%}$ decreased from 427 to 419 °C in the presence of NC. This indicated that the quantity of exfoliated NC used is insufficient to improve the thermal degradation of kenaf/rPE sample. The graph also showed kenaf/rPE residue at 600 °C has increased from 0.7% to 1.0% in the presence of NC. This indicates no improvement in thermal stability, as thermal degradation occurs more rapidly for kenaf/rPE/nanoclay. NC can act as a barrier, improving thermal stability, but it can also act as a catalyst, decreasing thermal stability [11].

Figure 2 shows the differential scanning calorimeter (DSC) curves of the composites. Only one peak of T_g observed in both samples. This showed that rPE and kenaf filler had good compatibility, which resulted in miscible blending. Melting temperature, T_m, decrease from 355.0 to 300.0 °C and crystallization temperature also decrease from 280 to 270 °C in the presence of NC. The decrease in T_g

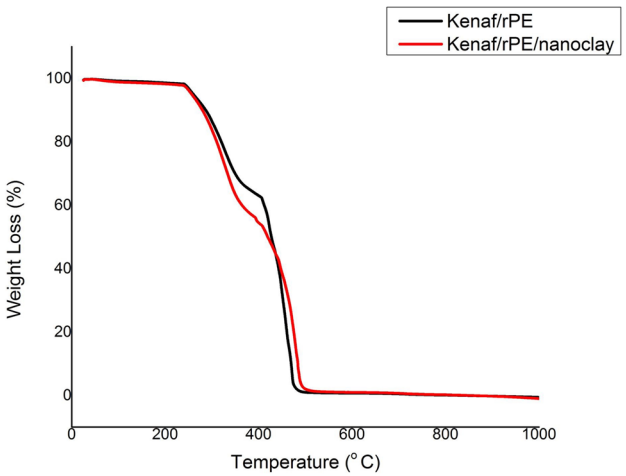

Fig. 1 TGA curves of kenaf/rPE and kenaf/rPE/nanoclay WPC

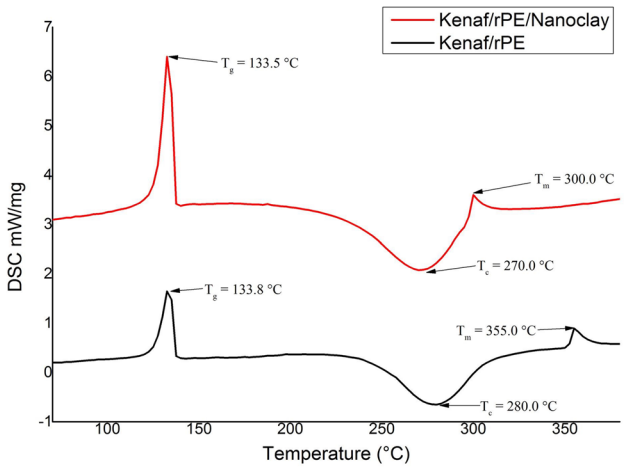

Fig. 2 DSC analysis of kenaf/rPE and kenaf/rPE/nanoclay WPC

may be attributed to the morphology of the nanocomposite, where partial exfoliation could obstruct crystalline growth within the composites. Additionally, it is believed that the organoclay contributes to nucleating effects that influence the degree of crystallinity [11].

Morphological analysis

Figure 3 shows the SEM images of kenaf/rPE (a) and, kenaf/rPE/nanoclay (b). Furthermore, Fig. 3a demonstrates the large holes formed in the kenaf/rPE sample due to fiber pull-out from the matrix. This revealed that the 40:60 ratio combination of kenaf and rPE resulted in weak interaction and poor mechanical adhesion between them. As previously mentioned, incorporating NC can lead to a reduction in tensile strength depending on its concentration. However, NC can also serve as a compatibilizer, facilitating its bonding with the blends and ultimately improving the properties of the composites. Figure 3b shows the surface fracture of kenaf/rPE/nanoclay. No holes were observed, and the surface became smooth, indicating an improvement in interfacial adhesion. Moreover, the NC was uniformly dispersed due to its particle size being less than 200 nm [12]. The addition of NC, which exhibits better dispersion and a smoother surface, can be correlated with an enhancement in impact strength [13].

Conclusion

The addition of 3 phr NC into kenaf/rPE WPC increased the impact strength from 6.1 to 8.2 kJ/m^2 and tensile modulus from 1471 to 2001 MPa. However, its not significantly affected the tensile strength and glass transition temperature, T_g of the composite. The SEM images of kenaf/rPE/nanoclay

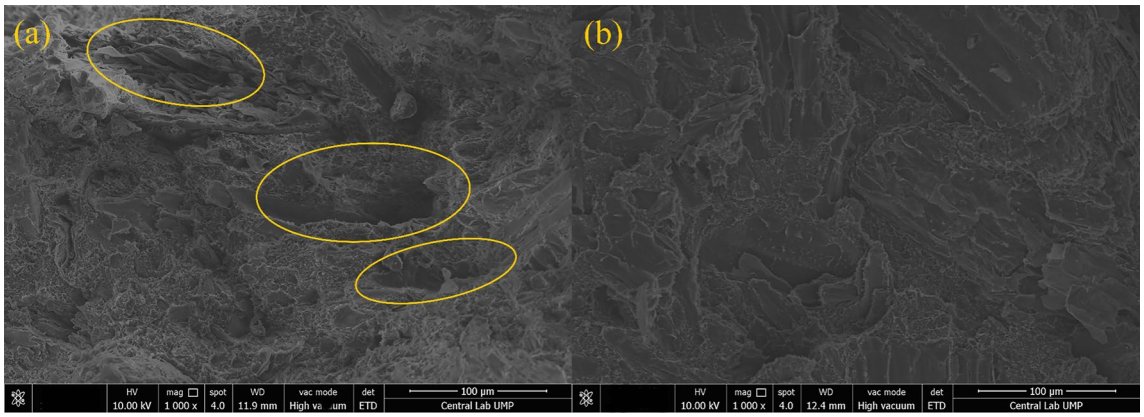

Fig. 3 SEM micrograph of **a** kenaf/rPE, and **b** kenaf/rPE/nanoclay (**b**) at 1000 × magnification

revealed that no holes were formed in the composite, indicating improved compatibility and dispersion between kenaf and rPE. Based on the results, it can be concluded that adding 3 phr of NC to kenaf/rPE has led to improvements in mechanical properties, surface morphology and not effected thermal decomposition of WPC. The novelty of this research lies in the use of NC and kenaf fiber to develop WPC.

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Author contributions INN: Conceptualization, formal analysis, methodology, analysis of the results and writing the original draft. RAR: Conceptualization, formal analysis, methodology, analysis of the results, reviewing the manuscript and funding acquisition. WAWA: Methodology and analysis of the results. RN: Analysis of the results, reviewing, and editing the manuscript. YML: Analysis of the results and editing the manuscript.

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Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare that there is no conflict of interest.

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