

MECHANICAL AND PHYSICAL PROPERTIES OF WOOD-PLASTIC COMPOSITES MADE OF POLYPROPYLENE, WOOD FLOUR AND NANOCLAY

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ABSTRACT

The focus of this study was to characterize mechanical and physical properties of experimental composition prepared from nanoclays (Cloisite® 20A), wood flour (WF) and polypropylene (PP). Nanoclays with different concentrations were used as reinforcing filler for wood plastic compositions (WPCs). Maleic anhydride grafted polypropylene (MAPP) was added as a coupling agent to increase the interaction between the components of wood-plastic composites. Nanoclay based wood-plastic composites were made by extrusion process and then injection molding. Mechanical and physical properties of the as-prepared composites were evaluated. The results of strength measurements showed that the flexural modulus of the composite was increased by 56.33 % with increasing of nanoclays contents to 5 wt. %, reaching approximately 3.58 GPa compared to WPC containing 0% of nanoclays. Moreover, the flexural and tensile strengths reached their maximum values when the concentrations of nanoclays was 2.5 wt. %. When maintaining the nanoclays at a low concentration, it was well dispersed in the WPC. However, when more nanoclays (4 –5 wt. %) was introduced, the enhancing effect began to diminish because of the agglomeration of nanoclays which caused poor interfacial adhesion. The addition of nanoclays decreased the average water uptake by 13 %, compared to the control sample (without nanoclays). The improvement of physical and mechanical properties confirmed that nanoclays has good reinforcement and the optimum effect of nanoclays was archived at 2.5 wt. %.

Keywords: Wood plastic composites; wood flour; Nanoclay; Mechanical properties; Physical properties.

INTRODUCTION

The term WPCs relates to any composites that contain plant (including wood and non-wood) fibers and thermosets or thermoplastics. Thermosets are plastics that, once cured, cannot be melted by repeating. These include resins such as epoxies and phenolic, plastics with which the forest products industry is more familiar. Thermoplastics are plastics that can be repeatedly melted. This property permits other materials, such as wood fibers, to be mixed with the plastic to form a composite product. Polypropylene (PP), polyethylene (PE) and polyvinyl chloride (PVC) are the widely used thermoplastics for WPCs (Panthapulakkal et al., 2006). Wood plastic composites (WPCs) are relatively new generation of composite materials and also the most promising sector in the field of both composite and plastic industries. In 1970s, the modern concept of WPC was developed in Italy and gradually got popularity in rest of the world (Pritchard, 2004).

In past ten years, wood-plastic composites (WPCs) have emerged as an important family of engineering materials. They have become prevalent in many building applications, such as decking, docks, landscaping timbers, fencing etc., partially due to the need to replace pressure-treated solid lumber (Pilarski and Matuana, 2005). Wood-plastic composites (WPCs) are obtaining a great attention in industrial sectors and academics due to their favourable properties, which include low density, low cost, renewability and recyclability as well as desirable mechanical properties (Zhang et al., 2012). Better stability and favourable mechanical properties has caused WPCs to become a preferred building material (Adhikary et al., 2008).

Wood flour (WF) is gaining more acceptance as a type of filler for polymers due to its easy availability, low density, biodegradation, renewability, high stiffness, and relatively low cost. Moreover, the renewable and biodegradable features of wood fibers facilitate their fast degradation by composting or incineration. According to the advantages of wood fiber, the production of wood plastic composites (WPCs) and its application in many fields has attracted much attention in the decades (Ashori, 2008). However, when combining thermoplastics with wood fibers by conventional methods, the highly hydrophilic natures of the lignocelluloses materials make them incompatible with the thermoplastics which are highly hydrophobic in nature. The incompatibility leads to weak interfacial adhesion between thermoplastics and wood filler, and poorer of the composite properties. Besides, the hydroxyl groups between wood fibers can form hydrogen bonds which can lead to agglomeration the fibers into bundles and unevenly distribution throughout the non-polar polymer matrix during the compounding processing (Raj and Kokta, 1989).

However, the WF is mainly composed of cellulose, hemicelluloses, lignin and pectins, which leads to water absorption of the WPC resulting in debonding fibers and degradation of the fiber-matrix interface. In addition, the high moisture absorption of natural fibers may cause dimensional instability of the resulting composite and leaned the interfacial adhesion (Singh et al., 1996). The incompatibility problem can be overcome by the use of coupling agents. These materials become chemically linked with the hydrophilic cellulosic fiber on one side, while facilitating the wetting of the hydrophobic polymer chain on the other side.

On the other hand, nano science and nanotechnology have provided a new way to develop WPCs (Lu et al., 2006). Nanotechnology is a very promising area for enhancing the mechanical, physical as well as other properties of WPCs using nanosized fillers. These improvements include high moduli; increased tensile and flexural strength, decrease in water absorbance and increased biodegradability of biodegradable polymers (Ashori and Nourbakhsh, 2009).

In the WPCs, different types of filler are used for improving the mechanical, physical as well as other properties. Among them, nanoclay is widely used as filler. The surface characteristics of Nano powders play a vital role in their fundamental properties from phase transformation to reactivity. A dramatic increase in the interfacial area between fillers and polymer can significantly improve the properties of the polymer (Song, 1996).

Nanoclays are nanoparticles of layered mineral silicates. They are weathering product produced by disintegration and chemical decomposition of igneous rocks with fine texture of particle size less than 0.002 mm (2 micron). Based on nanoparticle morphology and chemical decomposition, nanoclays are organized into several classes such as

montmorillonite (MMT), bentonite, kaolinite, hectorite, and halloysite (Singh-Beemat and Iroh, 2012). Among all, MMT is widely used as reinforcement for the clay-polymer nanocomposites.

One of the major advantages of using nanoclay particles in a polymer matrix is the substantial increase in the mechanical properties with inclusion of only a small amount of nanofiller (<10 wt.% and even less than 5%). In other words, nanoclays are not real fillers but rather additives. However, because of even in such small concentrations they improve physical and mechanical properties of materials (Klyosov, 2007). When compared with a conventional filler (glass, carbon black, talc, etc.), the addition of the nanoclay does not change the viscosity or the density of the system by all that much (Hetzer and DeKee, 2008). An increased number of polymer-particle and particle-particle interactions relative to traditional fillers are provided by the high specific surface area of nanoclay, which is due to its nanometer size and high aspect ratio (Litchfield and Baird, 2008). The reason behind this is the improved physical and mechanical properties of nanoclays filled composites.

Khanjanzadeh et al., (2013) and Madhoushi et al., (2013) exhibited that the water absorption and thickness swelling decreased with increasing amount of nanoclay. Also, the tensile strength of WPCs increased dramatically by adding 1–3% by weight of nanoclay, but properties gradually decreased by further addition of nanoclay (Ashori and Nourbakhsh, 2009). Faruk and Matuana, (2008) revealed that the mechanical properties of HDPE/wood-flour composites could be significantly improved with an appropriate combination of the coupling agent content and nanoclay type in the composites. Clay nanocomposites, especially composites reinforced with nanoclay, show dramatic increases in modulus, tensile and flexural strength, barrier properties, flammability resistance, weathering resistance, water uptake resistance and heat resistance compared with conventional composites (Lei et al., 2007).

The objective of this work was to examine the influence of wood flour, coupling agent and nanoclay loading on mechanical and physical properties of PP-based wood plastic composites (WPCs).

MATERIALS AND PREPARATION

MATERIALS

POLYPROPYLENE

Polypropylene was received from Polypropylene Malaysia Sdn. Bhd. Malaysia. Grade: G112, MFI@ 230 °C: 18 g/10 min, Density: 0.91 g/cm³, Flexural modulus: 1550 MPa, Tensile strength: 33 MPa.

WOOD FLOUR

The fresh wood flour was obtained from Leong Seng Sawmill, Gambang, Malaysia. The fresh wood flour was oven dried at 105 °C for till the attainment of constant weight. The dried wood flour was milled down to particle size of 40-60 mesh (400 – 250 micron). The sieved wood flour was kept in a container for subsequent use.

CLOISITE 20 A

Cloisite 20 A was obtained from Southern clay products, Inc. Gonzales, Texas, U.S.A. The Cloisite 20 A has cation exchange capacity of 95 mequiv/100g, Specific gravity: 1.77g/cc and XRD d001 (Å): 24.2. The Cloisite 20A was modified by Organic modifier: Dimethyl, dehydrogenated tallow, quaternary ammonium, % moisture: < 2 %, % weight loss on ignition: 38 %. The clay was oven dried in a vacuum at 60 °C for 24 h prior to use.

MALEIC ANHYDRIDE POLYPROPYLENE

Maleic anhydride polypropylene was received from Chemtura, China. Trade name: Polybond 3200, MFI@ 230 °C: 18 g/10 min, Density: 0.91 g/cm³, Flexural modulus: 1550 MPa, Tensile strength: 33 MPa.

COMPOUNDING OF MATERIALS

Table 1 shows the blend design for compounding of materials. Totally, 12 sets of blends and composite samples were fabricated. The compounding of materials was carried out in two different steps;

2.2.1. Preparation of polypropylene/ nanoclay composite

2.2.2. Preparation of wood plastic composites

PREPARATION OF POLYPROPYLENE / NANOCLAY COMPOSITE

In first step, the PP granules were reinforced with nanoclay, which were then used as a matrix in the manufacture of the wood plastic composites. As per table no.1, different contents of nanoclay and polypropylene were performed in a single-screw extruder (Brabender GmbH & Co. KG, Germany). The heating temperature profile of the screw were set at 180 °C in feed zone, 210°C in melting, whereas the temperature of the extruder die was held at 200 °C. The screw speed was 70 revolutions per minute and the die size is 5 mm. The PP and nanoclay were premixed before being fed into the first zone of the extruder. The extruder strand passed through a water bath and was subsequently palletized. The overall aim of this work was to make proper dispersion of nanoclay in wood plastic composites.

PREPARATION OF WOOD PLASTIC COMPOSITES

In this step, the granulated Polypropylene/ nanoclay pellets were used as a matrix for WPCs. According to table no.1 the wood flour, MAPP were performed along with polypropylene/ nanoclay granules in a single-screw extruder, which were granulated using the previously described processing condition.

Table 1: Compositions of the studied formulations

| Sample code | Polypropylene (Wt. %) | Wood flour (Wt. %) | MAPP (Wt. %) | Nanoclay (Wt. %) |
|-------------|--------------------------|-----------------------|-----------------|---------------------|
| PP | 100 | 0 | 0 | 0 |
| P0 | 78.0 | 20 | 2 | 0 |
| P1 | 77.5 | 20 | 2 | 0.5 |
| P2 | 77.0 | 20 | 2 | 1.0 |
| P3 | 76.5 | 20 | 2 | 1.5 |
| P4 | 76.0 | 20 | 2 | 2.0 |
| P5 | 75.5 | 20 | 2 | 2.5 |
| P6 | 75.0 | 20 | 2 | 3.0 |
| P7 | 74.5 | 20 | 2 | 3.5 |
| P8 | 74.0 | 20 | 2 | 4.0 |
| P9 | 73.5 | 20 | 2 | 4.5 |
| P10 | 73.0 | 20 | 2 | 5.0 |

Before injection moulding, the compounded pallets were dried at 60 °C for 24 h to remove the remaining moisture. The pallets were then injection moulded in a BOY 22M machine to produce the dog-bone shaped specimens to evaluate the properties of composites. The processing temperatures were set at 180 °C in feed zone, 220 °C in melting and 200 °C in

die zone. The cooling time was 20 seconds, clamping pressure 160 bars, injection pressure 100 bars and plasticizing back pressure 5 bars. The injection speed and screw rotation speed were 142 and 1 mm/ min respectively. Eventually, the dog-bone shaped specimens were conditioned at a temperature of 23 ± 2 °C and relative humidity of 50 ± 5 °C for at least 40 h according to ASTM D618-99.

CHARACTERIZATIONS

MECHANICAL PROPERTIES

Mechanical properties of WPCs in terms of flexural and tensile tests were performed using Universal Testing Machine (Instron, model 8112) according to ASTM D790 and D638, respectively. The specimens were tested at crosshead speed of 3 and 1.6 mm/min for flexural and tensile tests, respectively at room temperature (50% relative humidity and 23 °C). The dimensions of the test specimen were according to the respective ASTM standards. All the reported values for the tests were the average values of 5 specimens.

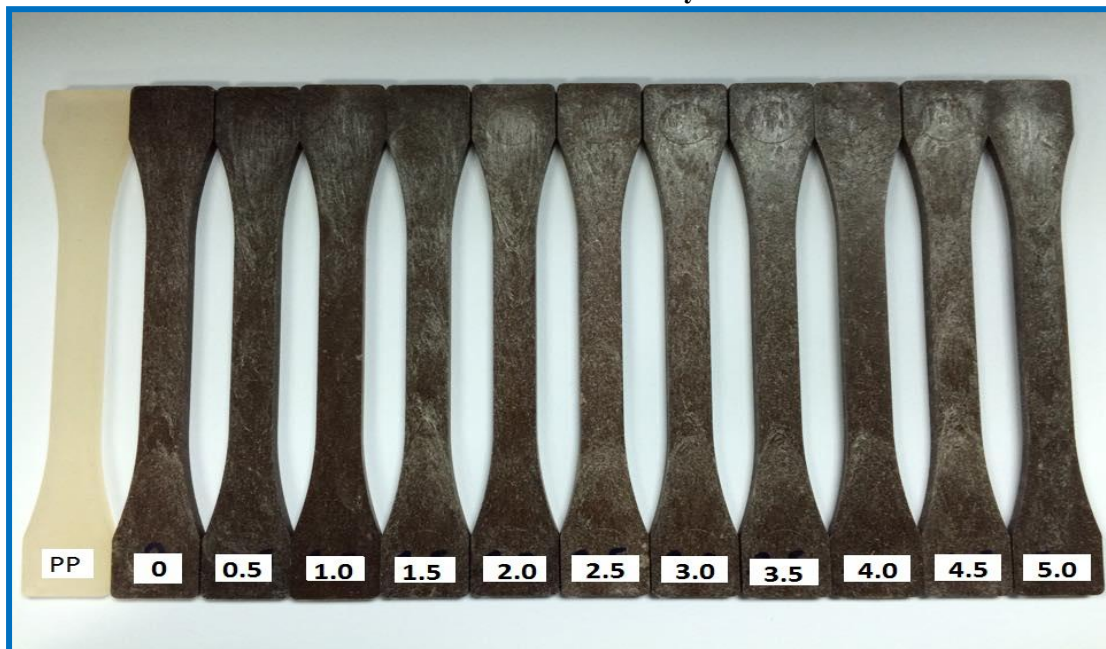
WATER ABSORPTION TEST

The water absorption (WA) test was carried out in accordance with ASTM D 570. Before testing, the weight of each specimen was measured and conditioned samples of each composite type were soaked in distilled water at room temperature for 24 h. Samples were removed from the water, patted dry and then measured again. Each value obtained represented the average of 5 samples. The value of the water absorption in percentage was calculated using the following equation:

$$WA(t) = \frac{W(t) - W_0}{W_0} \times 100$$

where WA (t) is the water absorption (%) at time t, W_0 is the oven dried weight and W (t) is the weight of specimen at a given immersion time t.

Figure 1: Image of sample made of pure polypropylene and images of samples made with different content of nanoclay

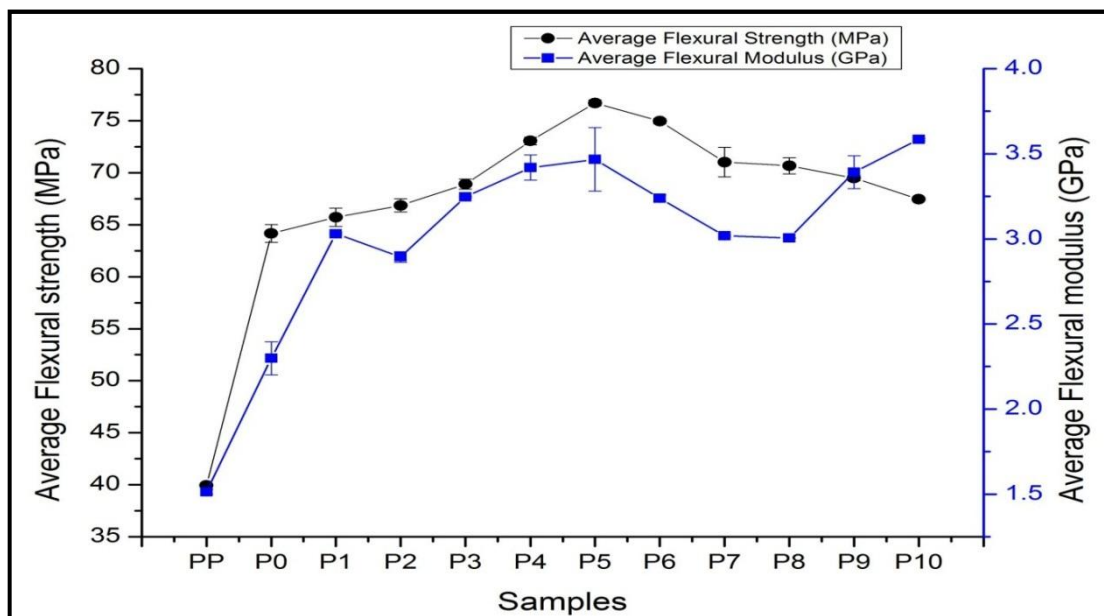


RESULTS AND DISCUSSION

FLEXURAL PROPERTIES

The flexural strength of the composites mainly depended on the interfacial interaction and the properties of constituents. The flexural properties of the composites vary significantly with nanoclay loading as shown in Fig. 2. The composites prepared with 2.5 wt. % nanoclay had better homogeneous dispersion and better interfacial interactions in the WPCs, which enabled effective stress transferring from matrix to fibers and then leading to high flexural strength, while neat PP and composites without nanoclay revealed the poor and lowest properties. The reason might be that the flexural modulus of nanoclay is considerably higher than WF and PP. The flexural modulus in composites is mainly a function of the modulus of individual components (Yildiz and Gumuskaya, 2007). An increased flexural property for 2.5 wt. % nanoclay loading is attributable to the high stiffness of nanoclay with high aspect ratio. In addition, the increase in flexural properties was expected due to the improved adhesion between components in the composites.

Figure 2: Effect of nanoclay loading on flexural properties of WPCs



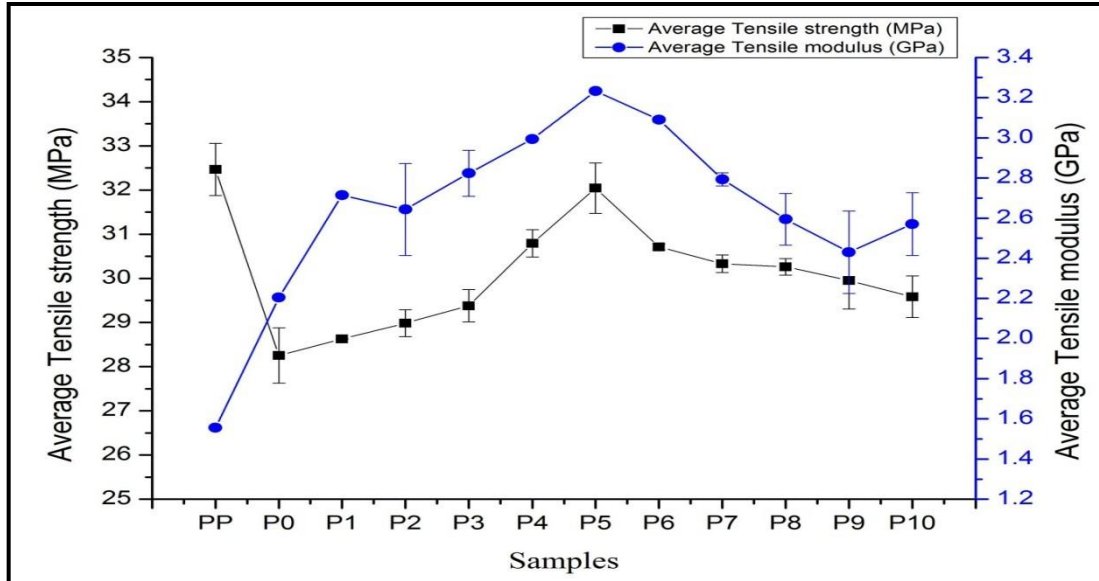
As it can be clearly seen in Fig. 2, that with increase in nanoclay loading from 3 to 3.5 wt.%, the flexural properties are considerably decreased. The maximum value of flexural strength and modulus was found at 2.5 wt. % of nanoclay concentration. Ashori and Nourbakhsh, (2009) reported that the modulus of composites at higher nanoparticles concentration reduced because of the agglomeration of nanoclay in WPCs. One of the most important parameters in fabricating the composites is nanoclay dispersion in the matrix. The agglomeration of nanoparticles caused the reduction of physical and mechanical properties of the resultant nanocomposites. The nanoclay concentration from 4 to 5 wt. % exhibited the instrumental error.

TENSILE PROPERTIES

Fig. 3 depicts the tensile strength and modulus of composites made with various concentration of nanoclay. The tensile strength and modulus results show that the composites containing 2.5 wt. % of nanoclay exhibited the highest value compared to the other samples. The tensile strength value was observed to be 28.25 MPa for composites made without nanoclay, while maximum tensile strength was approximately 32.04 MPa for composites made with 2.5% nanoclay. The tensile strength of pure PP is decreased by at least 15% when WF was added. This is not surprising since it is known that when wood flour is used in thermoplastics, the tensile strength decreases. The higher degree of brittleness introduces by the incorporation of wood flour in WPCs (Yeh et al., 2013). Unlike tensile strength, tensile modulus of the samples increased by 47% as seen in Fig. 3. The tensile strength of composites is mainly influenced by filler fraction and the interfacial adhesion between particles and matrix (Sun et al., 2006). The possible reason behind this

kind of behaviour may be the better interfacial adhesion between the matrix and WF. Better adhesion results in more restriction to deformation capacity of the matrix in the elastic zone and increased modulus. Similar observations were reported for other lignocellulosic fibers based PP composites (Ashori and Nourbakhsh, 2011).

Figure. 3: Effect of nanoclay loading on tensile properties of WPCs

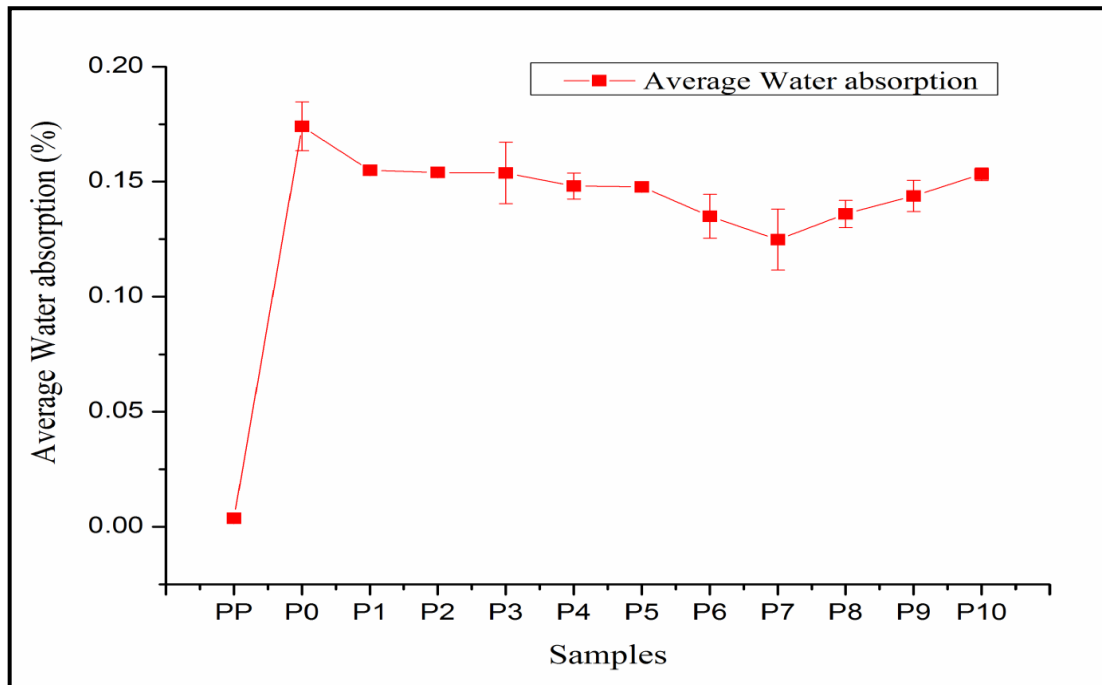


As can be seen from Fig. 3 both tensile properties were improved with the addition of nanoclay and this result is consistent with the general observation that the introduction of nano-sized particles into a polymer matrix increases its tensile properties (Hussain et al., 2006). The enhancement is easily understood because nanoclay as filler can carry more tensile load. As mentioned earlier, the nanoclay is much stiffer than polymer matrix and as a result it adds stiffness to the composites. In Fig. 3, it is clearly illustrates that unlike 2.5 wt. % of nanoclay further addition of nanoclay cannot considerably improve tensile properties and this could be explained by the agglomeration of nanoparticles. The importance of dispersions and their effect on mechanical properties of composites made with nanoparticles has been discussed in many research works (Breton et al., 2004; Coleman et al., 2006).

WATER ABSORPTION

Besides mechanical properties, water resistance is also important for WPCs. The water absorption behaviour is important to investigate the durability of the WPCs exposing to the environmental conditions. The results of water absorption of composites after 24 h immersion with different percentage of nanoclay loading are shown in Fig. 4. The results indicate that as the amount of nanoclay increases, the water absorption of the WPCs decreases significantly. It was also observed that an increase in clay content enhanced the moisture diffusion barrier properties, i.e., moisture absorption decreased with increasing clay content. As it can be seen, neat PP absorbed a very negligible amount of moisture around 0.03% due to its hydrophobic nature, indicating that moisture is absorbed by the hydrophilic woody component in the composite as well as voids and micro-gaps at the interface. The value of water uptake was suddenly increased after the addition of WF to the blend. The hydrophilic nature of wood flour caused an increase in the water uptake.

Figure 4: Water absorption of the composites as function of nanoclay loading



As WF content was constant (20 wt. %) in all blends, the different water absorptions among all the manufactured composites can be attributed to the role of nanoclay. The water uptake was decreased after the addition of nanoclay. WPCs loaded with 3.5 wt % showed lowest water uptake. The nanoclay layers provided tortuous path and increased the barrier property for water transport. According to Das et al., initially, water saturates the cell wall (via porous tubular and lumens) of the fiber, and next, water occupies void spaces (Das et al., 2000). Since composite voids and the lumens of WF were filled with nanoclay, the penetration of water by the capillary action into the deeper parts of composite was prevented.

CONCLUSION

This study examined the effect of nanoclay as reinforcing agent on the physical and mechanical properties of WPCs from Kempas wood flour. The incorporating of nanoclay into the PP matrix effectively improves mechanical properties, this improvement comes at proper nanofiller loading at 2.5 wt. %. The addition of nanoclay decreased the average water uptake by 13%, compared to control samples (without nanoclay). Since composite voids and the lumens wood flour were filled with nanoclays, this prevented the penetration of water by the capillary action into the deeper parts of composite. Therefore, the water absorption in composites filled with nanoclays was significantly reduced. The optimal loading of nanoclays, at which the least water uptake was observed, was at 3.5 wt. %. From this work, it has been concluded that nanoclay are promising materials for the improvement of the mechanical properties and dimensional properties of WPCs.

ACKNOWLEDGMENTS

The author is thankful to University Malaysia Pahang for providing post graduate scholarship and funding (GRS No.1403133) to complete this research.

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