Industrial Crops and Products 51 (2013) 310–316

Contents lists available at ScienceDirect

Industrial Crops and Products

journal homepage: www.elsevier.com/locate/indcrop

The utilization of organic vermiculite to reinforce wood–plastic composites with higher flexural and tensile properties

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ARTICLE INFO

Article history:
Received 25 June 2013
Received in revised form
14 September 2013
Accepted 22 September 2013

Keywords:
Organic vermiculite
Compatibility
Wood–plastic composite
Flexural property
Tensile property

ABSTRACT

In order to reinforce wood–plastic composites (WPC), organic vermiculite (O-VMT) was prepared by intercalating benzyl triphenyl phosphorus chloride (BTPPC) into vermiculite (VMT) and was used as reinforcing filler for WPC, so WPC/O-VMT composites were prepared. Characteristics, morphologies, water absorptions and mechanical properties of the composites were investigated. The results showed that O-VMT had homogeneous dispersion and strong interfacial interaction in the WPC. The WPC/O-VMT composites, with performances improved by O-VMT, displayed lower water absorption properties and higher flexural and tensile properties, suggesting the great potential applications as WPC-based engineering materials.

1. Introduction

Due to the need of replacing pressure-treated solid lumber, wood–plastic composites (WPC) have emerged in the last decade, and have been gaining great attention as important engineering materials (Ashori, 2008; Faruk and Matuana, 2008; Afrifah et al., 2010). They have become prevalent in many building applications, such as decking, docks, landscaping timbers, fencing, etc. (Lin and Renneckar, 2011; Alamri and Low, 2013; Islam et al., 2009; Guo et al., 2010). However, the highly hydrophilic characters of lignocellulosic materials make them incompatible with thermoplastics which are highly hydrophobic. Such incompatibility produces poor interfacial adhesion between matrix and filler, which results in poor mechanical property because stress could not be transferred properly from the matrix to the fibers (Hosseinaei et al., 2012; Deka and Maji, 2012a).

In order to overcome this disadvantage, various approaches are used for the improvement of mechanical properties of composites, such as maleic anhydride grafted copolymer of the matrix polymer (Ngueho Yemele et al., 2013), acetylation (Mwaikambo and Ansell, 1999), heat treatment (Hosseinaei et al., 2012), silane treatment (Lee and Wang, 2006), and treatment with sodium hydroxide (Ichazo et al., 2001). Besides, there are different treatments of lignocellulosic materials that have been used or tried to improve the interfacial bonding between lignocellulosic materials and polymers. The incorporation of nanoparticles as reinforcing filler is another method for improving the overall properties of lignocellulosic-thermoplastic composites (Tabari et al., 2011). A number of studies have reported the effects of montmorillonite and carbon nanotubes on mechanical properties of WPC (Devi and Maji, 2011; Deka and Maji, 2012b). To the best of our knowledge, no published reports are available regarding the effect of vermiculite (VMT) on the mechanical properties of WPC.

Just like montmorillonite, VMT is a 2:1 phyllosilicate, in which the negatively charged aluminosilicate layer is composed of one octahedral sheet sandwiched between two tetrahedral sheets. Magnesium and iron sites are also present within the sheets of typical VMT (Qian et al., 2011). The thermal and mechanical properties of composites increase as the vermiculite is added into polymer. Moreover, the vermiculite modified by organics shows better dispersion in composites and more compatibility with polymer compared with native vermiculite, which results in better properties of composites (Zeng et al., 2012; Qian et al., 2011). Generally speaking, the tensile modulus and tensile strengths of polymer matrix dramatically increase with incorporation of well-dispersed inorganic particles. Therefore, in order to improve the compatibility between the inorganic particles and the polymer, it is common to modify the polymer to become more hydrophilic or

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0926-6690/$ – see front matter.
http://dx.doi.org/10.1016/j.indcrop.2013.09.019

the inorganic particles to become more organophilic (Simons et al., 2011). The study has focused on modification of VMT to make VMT disperse well in polymer.

In this study, organic vermiculite (O-VMT) was used as reinforcing filler. First, benzyl triphenyl phosphorus chloride (BTPPC) was used to modify VMT to get O-VMT. Then, the hemicellulose extraction of wood flour (e-WF) was obtained by putting the original wood flour (o-WF) into boiled NaOH aqueous solution. After mixing polypropylene (PP), e-WF, o-WF and O-VMT, the composites were prepared. The effects of different contents of O-VMT on characteristics, morphologies, water absorption properties and mechanical properties of composites were investigated.

2. Experiment

2.1. Materials

The vermiculite (VMT, <54 μm) with cation exchange capacity of 135 mmol/100 g was purchased from Hebei Lingshou Micromineral Co., Ltd.; benzyl triphenyl phosphorus chloride (BTPPC) was synthesized by ourselves; polypropylene (PP, F401) was purchased from China Petroleum & Chemical Co., Ltd. (Guangzhou, China); the lubricant (stearic acid) and coupling agent (PP-g-MA, grafting degree was 0.8%) were supplied by Ma Ji Sen composite materials Co., Ltd.; wood flour (WF, <150 μm) was supplied by Wei Hua spice Co., Ltd. (Guangdong, China).

2.2. Preparation of BTPPC

Triphenylphosphine and N,N-dimethylformamide were added in 250 mL three-neck flask, and benzyl chloride was added in constant-pressure dropping funnel. After the triphenylphosphine was completely dissolved under magnetic stirring, benzyl chloride was dropped (1 drop/2 s) and the mixture was reacted at 80 °C for 10 h with nitrogen protection. The resultant product was washed with petroleum ether for many times and then was by suction filtration. Finally, the obtained powder was dried in vacuum drying oven at 80 °C for 1 d. The white powder was BTPPC.

2.3. Extraction of hemicellulose and unstable substance

WF was put into 0.25% NaOH aqueous solution (Wt_{WF}:Wt_{NaOH} = 20:1). Then the solution was heated to be boiled for 20 min and cooled down to room temperature. After that, the precipitate was washed to be neutral by deionized water and dried at 80 °C. The powder was gathered with 100 mesh sieve, and the resulting product was e-WF.

2.4. Preparation of O-VMT

Original VMT was fully saturated as Na-form using 1 M aqueous sodium chloride solution for 12 h at room temperature. Subsequently, the semi-finished product was dispersed in deionized water with the slow addition of BTPPC. The dispersion was sonicated under ultrasonic process for 2 h. Then the mixture was stirred vigorously at 80 °C for 8 h. The resulting compound was washed with deionized water for many times until no Cl^- was contained. After dried at 80 °C under vacuum, the layered compound was gathered with 300 mesh sieve, and the resulting product was O-VMT.

2.5. Preparations of samples

Formulations of the mixtures and abbreviations used for the respective composites were illustrated in Table 1. The o-WF, e-WF, PP, stearic acid and PP-g-MA were premixed before being fed into the first zone of the extruder. WPC and WPC/O-VMT composites were prepared by using a twin screw extruder (SHJ-20 with the average screw diameter was 20 mm and the average L/D ratio was 40), with a temperature profile of 120/160/165/170/175/175/170 °C and a rotating speed of 150 rpm, and then the extruded strand was passed through a water bath and pelletized. The pellets were injected into ASTM standard specimens by using an injection molding machine (HMT OENKEY) at 190 °C. The injection mold and actual samples are shown in the Fig. 1.

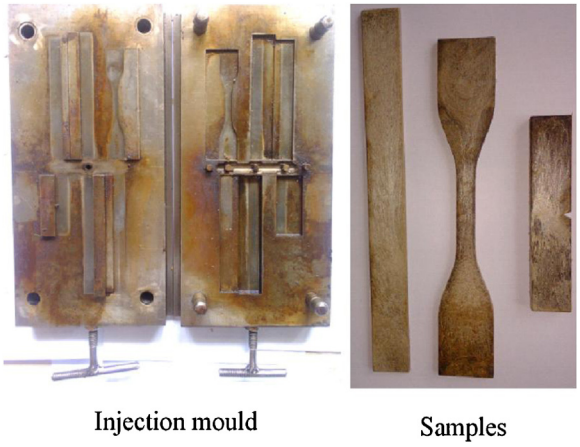

Fig. 1. The images of injection mold and samples.

2.6. Characterization

Fourier transform infrared spectrometer (FTIR) spectra between 500 and 4000 cm^{-1} were obtained on a Nicolet 6700 spectrometer (USA). X-ray diffraction (XRD) patterns were recorded on a diffractometer (D/max-1200) using graphite monochromatic Cu Kα radiation (λ = 0.1541 nm) at a generator voltage of 40 kV and a current of 40 mA; measurements were conducted within a 2θ range of 2.0–40.0° at a scanning rate of 1°/min. Scanning electronic microscope (SEM) was performed on JSM-6330F scanning electron microscope with an accelerating voltage of 20.0 kV; the fracture surfaces of samples were coated with a thin layer of gold before analysis.

2.7. Water absorption property

The water absorption test was conducted as per ASTM (2005). The dimensions of samples for water absorption test were 127 mm × 12.7 mm × 3.2 mm. The conditioned specimens were placed in a container of boiling distilled water, supported on edge and entirely immersed. At the end of 120 ± 4 min, the specimens were removed from the water and cooled in distilled water maintained at room temperature. After 15 ± 1 min, the specimens were removed from the water, and one at a time, all surface water was removed with a dry cloth. The percentage of water absorption was calculated according to the following equation:

$$WA(\%) = \left(\frac{W_2 - W_1}{W_1}\right) \times 100$$

Here W_1 is the weight of oven-dried composite samples before immersion and W_2 is the weight of the composite samples after immersion. The tests were made in quintuplicate and the results were reported as average.