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Original

Physical, thermal, and mechanical properties of polypropylene composites filled with rattan nanoparticles

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Abstract

Natural fillers are recognized as the materials that feature a poor fiber/matrix interaction. As a result, their composites behaviors are directly compromised. Existing evidence has exhibited that nanoparticle fillers can be employed as an alternative size to overcome this problem. We thus examined in this study the effects of rattan filler of nanoparticle size on the physical, thermal, and mechanical properties of the composite. Neat polypropylene (PP), PP with 5% rattan nanoparticle (PP/R5), and PP with 5% glass fiber (PP/FG5) were considered. For performance assessment, particle size analysis, morphology, X-ray diffraction, thermal inspection, and mechanical tests were carried out. The highest degree of crystallinity was discovered in PP/R5. Tensile properties of both PP/FG5 and PP/R5 were comparable although the former demonstrated higher moduli of elasticity and rupture. Well-distributed constituents were displayed in PP/R5 by means of morphological study, which offered insight into its highest average hardness, maximum strain, and therefore its advantageous ductile behavior compared to the other considered materials.

Keywords: Rattan nanoparticle; Natural filler; Mechanical properties; Polypropylene; Twin extrusion molding

1. Introduction

The abundant availability of natural fibrous materials presents a widespread potential that can be smartly exploited in various sectors of industry (Alves et al., 2010; Ashori, 2008; Bahari & Krause, 2016; Joshi, Drzal, Mohanty, & Arora, 2004; Lopes, Ferreira, Russo, & Dias, 2015; Versino, López, & García, 2015). The utilization of these natural resources in numerous engineering applications may straightly support the global developments particularly in the aspects of socio-economy, ecosystem, and green technologies. At present, the applications of natural resources as bio-filler or reinforcement in composite materials are among the most attractive research subject. This is because the specific mechanical behaviors of some natural fibers are closely comparable to those of synthetic glass fibers (Vilaseca et al., 2010). Furthermore, pressing motivation is derived from the heightened concern on the long-term adverse impact of synthetic fibers on the environment. To date, several studies have been carried out to investigate advantages and disadvantages of natural fibers when incorporated into matrix as composites (Arrakhiz et al., 2012; Ataeefard & Moradian, 2011; Balakrishna, Ismail, & Othman, 2014; Baniasadi, Ramazani, & Javan, 2010; Essabir et al., 2013; Jamil, Ahmad, & Abdullah, 2006; Ochi, 2008; Ruksakulpiwat, Sridee, Suppakarn, & Sutapun, 2009). Ruksakulpiwat et al. (2009) observed that the tensile strength and Young's modulus of composites with up to 10% of natural rubbers are higher than those of polypropylene (PP). Ochi (2008) reported that the tensile strength, flexural strength, and modulus of elasticity of kenaf fiber-reinforced composites increase linearly up to a fiber content of 50%. Also, Jamil et al. (2006) found that the tensile modulus and hardness of polyethylene/natural rubber blends increase via the introduction of rice husk loadings. Essabir

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et al. (2013) observed that the decomposition temperature of PP composites reinforced with Nut-shells of Argan (NA) particles decreases from 256 °C to 230 °C by increasing the particle loading from 10 to 25 wt.%. Balakrishna et al. (2014) noticed that incorporating composite rattan powder and 10 phr kaolin fillers in polypropylene raise 12% the composite tensile modulus compared with 0, 2, 4, and 6 phr kaolin fillers. Ataeefard and Moradian (2011) reported that the surface roughness of polypropylene based nanocomposites can be increased by including nanoclay and by raising its amount. Arrakhiz et al. (2012) obtained the highest improvement of about 35% in Young's modulus of PP reinforced with esterified alfa fiber when compared to those without reinforcement. A disadvantage of the natural filler was, however, reported by Baniasadi et al. (2010) who found that the thermal conductivity and thermal diffusivity of the composites decrease with banana fiber loading.

Recently, nanoparticles are highly regarded as the filler materials to improve physical and mechanical properties of the composites. Several works have been conducted to explore their benefits on physical and mechanical properties of the composites (Goyal, Tiwari, Mulik, & Negi, 2007; Lim, Zeng, & He, 2010; Lin et al., 2015; Wang, Lu, Ding, Zhang, & Chan, 2016; Zhang & Singh, 2004). Zhang and Singh (2004) found that, for the case of 4.5% volume fraction of well-bonded Al_2O_3 particles added to the unsaturated polyester, the fracture toughness can be increased by almost 100%. To emphasize the usefulness of nanoparticle fillers, Wang et al. (2016) reported that the smaller sized nano-γ-Al_2O_3 particles perform better than the larger sized nano-α-Al_2O_3 particles in reinforcing natural rubber. Recently, Lin et al. (2015) noticed that the composite matrix incorporating the ZnO nanoparticles doped graphene (nano-ZnO–GE) exhibits a higher wet grip property and lower rolling resistance compared with those of NR/conventional-ZnO composite. Lim et al. (2010) concluded that mechanical properties, namely, tensile modulus, tensile strength, and fracture toughness are affected by the geometry of the particles. Goyal et al. (2007) observed that poly(ether ether ketone) (PEET) containing nano-aluminum oxide (n-Al_2O_3) filler loading exhibits an improved thermal stability, crystallization, and coefficient of thermal expansion.

To date, fillers in the under-explored powder form are becoming more popular in the production of hybrid composites that utilizes natural resources (Balakrishna, Ismail, & Othman, 2012; Muniandy, Ismail, & Othman, 2012; Nikmatin, Syafiuddin, Kueh, & Purwanto, 2015). Muniandy et al. (2012) reported that the tensile strength, elongation at break, stress at 100% elongation (M100), and stress at 300% elongation (M300) of all composites increase corresponding to the rise in the carbon black (CB), mica, and calcium carbonate ($CaCO_3$) filler-loading ratios. Balakrishna et al. (2012) obtained from a series of measurements that the tensile strength, elongation at tensile failure, and impact strength decrease; while the stabilization torque, thermal stability, and water absorption increase, if the rattan filler loading is raised from 0 to 40 phr in PP composites. It is worthwhile to see that the majority of the above-discussed studies only focus on the physical and mechanical properties of the composites with fillers in the micrometer size range. Recently, Nikmatin et al. (2015) reported that incorporating rattan in nanoparticle size into polypropylene increases the thermal stability of the composite. Their study is, however, limited to investigating the rattan nanoparticle effect as filler for composite on thermal properties only. Therefore, it is of great importance to also examine the effects of rattan nanoparticle on the physical and mechanical properties of composites for further exploration of material behaviors as well as associated potential applications.

Aligning to the aforementioned research gap, the present study aims to investigate the effects of rattan nanoparticles as filler in polypropylene on the physical, thermal, and mechanical properties of composites. Several investigations had reported that the incorporation of small amount of natural filler into polymer matrix especially in the nanometer range enhances the mechanical properties of composites (Ismail, Edyham, & Wirjosentono, 2002; Kim, Moon, Kim, & Ha, 2008; Tajvidi & Ebrahimi, 2003). In the past, the effects of incorporating rattan nanoparticle into polypropylene with filler contents ranging from 2 to 20% on the composite behaviors had been examined (Nikmatin, 2012). The study found that the mechanical properties of the composites were the most optimal with 5% filler content. However, the mechanical performance decreased when the filler content was increased from 5% to 20%. Therefore, the current study only focused on the implementation of 5% of rattan nanoparticles as the composite filler content. This paper is organized as follows. Immediately after the short outlining for the layout of the paper, a brief summary of the current work is first offered. Constituent materials used to fabricate the composite are then described. Next, the procedures for the preparation of fillers and composites are presented. This is then followed by the exploration methodologies and findings in terms of particle size analyses, X-ray diffraction patterns, morphological study, thermal inspection, and mechanical tests. This paper ends with conclusions and suggestions for future works.

In general, the present work has successfully prepared and investigated rattan nanoparticle-filled polypropylene as biocomposite material in terms of physical, thermal, and mechanical properties compared to neat PP and its composite with 5% glass fiber. An optimal distribution of rattan nanoparticle size was obtained with 30 min of milling period. This study found that rattan nanoparticle-filled polypropylene has the highest degree of crystallinity, a better surface morphology, and the highest average hardness compared to all other studied materials. In conclusion, rattan with nanoparticle sizes in powder form has been proven to be potentially useful in improving the physical, thermal, and mechanical properties of composites.

2. Materials and methods

2.1. Materials

The raw material for the present study, rattan pole waste (see Fig. 1), was collected from Cirebon, West Java, Indonesia. Rattans are classified under the palm family (*Palmae* or *Arecaceae*). Currently, there are 610 different species under 13 genera in the world. They are chiefly available in the Southeast Asia region. For the matrix, we used the recycled polypropylene (PP)