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Effects of ammonium polyphosphate content on mechanical, thermal and flammability properties of kenaf/polypropylene and rice husk/polypropylene composites

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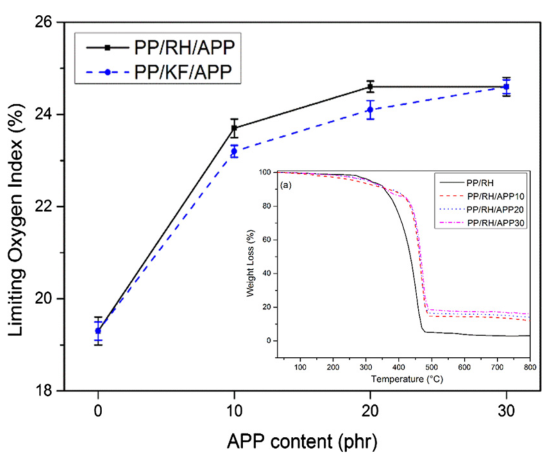
HIGHLIGHTS

- Incorporation of 10 phr APP significantly improved the flexural modulus of the PP/KF and PP/RH composites.
- Flexural strength of the PP/KF and PP/RH composites increased by the addition of 10 phr APP.
- Impact strength of the PP/RH/APP composites increased above 10 phr APP content.
- Incorporation of APP into PP/KF and PP/RH composites increased the char residue and thermal stability.
- Addition of APP increased the flame retardancy of PP/KF and PP/RH composites.

GRAPHICAL ABSTRACT



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ABSTRACT

This study investigated the effects of ammonium polyphosphate (APP) content on the mechanical, thermal and flammability properties of kenaf/polypropylene (KF/PP) and rice husk/polypropylene (RH/PP) composites prepared by melt mixing technique. Polyethyleneoctene grafted maleic anhydride (POE-g-MAH) has been used as compatibilizer. The PP/KF/APP and PP/RH/APP composites were investigated using flexural and impact tests, scanning electron microscope, thermogravimetric analysis (TGA), differential scanning calorimeter and limiting oxygen index (LOI) test. Flexural modulus of PP/KF/APP and PP/RH/APP composites significantly improved from approximately 1.1–2.5 and 0.9–2.1 GPa, respectively, by the addition of 10 phr APP. The flexural strength of the composites also increased by the incorporation of 10 phr APP. In addition, the impact strength of the PP/RH/APP composites increased above 10 phr APP content. From the TGA results, incorporation of APP into PP/RH and PP/KF composites increased the char residue and thermal stability of the composites. Furthermore, the addition of APP increased the flame retardancy of the PP/KF/APP and PP/RH/APP composites with a significant increase of LOI at 10 phr.

1. Introduction

Composite manufacturing is rapidly expanding in many applications by replacing metals with lightweight composite materials

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[1]. In addition, due to the environmental concerns, replacing synthetic reinforcements with natural alternatives in composite materials offers many advantages [2–4]. The advantages of natural fibers such as low cost, low density, high toughness, relatively high specific strength properties and low energy consumption in fabrication has led to use of these materials in the constructional and building applications in order to replace traditional expensive building materials like bricks and concrete in past recent years [5]. Previous studies have shown that the improvement in fiber-matrix compatibility led to enhanced mechanical properties. However, poor thermal stability and flammability performance are the major drawbacks of the natural fibers, when used in polymer matrices as reinforcement [6–8].

One common solution to improve the flammability properties is to introduce flame retardant components into the system; however, this may lead to the deterioration of the mechanical properties, depending on the amount added [9–11]. With the restrictions on halogen based flame retardants due to environmental regulations [12–14], non-halogen flame retardants such as ammonium polyphosphate (APP) have increasingly attracted application in flame retardancy of polymer nanocomposites [15]. APP is a flame retardant with nil affinity for generation of extraneous smoke during combustion, positioning it as an efficient environmentally compliant fire retardant [16]. APP acts as a flame retardant in the condensed-polymer phase through the mechanism of intumescence. During mechanism of intumescence, a material swells in the presence of heat or fire forming a porous-carbonaceous layering which function as hindrance to heat, combustion products and air thereby preventing their propensity to penetrate into the material-surface [17]. On exposure of APP based polymeric nanocomposites to fire, APP degrades to polyphosphoric acid, water and ammonia. The polyphosphoric acid would undergo reaction with some synergistic additives forming a non-stable phosphate-ester, which on dehydration would create a carbon char-foam on the polymer surface, thereby cutting off the heat path [18].

Polypropylene (PP) is a low cost, light weight, linear oleifinic thermoplastic commodity with good processability with application in packaging and fiber production. However, PP has some limitations such as low stiffness, poor thermal stability and low flame retardancy which positions it as a poor material where these properties are essential [19,20]. Recently, the demand for flame retardant materials has widely increased in many applications. PP burns rapidly with a relatively smoke-free flame and without leaving a char residue due to its wholly aliphatic hydrocarbon structure [21]. High flammability of PP comes from the high self-ignition temperature at 357 °C and a rapid decomposition rate compared to wood and other cellulosic materials. Many studies have been conducted to utilize natural fibers in PP composites [22–27]. In the field of technical utilization of natural fibers, Kenaf fiber (KF) reinforced polymer composites is one of the most important areas [28]. KF is an herbaceous annual plant that is available in a wide range of weather conditions; it has been actively cultivated since it grows faster [29]. Currently, many countries have begun to pay more attention to kenaf research and promotion because of its high biological efficiency and wide ecological adaptability [30]. On the other hand, Rice husk (RH) is an agricultural waste obtained from the rice mills after the separation of rice from paddy [31]; it is an alternative lignocellulosic material, and is cheap, biodegradable and has been abundant in Malaysia and many parts of the world [32]. In the case of composites, it is one of the favorite fillers and is the third most widely planted crop after palm oil and rubber. In the literature, there have been a number of researches on synthetic polymer and rice husk composites [26,32,33].

Premalal et al. [26] and Yang et al. [27] reported that the addition of RH into PP composites increased the Young's modulus and flexural modulus, whereas elongation at break decreased. However, the main issue of using natural fibers as filler in the polymer composites is the high sensitivity of natural fibers to a flame [34,35]. The incorporation of natural fibers increased the flammability of the PP composites [36]. Previous studies reported that the addition of a flame retardant material into PP/natural fibers improved the flammability properties of PP composites [9–11,37]. Subasinghe et al. [10] compared the flammability and degradation performance of KF filled PP composites under three different intumescent APP flame retardants. Thermal analysis of different APP compounded PP/KF composites showed lower decomposition rates compared to those of neat PP and PP/KF composites. In addition, the results revealed that the flammability property of PP/KF composites improved with an increased APP content, irrespective of their type. Furthermore, the addition of different APPs enhanced the mechanical properties compared to those of neat PP, although the degree of improvement varies with the type of APP. In our previous study [37], the effects of APP as flame retardant and KF as fillers on flammability, thermal and mechanical properties of maleated polypropylene (MAPP) compatibilized PP composites were investigated. The results showed that the addition of KF into PP matrix decreased the thermal stability of the composites compared to neat PP. However, the thermal, mechanical and flammability properties of the PP/KF composites increased with the addition of APP.

A comparison study on the effects of KF and RH on mechanical, thermal and biodegradability properties of polylactic acid (PLA) composites has been also reported by our research group [38]. It has been shown that KF has better mechanical properties than RH. This paper is the continuation from our previous study on PP/KF/APP composites that has been discussed earlier [37]. In the present study, the effects of APP content on the mechanical, thermal and flammability properties of PP/KF and PP/RH composites in the presence of polyethyleneoctene grafted maleic anhydride (POE-g-MAH) as compatibilizer were investigated and compared. To the best of our knowledge, no similar study has been reported in the open literature. POE-g-MAH exhibits faster mixing and better dispersion when blended with PP compared with conventional polyolefin elastomers [39,40]. It is interesting to note that POE-g-MAH acts as compatibilizer by forming hydrogen bond between maleic anhydride group of POE and hydroxyl group of fibers. Fig. 1 shows the mechanism of compatibilizing agent. The compatibilizing agent chemically bonded with hydrophilic natural fiber and blended by wetting in the PP polymer chain.

2. Materials and method

2.1. Materials

PP, heterophasic copolymer (SM-240) with a melt flow index (MFI) of 25 g/10 min (at 230 °C and 2.16 kg) and density of 0.894 g/cm^3 was supplied by Titan Chemical, Malaysia. KF was supplied by Malaysian Agricultural Research and Development Institute (MARDI) and RH fiber was supplied by Padi Bernas Nasional Berhad (BERNAS), Kuala Lumpur. General compositions of KF and RH are summarized in Table 1. APP (Exolit AP 750) with phosphorus and nitrogen content of 20–22 and 11.5–13.5 wt%, density and bulk density of 1.8 and 0.4 g/cm^3, respectively, decomposition temperature of >250 °C, and moisture content of 0.5% in white and free-flowing powder was supplied by Clariant (Malaysia) Sdn Bhd, Shah Alam, Selangor. The POE-g-MAH with elastomer grade of Fusabond® N MN493D was supplied by DuPont, Dow Elastomers, Wilmington DE, USA and used as compatibilizer to improve the interface bonding between the fiber and polymer.