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Original Research

Influence of alkaline treatment and fiber loading on the physical and mechanical properties of kenaf/polypropylene composites for variety of applications☆

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ABSTRACT

Due to current trend and increasing interest towards natural based fiber products, Kenaf (Hibiscus cannabinus) fibers have been used for the developments of many products. Therefore, Kenaf fiber-reinforced composites have been widely used in engineering and industrial applications. The present work deals with the fabricating and characterization of untreated and treated kenaf/polypropylene (PP)-reinforced composites. Composites of PP reinforced with treated and untreated kenaf fibers were fabricated using the injection molding technique. Different fiber loadings of 10, 20, 30, 40, 50 wt% treated and untreated kenaf composites were also prepared. X-ray diffraction (XRD), scanning electron microscopy (SEM), Fourier transform infrared (FTIR) spectroscopy and thermo gravimetric analysis (TGA) were performed on the treated, untreated kenaf fibers and kenaf/PP composites. Moreover, the alkaline-treated kenaf composites exhibit better physical, morphological, and mechanical properties because of the compatibility of kenaf with PP. However, variations in tensile and flexural properties depend on treatment and kenaf fiber contents. The percentage increase in the mechanical properties of the treated kenaf/PP composites relative to that of PP was also measured. In addition, 40 wt% kenaf fiber loading resulted in higher mechanical properties. By contrast, kenaf/PP composite with 50% fiber loading was not successfully prepared because of improper mixing and the burning of kenaf fibers in the PP matrix. To conclude, 40% kenaf/PP composites with superior physical and mechanical properties may be used in variety of applications such as automotive, sports, construction, animal bedding, and mass production industries.

1. Introduction

In recent decades, natural fibers have gained popularity over synthetic fibers because of their low cost, light weight, abundance as natural and renewable resources, and versatile mechanical properties, among others [1,2]. Natural fibers with better properties than synthetic fibers are favored by researchers and industries because of their numerous applications in many fields such as automotive, textile, fiber board, cushion, paper, mattress, door, wall panel, air cleaner, dashboard, and insulation mat manufacturing, as well as in the construction and transportation industries [3–5]. These materials provide reinforcement from bast and core fibers, [6] such as hemp [7,8], flax [9,10], jute [11–13], sisal [14–16], ramie [17], and kenaf [18,19], which are used in various fields, including the plastic ware, aerospace, and automotive industries. Natural fibers exhibit low density, specific strength, CO_2 neutrality, and low energy consumption during fabrication [20]. Polymer-based composites reinforced with natural fibers are important because they are cheap, renewable, and environment friendly [21].

Among different types of natural fibers, kenaf (*Hibiscus cannabinus*) is preferable because it is cheap and grows under various climates [22]. The choice of polymer is also important and preferable

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for kenaf polymer composites. In general, polymers are categorized into two main types: thermosetting and thermoplastics. Epoxy, phenolic, and polyester resins are the most commonly used polymers for thermosetting matrices, whereas polyethylene (PE), polyvinyl chloride (PVC), polylactic acid (PLA), and polypropylene (PP) are used for thermoplastic materials [23]. PLA is completely biodegradable, and thus, is preferable. However, the cost of PLA is significantly higher than that of PP. PP is also easier to recycle compared with other polymers. Therefore, industries prefer kenaf/PP composites for commercial purposes [24].

At present, the rapid development of markets urgently requires manufacturers that fabricate quality parts at a low price, which is practical with regard to production time, volume, and cost of composite systems [25,26]. Injection molding is preferred over other fabrication techniques in producing polymer composites because it has been used in various industries and by numerous researchers for a long time. In general, injection molding is a well-established method used to manufacture composites reinforced with natural fibers. Fiber dispersion, as well as the mechanical properties of the composite, is improved by using this method [27]. However, the processing parameters are significantly affected by the physical and mechanical properties of the parts of the injection mold [26]. The major drawback of this method is that only a low processing temperature is allowed because a high temperature degrades fibers and produces volatile emissions that can affect the properties of the developed composite. The injection molding process also results in high fiber attrition, which depends on fiber content, polymer melt viscosity, and melt-flow velocity [28].

Another critical issue that should be addressed in developing natural fiber composites is the interfacial bonding between fibers and the polymer matrix. One solution that has been introduced recently is adding a coupling agent or a compatibilizer, which improves the interaction and adhesion of polar and hydrophilic lignocellulosic fibers with the non-polar and hydrophobic matrix. Using a coupling agent or a compatibilizer will result in high moisture absorption of the fibers, which causes swelling that affects dimensional stability in natural fiber composites [19]. The performance of kenaf-reinforced composites can be improved by chemical and physical processes. Chemical and physical treatments improve the compatibility of the fibers and the matrix, as well as modify the their structure and surface [29]. The mercimerization process involves immersing fibers into an alkaline solution to treat them. This process increases interfacial bonding between resins and fibers, reduce the diameter of fibers, and remove oil and hemicellulose from fibers [30]. Adding sodium hydroxide (NaOH), which is an alkaline treatment, causes the acetylation of some of the hydroxyl groups on the surface of fibers; consequently, the moisture absorbed in the fiber cell wall is reduced, which results in the good wetting capability of the fibers through the matrix [31]. Alkaline treatment is also used to increase the surface roughness of kenaf fibers, which leads to an increase in mechanical bonding between the fibers and the polymer [32]. Many researchers have used different weight percentages of alkaline solutions with various lengths of immersion time to treat kenaf fibers. According to previous studies, 6% NaOH solution results in good thermal and mechanical properties of kenaf fibers [33]. The mechanical and physical properties of kenaf-reinforced composites depend on the surface modification, structural properties, as well as extraction and climate conditions of the fibers [34]. Fibers can be modified by alkaline treatment. In general, alkaline treatment improves surface roughness and increases the number of cellulose on the surface of fibers. Therefore, kenaf fibers are treated with NaOH alkaline solution to improve their physical and mechanical properties.

In the present study, untreated and alkaline-treated kenaf/PP composites with different loadings of 10, 20, 30, 40, and 50 wt% were prepared via the injection molding technique. The physical, morphological, and mechanical properties of the untreated and alkaline-treated kenaf fibers and kenaf/PP composites were then evaluated. The critical fiber loading of the alkaline-treated kenaf in the PP matrix were also investigated. Scanning electron microscopy (SEM) was performed to identify surface modification in the treated kenaf fibers and kenaf/PP fiber-reinforced composites. This study aims to increase kenaf fiber loading in the PP matrix to improve the physical and mechanical properties of kenaf/PP composites. Most studies have done on the kenaf composites through different methods. However, to the best of our knowledge, the comprehensive study on the kenaf/PP composites prepared by injection molding technique is still limited. Furthermore, the effect of alkaline treatment on the physical and mechanical properties of kenaf/PP composites is also discussed in this study. Finally, these physical and mechanical testing's were carried out to suggest these alkaline treated kenaf/PP composites for their use in variety of applications.

2. Materials and methods

2.1. Preliminary studies of PP and kenaf fibers

Kenaf short fibers with a mesh size of 40 were supplied by Lembaga Kenaf dan Tembakau Negara (Malaysia). Granular PP was provided by Sigma-Aldrich Corporation (United States). The NaOH and ethanol used in this work were of analytical grade and also obtained from Sigma-Aldrich.

2.2. Chemical treatments of kenaf fibers

For the chemical treatment of kenaf fibers, NaOH with 6 wt% concentration solution was prepared. Kenaf fibers were then immersed in the NaOH solution for 24 h. The soaked kenaf fibers were rinsed and immersed into a solution that contained distilled water and 1 wt% acetic acid to neutralize the remaining NaOH molecules from the kenaf fibers. The pH was maintained at 7–9 to maintain neutrality. After washing, the kenaf short fibers were dried in an oven for 24 h [24].

2.3. Mixing of PP and treated/untreated kenaf fibers

Afterward, PP and treated/untreated kenaf fibers were mixed using a sigma blade mixer under optimum processing conditions (mixing temperature: 180 °C, time: 25 min, and rotating speed: 35 rpm).

The mixing temperature was set based on the melting temperature of PP, which was 171 °C. The mixing temperature should be higher than the melting point of the polymer matrix to ensure that the polymer is homogenously mixed with the fiber particles. Then, PP was added into the mixer. The fiber particles were added when the torque stabilized.

2.4. Fabricating PP and kenaf/pp composites using the injection molding technique

The injection molding technique was used to fabricate PP and treated/untreated kenaf composites. Three types of samples (PP, untreated kenaf/PP, and treated kenaf/PP composites) were formed into dumbbell shapes by injection molding. Different weight percentages, namely, 10, 20, 30, 40, and 50 wt% compositions of treated/untreated kenaf/PP composites were used.

Two types of molds were selected according to the ASTM standard for measuring tensile and flexural properties. As shown in Fig. 1(a,b), 10% and 50% kenaf/PP injection-molded samples were used for flexural measurements, whereas Fig. 1(c,d) indicates 10 wt%, 20 wt%, 30 wt%, and 40 wt% and 50 wt% kenaf/PP injection-molded samples for tensile measurements. Moreover, it was observed that 50 wt% kenaf/PP samples were not fully injected, as shown in Fig. 1d, because a huge amount of PP was mixed with the kenaf fibers compared with the others samples.