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PUBLICATION DATE

01-01-2020

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To cite this article: Chenxin Li *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **729** 012056

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Alkali treatment of bamboo powder mixed polypropylene and its effect on properties

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Abstract. Bamboo powder (BP) was treated with different concentrations of alkali solution, and modified polypropylene material of bamboo powder/polypropylene blend was prepared. Using the scanning electron microscopy (SEM) and X-ray diffractometry (XRD) to study the effects of alkali treatment and various alkali concentrations on the micro-structure and mechanical properties of the modified polypropylene. The test results illustrate that the alkali treatment can remove the amorphous cement between lignocellulose, form more fine mesh structure, and increase the surface area, which is beneficial to improve the mechanical interlock between the fiber and the polymer matrix. Thus, improving the mechanics performance of composites by this method. As the increase of alkali solution concentration, the impact strength of bamboo powder/polypropylene composites show the trend of rising up and then descending. When the concentration of sodium hydroxide is 3%, the bamboo powder/polypropylene composite material has better normal temperature impact strength. When the sodium hydroxide concentration is 9%, the bamboo powder/polypropylene composite has the optimal yield strength.

1. Introduction

With the acceleration of industrialization, the demand for materials has deeply increased. Polypropylene (PP) is a kind of thermoplastic synthetic resin with excellent performance. It is the shortest and fastest growing variety among the five general-purpose thermoplastic resins[1], which has excellent comprehensive properties, such as good processing performance, high tensile strength and modulus of elasticity, low relative density, excellent stress resistance and chemical resistance; raw materials are abundant, non-toxic, easy to recycle, low energy consumption, and less pollution. Therefore, it is widely used in the automotive industry, electronics, household appliances, furniture, packaging and building materials[2]. However, polypropylene also has various disadvantages. For instance, large molding shrinkage, low temperature brittle fracture, poor abrasion resistance, bad notched impact strength, and low heat distortion temperature[3].

As technology advances, high performance materials are required to the variety of industries. At the same time, environmental protection and eco-friendly living space development have always been the focus of attention over all countries of the world. The environmental pollution caused by the soaring economy and industrialization cannot be underestimated, and sustainable development is imminent, exactly. Single and environmentally hazardous materials are no longer sufficient to meet



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market needs, and there is increasingly number of researchers are turning their attention to environmentally friendly composites.

Researchers have attached more importance to natural resources, which are numeric in storage, widely sourced, and low in cost[4-6]. The natural plant fiber is easy to take, simple to make, less loss to processing equipment during experiments, and low energy consumption. The comprehensive performance of most natural fibers is remarkably prominent. The density of plant fibers is lower than that of inorganic fibers. In addition to, compared to the general metal materials, the tensile strength can reach 500 MPa approximately[7-10]. At the same time, the strength is much higher than that of metallic materials. Last but not least, natural plant fibers release less carbon dioxide when they are incinerated or land-filled in natural plant fiber/thermoplastic resin composites. Repeated melting and cooling processes can maintain plasticity and facilitate recycling[11,12]. When it comes to the composites, there are the first generation composite materials of glass fiber/thermoplastic resin composite materials and the second generation composite materials such as carbon fiber and synthetic fiber/thermoplastic resin composite materials. Moreover, the third generation composite material--natural plant fiber/ thermoplastic resin composite material have the outstanding characters like eco-friendly and good mechanical properties.

Among natural plants, bamboo is one of the fastest growing plants with a short maturity[13]. It is worth mentioning that China is one of the centers of origin and distribution of bamboo plants and the main bamboo producing country in the world. However, to some extent, the utilization rate of bamboo resources in China is poor. Generally, there are bamboo handicrafts, household item, etc. There are few applications in engineering, and more functions of bamboo fiber have yet to be explored. From the perspective of bamboo fiber morphology, it can be divided into bamboo fiber bundles, bamboo pulp fibers and bamboo powder particles[12]. What surprises the researchers is that bamboo fiber is comparable in stiffness and strength to glass fiber. Renewability and suitable mechanical properties make bamboo a superior reinforcement for natural fiber reinforced thermoplastic composites. At the same time, bamboo fiber has many uncontrollable factors due to its complex composition, and the technical problems faced by the composite of bamboo fiber and thermoplastic resin need to be solved urgently. The high polarity of the bamboo fiber surface makes it poorly compatible with the non-polar polymer, which seriously affects the mechanical properties of the composite. The main components of bamboo fiber, cellulose, hemicellulose and lignin, as well as a small amount of pectin, fatty waxy gray matter, etc., are all soluble in NaOH solution. Therefore, with the help of the alkali treatment of bamboo powder, the blending ability between the polymer and the polymer is improved, so that the common BP/polypropylene composite material achieves better mechanical properties[14,15].

The main purpose of this experiment is to explore the effect of alkali-treated bamboo powder on the micro-structure and mechanical properties of bamboo powder/polypropylene composites. At the same time, choosing the optimum alkali solution concentration of BP under a certain condition and using SEM and XRD to analyze bamboo. Impact strength and tensile properties of the prepared samples were measured simultaneously, and comprehensive analysis was carried out in order to draw conclusions.

2. Materials and Methods

2.1. A Materials

In this study, the following materials were used as follows: Polypropylene (injection molding-grade; Zhejiang Ningbo Taisu industry Co., Ltd., China); the BP(60-80 mesh; Jiangsu Lianyungang Straw processing Co., Ltd., China) were extracted from moso bamboo. Chemicals such as sodium hydroxide (NaOH with minimum assay 99.00%; Sinopharm Chemical Reagent Co.; Ltd., China) were used for the surface modification of the BP.

2.2. A Sample Preparation

2.2.1. Chemical Modification. The BP were treated with NaOH solution at 1%, 3%, 5%, 7%, 9%, 10% (NaOH to water mass ratio). The BP were soaked in NaOH solution for 24 h at room temperature. The BP were then washed to neutral with distilled water to allow absorbed alkali to leach from the powder and then to pump filter to a certain extent. Then put the bamboo powder to the oven dried at 140°C for another 6h. The dried powder were broken in a high-speed mill and put aside.

2.2.2. Preparation of the BP-Reinforced PP Composites. Untreated or treated BP, PP were blended at a mass ratio of 10:90. Then material master batch was prepared in a co-rotating twin-screw extruder and then pelletized for injection mold after water cooling. Setting temperature of the co-rotating twin-screw extruder were 190, 185, 185, 185, 185, 190°C, respectively, and rotor speed of the main machine and feeder was 5.0 and 2.0 rpm, respectively. The obtained master batch was dried at 80°C for 4h in the oven. Then using the injection molding machine to make the samples. The temperature of the injection molding machine were 180, 180, 180, 180, 180, respectively.

2.3. A Sample Preparation

2.3.1. Mechanical Properties. Tensile test was carried out with a tensile speed of 50 mm min⁻¹. Notch impact test was carried out and the bottom radius of notch is 2.0mm and the notch angle is -150.43°.

2.3.2. X-Ray Diffraction. Bamboo Powder were characterized by XRD. The continuous scanning angle range use with a step interval of 0.05° and the machine was operation at 40kV and 40mA.

2.3.3. Scanning Electron Microscopy. The surface structures of raw BP and BP treated by NaOH were evaluated by SEM.

3. Results

Through the bamboo powder modified polypropylene, the impact properties and tensile properties of the obtained bamboo powder/polypropylene composite material are improved. The mechanical properties of the composites obtained by NaOH-treated bamboo powder are better than those of untreated bamboo powder composite polypropylene. The experimental results show that when the concentration of NaOH is 3%, the impact performance of the composite is up to 78.205KJ/m², which is 18.5% higher than that of untreated BP, and 67.7% higher than that of pure PP without BP. When the NaOH concentration is 9%, the composite has the best yield strength, which can be about 22 MPa, which is better than the BP/PP composite without alkali treatment.

4. Discussion

4.1. The Effect of Alkali Treatment

The mechanical properties of the untreated BP-reinforced PP composites and ABP-reinforced PP composites in different concentration. And the changes of impact strength are shown in the figure 1.

As shown in the figure 1 below, the impact properties and yield strength of bamboo powder/polypropylene composites blended with bamboo powder are significantly improved, which indicate that bamboo fibers are indeed a good natural material for modified thermoplastic resins. At the same time, it can be concluded that with the increase of alkali concentration, the impact performance of the BP/PP composites firstly rise up and then go down. To sum up, when NaOH concentration is 3%, the properties of impact reach the best situation. From the figure 2, when the alkali concentration is 9%, the yield strength of the composite material is superior, and the general trend is the same as the impact performance.

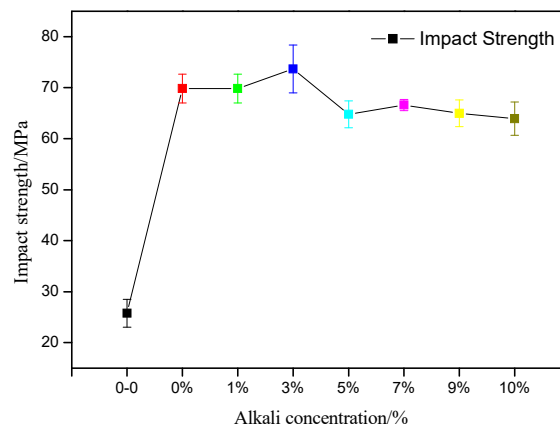


Figure 1. The effect of alkali concentration on composite impact strength.

The addition of bamboo powder increases the toughness of the composite material. The alkali-treated bamboo powder, hemicellulose, pectin and other impurities are totally reduced, the cellulose content is increased, and the fiber function is fully exerted. However, as the concentration of the alkali solution increases, the toughness decreases. One of the reason is that a large amount of hydroxyl groups (-OH) exist on the surface of the bamboo fiber, and strong hydrogen bonds are formed between the molecular chains of the bamboo cellulose, which makes the surface strong. Water absorption and chemical polarity, while polypropylene is non-polar and hydrophobic, so that the interface wet-ability and adhesion between the two materials deteriorate, resulting in a decrease in the mechanical properties of the composite. Considering the comprehensive consideration, the choice of 3% alkali concentration is a better parameter for the subsequent exploration of the effect of suitable dispersants on the properties of the composite.

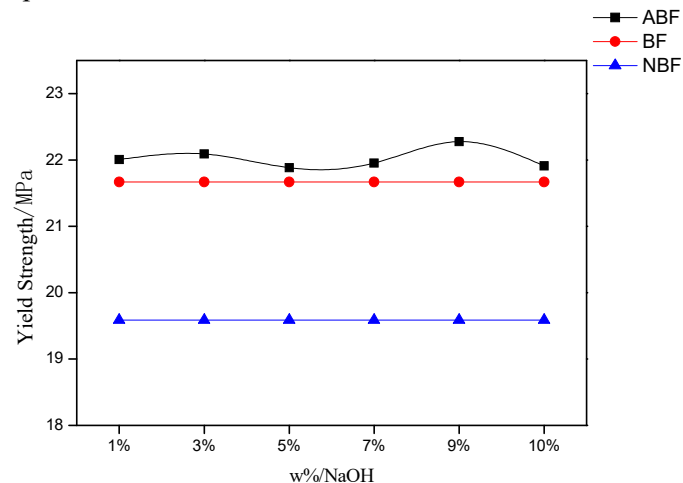


Figure 2. The effect of alkali concentration on composite yield strength.

4.2. Morphology

It is acknowledged that the interface strength between the reinforcements and matrix has a significant influence on the properties of the composites since the interface is regarded as one of the most essential factors to improve the composite characteristics.

The SEM images for the surface of untreated BP and ABF are presented in Figure. As shown in the figure 3(a) and figure 3(b), compared with the smooth surface structure of the BP without alkali

treatment, the surface of the alkali-treated bamboo powder is rough and presents pores along the fiber direction. The main reason is that alkali treatment can remove lignocellulose and other impurities, enhance the interfacial adhesion between bamboo powder and polymer, and increase the surface active point of the fiber, form more fine mesh structure and increase the surface area. It will help to improve the mechanical interlock between the fiber and the polymer matrix and the mechanical properties of the composite.

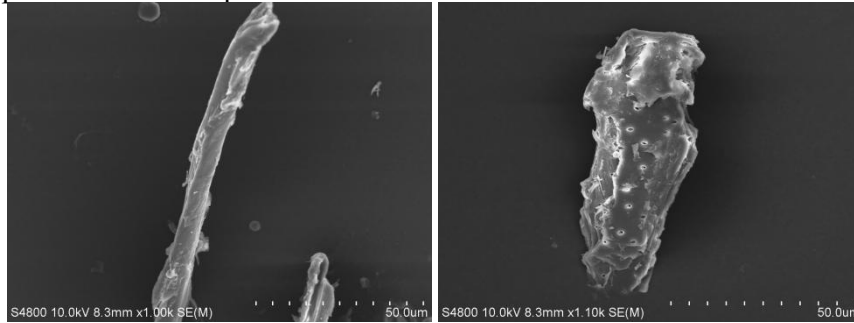


Figure 3(a). SEM images of bamboo powder without alkali treatment.

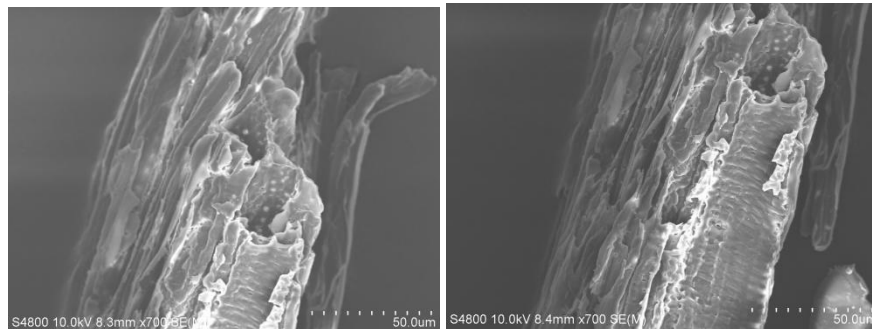


Figure 3(b).SEM images of bamboo powder after alkali treatment.

4.3. X-ray diffraction analysis

As is depicts in the figure 4, after the alkali-treated bamboo powder, the amorphous region of cellulose is destroyed, and the regular crystallinity of the structure is not damaged, and the crystallinity is remarkably increased that indicates that the alkali treatment removes other impurities and the surface of the fiber becomes rough, which is beneficial to the mechanical properties of the bamboo powder/polypropylene composite.

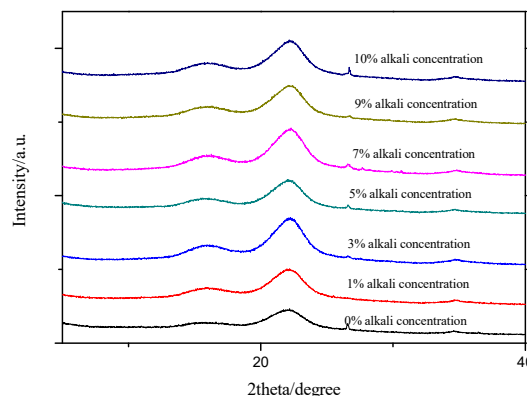


Figure 4. XRD images of different NaOH concentrations to treat bamboo powder.

5. Conclusions

Alkali treatment of bamboo powder will effectively improve the mechanical properties of BP/PP composites. In the range of 1%-10%, there is an optimum alkali treatment concentration to obtain the best impact strength and yield strength. However, as the alkali concentration increases, the mechanical properties of the composites tend to decrease, which is closely related to the interfacial compatibility between the bamboo powder and the polymer. How to improve the dispersion of bamboo powder in polymers is also one of the focuses of future research.

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