



Banana fibers and microfibrils as lignocellulosic reinforcements in polymer composites

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ARTICLE INFO

Article history:

Received 5 January 2010
Received in revised form 25 March 2010
Accepted 29 March 2010
Available online 9 April 2010

Keywords:

Polymer matrix composites
Fibers
Microfibrils
Polyethylene
Maleic anhydride
Mechanical properties

ABSTRACT

Banana plant waste, as lignocellulosic fiber, was treated with alkaline pulping and steam explosion to produce banana fibers and banana microfibrils. The chemical composition of the ensuing fibers and microfibrils was determined. The chemical modification, with maleic anhydride, of the produced particles was further carried out. The FT-IR analysis and scanning electron microscopy observations of the resulting modified and unmodified banana fibers were investigated. Composite materials were processed from these natural unmodified and maleated lignocellulosic fibers using polyethylene as the polymeric matrix. The thermal and mechanical properties were studied by differential scanning calorimetry (DSC) and tensile tests, respectively. The morphology of processed composites was studied by scanning electronic microscopy (SEM). Better compatibility and enhanced mechanical properties were obtained when using banana microfibrils. The chemical composition of fibers, in terms of lignin and cellulose, as well as their degree of crystallinity, were found to have a strong influence on the mechanical properties of the composites.

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1. Introduction

It is well known that over the past few decades, polymers have replaced many conventional materials in various applications, which is obviously due to the advantages of polymers over conventional materials (Georgopoulos, Tarantili, Avgerinos, Andreopoulos, & Koukios, 2005). Polymers can be modified by the use of fillers and reinforcing fibers to suit the high strength/high modulus requirements. Fiber-reinforced polymers offer additional options over other conventional materials when specific properties are required and find applications in diverse fields, ranging from appliances to spacecraft (Nabi Saheb & Jog, 1999).

Natural fiber is a reinforcement which has recently attracted the attention of researchers because of its advantages over the other established materials (Bledzki & Gassan, 1999; Nabi Saheb & Jog, 1999). Natural fibers are composed of various organic materials (primarily cellulose, as well as hemicelluloses and lignin) and therefore their thermal treatment leads to a variety of physical and chemical changes (Georgopoulos et al., 2005).

The strength of short-fiber-reinforced composites is highly dependent on the degree of interfacial adhesion, whereas the modulus is controlled by the fiber orientation (Maldas & Kokta, 1993).

An important factor which influences the fracture properties is the aspect ratio. In short-fiber-reinforced composites, a critical length of the fiber is required to develop its fully stressed condition in the polymer matrix (Nabi Saheb & Jog, 1999). An improved combination of fiber and polymer is achieved by impregnation of fibers with polymers compatible with the matrix. An effective method of chemical modification of natural fibers is graft co-polymerization. The resulting co-polymer displays the characteristic properties of both fibrous cellulose and grafted polymer (Dale Ellis & O'Dell, 1999; Patil, Gajre, Dusane, Chavan, & Mishra, 2000).

In an effort to improve the mechanical properties of recycled high-density polyethylene/wood fiber (HDPE/wood) composites, Selke, Yam, and Nieman (1989) investigated the use of several additives with possible effect on the fibers/matrix adhesion or fibers dispersion into the matrix. They found that maleic anhydride modified polypropylene appears especially promising, since its use at a concentration of 5% in composites with 30% wood fibers results in an increase in tensile strength and elongation at break. Similar results were found in the study of Dalvag, Klason, and Strom vall (1985), who also reported that the composites's elastic modulus remained unchanged.

In the recent years, an increased interest in obtaining composite materials with organic micro (nano) reinforcement has been observed. This can be explained by the extraordinary properties induced in polymers by the nano-metric size reinforcement and by the favorable effects on the environment (Panaitescu et al., 2007).

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Cellulose microfibrils with diameters of 50–5000 nm have already been prepared (Chakraborty, Sain, & Kortschot, 2005; Nakagaito & Yano, 2004). Cellulose microfibrils with micron and submicron diameters were prepared by mechanical treatment of pulp fibers and were used for micro (nano) composites preparation (Nakagaito, Iwamoto, & Yano, 2005). The great advantage of using cellulose microfibrils for polymers reinforcement arises from the remarkable mechanical properties of such fibers. However, cellulose microfibrils do not develop in polymer composites their reinforcement capacity because of poor adhesion to common non-polar matrices (Panaitescu et al., 2007). The presence of absorbed water and hydroxyl groups reduces the ability of cellulose microfibrils to develop good interface adhesion to most polymer matrices (Laka & Chernyavskaya, 1996). To avoid these drawbacks, cellulose microfibrils can be submitted to specific surface modifications by physical, physicochemical, or chemical treatments (Laka & Chernyavskaya, 1996; Maskavs, Kalnins, Laka, & Chernyavskaya, 2001).

In a previous work (Habibi, El-Zawawy, Ibrahim, & Dufresne, 2008), cotton stalk, rice straw, bagasse and banana were used without modification as fiber reinforcement. The results indicate that for better polymer–fiber bond we have to use a modified polymer in the presence of a compatibilizer. In the present work, a decision was made to modify the lignocellulosic fibers in a trial to match a good fiber–polymer bond without addition of a compatibilizer. According to that, polymer composites from polyethylene (PE) and two types of lignocellulosic fibers from waste biomass were prepared and characterized. Banana plant waste, as the biomass material, was treated chemically and physicochemically, by alkaline pulping and steam explosion, to produce lignocellulosic fibers (BF) and lignocellulosic microfibrils (BMF). To enhance the compatibility of the produced fibers and microfibrils with the PE matrix, chemical modification for the alkaline pulping banana and steam-exploded banana were carried out with maleic anhydride (MA). The efficiency in PE composites with various concentrations of banana fibers (BF) and microfibrils (BMF) was investigated by morphostructural and physicochemical characterization.

2. Experimental

2.1. Materials and chemicals

Commercial high-density polyethylene (PE) (density 0.922 g/cm³) was used as the polymer matrix. Maleic anhydride (MA) was purchased from s.d. Fine-Chem Ltd., and xylene was purchased from Surechera Products Ltd. (UK). All materials were used without further purification.

Banana plant waste was used as the biomass raw material source for the natural lignocellulosic fibers. It was pulped with 10% sodium hydroxide (NaOH) to produce banana fiber (BF) and steam exploded to produce banana microfibrils (BMF). The fibers and microfibrils used in this study were chemically characterized for holocellulose (TAPPI T257 om-85), Klason lignin (TAPPI T222 om-88) and ash content (TAPPI T211 om-85).

2.2. Fiber preparation

2.2.1. Pulping

Banana fiber (BF) was prepared applying the alkaline pulping process. The pulp was prepared from the banana plant waste on an electrically heated rotatory autoclave. The pulping conditions were as follows: total chemicals as NaOH was 10% (w/w), and liquor to fiber ratio was 10:1. The cooking cycle employed at (a) time from room temperature to 170 °C was 1 h, and (b) time for cooking at 170 °C was 2 h.

2.2.2. Steam explosion

Steam explosion technology involves treating various biomass feedstocks with saturated steam at various reaction times. In steam explosion the biomass is pressurized with steam for a short time and then explosively discharging the product to atmospheric pressure, which results in a sudden decomposition. This explosive discharge changes the starting material (solid) into fibrous mulch producing cellulosic microfibrils.

Steam explosion of the banana plant waste (BPW) sample was carried out in a 25-l batch reactor located at the Thomas M. Books Forest Products Center, Blacksburg, VA. The procedure reported by Jeoh & Agbelvor (2001) was used in this study. About 1 kg of BPW sample was weighed and loaded into a 25-l batch steam explosion chamber and the ball valve was closed. Saturated steam was admitted into the chamber and the biomass temperature was raised to 220 °C. When the material attained the reaction temperature, timing of the reaction was started. For this experiment, 240 s was used for the reaction. After 240 s, the release valve was opened which caused a rapid reduction in pressure, explosive decomposition and disintegration of the biomass material. The steam explosion chamber was washed with water to recover any residual fiber trapped in the unit. The sample was bagged and stored in a cold room until the time of polymer composite preparation.

2.3. Preparation of maleated lignocellulosic fibers

The modification of BF resulting from pulping and BMF resulting from steam explosion was conducted in a round flask in the presence of a solvent. The reaction procedure used for synthesizing maleated lignocellulosic fiber and microfibrils was as follows: 250 ml of solvent (xylene) was placed in a 500 ml round flask fixed with a condenser and stirred to 100 °C. After reaching this temperature, 67–70 g of MA, 3 g of either BF, or BMF, and 1 g of sodium hypophosphite monohydrate were placed in the flask. The reaction was carried out for 2 h at 100 °C. After the reaction, the mixture was filtered to isolate the reacted BF and BMF, subjected to Soxhlet extraction with xylene for 24 h to remove the unreacted anhydride, and oven dried at 70 °C for 24 h. The reaction product thus obtained was characterized by FT-IR and scanning electron microscopy (SEM).

2.4. Composites preparation

The incorporation of lignocellulosic fibers and maleated fibers into the PE was carried out thorough mixing at high temperature, in xylene, for sufficient time to achieve the maximum possible dispersion. PE was first soluble in 10% (w/v) xylene at high temperature then the fibers were mixed with the soluble polymer with stirring until homogeneity. After mixing, the samples were left to cool at room temperature and left overnight to solidify then put into a steel mould and left for 5 min in the hydraulic press, preheated at 130 °C to form films of ~0.6 mm thickness.

2.5. Characterization and properties

2.5.1. FT-IR spectra

FT-IR spectroscopy was used to confirm whether an esterification reaction occurred between BF and/or BMF and MA. Also, it was used to access the crystallinity index of the fiber and the maleated fiber according to O'Connor, DuPré, and Mitcham (1958), which is based on the ratio of the absorbance of the bands at 1429 (CH₂ scissoring) and 893 cm⁻¹ (C₁₁ group vibration).

The IR spectra of BF, BMF, maleated banana fiber (M-BF) and maleated banana microfibrils (M-BMF) were performed using a Thermo-Nicolet Model 670 Instrument (Thermo Electron, Inc., Madison, WI). The result of FT-IR spectrum of MA was taken from

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