Materials and Design 49 (2013) 285–289

Contents lists available at SciVerse ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Mechanical and thermal properties of environmentally friendly composites derived from sugar palm tree

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ARTICLE INFO

Article history:
Received 28 November 2012
Accepted 23 January 2013
Available online 7 February 2013

Keywords:
Mechanical
Thermal
Absorption
Adhesion
Biocomposites

ABSTRACT

The aim of this paper is to study the effect of fibre content on mechanical properties, water absorption behaviour and thermal properties of sugar palm fibre (SPF) reinforced plasticized sugar palm starch (SPF/SPS) biocomposites. The biocomposites were prepared with different amounts of fibres (i.e. 10%, 20% and 30% by weight percent) by using glycerol as plasticizer for the starch. The mechanical properties of plasticized SPS improved with the incorporation of fibres. Fibre loading also increased the thermal stability of the biocomposite in this investigation. Water uptake and moisture content of SPF/SPS biocomposites decreased with the incorporation of fibres, which is due to better interfacial bonding between the matrix and fibres as well as the hindrance to absorption caused by the fibres. Fractographic studies through scanning electron microscopy showed homogeneous distribution of fibres and matrix with good adhesion which play an important role in improving the mechanical properties of biocomposites.

1. Introduction

Increasing awareness among the world population to protect our environment has promoted research in agriculture residues. This is due to the abundant sources of agriculture crop wastes that cause problem to handle them. Agricultural crop residues such as oil palm, pineapple leaf, banana, and sugar palm. produced in billion of tons around the world. They can be obtained at abundance, low cost, and they are also renewable sources of biomass. Among these large amounts of residues, only a small quantity of the residue was applied as household fuel or fertilizer whereas major portion of the residue is burned in the field. As a result, it will give a negative effect to our environment due to the air pollution [1]. The vital solution to solve this problem is to use these residues as filler in polymer materials.

Natural fibres have gained a considerable attention due to benefits such as high strength, low density, renewability, biodegradability, less health hazards and reduction in weight and cost. The most interesting about natural fibres is their positive impact to environmental. Natural fibres will play a key role in the emerging "green" economy based on energy efficiency. The use of biodegradable sources in polymer products will reduce the carbon emissions due to plastics burning [2,3].

Lack on compatibility is the biggest challenge in developing of natural fibre reinforcing polymer composites. This is due to the hydrophobic in nature of petroleum based polymer and hydrophilic behaviour of natural fibre makes them hard to combine. So, the vital solution is to use polymer that derived from natural resources which have the hydrophilic properties same as natural fibres. No previous research has been done on sugar palm fibre (SPF) reinforced biomatrix such as starch, however, SPF has been used as reinforcement in petroleum based polymer either thermoset or thermoplastic [4–9]. A recent reviews were conducted for sugar palm fibre and its composites [10,11].

Due to unique behaviour of starch such as cheap, renewable and biodegradable, many researchers have been using it as biomatrix. Teixeira et al. [12] used plasticized cassava starch as a biomatrix and combined it with cassava bagasse cellulose nanofibrils as reinforcing materials. Development of corn starch based green composites reinforced with graft copolymers of *Saccharum spontaneum L.* (Ss) fibre was carried out by Kaith et al. [13]. Prachayawarakorn et al. [14] prepared biodegradable polymer from thermoplastic rice starch (TPRS) and cotton fibre and low-density polyethylene (LDPE) were added into TPRS matrix in order to improve the poor tensile properties and high water absorption of TPRS. Recently, Vallejos et al. [15] applied corn and cassava starches plasticized with 30 wt% glycerin as biomatrices and using fibrous material obtained from ethanol–water fractionation of ba-

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http://dx.doi.org/10.1016/j.matdes.2013.01.048

gasse as reinforcement. Another important research based on starch materials was carried out by Duanmu et al. [16]. They determined moisture absorption, dimensional stability and mechanical properties of wood fibre reinforced allyl glycidyl ether modified (AGE) – potato starch composites. However, no research has been carried out to evaluate the potential use of sugar palm starch (SPS) as a biomatrix.

SPS absorbs moisture when exposed to humidity. One of the methods to overcome these negative attributes, as well as to improve the strength properties in general, SPS was incorporate by abundant and relatively inexpensive lignocellulosic materials, sugar palm fibre (SPF). The resulting materials are termed "biocomposites" or "green" composites, which are considered to be totally biodegradable. Thus, the main objective of this paper is to investigate the influence of fibre content on mechanical properties, water absorption behaviour and thermal properties of sugar palm fibre reinforced plasticized sugar palm starch (SPF/SPS) biocomposites.

2. Materials and methods

2.1. Preparation of materials

The sugar palm fibre (SPF) was collected at Jempol, Negeri Sembilan in Malaysia. All of the fibres were grind and screened using Fritsch pulverisette mill to obtain 2 mm fibre size. For the extraction of sugar palm starch (SPS), firstly, the woody fibres and starch powder was obtained from the interior part of the trunk. Then, this mixture (woody fibres and starch powder) was carried out for washing process to obtain the starch. Then starch was kept in an open air for a moment and dried in an air circulating oven at 120 °C for 24 h.

2.2. Fabrication of SPF/SPS biocomposites

Sugar palm starch (SPS) 70 wt% and glycerol 30 wt% were mixed using mechanical stirrer for 30 min. Subsequently, the sugar palm fibres were added and stirred for 20 min. The mixture was cast in an iron die and was kept for pre-curing at room temperature (28 °C) for 24 h. Finally, the sample was cured by hot pressing in a Carver hydraulic hot press at 130 °C for 30 min under the load of 10 tonne. The final products were in the form of plates with dimensions 150 cm × 150 cm × 0.3 cm. By changing the content of sugar palm fibres of 0, 10, 20 and 30 wt%, a series of SPF/SPS biocomposites was prepared with different content of SPF and coded as SPS, SPF10, SPF20 and SPF30, respectively.

2.3. Mechanical characterization

Tensile and three point bending flexural tests were conducted using Instron 3365 machine, according to ASTM: D638 and ASTM: D790 respectively. Specimens of tensile were cut by using vertical saw with dimensions of 150 mm (L) × 25 mm (W) × 3 mm (T), while flexural specimens were cut with dimensions of 130 mm (L) × 13 mm (W) × 3 mm (T). Five specimens were tested with crosshead speed of 5 mm/min for tensile and 2 mm/min for flexural. Notched impact strength was measured by 43-02-01 Monitor Impact Tester, according to ASTM: D256. At least, five specimens were cut into 50 mm (L) × 13 mm (W) × 3 mm (T). Impact strength (kJ/m^2) was calculated by dividing the recorded absorbed impact energy by the cross-section area of the samples.

2.4. Thermogravimetric analysis

Thermogravimetric tests were carried out using a Mettler Toledo TGA/SDTA851^e analyzer. The tests were performed in the temperature range between room temperature and 800 °C at a heating rate of 10 °C/min in an atmosphere of nitrogen and a, flow rate of 20 ml/min. A sample of 5–20 mg of the materials was heated in the sample pan.

2.5. Determination of moisture content

All of the specimens with a dimension of 10 mm × 10 mm × 3 mm were weighted using a weighing balance and recorded as M1. The samples were dried in the oven at 105 °C for 24 h and reweighted (M2). The moisture content was calculated using formula shown below:

$$\text{Moisture content } (\%) = \frac{M_1 - M_2}{M_1} \times 100 \quad (1)$$

where M_1 = weight of air dried sample (g) and M_2 = weight of oven dried sample (g).

2.6. Water absorption testing

The specimens were stored in humidity chamber at RH = 75% for 72 h. Prior to the water absorption measurements, the samples were dried at 80 °C with a constant weight. Five specimens of each type of biocomposites were tested and average value was taken as a final result. Weight gain was calculated using the following equations:

$$\text{Weight gain, } WG\ (\%) = \frac{W_t - W_0}{W_t} \times 100 \quad (2)$$

where W_0 = weight before soaking into water (g) and W_t = weight after soaking into water (g).

2.7. Fourier transform infrared spectroscopy

Fourier transform infrared (FT-IR) spectroscopy was used in order to detect the presence of the functional groups existed in plasticized SPS. The spectra were obtained using an IR spectrometer (100 Series type, Perkin–Elmer). About 2 mg of sample which is in powder form was mixed with potassium bromide (KBr) and pressed into a disc of about 1 mm thick. The FT-IR spectra of the sample were collected within the range of 4000–200 cm^{-1}.

2.8. Scanning electron microscopy

A Hitachi S-3400N scanning electron microscope with operating voltage of 0.3–30 kV was used to obtain SEM micrographs from the fractured tensile test samples of both the SPS biomatrix and SPF/SPS biocomposites to evaluate the homogeneous distribution of fibres and matrix and good adhesion between fibre and matrix.

3. Results and discussion

3.1. Mechanical properties

Fig. 1 demonstrates the effect of fibres loading on the tensile properties of SPF/SPS biocomposite. The tensile strength and modulus of SPF/SPS biocomposites showed increasing trend with increasing SPF loading, while the addition of the SPF made the elongation fall from 8.03% to 3.32%. A considerable increase of tensile strength with the increase of SPF indicated that the natural cellulose fibre has a great impact and in formation of good bonding