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Full Length Article

Thermal and physico-mechanical stability of recycled high density polyethylene reinforced with oil palm fibres

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ABSTRACT

The impressive physical and mechanical properties achievable with organic fillers make them a good choice for polymer composite reinforcement. In this study, oil palm fibres (OPF), often hardly thought of as having any reasonable economic value in developing economy was used as reinforcing fillers in recycled high density polyethylene (rHDPE). Thermal behaviour, physical and mechanical stability of rHDPE filled with OPF have been studied. Fourier Transform Infrared Spectroscopy (FTIR) results present band spectra characteristic of —OH stretching vibration in the cellulose of the fibre material. The absorption bands of the spectra are attributed to the presence of stretching vibration of C═O group mostly found in the form of hemicelluloses and lignin structure in the fibre. Upon examination of the test specimens produced through compression moulding technique, it was found that the addition of OPF (filler) into rHDPE (matrix) increased the composites' water absorption rate linearly for the first 16 days of exposure to the water environment. Stability was achieved for all the materials after this period. Thermal studies of the various compositions (OPF/rHDPE: 5/95, 10/90, 15/85, 20/80 and 25/75) using derivative thermogravimetric analysis (DTGA) showed two main degradation peaks at 490 °C and 380 °C. The mechanical study revealed that the composite with 20 wt% filler contents was the most eco-friendly and had the best mechanical properties while that with 25 wt% was the most thermally stable. This material was thermally stable up to approximately 330 °C. Microstructure examination of the different components of the composites further explains the reason for good physical and mechanical strength of the sample with 20 wt% filler. It can, therefore, be inferred from the results of the various analyses conducted that OPF is a good reinforcing phase for rHDPE and a potential material for construction and automotive industries.

1. Introduction

A composite can be described as a structural material made up of two or more constituents that are combined at macroscopic level and are not soluble in each other [2]. While one constituent is called the reinforcing phase and may be in the form of fibres, particulates or flakes, the other constituent in which the reinforcing phase is embedded is called the matrix phase and is generally continuous [18]. There are naturally occurring composites like wood, where the lignin matrix is reinforced with cellulose fibres and bones in which soft collagen is reinforced with bone-salt plates made of calcium and phosphate ions [28]. Advanced composites are traditionally used in the aerospace and other high-tech industries are also in existence. They have high-performance reinforcements of a thin diameter epoxy in aluminium matrix [12]. These have also found applications for commercial industries worldwide.

The demands of today's advanced technologies require more than what monolithic metals and their alloys have to offer. It combines several materials to meet up with the performance requirements for the purpose of engineering applications [31,7]. For load-bearing applications, natural fibres are often mixed with polymers or precursor resins in order to increase stiffness, strength, and toughness. These enhancements depend on filler diameter, aspect ratio, alignment, dispersion and interfacial interaction [4,5,8]. For instance, engineers are continuously searching for ways of

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lowering the overall mass of the aircraft without decreasing the stiffness and strength of its components. This can be achieved only by replacing conventional metal alloys with composite materials. Although the initial composite's cost is high, the reduction in the number of parts in an assembly and fuel efficiency arising from light weight compensates for the initial cost. With fuel expenses consuming about 25% of the total operating costs of commercial airlines, reducing 0.453 kg of mass in a commercial aircraft can save up to 1360 l of fuel annually [12].

The advantages of using natural fibres in composites include light weight, high quality, low cost, annual renewability, good mechanical properties, reduced energy consumption and environmental friendliness [34]. Armin and Alan [3] reported that natural fibres which have high strength and modulus with good adhesion and uniform dispersion can impart better mechanical properties to the host polymer in order to obtain composites with better properties than those of the unfilled polymer. A coupling agent reduces the surface tension of the hydrophilic wood fibres to a level close that of the molten polymer [21]. Therefore, wetting and adhesion are improved through diffusion and mechanical interlocking between the two entities. Catto et al. [9] and Ndiaye et al [24] addressed the problem of compatibility between wood reinforcement and polymer host matrix. According to their reports, wood fibres will not ordinarily adhere suitably to the polymer matrix because they are primarily incompatible. The introduction of a compatibilizer (sodium hydroxide, in this case) will enhance matrix-fibre adherence, and hence composite properties.

Oil palm fibre (OPF) is popular for its usage as alternative energy source. It is available in large quantity in Nigeria as the 5th largest producer of palm oil in the world, generating a significant amount of oil palm waste [11]. Rather than being a boost to the economy, this has, in no small measure, contributed to environmental pollution experienced in Africa. Oil palm waste is often used in the rural areas for cooking; hence the need to redirect this low-level utilisation to a better, safer and more profitable use. Zuhri et al. [35] reported that reinforcing rubber with short OPFs imparts good strength and stiffness to soft as well as tough rubber matrices. In a similar work, Redwan et al. [27] found that impact strength is adversely affected by the incorporation of empty fibre bunches (EFBs) into modified and unmodified unplasticized polyvinyl chloride (PVC-U). In a similar study, Khairiah and Khairul [13] reported that the highest hardness as well as better impact and flexural strength are imparted on EFB/polyurethane (PU) composite with a ratio of 35:65. They also found that better adhesion between PU matrix and EFB fibres results in better water resistance.

The objective of the study is to develop biodegradable composites from OPF and rHDPE; provide viable test data that will help in tailoring their applications appropriately as candidates for application in both construction and automotive industries.

2. Materials and methods

2.1. Materials

Recycled high-density polyethylene (rHDPE) was collected from the Federal Polytechnic Bida, Nigeria. Oil palm fibres were sourced from a local oil mill in Bida local government area of Niger State, Nigeria. Sodium hydroxide of analytical grade with percentage purity of 99.99% and manufactured by Burgoyne & Co. Mumbai, India was supplied by Panlac Nig. Ltd, Minna, Nigeria. The distilled water used throughout the experiment was produced at the Centre for Genetic Engineering and Biotechnology, Federal University of Technology, Minna, Nigeria.

2.2. Methodology

The rHDPE was thoroughly washed with clean water followed by rinsing with distilled water and dried at room temperature for 24 h. Because of the crude method used by the local millers for oil extraction, it was noticed that the OPFs still contained some oil that must be extracted before usage. In order to remove the residual oil, therefore, the fibres were boiled for three hours and the oil was removed to the barest minimum, dried and pretreated with superheated steam. In order to enhance their interfacial interaction with the host polymer matrix, the fibres were soaked in 2 M concentration NaOH for 24 h and then washed thoroughly until its pH value became neutral. The fibres were again dried in air and milled to smaller particles after which sieve analysis was carried out to separate the particles into sizes. Size 150 μm sieve was used in this study. The composites were compounded using compression moulding manufacturing technique. The superheated steam-treated oil palm fibres (0, 5, 10, 15, 20 and 25 wt%) were used to reinforce recycled high-density polyethylene (rHDPE). The compounding followed the procedure described by Nemati et al. [25].

Using counter-rotating two-roll open mill (5183, USA) with rotor speeds for the front and rear rolls adjusted to 30 rpm and 18 rpm respectively and working distance of 300 mm, the rHDPE was masticated for 4 mins and OPF of different wt%, as stated above, were introduced into the mix. Mixing continued for additional 6 mins to ensure homogeneous distribution of the treated fillers. The fully masticated and mixed composite was then put in a pre-heated mould fabricated for the purpose of the study; it was then cured at 100 °C for 10 mins in an electrically heated hydraulic press. Thereafter, the specimen was cooled under pressure (3 bar) at room temperature and neatly packed for analyses.

2.3. Water absorption

The composite samples with dimensions, 50 mm long, 10 mm wide and 3 mm thick, were dried in the oven at 70 °C for 45 mins, until constant weights were achieved. They were then immersed in distilled water at room temperature for a period of 1200 h according to ASTM D570. At predetermined interval, specimens were removed, dried, weighed and returned to the water. Percentage of moisture content was calculated according to Eq. (1) [19].

$$M_n = \frac{W_w - W_d}{W_w} \times 100 \quad (1)$$

where M_n is the moisture content (%) of the different samples, W_w is the wet weight of the samples and W_d is the final weight of the sample after a defined period of 240 h.

2.4. Thermogravimetric analysis

Thermal decomposition was observed in terms of global mass loss by using a TA Instruments, TGA Q50 thermogravimetric analyser. To determine the thermal stability of the samples, argon gas was allowed to flow through the system at the rate of 20 ml/min and at a pressure of 3 bar. 10 mg of the sample was evenly and loosely distributed in an open sample pan of 7.4 mm diameter and 4.2 mm deep. The temperature was set between 25 ± 3 °C and 900 °C at a heating rate of 20 °C/min. The data and corresponding TGA curve was then generated.

2.5. Scanning electron microscopy

Phenom ProX SEM machine was used to take the microstructure images of the samples at 1500x magnification and an accelerating voltage of 15 kV. Fractured samples were used to study fibre distribution in the composites. About 1.0 g of the composite sample was

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