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Mechanical and water swelling properties of waste paper reinforced unsaturated polyester composites

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HIGHLIGHTS

- Unshared waste paper based composite fabrication process is summarized.
- Physicochemical characterization of reinforcing material is presented.
- Mechanical and water absorption properties of composites is evaluated.
- Waste paper has a great potential to be used as reinforcement material.

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ABSTRACT

In the present work, unshredded waste newspaper based composites have been prepared in polyester resin matrix. Reinforcing material, waste newspaper is characterized by chemically, X-ray diffraction (XRD) methods, Fourier transform infrared spectroscopy (FTIR) and tensile properties. Three different fibre content composite samples, namely 25%, 34%, and 50% (by weight) are prepared by hand lay-up techniques. Water absorption and thickness swelling tests are conducted by immersing composite samples in distilled water at room temperature. It is found that the percentage of moisture uptake and thickness swelling are increased as the fibre volume fraction is increased due to the high cellulose content. The tensile, flexural and interlaminar shear strength properties of water immersed samples are investigated and compared with dry composite samples. It is observed that after swelling the mechanical properties of composites are found to decrease with increase in percentage moisture uptake.

1. Introduction

Due to growing environmental concerns researchers have been trying to develop an environmentally friendly composite which leads to replacement of synthetic fibres to natural fibres as reinforcement material. In recent years the use of natural plant based cellulosic fibres as reinforcement material in polymer matrix composites has created great attention among researcher to produce eco-friendly low cost engineering materials [1–3]. Field of application where composite find dominance is construction, transportation, marine application, aerospace, consumer products etc. Natural fibre based composites have been used in construction and building materials for thousands of years. Worldwide construction sector became one of the largest consumers of polymer composites. Fibres are used to reinforce the polymer for improving the mechanical properties of polymers for use in primary load bearing applications [4].

Most commonly used natural fibres in polymer matrix composite such as flax, hemp, jute, wood, etc which are low cost, good specific strength, lower pollutant emissions, biodegradability etc. which makes them advantageous over synthetic fibres as reinforcement [5]. Polymer composite based on cellulosic fibres were initially aimed at the replacement of glass fibre reinforced composites. Among all natural cellulosic fibres, lignocellulosic fibres are most widely used, as reinforced material due to its low cost, easily availability and these fibres have a number of interesting mechanical and physical properties [6–8]. Lignocellulosic biomass is the most abundant renewable resource on earth, is composed mainly of cellulose, hemicellulose and lignin. Pulp and paper are manufactured from raw materials containing short length cellulose fibres, which comes from lignocellulosic biomass or recycled paper [9–11]. Paper and pulp industries of the world produce around 400 million tons of paper and board, in 2013 [12] which are used by the consumers of various countries. As wastes are being generated in increasing rate due to modern urbanization, waste management is a big issue of concern for government legislation as well as

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environment. Paper, as one of the largest solid waste materials, recycling of waste papers reduces environmental pollution by decreasing the flow of waste papers to landfills. Further value addition and other suitable uses of waste papers reduce the disposal problem [13]. Thereafter, a part of the used paper material is recycled and exploited commercially, while the remaining amount is thrown out or burned, which obviously creates environmental burden. As waste paper is a good source of cheap alkali treated cellulosic fibre, in the form of thin compressed sheet so it might be used as reinforced material [14]. Different shape of fibrous materials is used as reinforcement such as fibre mat, fabric, non-woven etc, fibres in paper arranged network form which is comparable with non-woven fibre mat. Few numbers of literatures are available which deals with the use of waste paper as reinforcing material in polymer matrix composites. In this regard Sanadi and Young [15] used recycled newspaper flaxes as reinforcing fillers in thermoplastic matrix. They produced the reported thermoplastic composite by using paper flaxes, polypropylene and a coupling agent. Further, they modified the matrix material and produced anhydride-grafted and acrylic acid-grafted polypropylene to improve the interfacial properties of matrix and paper. As a result, the tensile and Izod impact strength were improved from 34.1 MPa to 57 MPa and 112 J/m to 212 J/m, respectively. Another group of researchers reportedly prepared composite by using cement, sand and re-pulped waste paper [16]. Their experiments showed that the addition of re-pulped waste paper had caused high water absorption in the composites, resulting in reduction of thermal conductivity, bulk density and compressive strength. Madani et.al used magnetite treated old newsprint paper as filler in radiation shielding rubber composite. They studied swelling, electrical and mechanical properties, as well as gamma and neutron-shielding power of composites produced from untreated and treated newsprint in the rubber matrix. This study led to the conclusion that composite samples containing 6% wax and 54% newspaper or 18% wax and 42% modified ONP has the higher behavior to γ-irradiation dose. The incorporation of modified waste paper into the rubber matrix increases its conductivity and enhances the mechanical properties of produced composites. At higher non modified and modified newspaper loadings a serious loss of rubber elasticity was noticed. Composite with good attenuation properties for both gamma rays and thermal neutrons was produced from incorporation of 54% modified newsprint with 6% paraffin wax [17]. López, J. P., et al. [18] prepared three types of randomly distributed short lignocellulosic fibres based composites in polypropylene matrix. They used mechanical pulp, deinked pulp, and jute strands as reinforcing material and maleated polypropylene as coupling agent. They reported that with addition of 6% (wt/wt) of MAPP resulted in a significant improvement in the interfacial shear strength of composites. They used Bowyer–Bader and Hirsch models to analyse the mechanical properties of these composites. Thakur et al. investigated mechanical and swelling properties of composites prepared from pine needles in formaldehyde polymer matrix [19,20].

This research paper focuses on the characterization of newspaper as a suitable reinforcement and fabrication of composites by using unshredded newspaper. The aim of this paper is particularly targeted at the tensile, flexural, interlaminar shear strength and water swelling properties of these composites. We have analysed the effect of water absorption on tensile properties of composites.

2. Materials and methods

2.1. Materials

The reinforcement material, waste newspapers of 44 g/m^2 were purchased from the local market of Mumbai, Maharashtra, India. The matrix material used in this study was based on a commercially available unsaturated polyester resin for general purpose composite laminates supplied by Swastik Interchem Pvt. Ltd. The curing agent, Cobalt octoate (accelerator) and methyl-ethyl-ketone peroxide (initiator) manufactured by Triveni Interchem Pvt. Ltd., Mumbai, Maharashtra, India was also used.

2.2. Composite fabrication process

A hand lay-up method was used to prepare the newspaper-polyester composite samples. The newspaper layers were marked with a marker pen to indicate the machine and the cross-direction and paper layers were laid one after another during composite fabrication process keeping the same fibre direction. Small size holes were created randomly in the newspaper by an awl to facilitate the resin flow throughout the paper. The resin formulation was prepared by mixing 2(w/w) % accelerator and catalyst with the resin. The first coat of the resin was applied over a polyester sheet, kept on a smooth steel plate. The paper layers were laid accordingly in machine and cross direction wise. Three layers of paper were placed on the top of the resin-coated polyester sheet and then the resin was again applied on the top layer of the paper layer with a brush. Then again three paper layers were placed on the top of the resin coated paper layer and the process was repeated until the desired thickness of the composite was achieved. After the laying of the final paper layer, the same was covered with a polyester sheet, a smooth steel roller was used to even out the resin by rolling it over the other polyester sheet placed on the top of the first paper layer, thus removing excess resin and any entrapped air into it. Then, the laminates were covered by a smooth steel plate and allowed to sit for 30 min by applying pressure to solidify and to give it a shape. Three different compressive pressures namely 5 kg/cm^2, 36 kg/cm^2 and 57 kg/cm^2 were applied on the mould, so as to vary the fibre content in the composite samples. Accordingly, composite samples with fibre content of 25%, 34% and 50% (by weight) were produced. The thickness of each composite sample was in the range of 3 mm. We used 26, 34 and 36 newspaper layers to produce 25%, 34% and 50%(w/w) composite samples, under similar experimental conditions with varying compressive pressure. Post removal from the mould, the composite samples was post cured at 70 °C for 2 h. The schematic representation of the composite fabrication process is shown in Fig. 1.

3. Testing: characterization of paper and composite material

3.1. Chemical analysis of newspaper

The alpha-cellulose content of newspaper was carried out according to TAPPI T 429 cm-10 method and the results are presented in Table 1.

3.1.1. Ash content of the newspaper was carried out in accordance with TAPPI T211 om-93

3.2. X-ray diffraction analysis

Wide-angle X-ray diffraction (XRD) measurements of samples were carried out with a X'Pert Pro XRD machine at 40 kV and 30 mA with a copper radiation of 1.54 Å and XRD radial scan ranging from 4° to 80°. The XRD pattern is presented in Figs. 2 & 3.

According to the peak height method [21] the XRD crystallinity index (CI) was measured from the following height ratio:

$$CI(\%) = \frac{I_{002} - I_{am}}{I_{am}} \times 100$$