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Investigation on Bio-waste Reinforced Epoxy Composites

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ABSTRACT: In this paper, the alkali treated keratin present in natural fibers like chicken feathers are used as reinforcing phase in epoxy matrix to form composites. Mechanical properties of these composites such as tensile strength, flexural strength, etc. are evaluated and possible chemical reactions taking place during composite making are identified. The present communication also throws light on the structural features engraved on alkali treated keratin and the functional groups involved in the composition of the resulting composite material by Fourier transform infrared (FTIR) spectroscopic analysis.

KEY WORDS: keratin, poultry feather, bio-waste, epoxy resin, FTIR analysis.

INTRODUCTION

CHICKEN FEATHER IS a very inconvenient and troublesome waste product of the poultry farming industry. The feather is basically made up of keratin which contains ordered α-helix or β-helix structure and some disordered structure. The feather fiber fraction has slightly more α-helix over β-helix structure. The outer quill has more β-helix than α-helix structure [1]. Chicken feather are approximately 91% protein (keratin), 1% lipids and 8% water [2]. The amino acid sequence of chicken feather is very similar to that of other feathers. The sequence is largely composed of cystine, glycine, proline, and serine, and contains almost no histidine, lysine, or methonine [3]. The amino acid content of keratin is characterized by a high cystine, which may vary between 2 to 18 wt%. Keratin is insoluble in water, acids, as well as organic solvents, but when it was treated with alkali solution like sodium hydroxide at high concentration, the amide bonds present in keratin are hydrolyzed to form free amine and free carboxylic acid solution [4]. The disulfide bonds which formed between two cysteines is responsible for the high strength of keratin, and not hydrolyzed by alkali solution [5]. The density of chicken feathers is about 0.8 g/cm^3 compared to about 1.5 g/cm^3 for cellulose fibers and about 1.3 g/cm^3 for wool [6,7]. Many researchers have investigated the mechanical properties, especially the interfacial performances due to the poor interfacial bonding between the hydrophilic natural fibers such as sisal, jute, and palm fibers with the hydrophobic polymer matrices [8,9]. In spite of this, there has been a growing global attention on natural fibers such as jute, sisal, bagasse, etc., primarily because they are environmentally friendly and

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secondly for their very low cost. In recent years, a number of investigations have been made which prove the worth of natural fibers against their synthetic counterparts such as glass and/or carbon fiber reinforced polymer composites [10–14]. The reported studies on short fiber reinforced composites by different investigators are found to have focused mostly on the strength properties of the composites. Beyerlein et al. [15] have described the influence of fiber shape in short fiber composites. Kari et al. [16] have evaluated (numerically) the effective material properties of composites with randomly distributed short fibers. Hine et al. [17] have presented a numerical simulation of the effects of fiber length distribution on the elastic and thermo-elastic properties of short fiber composites. Fu et al. [18] have studied the flexural properties of misaligned short fiber reinforced polymers by taking into account the effects of fiber length and fiber orientation. It is evident from the existing literature that polymer composites reinforced with natural fibers like jute, sisal, etc. have long been used in various structural applications. The present investigation deals with processing and characterization of a new type of polymer composite in which alkali-treated chicken feathers are used as a reinforcement. The bonding properties between keratin and epoxy resin and the cause of the high strength of this natural composite are studied by FTIR spectroscopy.

EXPERIMENTAL DETAILS

Epoxy LY 556, chemically belonging to the 'epoxide' family is used as the matrix material. Its common name is Bisphenol A Diglycidyl Ether. The hardener with IUPAC name *NN′*-bis(2-aminoethylethane-1,2-diamin) used with the epoxy has the designation HY-951. The epoxy resin and the hardener were supplied by Ciba Geigy India Ltd. The chicken feathers were collected from a farmhouse at Rourkela, located in the eastern part of India. Feathers distinguish birds from other vertebrates and play an important role in numerous physiological and functional processes. Feathers not only confer the ability of flight, but are essential for temperature regulation. Feathers are highly ordered, hierarchical branched structure, ranking among the most complex of keratin structures found in vertebrates. Sodium hydroxide is used as alkali for the hydrolysis of keratin present in chicken feather. Pest of chicken feather is taken as reinforcing phase in epoxy matrix.

The chicken feathers collected from poultry units were cleaned with a polar solvent, like ethanol, and are dried. The quills were removed and the short fibers (10–15 mm length) were obtained. The required amounts of chicken feathers, i.e., 20 g were treated with 100 mL of 1 N solution of sodium hydroxide for three days to form a pest. To prepare the composite slabs, this pest at 20 wt% proportion was mixed (with stirring) uniformly with the epoxy resin. A block of size ($300 \times 150 \times 8$ mm) was cast. The casting was put under 15 kg load for about 24 h for proper curing at room temperature. Specimens of suitable dimension were cut using a diamond cutter for physical and mechanical characterization.

The short beam shear (SBS) tests were performed on the composite samples at room temperature to evaluate the mechanical properties. The SBS test was conducted as per ASTM standard, D 2344-84. Span length of 40 mm and the cross-head speed of 1 mm/min were maintained. Fourier transform infrared (FTIR) spectroscopy is an important analysis technique which detects various characteristic functional groups in molecules of any matter [19]. On interaction of an infrared light with the matter, chemical bonds will stretch, contract, and bend, and as a result, each chemical functional group tends to absorb infrared radiation in a specific wavelength range regardless of the structure of the rest of the molecule. Based on this principle, functional groups present in composite materials were identified. It was performed in a FTIR spectrophotometer interfaced with IR microscope operated in reflectance mode. The microscope was equipped with a video camera, a liquid nitrogen-cooled mercury cadmium telluride (MCT) detector and a computer controlled translation stage, programmable in the x and y directions. The spectra was collected in the 400–4000 cm^{-1} region with 8 cm^{-1} resolution, 60 scans and beam spot size of 10–100 μm. The FTIR imaging in the present investigation is carried out using a Perkin–Elmer Spectrum RX.

RESULTS AND DISCUSSION

From the mechanical test results it is visualized that, with reinforcement of poultry feather, the density of the composite decreases to 0.829 g/cc (density of epoxy being 1.28 g/cc), which is an advantage of such composites. The flexural strength and elastic modulus of the composite made with alkali treated feather is higher (i.e., 24.192 and 4.339 N/mm^2, respectively) than that of the composite prepared with untreated feather (i.e., 18.816 and 1.216 N/mm^2, respectively). However, there is not much variation in the inter-laminar shear strength between these composites. It is known that chicken feather contains approximately 91% protein (keratin), 1% lipids and 8% water. The structures of keratin, the primary constitute of chicken feather affects the chemical durability. Because of extensive cross-linking and strong covalent bonding within its structure, keratin is responsible to provide high resistance to degradation [20]. To evaluate the structural changes taking place during composite fabrication, FTIR studies are made. The various functional groups present in chicken feather (as observed from FTIR investigation) are listed in Table 1.

The keratin present in chicken feather, which is a polypeptide chain compound, when treated with alkali solution (NaOH) of high concentration, hydrolyzed and forms a peptide bond (at C–N bond site), forming free amine and carboxylate ion. The alkali treated chicken feather when mixed with epoxy resin, the free amine and carboxylate ion react with active epoxy group (present in epoxy resin) and forms an additional chain with epoxy matrix. From FTIR investigations, the peak range about 1210–1000 cm^{-1} and 1350–1280 cm^{-1} envisages the formation of ester and secondary amine.

From this study it can be said that, when the feather is treated with alkali solution before mixing with the resin, chemical reaction between the matrix and reinforcement takes place (i.e., chicken feather) which gives rise to formation of ester and amine. This is the main cause for increase in flexural strength of the composite, made with alkali treated chicken feather.

Table.1. FTIR peaks of corresponding functional groups present in chicken feather.

Functional group present	IR peaks
N–H stretching H-bonding	3285 cm^{-1}
N–H bending vibration	1537 cm^{-1}
C–S stretching vibration	718 cm^{-1}
C–S bending vibration	500–400 cm^{-1}
C–N stretching in amid group	1644 cm^{-1}

CONCLUSIONS

Poultry feather reinforced (epoxy resin) composite could be made. It is found that the density of composite decreases drastically than that of the epoxy resin. When the composite is made with treated and untreated poultry feathers, the density and flexural strength get affected. The interface bonding between the matrix and reinforcement might have been beneficial (i.e., the epoxy resin and feather) due to the formation of ester and amine groups, which is evident from FTIR observations. The presences of these functional groups are responsible for the variation of flexural strength and elastic modulus of these composites.

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