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A Comparative Study on Mechanical Properties of Treated and Untreated Animal Fibers Reinforced Unsaturated Polyester Resin Composites

Farhad Ali*, Sahadat Hossain, Samina Ahmed and A.M Sarwaruddin Chowdhury

Department of Public Health, Atish Dipankar University of Science and Technology, Bangladesh

Abstract

Huge amounts of unusable portion of leather and cattle hair from leather industries and chicken feather from poultries are polluting the environmental atmosphere tremendously. To reduce environmental pollution, these discarded parts need to use to produce other products. In this research, cow hair, chicken feather and waste leather were used to prepare useful composites combining with unsaturated polyester resin (UPR) to consider their reinforcement property and chemical property with view to curtail the environmental pollution. One portion of washed fibers was treated with aqueous solution of sodium hydroxide and the left portion was untreated. Then the chemically treated and untreated both portions of fibers were used to unsaturated polyester resin at 2, 5, 7, 10, 12 and 15 wt% fiber loading respectively. The composites were produced by hand lay-up technique and prepared composites were characterized by tensile and bending properties, Fourier Transform Infrared (FTIR) spectroscopy, Scanning Electron Microscopy (SEM) and Thermo Gravimetric Analysis. Obtained all the results revealed best outcomes and significant enhancement in the properties of the composites with the optimum combination by 5 wt% treated cow hair fiber.

Keywords: Fourier transform infrared • Unsaturated polyester resin • Fibers

Introduction

Scientists and engineers are undergoing intensive research on the development of natural fibers reinforced polymeric composites in order to take the advantage of nature's gift and decrease the development cost of synthetic fibers [1]. Natural fibres have become suitable substitute for synthetic fibers like glass fiber, carbon fiber etc. due to their availability, cheapness, degradability, and good mechanical properties [1,2]. According to the origin, natural fibers are classified into three groups: vegetables, animal and mineral [3]. There has been a radical change to replace synthetic fibers with natural fibers in supplementary industrial prospects [4]. So, researchers have a great interest in natural fiber reinforced polymeric composites for fundamental research and industrial applications.

There are two main components in a reinforced plastic: a matrix of either thermoplastic or thermosetting and reinforcing fillers [5]. Unsaturated polyesters have versatile properties and applications and used in composites as a popular thermoset polymer matrix. There are several reports on the reinforcement of polyesters with natural fibers such as Polyester jute [6,7], polyester coir [8], polyester straw [9]. Normally fiberglass or ground mineral are used to strengthen unsaturated polyester that are used to make structural parts such as boat hulls, pipes, and countertops. Unsaturated polyesters are prepared from a saturated di-carboxylic acid or its anhydride (usually phthalic anhydride) as well as an unsaturated di-carboxylic acid or anhydride (usually maleic anhydride) which are reacted with one or more Di alcohols, such as ethylene glycol or propylene glycol, to produce the characteristic ester groups that link the precursor molecules together into long, chainlike, multiple unit polyester molecules. The mixture is usually poured into a mold to form a three dimensional network structure that bonds well with fibers or other reinforcing materials [10]. UPR are used extensively in composite materials, wood paints, flat laminated panels, corrugated panels, ribbed panels, gel coat for boats, automotive and bathroom fixtures, coloring pastes, fillers, putties and chemical anchoring's, self-extinguishing composite materials, quartz, marble and artificial cement [11]. Numerous approaches have been applied to overcome limitations using different reinforcements from micro fibers to nanotubes in the matrix of UPR are present in existing literature [12-14].

The waste feather produced from poultry industry causes a serious solid waste problem in many countries [15,16]. Similarly, cow hair and trimmed waste leather cause pollution to a great extent. The feather fiber and quill both contain insoluble and highly durable protein, keratin (about 90% by weight), which is also a major component of hair, hoofs and horns of animals [17,18]. These keratins are scaffolding proteins which form a network of intermediate filaments in the cytoplasm of epithelial cells and their functional roles are to provide structural maintenance for cells and tissues, cell growth, hair cycling, wound repair and tissue remodeling (Sinclair, 2007). Keratin is formed of around 90 amino acids but cystine, lysine, proline and serine are the main ones [19,20]. The basic component of leather is a fibrous protein called collagen. Collagen is formed by 21 types of amino acid creating polypeptide bond among them. By cross linking with one another these amino acids form disulfide or hydrogen bonds making fibers tough, strong lightweight and with good thermal and insulating properties [18-21]. Fibers from chicken feathers have small diameter (5 microns) and have excellent adsorbent properties [22]. Structure and mechanical properties of proteins have been discussed by Marc Andre Meyers et al. [23].

In this study, animal fiber based UPR composites is fabricated, and their properties have been observed. Properties of plant and animal based natural fiber reinforced composites have been investigated by several

***Address for Correspondence:** Farhad Ali, Department of Public Health, Atish Dipankar University of Science and Technology, Bangladesh, Email: farhad.ilet@du.ac.bd*

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authors [24-28]. Though natural fibers in composite materials show some limitations like high moisture sorption, poor dimensional stability, low thermal resistance, isotropic fiber resistance and variability of composition (Shambolism A, 2000). A strong adhesion is needed to use natural fibers as reinforcements in composite materials (Aziz S, 2004; Gamstedt EK, 2002) because the macroscopic mechanical properties depend on the fiber matrix interface. Physical and chemical treatments is applied for maximizing this interface to increase adhesion (Bledzki AK, 1999). For example, reactive chemical coatings in the fibers induce chemical bonds between the matrix and the fibers (BC, 1976; Bisanda ETN, 1991).

Materials and Methods

Materials

The materials utilized for this research work were done in Bangladesh. The chicken feather, the cow hair and waste leather collected from commercial poultry farm and Leather Manufacturing Laboratories, Institute of Leather Engineering and Technology, Dhaka, Bangladesh respectively while the unsaturated polyester resin and MEKP were purchased from Hatkhola, Dhaka, the Cosmoplene Polyolefin Company Ltd.

Methods

Preparation of CFF-UPR and CHF-UPR reinforced composites: For preparation of the composites, the selected Chicken feathers (CFF), Cow hairs (CHF) and waste leather (LF) were washed with distilled water and detergent dried in sunlight for 12 hours and then dried in oven at 30°C for five days to remove different types of contaminants from the feather, hair and leather surface. Then they were cut into average length of 5 mm (cutting machine, FRITSCH, Industriestr. 8, 55743 Idar-Oberstein, Germany) and divided into two portions. One portion of the cleaned samples was treated by using 0.25 M NaOH maintaining 50°C temperature for 2 hours and dried in the oven at 60°C for 5 hours and the other portion was untreated. The CFF-UPR CHF-UPR an LF-UPR reinforced composites were prepared by hand lay-up method by mixing together the fiber portions of 2%, 5%, 7%, 10%, 12% and 15% by weight with the matrix (UPR). It was kept in the fume hood at 250 for 24 hours and prepared composites were then packaged in polythene bags.

Mechanical testing of composites

The tensile strength (TS), tensile modulus (TM), elongation at break (EB) and bending test of the composites were measured by Testometric universal testing machine (M-500-30 KNCT) with an initial clamp separation of 20 mm and a cross head speed of 10 mm/min. The sample piece with dimensions of 60 mm×10 mm×1.6 mm was hooked on the grip and the test begun. The samples were conditioned for three days before testing and all the tests were conducted under the same conditions with a relative humidity 50 percent and at 25°C. All the test values were considered at least five samples.

Results and Discussion

Tensile properties

In Figure 1 the tensile strength at peak of the control sample UPR, the CHF-UPR reinforced composites, CFF-UPR reinforced composites and LF-UPR reinforced composites are compared. The control sample showed 18 N/mm$_2$ at the peak. By comparing all the results, it was found that the maximum tensile strength was showed by 5% TCHF-UPR composite (32.25 N/mm$_2$) which increased 30.83% than that of the untreated cow hair fiber (UTCHF) with a value of 28.32673 N/mm$_2$ at the same fiber loading and 79.10% better than the control sample. The minimum tensile strength was showed by 2% UTLF-UPR composite (25.94 N/mm$_2$) and also increased about 44.11% than the control sample. From the results, it was observed that treated and untreated both fiber loading gave the better results in comparison with the control sample. From the above discussion it was found chemical treatment of cow hair fiber at 5% loading showed very positive result.

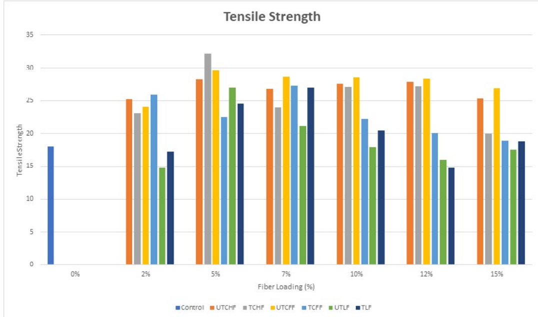

Figure 1. Variation of tensile strength peak of control sample, CFF-UPR, CHF-UPR and LF-UPR composites

Figure 2 represents the tensile modulus of the control sample UPR, CHF-UPR, CFF-UPR and LF-UPR reinforced composites. These results showed that the tensile modulus at peak of the control sample was 650. The 7% TCHF reinforced composite gave the best result with a value of 1138.54 N/mm2 and the second highest value was found for 7% UTLF loading composites which increased 75.16% and 74.69% respectively than that of control sample. Chemical treatment has increased the values of tensile modulus was better for 2%, 5%, 10% and 15% TLF-UPR composites.

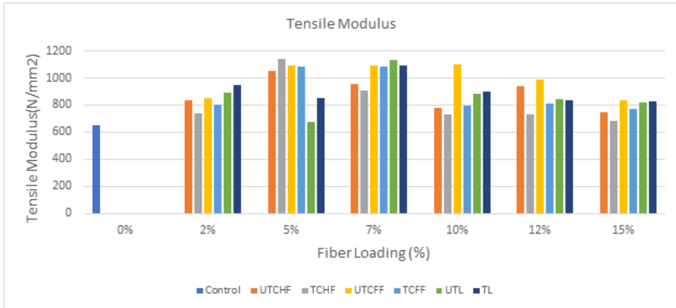

Figure 2. Variation of tensile modulus peak of control sample, CFF-UPR, CHF-UPR and LF-UPR composites

In Figure 3 the results for elongation at break of the control sample, CHF-UPR, CFF-UPR and LF-UPR composites are represented. The value of elongation at break for the control sample was best in the tested results with a value of 5. 7% fiber loading of the TCHF reinforcement produced the best results compared to other reinforcement composites with a value of 2.878 which is 42.44% lower than the control sample. For most cases, chemical treatment has increased the value of elongation at break.

The results revealed that the effect of the chemical treatment on the 5% cow hair fiber was more effective at tensile strength and tensile modulus but best result of elongation at break was found for 7% chemically treatment cow hair fiber loading that means tensile properties were improved by chemically treatment for almost composites

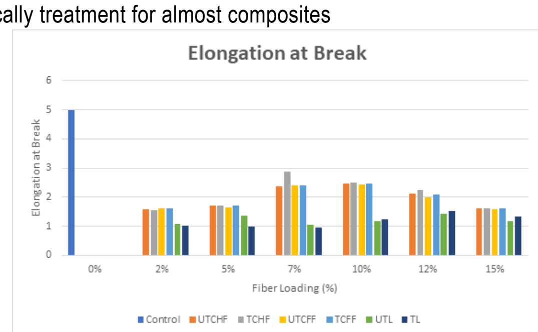

Figure 3. Variation of elongation at break peak of control sample, CFF-UPR, CHF-UPR and LF-UPR composites

Bending properties

The Figure 4 indicated the results of bending strength of the control sample, CFF-UPR, CHF-UPR and LF-UPR reinforced composites. The control sample showed 25 N/mm2 bending strength. The best result was found for 5% fiber loading of TCHF reinforced composite with a value of 79.88 N/mm_2 and increased 219.52% and 5% UTCHF loading composite gave the value of 77.39 N/mm_2 which is better 209.58% than that of control sample. The 5% chemically treatment cow hair fiber loading showed 3.22% better result than the untreated fiber loading composite. This study shows that chemical treatment of reinforcement materials enhances the bending strength for maximum cases. This enhancement indicates improved interfacial adhesion which helps more efficient translocation of stress. The fiber matrix interface has a great impact on the overall mechanical properties of any fiber reinforced polymeric composite [29].

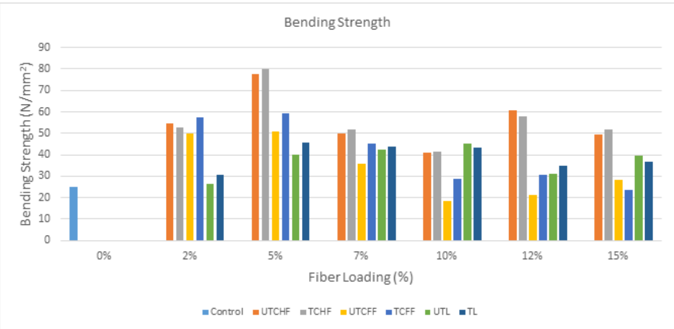

Figure 4. Variation of bending strength peak of control sample, CFF-UPR, CHF-UPR and LF-UPR composites

Figure 5 represents the comparison of bending modulus in the control sample, CHF-UPR, CFF-UPR and LF-UPR composites. Bending modulus for the control sample was 700 N/mm2. The maximum and minimum value were obtained for 5% TCHF-UPR and 2% UTCFF-UPR composites respectively. The increased for highest value was 549.94% more than the control sample and the 5% chemically treatment cow hair fiber loading composite gave 4.53% better result than the composite of untreated fiber loading. All the results showed that chemically treated cow hair fiber reinforced unsaturated polyester resin composites gave the best tensile and bending properties for 5% fiber loading.

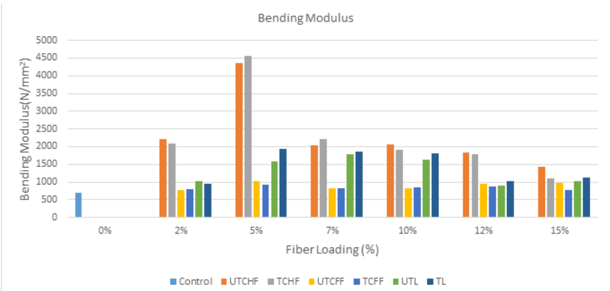

Figure 5. Variation of bending modulus peak of control sample, CFF-UPR, CHSSF-UPR and LF-UPR composites

SEM analysis

Figure 6 represents Interfacial properties of UPR composites of untreated and treated cow hair fiber, chicken feather fiber and leather were analyzed by SEM. This analysis indicated that there is a considerable difference in the fiber matrix interaction between untreated and treated cow hair fiber, chicken feather fiber and leather fiber reinforced UPR composites. Some gaps between fiber and matrix are clearly found for most of the composites which are responsible for the low mechanical properties. It indicates at 5 wt% of fiber reinforcement of F1, the fibers are capable to provide to the effective stress transfer between fibers and UPR matrix and at the same time increases the tensile and bending properties. The SEM image of the fracture surface explains that the cow hair fiber pull out is quite low in Cow hair Fiber/UPR this analysis indicated that the mechanical properties increased at 5 wt% cow hair fiber loading. There was no void space in the prepared composites. The void space showing in the figures are for the fiber pullout from the matrix. There was good bonding between the fiber and matrix, which carries good evidence for the slightly better mechanical properties in composites. From the SEM analysis it is clear that the fiber matrix adhesion of the composites increased with addition of fibers.

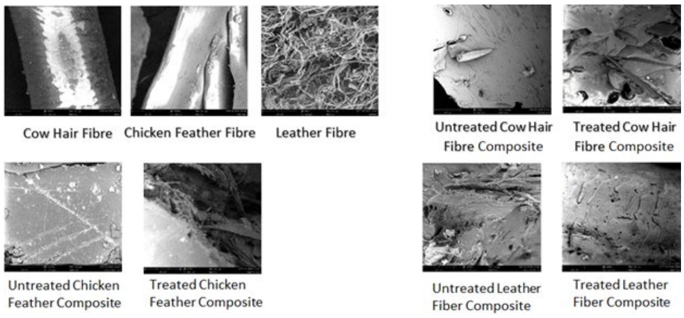

Figure 6. SEM analysis

FTIR analysis

Figure 7 represents to identify the functional group of the composites Fourier Transform Infrared Spectroscopy was used. These graphs for composites show a prominent peak at about 1720.00 cm^{-1} for carbonyl (C=O) groups. C-O-C is a prominent feature in the spectrum appearing at about 1269.37 cm^{-1}. A strong peak at 740.00 and another weak peak at 2928.72 cm^{1}-2951.62 cm^{-1} assign to =C-H out of plane bending and to -C-H stretching respectably. The FTIR functional group analysis shows the same functional group in the same region in the IR spectra. For the presence of $-NH_2$ group, the peak appeared in the wave number of 2900 cm^{-1}. In the region of 1700 cm^{-1}, another peak was observed and this peak was for the presence of CH_3 and CH_2 groups (for sp3 bending). In the region of 2800 cm^{-1} another peak was observed for CH group (for sp3 stretching). In the region of 1575 cm^{-1}, another peak was observed and this peak was for the presence of CH_3, CH and CH_2 group (for sp3 bending). At 1690-1750 cm^{-1} another peak was observed for the functional groups of C=O. For the presence of polymeric -OH group's very broad peaks appeared in the wavenumber of 3400 cm^{-1}. So, there was no chemical bond between the fibers and UPR. The improved mechanical properties were due to the mechanical bond among the chicken feather fiber and UPR.

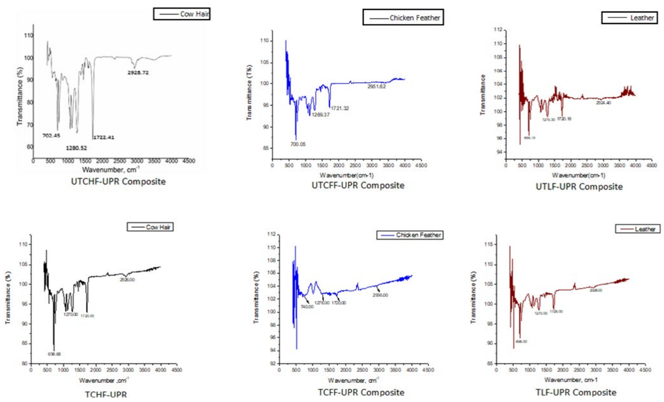

Figure 7. FTIR analysis

TGA analysis

Figure 8 represents thermo gravimetric analysis was carried out to analyze the thermal behavior of the prepared composite. The starting temperature was 50°C and the final temperature was 490°C. At 135°C temperature, 90% of the control composite remained, and then a slight decrease was noticed up to 225°C temperature. From 225 to 385°C temperature, the composite showed a rapid decrease, and the remaining percentage was formed 90 to 30%. From 385°C to the final temperature, the composite showed a very high degradation.

Compared to the control UPR composite, the 5% fiber loading composites showed a very good temperature resistance up to 315°C. The composites remain 99% at the temperature of 135°C compared to the untreated composite at the same temperature. Up to 315°C temperature, the degradation rate was very slow and then rapid degradation was observed and continued to 450°C. For the control sample, rapid degradation started at 207°C, but for the composite it started at 385°C with 84% remaining of each.

Figure 8. TGA analysis

Conclusion

In this research cow hair, chicken feather and leather fibers were used to prepare natural fibers reinforced unsaturated polyester resin composites. The addition of these animal fibers to the matrix was able to enhance the flexural and tensile properties of the developed composite materials. The best % fiber loadings for these treatments laid between 5 wt%-7 wt%. This was revealed from the outcome of the results where chemically untreated animal fiber reinforced unsaturated polyester resin composites gave the best performance in the flexural properties and elongation at break under tensile properties in comparison with the treated animal fiber reinforced unsaturated polyester resin composites. For engineering application where high tensile strength and high ductility of unsaturated polyester resin are required, 5 wt% fiber loading reinforced-UPR should be used. The work justifies the economic consumption of these waste materials that are detrimental as environmental pollution agent.

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