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ANALYSIS OF THE INFLUENCE OF CHEMICAL TREATMENTS ON THE PHYSICO-CHEMICAL AND TENSILE PROPERTIES OF AVIAN FIBER

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ABSTACT: This work has been carried out to investigate the influence of chemical treatment on the physico-chemical and tensile properties of turkey feather. The turkey feathers was obtained from the poultry and were prepared by cutting and washing before they were sun dried. Chemical treatments were carried out on the fibers in a shaker water bath and sun dried for 5 days. Samples were prepared for elemental, physico-chemical and tensile test analysis. From the results, it was observed that chemical treatments proven to be a potential means of modifying the compositional constituents thereby enhanced the physico-chemical and tensile properties of the fibers. All the chemical treatments; H_2O_2, NaOH and KOH gave better performance than the untreated sample in one area or the other.
Keywords: Avian fiber, chemical treatment, constituents, tensile properties

1. INTRODUCTION

Feathers distinguish birds from other vertebrates and play an important role in numerous physiological and functional processes. Most adult birds are covered entirely with feathers, except on the beak, eyes, and feet. Feathers not only confer the ability of flight, but are essential for temperature regulation. Feathers are highly ordered, hierarchical branched structures, ranking among the most complex of keratin structures found in vertebrates [1].

Currently, 4 billion pounds of chicken feathers produced annually in the United States are principally consumed by the feather meal industry, which utilizes the feather material in livestock feed [2]. The development of alternative industry consumers of chicken feathers may increase the value of these feathers, which are currently valued at approximately $250/ton when sold for feather meal [3]. As well, new applications will provide alternatives to landfilling of the material at a cost of $30/ton, should government regulation inspired by public concerns about bovine spongiform encephalopathy and avian influenza jeopardize the feather meal industry [4]. The FDA and USDA recently solicited comments and scientific opinion on “prohibiting the use of all mammalian and poultry protein in ruminant feed” [5]. This suggests that feather meal may not always be approved for use in feed. In the European Union, for example, poultry feather meal has been banned since 2001 [6].

Chicken feathers possess unique properties - including low relative density and good thermal and acoustic insulating properties- which could be used advantageously in a number of applications which would serve as alternatives to feather meal and feather disposal. In addition, technologies for processing chicken feathers into fibrous (feather fiber) and particulate (quill) fractions have been developed and patented (United States Patent Application 20020079074 and United States Patent 5705030) [7-8]. However, although a number of commercial applications have been investigated, market mechanisms have failed to produce alternative *high volume* consumers of the processed materials. While a nutraceutical product from feather protein has been marketed, it is unlikely that the nutraceutical industry could be an adequately high volume consumer [9]. Composite building materials containing chicken feather materials (CFM) are high volume applications which could potentially consume all of the chicken feathers produced annually in the United States and raise their market value. Based upon processing costs and the price of similar fibers, Walter Schmidt has estimated that feather fiber could yield a profit of $1000/ton [10]. Chicken feather has been used to produce computer chips, circuit boards, nonwoven insulation batting, assortment of paper products etc.[11-14].

Geo-fabrics for erosion control have been developed from latex-bonded non-woven turkey feather material. When compared to traditional products made of jute and coconut, the turkey feather fabrics performed similarly in terms of light and water transmittance. The feather fabrics did not affect pH, nitrogen, or phosphorous content of the soil, and actually increased moisture content while decreasing compaction [15].

A variety of studies have investigated the influence of chicken feather fiber inclusion on composite properties. Winandy et al. (2003) studied aspen fiber medium density fiberboard composite panels with feather fiber replacement in amounts ranging from 20% to 95% where 5% phenol formaldehyde was used as an adhesive.

Going by the efforts of the researchers mentioned above on the use of feathers from chicken and turkey, there is need to expand the scope of the use of animal fibers by looking inwards on how to enhance the properties of these animal fibers so as to further encourage their use as engineering materials.

In order to successfully develop applications for these animal fibers in the realm of composite materials, the physical and mechanical properties of these animal fibers must first be understood. This data can be used to target applications and to develop financial analyses informed by an understanding of necessary processing costs and potential financial benefits. For these reasons, this work was carried out to investigate the influence of chemical treatment on the turkey feathers with respect to the constituents and strength.

2. MATERIALS AND METHODS

The major materials for this work are; turkey feather, hydrogen peroxide, sodium hydroxide, potassium hydroxide, distilled water and litmus paper.

In other to process the fibers, the following procedures were adopted after the turkey feathers were cut into long strands, sorted, washed with water and sun dried for 5 days.

To carry out the chemical treatment, the solutions were prepared as follows:

a. Sodium hydroxide (NaOH) solutions: Sodium hydroxide pellets were weighed on the electronic weighing machine accordingly in order to obtain 0.1, 0.15 and 0.2 molar solutions respectively. This was achieved by dissolving 4, 6 and 8 g in 250 ml of distilled water respectively in beakers.
b. Potassium Hydroxide (KOH) Solutions: The solutions were prepared by dissolving 5.6, 8.4 and 11.2 g of potassium hydroxide pellets in 250 ml of distilled water to obtain the respective concentrations of 0.1, 0.15 and 0.2 molar solutions.
c. Hydrogen Peroxide (H_2O_2) solution: The hydrogen peroxide solutions were prepared by measuring 1, 1.5 and 2 ml out and mixing each of them with 250 ml of distilled water to obtain 0.1, 0.15 and 0.2 molar solutions.

2.1. Treatment of the fibers using the shaker water bath.

The sun dried fibers were measured out into 2.5 g each for the different chemical treatments carried out and were added to their respective beakers containing the chemicals. The mixtures were put inside the shaker water bath maintained at 50 °C for 4 hours. The treated fibers were washed with tap water and finally with distilled water to obtain neutral status and sun dried for 5 days.

2.2. Compositional analysis test

i. Moisture content determination

This was done using the oven-drying method. Cleaned, dry and well-labeled petri dishes were weighed (W_1). About 5 g of each sample were weighed into the dishes (W_2) and transferred into the oven maintained at 105 °C for 3 hours. After the three hours, they were transferred into the desiccators to cool and then weighed (W_3). This process was continued every hour until a constant weight was obtained. The analysis was carried out in duplicate.

$$\%\ \text{Moisture} = \frac{\text{Loss in weight of Sample } (W3-W2)}{\text{Weight of sample before drying } (W2-W1)} \times 100 \qquad (1)$$

ii. Crude protein determination

This involved three stages namely; digestion, distillation and titration.

Digestion. About 0.5g of sample was weighed into 500ml kjeldahl flask. Concentrated H_2SO_4 (10ml) and selenium catalyst were added and boiled until the sample turned into clear solution. It was cooled and made up to 50ml with distilled water. The sample was stored in a bottle.

Distillation. To carry out distillation, 5ml of 2% H_2BO_3 (Boric acid) was put into the conical flask and 2 drops of mixed indicator (0.198g bromocresol green plus 0.132g methyl red into 200ml alcohol) were added. The receiving flask was positioned so that the tip of the condenser tube was below the surface of the boric acid. The 5ml of digested sample was pipetted into the condenser's cup and 10ml of 40% NaOH was added. This was then washed down with distilled water. The joints were tightened and distillation was done till a volume of 50ml was reached in the receiving flask.

Titration. The distillate was titrated with 0.1ml HCl until the end point (pink color) was reached.

$$\%\ \text{Nitrogen} = \frac{\text{Molarity of acid x titre value x 0.014 x 0.25 x V1/V2}}{\text{Weight of Sample}} \text{ x } 100 \quad (2)$$

where, V_1 - volume of digest (50ml) and V_2 - volume of digest used (5ml), % Crude protein = %Nitrogen x 625

iii. Ash content determination

Dry and clean crucibles were weighed (W_1) and their respective weights recorded and, about 1g of the samples were added and weighed again (W_2). The crucibles and contents were placed into the muffle furnace at 600°C until a light grey colour of ash was obtained. The crucibles were removed and allowed to cool in the desiccators and then weighed (W_3).

$$\%\ \text{Ash} = \frac{\text{Weight of Ash (W2}-\text{W3)}}{\textit{Weight of Sample}\ \text{(W2}-\text{W1)}}\ x\ 100 \quad (3)$$

2.3. Tensile Test

The Instron 3369 machine at Central for Energy Research and Development (CERD) OAU Ile-Ife was used to carry out the tensile test.

3. RESULTS AND DISCUSSION

The elemental constituents were determined with Atomic Absorption Spectrometer (AAS). Elemental micro constituents and tensile tests were carried out on the chemically treated fibers and the untreated fiber to determine the effects of chemical treatments on the elemental constituents and tensile properties of the fibers.

Table 1: Elemental Constituent of the Turkey Feather

S/N	Chemical Treatment	Potassium (K) (%)	Sodium (Na) (%)	Sulphur(S) (ppm)	Calcium (Ca) (%)	Magnesium (Mg) (%)	Phosphorus (P) (%)
1	Control	1.42	1.47	640.00	0.81	1.03	3.41
3	H_2O_2(0.1)	0.28	0.47	1360.00	1.27	1.29	2.58
4	H_2O_2(0.15)	0.20	0.55	1440.00	0.69	1.92	2.83
5	H_2O_2(0.20)	0.34	0.53	980.00	0.87	0.97	2.75
9	NaOH (0.10)	0.52	2.95	640.00	0.65	0.78	4.50
10	NaOH (0.15)	0.39	1.25	800.00	0.65	0.94	3.33
11	NaOH (0.20)	0.60	2.80	1280.00	0.93	2.46	3.75
15	KOH (0.10)	4.02	1.27	1440.00	0.70	1.35	3.66
16	KOH (0.15)	3.27	1.01	960.00	0.65	1.72	2.75
17	KOH (0.20)	2.45	1.52	1120.00	0.74	0.44	3.33

3.1. Compositional Constituents

(a). Moisture Content

The result of the variation of moisture content with the chemical treatment was as presented in Figure 1. From the results, it was observed that, KOH followed by NaOH treatments led to the reduction of the moisture content of the fibers. The result show similar trends for the alkali treatments contrary to that of the peroxide. Whereas there is reduction in moisture content as the concentration of the alkaline solutions increases, the reverse was the case for the peroxide treatment, where it was noticed that, the moisture content increases as the concentration of the peroxide treatment increases. This increase was due to the release of more water molecules from the peroxide as the concentration increases. The moisture content of the 0.2 M KOH treated turkey feather was 6.46 % as against the untreated feather with a value of 10.09 %. This implies that the treatment has led to the reduction of the moisture content by 36 %. The effect of high percentage of moisture content in fibers is deleterious and undesirable as this will usually cause the fibers to degrade early in service. Therefore, from this result, it was observed that alkali treatments can be used to reduce the effect of moisture content on natural fibers.

The ability of chicken feathers to absorb moisture from the environment has important implications for the processing, storage, transportation, and durability of chicken feathers -containing composite materials, as increases in moisture content may interfere with processing or bonding, increase weight (and hence transportation costs), or lead to more rapid deterioration [16].

The composition of chicken feathers has been reported as 91% protein (keratin), 1% lipid, and 8% water. Moisture contents of 16-20 % indicate that chicken feathers are hygroscopic [17]. These show that chicken feathers are more hygroscopic than turkey feathers. Keratin can be considered to have both hydrophilic and hydrophobic properties. While 39 of the 95 amino acids in the keratin monomer are hydrophilic, serine, the most abundant amino acid, gives chicken feathers the ability to attract moisture from the air, because of the free OH^- group on the surface of each serine molecule [18]. Thus, chicken feathers may be considered to be hygroscopic. The reduction in moisture content observed from the alkaline treatment in this research may be due to the reaction between the alkaline and the free OH^- group on the surface of each serine molecule.

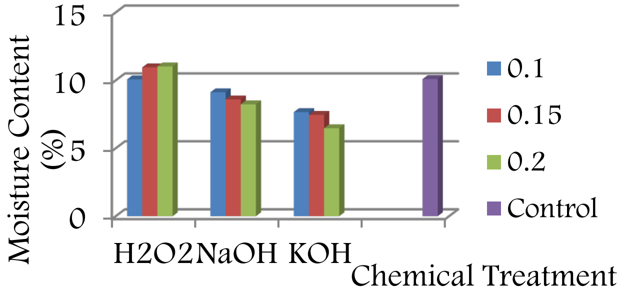

Figure 1. Effect of Chemical Treatment on the Moisture Content of the Turkey Feather

(b). Protein Content

The structure of protein (keratin), the primary constituent of chicken feathers, affects its chemical durability. Because of extensive cross-linking and strong covalent bonding within its structure, keratin shows good durability and resistance to degradation. Efforts to extract keratin proteins from feathers illustrate this point. Extraction is a difficult task because it can only be achieved if the disufide and hydrogen bonds are broken. Keratin was found to be insoluble in polar solvents like water as well as in nonpolar solvents [20]. The most common method for dissolving feather keratins is solubilization with concomitant peptide bond scission via acid and alkali hydrolysis, reduction of disulfide bonds with alkaline sodium sulfide solutions, or a combination of enzymatic and chemical treatment [21]. Although these techniques are effective for extracting keratin (75% yield), they require extremely high reagent concentrations that are much higher than keratin fibers would ever be exposed to in nature. One can deduce from this that keratin is a relatively sturdy and stable protein.

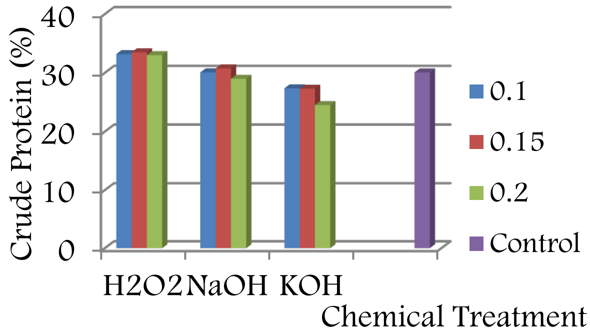

Figure 2. Effect of Chemical Treatment on the Crude Protein Content of the Turkey Feather

The mechanical properties of chicken feather are related to the structure of keratin. Keratin, like other biological polymers, possesses a structure with covalent bonds that transfer forces while only negligibly distorting. Strains are largely produced by changes in the hydrogen bonds, van der Waals, and Coulombic interactions. According to [22], this consistency among natural protein fibers results in similar moduli of elasticity. However, [23] summary of studies since 1966 reports moduli of elasticity for feather keratin ranging from 0.045 GPa to 10 GPa. This range could indicate a high degree of interspecific heterogeneity in keratin properties [24]. Alternatively, differences in testing methodology could explain the range. From the result of the effect of chemical treatment on the protein content in Figure 2, it was observed that H_2O_2 treatment enhanced the presence of protein followed by the NaOH treatment that gave a marginal improvement with respect to the untreated feather. The KOH treatment brought about reduction of the protein content. The best result was obtained from 0.15 M H_2O_2 treated sample with a value of 33.49 % while the untreated feather was with a value of 30.07 %. By this, 11 % improvement has been achieved. Since the presence of protein is highly essential for effective strength for the fiber, this treatment will be very good for protein enhancement in animal fibers.

(c). Ash Content

Figure 3 show the variation of the ash content with the chemical treatments. From the results, it was observed that as the concentration of the alkaline treatment increases, the ash content decreases with the evolution of more ash content except for 0.15-0.2 molar solutions of NaOH treatments. In contrast, H_2O_2 treatment brought about severe reduction of the ash content especially at higher concentration of between 0.15-0.2 molar solutions.

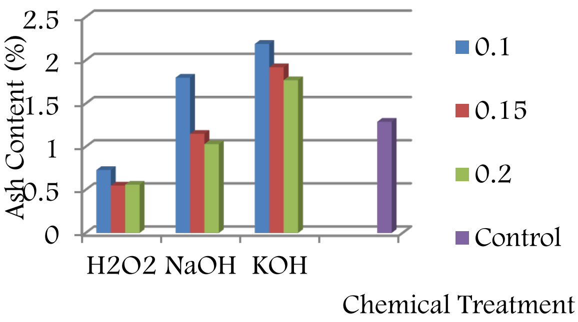

Figure 3. Effect of Chemical Treatment on the Ash Content of the Turkey Feather

These show that higher concentration of the chemicals aid the removal or reduction of the proportion of the ash content of the fibers while lower concentration of the alkaline treatment improve the development of ash content. From the results, the sample with highest amount of ash content was obtained from 0.10 M KOH treatment with a value of 2.19 % compared to the untreated sample with a value of 1.29 %. This treatment has increased the ash content by about 70 % which show that more ash can be obtained from the avian fiber by carrying out alkaline treatment. Ashes from natural fibers have been used extensively to enhance the properties of both polymer and metal matrix composites. Therefore, this method can be adopted for the production of ash that is needed for the development composite materials for engineering applications.

3.2. Tensile Properties

The analysis of the results of the tensile strength properties was as shown in Figure 4. The results revealed that, the chemical treatments with exception of KOH treatment enhanced the tensile strength of the fibers. From the results, it was noticed that H_2O_2 treatment gave the best influence on the feather for the improvement of both tensile stress at maximum load and at yield with a value of 0.142 and 0.068 MPa from 0.2 and 0.1 molar solutions of H_2O_2respectively compared to the untreated fiber with a value of 0.072 and 0.046 MPa respectively. The percentage increase in these properties are; 97 % and 49 % respectively. This show that chemical treatment can be used to enhanced the tensile properties of animal fibers just as it has been established for plant fibers [24]. The enhanced strength observed in H_2O_2 treated samples may be due to increase in the protein content of the H_2O_2 treated samples as shown in Figure 2. This was in agreement with previous results where it was stated that the presence of higher amount of protein content led to the enhancement of tensile properties.

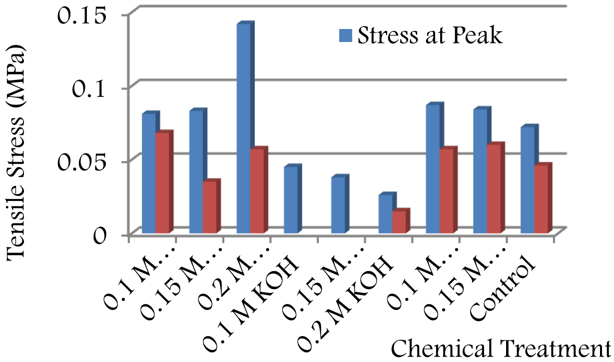

Figure 4. Effect of Chemical Treatment on the Tensile Strength of the Turkey Feather

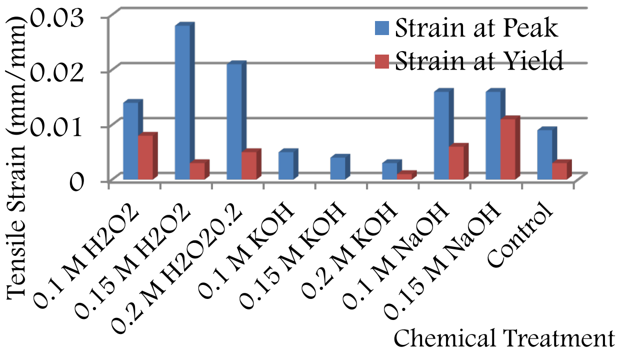

Figure 5. Effect of Chemical Treatment on the Tensile Strain of the Turkey Feather

Bonser and Purslow (1995) performed uniaxial tension tests on 25 mm sections of keratin cut from the rachis dorsal surface of flight feathers from eight volant species that are each from a separate order. The Young's modulus was found to be approximately 2.5 GPa for all species except the grey heron (1.78 GPa). George et al. (2003b) studied turkey feather fiber properties for fibers at different positions along the rachis. It was found that both the tenacity and modulus of turkey feather fiber, measured in g/denier, increased with the distance from the calamus. Turkeys are volant, though they only fly in short bursts.

The result of the effect of chemical treatment on the tensile strain of the feather was as shown in Figure 5. The results show similar trends to that of tensile stress results in Figure 4 as it was observed that H_2O_2 followed NaOH treated samples possess the best tensile strain at maximum load and yield respectively. However, from the results, 0.15 M treated samples from H_2O_2 and NaOH gave the best tensile strain at maximum load and yield of 0.028 and 0.011 mm/mm compared to the untreated feather that has 0.009 and 0.003 mm/mm tensile strain at maximum load and yield respectively. From these, about 211 % and 267 % enhancement of strain ability has been achieved compared to when the feathers are not treated. This suggests that by treating the feathers, they can withstand more strain and hence, able to delay the failure of the materials in service.

4. CONCLUSION

The work has been carried out to investigate the effectiveness of chemical treatment on the physico-chemical and tensile properties of turkey feathers from where the following conclusions were drawn out. Chemical treatments have proven to be a potential means of modifying the physico-chemical properties and therefore, enhancing the tensile properties of the feathers to be used for engineering applications as reinforcement in polymer and ceramic matrix materials. This was the case because the entire chemical used, H_2O_2, NaOH and KOH gave better performance than the untreated sample in one area or the other. However, H_2O_2 treatment gave the best overall performance from all the analysis carried out with the exception of the area of moisture content where, KOH gave the best performance. To fully optimize the feathers properties, H_2O_2, NaOH and KOH can be utilized in a synergistic form so as to cater for the limitations of the effect of the individual chemicals.

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