Study of Different Chemical Treatments for the Suitability of Banana (*Musa oranta*) Fiber in Composite Materials

Md. Mamunur Rashid, Sabrin A Samad, M. A. Gafur, A. M. Sarwaruddin Chowdhury

Abstract—The present works demonstrate banana fibers which were chemically modified with 7.5% NaOH & 0.055% $KMnO_4$. The effects of modification were determined by measuring various physical and mechanical properties such as moisture absorbance, tensile strength, % elongation break and characterized by various methods such as SEM, IR etc. The ultimate tensile strength of treated fibers was lower than that of raw fibers. Percentage elongation and moisture absorption increase on treatment.

Keywords— Banana fiber (Natural filler), Chemical treatment, Mechanical properties, Physical properties, Polypropylene (Matrix), Polymer composites

1 INTRODUCTION

Fibers are used in composite materials as reinforcing constituents. Early in the development of composites, the only reinforcements available were derived from traditional textiles and fabrics. Particularly in the case of glass fibers, experience shows that the chemical surface treatments or "sizing" required processing these materials into fabrics and other sheet goods were detrimental to the adhesion of composite polymer to the fiber surface.[1] Techniques to remove these materials were developed. Simultaneously natural fibers were considered as the substitution for glass and carbon fiber in polymer composites. Their potentiality for being used in molded article, not needing high strength for acceptable performance, has been tried in equipment housing, roofing, low cost housing, large diameter piping, and many other purposes. Among all natural fibers jute is the most frequently used fiber [2]. Natural fibers are naturally obtained from different types of plants. Natural fibers can be divided into three groups, i.e. vegetable fibers (flax, hemp, sisal, etc.), protein fibers (wool, silk, chitin, etc.), and mineral fibers (asbestos, etc.). Vegetable fibers are renewable with good mechanical properties which justify their use as reinforcement for polymers. They are now being used or expected to be used extensively for composite materials due to the following advantages [3]. Low specific weight, which results in a higher specific strength and stiffness than glass, is a benefit especially in parts designed for bending stiffness. It is a renewable resource, the production requires little energy, and CO_2 is used while oxygen is given back to the environment. It is produced with low investment at low cost, which makes the material an interesting, predicable for low wage countries. Ethnically processed, no wear of fooling, no skin irritation, and thermal recycling are possible, where glass causes problem in combustion furnaces. They have good thermal and acoustic insulating properties [4, 5, 6]. In spite of having a lot of advantages, natural fibers have some disadvantages such as lower strength properties particularly its impact strength, variable quality which depends on unpredictable influences such as weather and high moisture absorption which eases swelling of the fibers, low processing temperature, and low durability which can be improved by fiber treatment considerably.

Banana is the common name for a type of herb and also the name for the herbaceous plants that grow this herb. These plants belong to the genus Musa. They are native to the tropical region of Southeast Asia. There are about 100 different species of banana. In general, banana is of the leaf fibers that are coarser than the baste fibers [7]. Applications are ropes and coarse textiles. Within the total production of leaf fibers, sisal is the most important. The stiffness is relatively high and it is often applied as binder twines. In some interior application sisal is preferred because of its low level of smell compared to fiber like flax which at increased temperatures (NMT) during manufacturing process can cause smell [8].

Since the fiber reinforced composite material relies on the fiber for its strength and stiffness, it is essential that this constituent passes high strength and high modulus compared to the matrix, then with the appropriate volume traction accompanied by control of fiber orientation and fiber dimensions the mechanical behavior such as strength, toughness and stiffness can be optimized. Variability in strength of fiber is also a con-

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cern in composite materials, since some fibers are inherently stronger than others. For example, where bundles of fibers are axially strained, the water fibers fail first, thereby increasing the load on the remaining fibers.

Chemically speaking, banana fiber is a composite leaf fiber extracted from the banana plant by retting in water. Banana fiber is obtained from the edible-fruit- bearing plant, species ***Musa oranta***. The fibers are obtained mainly from the inner bark of the plant. About 37 kg of stem yield 1 kg of good quality fiber; the yield is 1-1.5% of dry fiber [9]. The fiber obtained from the central core is of the best quality. The fiber has not been exploited much commercially hitherto, as it was considered inferior to abaca and other available hard fibers. It can be extracted by hand scraping, by retting, or by raspador machines; it can also be extracted chemically, for example by boiling in NaOH solution. Banana fiber is extracted for local use or for cottage industries such as due to its high cellulose and low lignin content its uses in the paper industry (tissue, filters, document, printing, etc.) have been reported. Over the years, there has been a considerable interest in exploiting it for a variety of household and industrial uses on a commercial scale. For instance, the use of banana fiber as reinforcement with autoclave cement mortar, with air-cured cement, or with air cured plaster is being investigated. Therefore, the development of mechanical decorticating methods is reported to be in progress. So, immediate attention must be given for proper utilisation of this high cellulose and low lignin content fiber. Advantage of using banana fiber as reinforcing materials is its low cost. Since the specific gravity of banana fiber is much less than that of glass fiber. The cost per unit volume is further enhanced. The specific gravity of a banana polymer laminate can be up to 25 percent less than that of a glass polymer construction. The use of woven material ensures uniformity of reinforcement thickness throughout the area of the laminate. A banana polymer laminate and a glass polymer laminate of the same dimensions will have equal stiffness. Banana reinforcement is therefore a means of providing structural rigidity with low weight.

The aim of this scientific investigation is to fabricate biodegradable, environment friendly and low cost banana fiber, and to study the chemical changes of raw and treated fiber to evaluate its suitability for the manufacture of banana fiber reinforced composite.

2 EXPERIMENTAL

2.1 MATERIALS

The banana fibers were collected from stem of the banana plant. It is obtained from the species *Musa oranta* (Sagor Kala). These fibers are the "filler" of composite. Detergent (jet brand), 95% NaOH (pellet), 98.5% $KMnO_4$, 100% CH_3COCH_3 were used as chemicals which were laboratory grade.

2.2 Methods

2.2.1 PREPARATION OF BANANA FIBER

A variety of banana fiber was collected from banana plant of Curzon Hall area. The fiber was about 30 cm long. When banana plants got matured, the bark of the plant was cut down in small pieces and separated layers tied up in bundles. The bundles were put under compost fertilizer mixed water in two bucket for twenty days. When rotten, the fiber was taken out from the plant layers and washed thoroughly with water several times and dried in open air without exposure to sunlight. The removal of impurities such as dirty materials and gummy substances is carried out by surface-active agents such as soda, detergents. 6.5 gm detergent per liter of water was used. Then fibers were immersed in that solution at 70-75°C for 30 min in a beaker. Fiber to solution ratio was 1:50 (by weight). Then it was washed thoroughly with distilled water and dried in an oven at 50°C for 20 min before drying in an open air for 24 hrs and stored in a desiccator.

2.2.2 Composition measurement of Banana fiber

2.2.2.1 ESTIMATION OF ALPHA-CELLULOSE AND HEMICELLULOSE

All non-cellulosic matters of fiber are removed by the treatment of the bleaching agent, such as sodium chlorite when chlorite holocellulose, a combination of α-cellulose and hemicelluloses is obtained.

2.2.2.2 SEPARATION OF ALPHA-CELLULOSE FROM HOLOCELLULOSE

Prepared holocellulose mixed with 100ml of 17.5%NaOH and manually stirred for half an hour. Then added 100ml of distilled water and again stirred for half an hour. After that filtered through sintered crucible and washed with distilled water several times. Then 50ml of 10%CH_3COOH added and stayed for 1min without suction. Again added 50ml of 10%CH_3COOH and kept for 1min without suction. Fibers were properly washed with distilled water several times**.**

2.2.2.3 ESTIMATION OF LIGNIN

1gm of sample was taken in 100gm beaker and added 15ml of 72% $H2SO_4$. Then stirred with glass rod frequently and kept for 2 hours. Then the solution was transfered to1000 ml conical flux and added 560 ml distilled water. Then fibers were heated in autoclave for 1hr. After that filtered through sintered crucible and washed with distilled water several times.

Lignin% = (A × 100) ÷ W

Where, A = weight of lignin, W = weight of moisture free sample

2.2.3 Methods of chemical treatment

2.2.3.1 Alkali treatment

Raw banana fibers were cut into 15-20 cm length. Small quantities of fibers were weighted by a digital balance. Then fibers were placed in a container with pre-mixed NaOH at room temperature. Fiber to liquor ratio was 1:15 by weight and NaOH concentration was 7.5%. The fibers were kept about 2.5 hour in alkali liquor. After treatment, fibers were thoroughly washed for several times with distilled water until pH 7. After 48 hours of drying, fiber was weighed to determine the weight loss.

2.2.3.2 Permanganate treatment

The alkali treated fibers were soaked with $KMnO_4$ solution in acetone having the concentration 0.0555% for 1 min. After treatment, fibers were thoroughly washed for several times with distilled water until pH 7. Then fibers were decanted to dry in the air for 48 hours.

2.2.4 Moisture content

The raw fiber contains moisture. It was measured by drying fiber in an oven at 50° for 24 hrs. Then cooled in a desiccator and immediately weighed in a digital balance machine to 0.001g. Then the fiber was kept in an open air for 24 hrs and weighed in a digital balance machine to 0.001g. From the difference in weight of fiber moisture content of fiber was determined.

2.2.5 Tensile strength analysis of Fiber

This process involves gluing individual fibers across a window in a thin card which is glued to another thin card. Tensile strength of fiber is measured by cutting the sides of the card window frame carefully to leave the fiber free, gripping the card in the jaws of tensile machine, and loading it to failure at a slow crosshead speed.

2.2.6 IR analysis

IR was used mainly for evaluation of structural idea. It was used for the comparison between treated and untreated fiber. Infrared radiation spectra give the graph of % transmittance vs. wave number. Model IR-17A Shimadzu is used for functional group analysis.

2.2.7 SEM analysis

SEM was used to study the surface morphology of different treated and untreated fibers and composites.

3 Results and Discussions

3.1 Chemical composition of banana fiber

Banana fiber is a complex mixture of chemical compounds which are built up by the natural process (Photosynthesis) during the growth of the banana fiber in the plant. The composition of banana fiber is not uniform. The condition of soil, climate, maturity of the plants, retting and other cultured practices make considerable variations in the constituents of the fiber. Banana fiber is mainly composed of α-cellulose, hemicellulose and lignin. Other constituents of the banana fiber are fatty and waxy matter, pectin matter etc. The properties of natural fiber largely depend on the chemical composition of the fiber and the properties of composites made from natural fibers are strongly influenced by this fiber composition. The chemical composition of banana fibers is shown in Table -3.1. It is evident from the composition of the banana fiber that the main constituents are α-cellulose (65.112 %), hemicellulose (17.325 %) and lignin (8%). The rests are very minor in portion, so give very little influence to the structure of banana fiber.

Table-3.1: Chemical composition of banana fiber

Constituents	Amount (% dry basis)
α-cellulose	65.112
Hemicellulose	17.325
Lignin	8.018
Ash & Waxy matters	2.502
Pectin matters	2.124
Others	4.919
Total	100

3.2 Physical & Mechanical properties of raw and treated banana fibers

3.2.1 Moisture absorption of raw and treated banana fibers

Fig-3.1. shows the moisture absorption capacity of raw, NaOH and $KMnO_4$ treated fiber. The raw banana fiber is taken as control for comparison. It is clearly observed that in case of NaOH treatment, water absorption is most. This may be due the creation of pits and removal of lignin which is hydrophobic in nature. So removal of lignin increases hydrophilicity of fiber thus increases water absorption. But moisture absorption decreases in case of permanganate treatment. This may be due to the drastic nature of permanganate which removes lignin along with hemicellulose which is hydrophilic in nature.

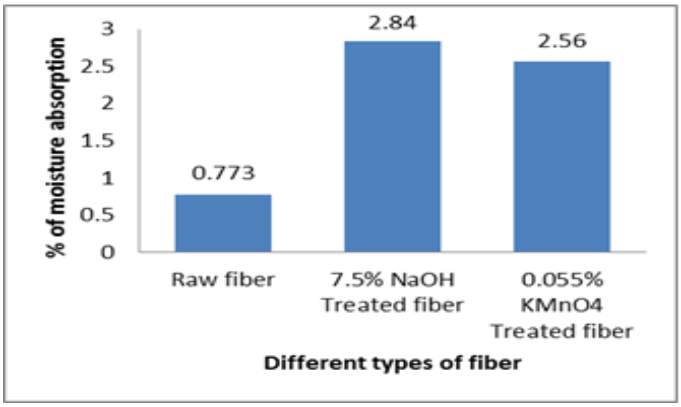

Fig- 3.1: % of moisture absorption of raw & treated fiber after 24 hrs.

Thus decreases the hydrophilicity compared to NaOH treated fiber.

3.2.2 Effect of Chemical treatment on fiber weight loss

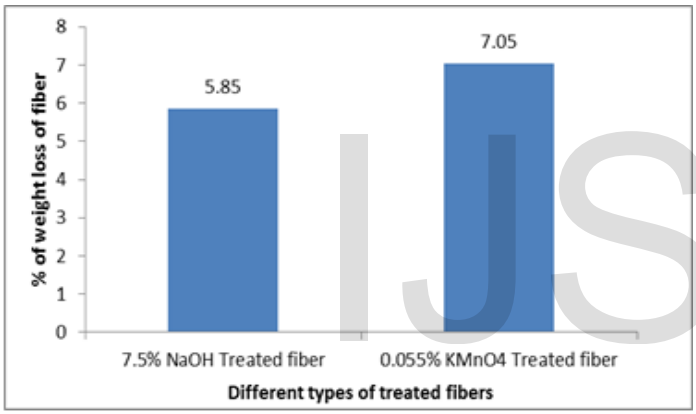

Fig-3.2: % of weight loss of fiber on various chemical treatments

Fig-3.2. shows the weight loss as an effect of alkali treatment on the raw fiber. Weight loss increases because of $KMnO_4$ treatment. This is due to the more drastic nature of $KMnO_4$ which dissolutes more soluble matters such as hemicellulose in addition to lignin. Increase in weight loss and decrease in cross-section can be attributed to the increase in reaction rate with $KMnO_4$ treatment.

3.3 SEM analysis of Banana fiber

Figure-3.3 shows the SEM images of raw Banana fiber at different magnitudes. (A) shows dirty surface of untreated fiber due to some broken parts and entangled microfibrils of the fiber. It may be due to the extraction process of the fiber. (B) shows that the unit cells with parallel orientation. The intercellular space is filled by the binder lignin and fatty substances-wax, oil- which hold the microfibrils firmly in a fiber. In Figure-3.4 shows the SEM picture of 7.5% NaOH treated Banana fiber. The multi-cellular nature of fiber filament is clearly revealed in alkali treated fiber. Compared to the raw fiber with 7.5% NaOH treated fiber, it seems that the fiber surface roughen on alkali treatment. It also seems that some big voids

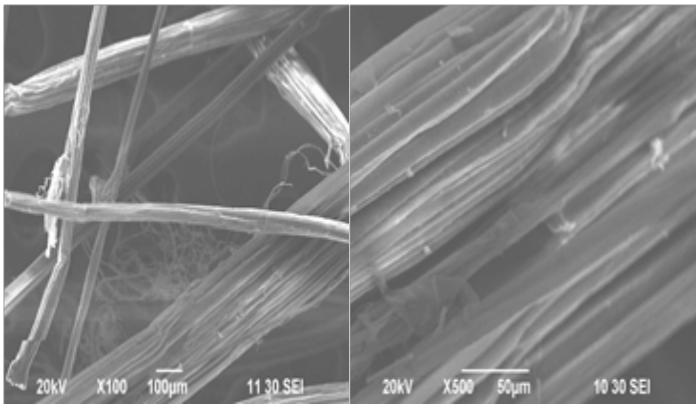

Fig-3.3: SEM morphology of Raw Banana Fiber A (left) & B (right).

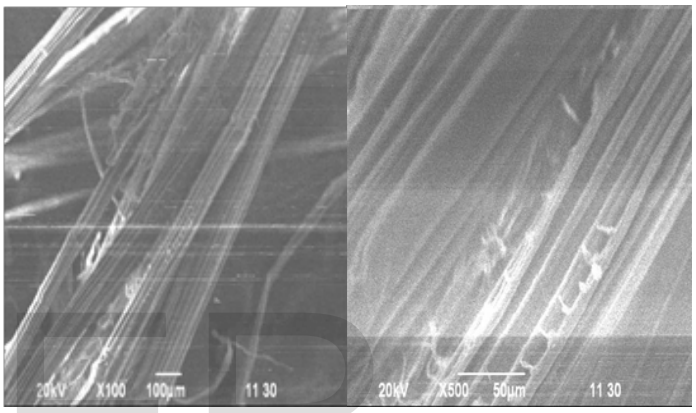

Fig-3.4: SEM morphology of **7.5**% NaOH treated Banana fiber.

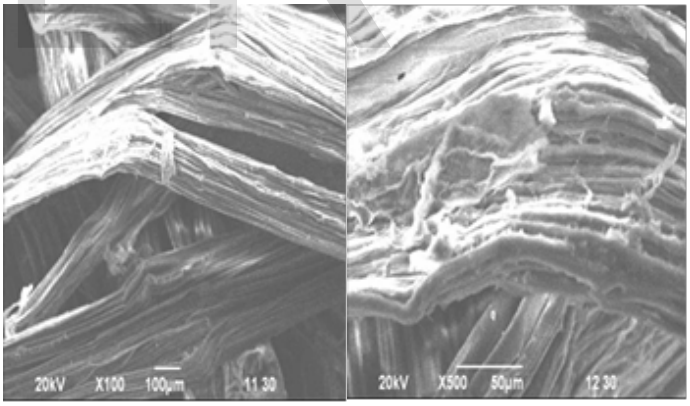

Fig-3.5: SEM morphology of 0.055% KMnO4 treated Banana fiber

and pull out of microfibrils are present. This may be due to the removal of lignin and also a part of hemicelluloses during the alkali treatment. Figure-3.5 shows the SEM images of 0.055% $KMnO_4$ treated Banana fiber. The multi-cellular nature of fiber filament is clearly revealed in permanganate treated fiber. Compared to the raw fiber with 0.55% permanganate treatment, it seems that the fiber surface roughen on alkali treatment. Second image clearly reveals the removal process of the protective layer of fiber. It suggests the wax and lignin free cleaned surface.

3.4 IR analysis of banana fiber

Figure-3.6 shows the IR spectrum of raw banana fiber. From figure, it can be noted that there is an absorption peak at~3377.36 cm^{-1} indicates O-H stretching absorption band. Here, C-H symmetrical stretching band at~2887.44 cm^{-1} and in-the-plane C-H bending band at~1325.1 cm^{-1} for CH_2 and CH_3 group, C=C stretching band at~1635.64 cm^{-1}, C-C plus C-O plus C=O stretching absorption band at~1246.02 cm^{-1} and C-C, C-H, C-OH absorption band at~1037.7cm^{-1}.Figure-3.7 (a) and (b) shows the IR spectrum of of NaOH treated and $KMnO_4$ treated Banana fibers respectively. The absorption peak near 3000~3500 cm^{-1} indicates O-H stretching vibrations. In case of NaOH the absorption peak is broad due to removal of lignin and part of hemicellulose from surface and intermolecular space. This also reveals that the treated fiber is hydrophilic in nature. In case of $KMnO_4$ treated Banana fiber the absorption decreases indicating the decrease of hydrophilic nature of fiber due to the removal surface impurities and also a part of hemicellulose, hydrophilic in nature, with lignin during $KMnO_4$ treatment from both surface and intercellular space.

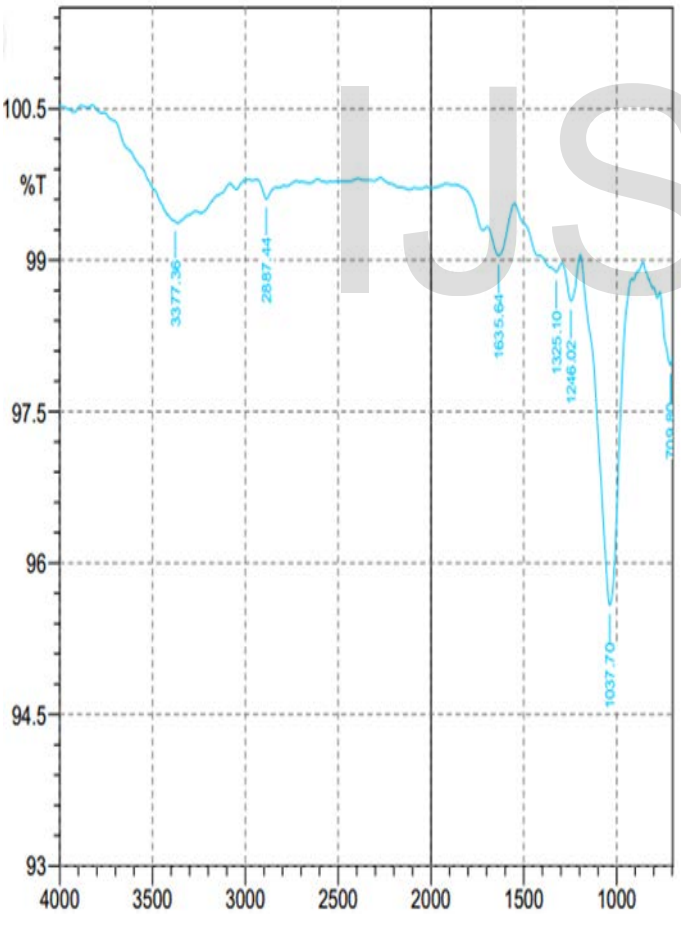

Fig-3.6: FTIR spectrum of Raw Banana fiber

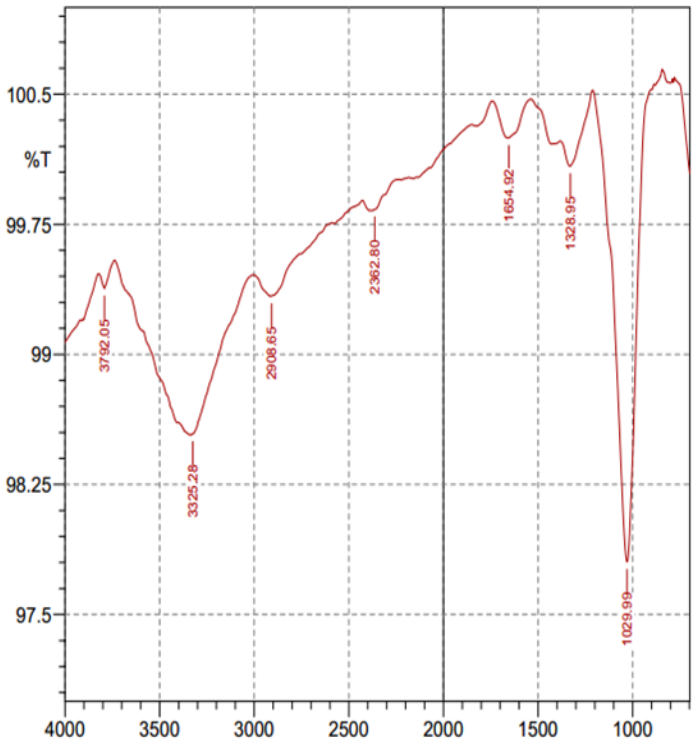

Fig-3.7(a): FTIR spectrum of NaOH treated Banana fiber.

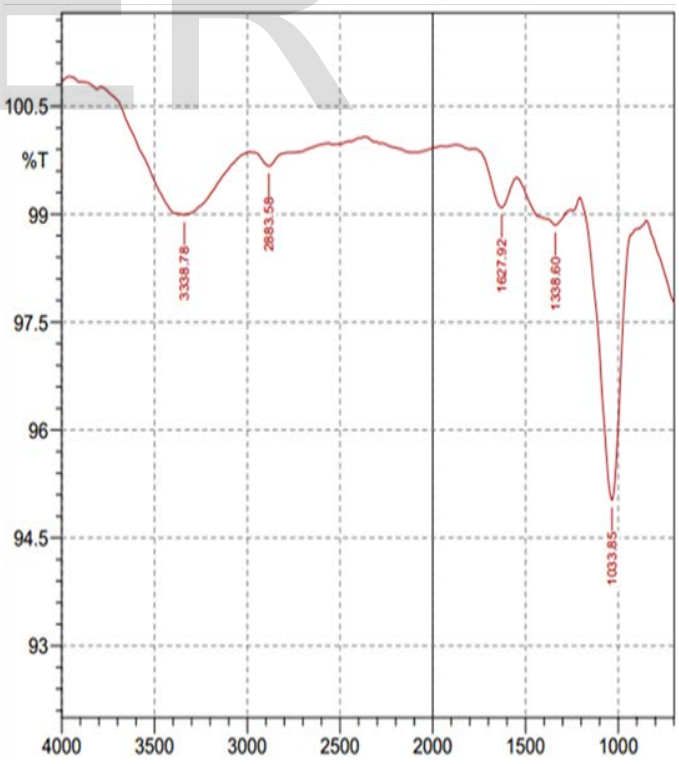

Fig-3.7(b): FTIR spectrum of KMnO4 treated Banana

3.5 Ultimate tensile strength (UTS) of raw & treated banana fibers

Fig-3.8. shows the effect of chemical treatment on ultimate tensile strength (UTS) of banana fibers. Here raw banana fiber is taken as control for comparison. From figure, it is observed that maximum UTS is obtained for raw banana fiber. When raw fiber was treated with 7.5% NaOH then the UTS of fiber decreased. This may be due to the removal of lignin and part of hemicellulose from surface and intermolecular space. From the figure, UTS of fiber decreases on $KMnO_4$ treatment. This may be due to the removal of more lignin, surface impurities and also a part of hemicellulose during $KMnO_4$ treatment from both surface and intercellular space. Decrease of tensile strength shows that effect of removal of lignin is predominant here.

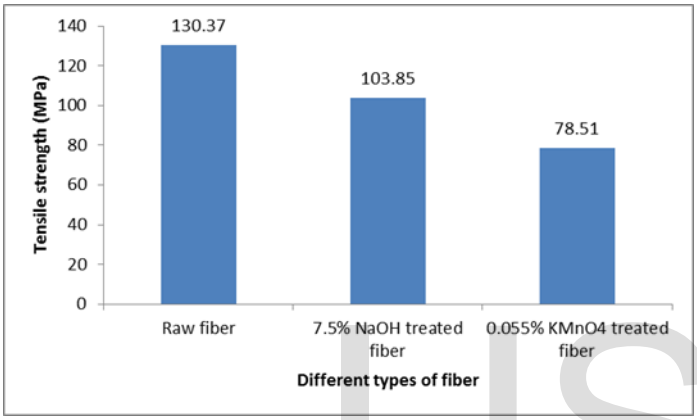

Fig-3.8: Tensile strength of raw, NaOH & $KMnO_4$ treated fiber

3.6 Effect of chemical treatment on % Elongation break of raw & treated banana fibers:

Fig-3.9. shows the effect of chemical treatment on % Elongation break of banana fibers. Here, raw banana fiber is taken as control for comparison.

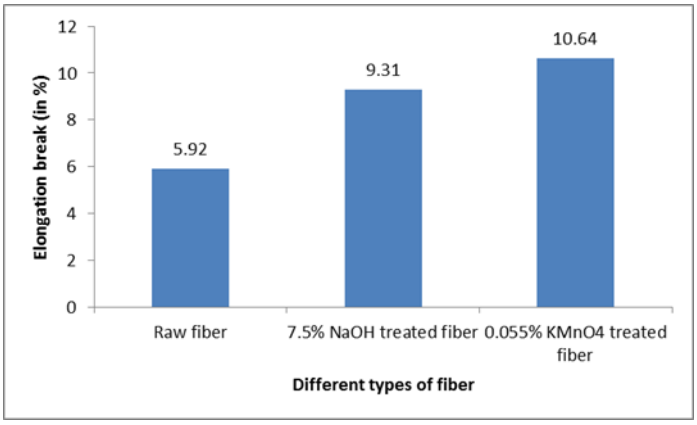

Fig-3.9: Elongation breaks of raw & NaOH treated fiber.

From figure, it is observed that maximum % elongation is obtained for $KMnO_4$ treated fiber and also observed that % Elongation also increases in case of NaOH treated fiber.

4. Conclusion

This study has been done aiming to attribute some properties which will enhance the adhesion between matrix and banana fiber during the manufacture of composite. The Percentage weight loss of raw banana fiber shows that chemical treatments partially removed lignin which can be explained by the moisture absorption of treated fiber. On chemical treatment, two opposing phenomena had taken place. Removal of lignin weakened the fiber while it also helped the cellulose chains to array themselves in an ordered manner which increased the crystallinity of fiber, enhancing the % Elongation of fiber. Following findings have been found to be helpful in assessing the composite properties. Banana fiber can be used in textile, paper, and furniture industry as it has high cellulose content, thus reducing deforestation. This study made a conclusion that treated banana fiber has good surface properties compared to raw banana fiber, and thus it can be used in manufacturing composite materials. So it is a potential alternative for synthetic fiber.

Acknowledgment

This research work was partially supported by NST (National Science and Technology) fellowship given by the Ministry of Science and Technology of Bangladesh. The authors are thankful to Centre for Advanced Research in Sciences (CARS), University of Dhaka for providing additional research facilities.

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