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Effect of chemical treatments on physical properties of kenaf bast fibres

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In the present study, kenaf bast fibre surfaces have been modified using different chemicals with varying concentration. The effects of these chemical treatments on moisture content, water absorption, fibre diameter and bundle strength are investigated. The benefit of chemical treatments in the removal of impurities from the fibre surfaces has been established by scanning electron microscopy. It is found that the fibres treated with sodium hydroxide and acetic acid show major effect on fibre diameter. Compared to untreated kenaf fibre, strong alkali (NaOH) treatment show maximum water absorption (78.76%) and moisture content (8.15%). In fibre bundle tensile strength, sodium hydroxide and sodium carbonate treated fibres show more than 80% improvement in the tensile strength of fibre. Kenaf fibre treated with 10% Na_2CO_3 show highest tensile strength of 410 MPa.

Keywords: Chemical treatments, Kenaf fibre, Physical properties, Tensile strength

1 Introduction

The increased environmental awareness is encouraging the use of eco-friendly fibres taken out from animals, plants and vegetables in lieu of synthetic fibres. Now a day’s various types of natural fibres such as banana, sisal, jute, pineapple and flax are available in ample amount.

Compared to conventional synthetic fibre, natural fibres have advantages, such as low density, low cost and biodegradability[1-3]. Natural fibres are composed of cellulose, hemicellulose, lignin, pectin, waxes and water soluble substances. However, their chemical composition and physical characteristics also defer with climatic conditions, age and retting process. In South East Asian countries kenaf fibre (KF) is an excellent substitute of synthetic fibres. KF is very attractive option because of its fast growth, low cost, abundant availability and climatic tolerance[4]. Kenaf fibre could be utilized as reinforcement material for polymeric composites as an alternative to glass fibre. Various chemical treatments have been used to improve the mechanical performance of the natural fibre including jute and hemp by many researchers in the past[5].

The surface of a natural fibre can be modified by means of physical methods and chemical treatment. Commonly used chemical methods for modification of the fibre surface include alkalization, acetylation, benzoylation, bleaching and silane treatment[6,7]. Basically, after such treatments, the fibres are individualized from bundles and have rougher surfaces[8]. Surface treatments help in enhancing the surface properties by the removal of hydroxyl groups, thus improving the fibre–matrix adhesion and providing higher mechanical strength[9]. Treatment duration, concentration of solution and alkali used play major role in fibre surface treatment[10]. The mechanical performance of natural fibres is influenced by various parameters, such as fibre diameter, micro-fibril angle, cellulose content and water content inside the fibres[11]. During literature study, it was found that mechanical properties of natural fibres can be improved by alkalization process for different soaking periods and at different concentrations[12].

The kenaf plant belongs to the hibiscus family (*Hibiscus cannabinus* L.) which is grown in United State of America, India, Bangladesh, Malaysia, Indonesia, Thailand, Vietnam, and some specific parts of south-east Europe. Kenaf plant fibrous stalk comprises bast fibres and core fibres. Kenaf fibres have very useful characteristics as compared to other natural fibres, i.e. long fibre, small diameter, and high interfacial adhesion to matrix. However, it was found that less work has been done on the kenaf fibres to

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comprehensively understand the possibility of using such fibres for polymeric composites[13]. Many researchers looked into the mechanical and chemical properties of the materials which are produced with natural fibres such as sisal, kenaf, abaca, hemp, grass, flax, bamboo, etc[14]. The key attractiveness of the kenaf plant is the bast fibres because of their specific high strength to low density[15]. In this research work, we used different chemicals for kenaf fibre surface treatment by varying their concentrations. The effects of these chemical treatments on physical properties of kenaf fibre are also studied.

2 Materials and Methods

2.1 Materials

Kenaf bast fibres were collected from Yavatmal district, Maharashtra, India. The chemicals used for the fibre surface treatment are zinc chloride ($ZnCl_2$), acetic acid (CH_3COOH), ortho phosphoric acid (H_3PO_4), sodium carbonate (Na_2CO_3), and sodium hydroxide (NaOH). All the chemicals used for surface modification were of analytical grade and supplied by Fisher Scientific, Mumbai, India.

2.2 Chemical Treatment

Kenaf bast fibres were treated separately with five types of chemicals. The fibres were immersed for 24h into the distilled water with different concentrations of each chemical, such as 2%, 4%, 6%, 8% and 10%. After treatments, the fibres were cleaned absolutely with flowing water many times. The fibres were then dried at 80^0C in hot air oven for 5h.

2.3 Characterizations

2.3.1 SEM Study

Morphological analyses were performed on the untreated and treated kenaf fibre using scanning electron microscope (SEM) machine (Model: HITACHI S-3400N). SEM instrument was used at an emission current of 58 μA, acceleration voltage of 5.0 kV, and the working distance of 6.2 mm. Before SEM analysis, samples were coated with gold. SEM was used for microscopic analysis and characterization of fibres on the basis of surface morphology and structural changes.

2.3.2 Diameter Measurement

As shown in Fig. 1 the diameter test was performed on a single kenaf fibre at room temperature of (28±2°C). Accuracy of diameter measurement in natural fibre is very difficult to achieve because natural fibres are irregular in shape and thickness is not uniform. Natural single fibre bundle consists of large amount of element fibres along with matrix of lignin and hemicelluloses. Because of this, cross section of fibre was irregular along its length. However, circular cross section was used in diameter measurement and calculation of tensile properties[4]. Ratna Prasad *et al.*[16] also measured fibre diameter using an optical microscope and calculated cross-section area of fibre, considering its cylindrical shape. Paramount Q-Projection microscope with ×20 magnification is used for checking single fibre before diameter measurement. The diameters of untreated and treated kenaf fibre were measured using an American Optical microscope with ×10 magnification and least count of 0.0064mm. For each sample, 15 readings were taken along the fibre length and the average diameter of each fibre was calculated.

2.3.3 Water Absorption

The percentage of water absorption of untreated and treated kenaf fibre was obtained. The test was conducted for 5 samples each and the mean was recorded. First, the dried fibre was weighted as M_0 before being immersed in fresh water at room temperature of (28±2°C) for 24h. After 24h of immersion, the fibres were taken out, and once the water drips out from the fibre it is weighted again as M_1[17]. Following equation was used for measuring water absorption:

$$\text{Water absorption (\%)} = [(M_1 - M_0) / M_1] \times 100 \qquad \text{... (1)}$$

2.3.4 Moisture Content

The percentage of moisture content of untreated and treated kenaf fibre was measured. The test was conducted for 5 samples each and the mean was recorded. Initially the weight of fibre was measured as

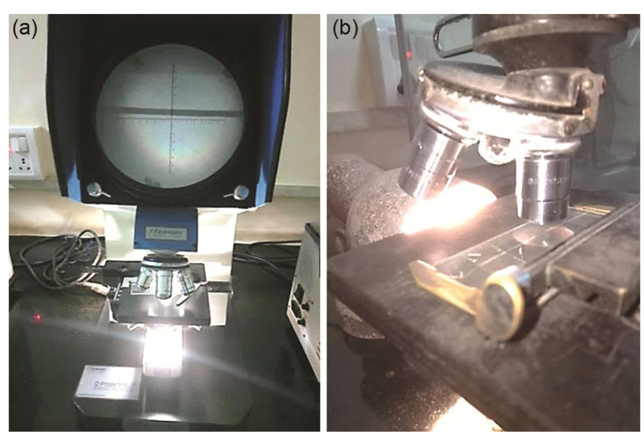

Fig. 1 — Single fibre diameter measurement (a) Paramount Q-Projection microscope and (b) American Optical microscope

M_0. The fibres were then heated in an oven for 24h at 105°C. After 24h in an oven the fibre was weighted again as M_1[17,18]. Following equation was used for measuring moisture content:

$$\text{Moisture content (\%)} = [(M_1 - M_0) / M_0] \times 100 \quad \text{... (2)}$$

2.3.5 Fibre Bundle Tensile Test

Fibre bundle tensile strength tests were performed using 5 kN Tinius Olsen machine with a gauge length of 100 mm and a crosshead speed of 5 mm/min. Ratna[16] also reported that since these natural fibres are highly irregular in shape, the test was conducted for ten specimens to get a valid average. So, for every set of chemical treatment, 10 specimens were tested to determine the average fibre bundle strength. The tests were conducted at a standard laboratory atmosphere. The maximum breaking load was noted and the unit break (UB) was calculated using the following equation[5]:

$$UB = F/A \quad \text{... (3)}$$

where F is the maximum breaking load (N); and A, the cross-sectional area of fibre (mm^2).

3 Results and Discussion

3.1 Physical Properties

Physical properties of natural fibres depend on various factors, such as extraction process, origin of fibre, maturity of plant, etc. So, it is difficult to get consistent properties of natural fibres[15].

3.2 SEM Study

The morphology of KF before and after chemical treatments has been compared. The microscopic analysis of fibre surface is of major importance to signalize the structural changes that take place after treatment. Fig. 2 shows untreated and treated surfaces of KF. In Fig. 2(a), the SEM micrograph of untreated KF shows many impurities on the fibre surface. In Fig. 2(b), alkali treatment increases the surface roughness by removing hydrophilic hemicellulose[19]. This helps in improving interfacial bonding between fibre and matrix. In Figs 2 (c)-(f), small pores are seen on fibre surface which indicate removal of hemicellulose and lignin. In Fig. 2(f), Na_2CO_3 treated KF shows many voids, which helps in making strong interfacial bonding and ultimately can give better tensile strength as compared to other chemical treatments.

3.3 Diameter Measurement

Figure 3 shows that untreated fibres are larger in diameter than treated fibres. The chemicals attack on fibre surfaces, breaking the web of lignin and hemicellulose, and then separate fibres from the bundles. It is observed that the diameters of chemical treated fibres are more uniform and smaller than untreated fibres. Among all the treatments, the fibre diameter is most affected by sodium hydroxide and acetic acid treatments. A typical untreated natural fibre appears to be surrounded by cementing materials like lignin, hemicellulose and other impurities like wax and oils, whereas the alkali-treated natural fibres are found to be clean and rough due to the partial removal of lignin, hemicellulose and other impurities. NaOH reacts with the hydroxyl group of the natural fibres and take out the lignin, hemicellulose, wax and oils that surround the external fibre surface, enhancing the surface roughness[6]. The removal of non-cellulosic materials including hemi-cellulose, lignin and pectin has resulted in fibre diameter reduction and increase in tensile properties[20].

3.4 Water Absorption

To improve hydrophobic nature of fibre the surface treatment of fibres can be carried out[15]. After chemical treatments, the removal of waxy and gummy substances from control fibre increases its ability to absorb water. From the results obtained, the percentages of water absorption of untreated kenaf fibre is 74.41 %, and it is found highest for strong alkali (NaOH) treated kenaf fibre (78.76 %). Also, it is 77% for weak alkali (Na_2CO_3) and strong acid (H_3PO_4) treated fibre as shown in Fig. 4.

3.5 Moisture Content

While choosing natural fibre as reinforcement, the moisture content is major criteria required to be studied. Moisture contents have significant influence on porosity, tensile strength, swelling and dimensional stability of natural fibre in composites. From the literature, it is found that to overcome these problems, low moisture content of natural fibre is advantageous for polymer composites. The moisture content of untreated kenaf fibre is 7.24%, but for NaOH, $ZnCl_2$ and H_3PO_4 treated kenaf fibres it is 8.15 %, 8.02 % and 8 % respectively, as shown in Fig. 4.

3.6 Fibre Bundle Tensile Strength

Figure 5 shows effects of chemical treatments on variation of tensile strength of untreated and treated KF. It is observed that chemical treatment of fibres enhances the tensile strength of fibres. The results indicate that tensile strength of NaOH, Na_2CO_3 and $ZnCl_2$ treated fibres improves significantly over that of untreated fibres. Ridzuan *et al.*[12] also reported that

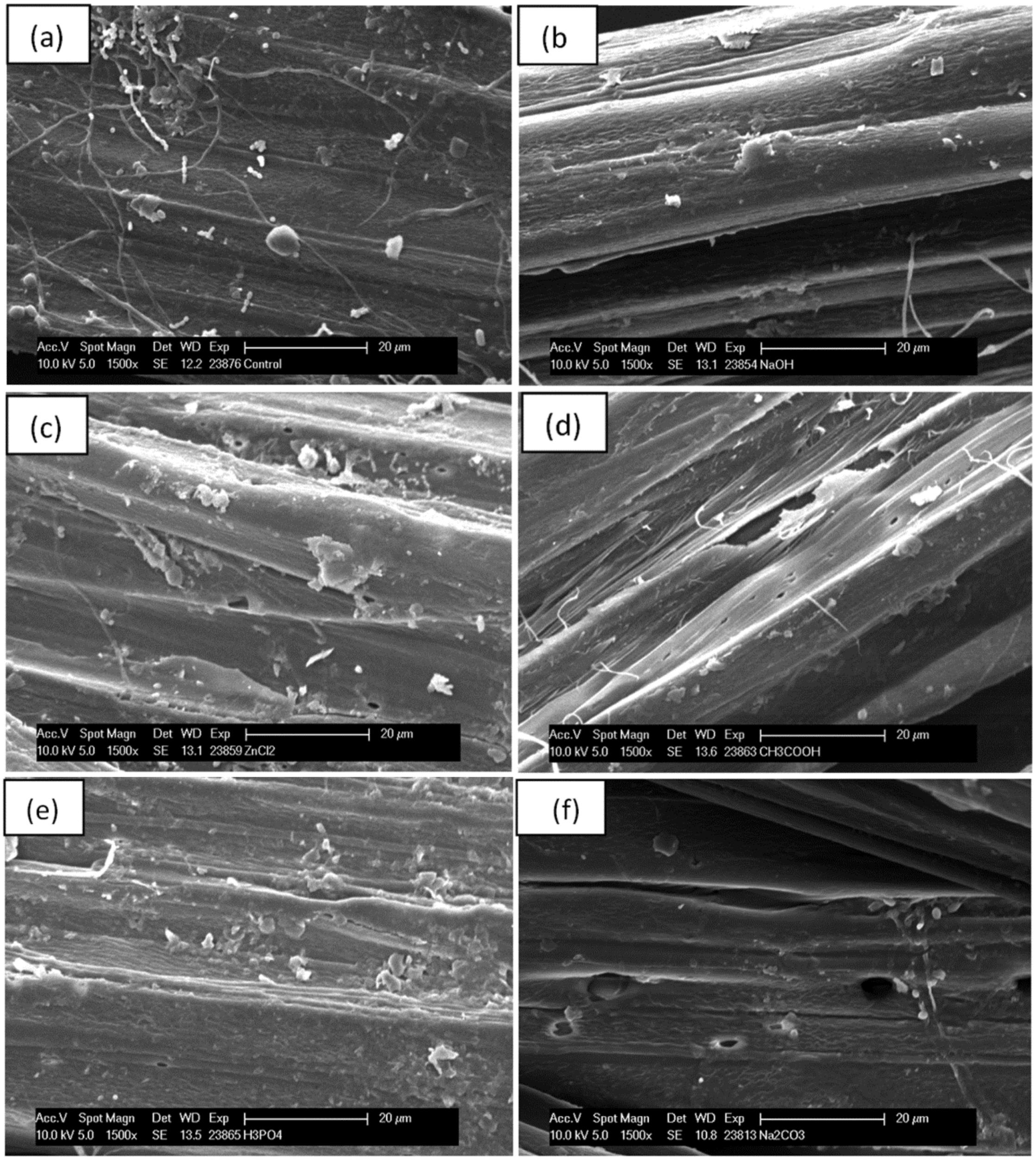

Fig. 2 — SEM images of (a) untreated and (b) NaOH, (c) $Zncl_2$, (d) CH_3COOH, (e) H_3PO_4 and (f) Na_2CO_3 treated KF

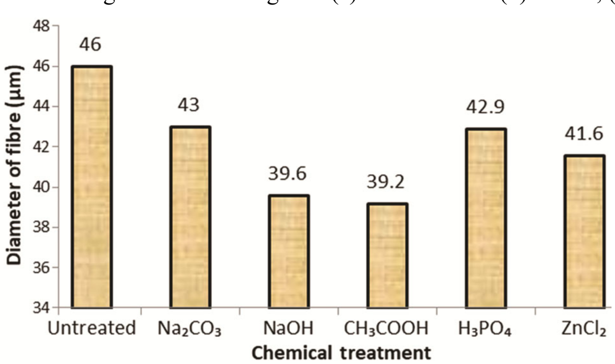

Fig. 3 — Diameter of untreated and treated kenaf fibres

10% of alkaline treatment of Napier grass fibre for 24h duration yields the highest strength as compared to untreated fibre. Nasmi *et al*.[21] reported in their research that 5% NaOH treated corn husk fibre shows around 50% increase in strength as compared to raw fibre. The increase in tensile strength is associated with the decrease in fibre diameter because of the loss of hemicellulose in the fibres and increase in cellulose content in fibres due to alkali treatment. Untreated KF shows tensile strength of 215.11 MPa. While 8% NaOH, $ZnCl_2$ and H_3PO_4 treated KF shows highest tensile strength of 397.15 MPa, 275.51 MPa and

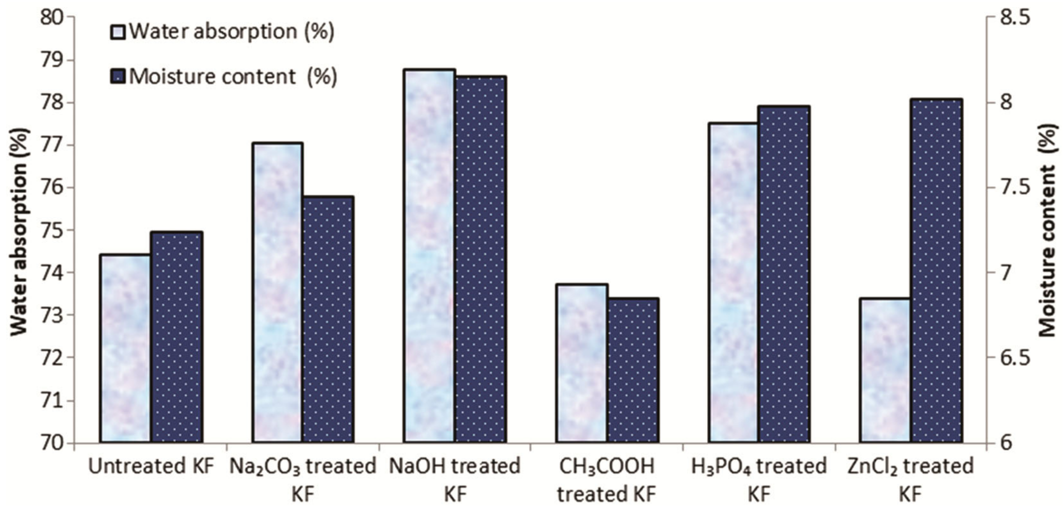

Fig. 4 — Water absorption and moisture content of untreated and treated kenaf fibres

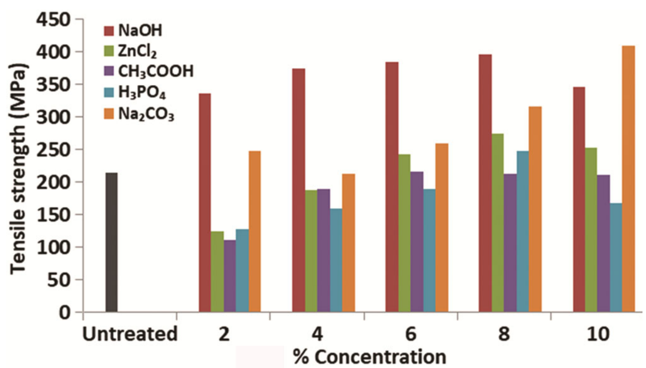

Fig. 5 — Tensile strength of untreated and treated kenaf fibres

248.32 MPa respectively. 6% CH_3COOH treated and 10% Na_2CO_3 treated KF shows tensile strength of 217.27 MPa and 410 MPa respectively.

4 Conclusion

The effects of different chemical treatments on the physical, morphological and tensile properties of kenaf fibre have been investigated. It is found from SEM micrographs that non cellulosic materials are removed from all treated KF. In comparison to untreated KF diameter, NaOH and CH_3COOH treated fibres show 15% reduction in their diameter. Due to the partial removal of impurities like lignin, wax and oils, strong alkali treated fibre shows more moisture content and water absorption. Among all chemical treatments, 8% NaOH and 10% Na_2CO_3 treated KF show highest tensile strength of 397.15 MPa and 410 MPa respectively.

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