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Original Article

Investigation of the Use of Kapok Fibres as Non-Absorbent Non-Woven Material

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Abstract - *Kapok fibre originates from the kapok tree and is found in many regions around the world. The fibre has a circular cross-section with an air-filled lumen. The hollow structure of the kapok fibre gives the material a very low density. The trapped air within the kapok fibre lumen serves as a thermal and acoustic insulator. However, the air trapped within the fibre makes it susceptible to flame propagation. Furthermore, the wax on the fibre surface makes the fibre more flammable. The study sought to study the potential use of kapok fibres as a non-absorbent non-woven material. The methodology involved the extraction of the kapok fibre and fabricating a chemically bound non-woven material. The chemical binding agent varied between 0 – 50%, and then the fabricated non-woven was tested to ascertain its tensile strength, absorption properties, antimicrobial properties, and fire retardancy properties. Sample A, containing 30% binder, recorded the highest tensile strength of 12.593 N and an elongation at peak averaging 4.326 mm. Sample B, with 40% binder, had the highest absorbency value. All the samples failed the flame-retardancy test, indicating a strong need for a flame-retardant finish. The non-woven material produced is suitable for various end uses such as mattress protectors. There is a need for further research into hybridizing the kapok with other fibres to increase the strength of the non-woven as well as the flame retardancy.*

Keywords *- Flame retardancy, Kapok fibre, Mechanical properties, Non-woven.*

1. Introduction

Kapok (*ceibapentandra*) is a large deciduous tree, as shown in Figure 1. The kapok tree typically reaches a height of approximately 30-40 m, but other species of kapok, such as caribaea, can attain a height of 70 m [1]. Kapok tree produces large, clustered flowers that are yellowish white to rose, silky, and densely hairy on the outer surface. The kapok fruit is in the form of a capsule that hangs from the branches, is approximately 10-30 cm, and has about 120-175 rounded dark brown to black seeds embedded in a mass of grey woolly hairs [2]. The kapok tree grows rapidly and starts producing within 4 to 5 years. The yield of kapok increases for about 8 years and then becomes constant during its lifespan of about 60 years [2]. A typical kapok tree gives a yield of approximately 330-400 fruits per year. This implies that about 15-18 kg of kapok fibre gives a yield of about 450 kg/ha [3]. The kapok tree requires high rainfall during its vegetative development. However, the flowering and fruiting occur during the drier season. The kapok tree is normally found in areas with yearly rainfall of about 750 to 3000 mm and where dry seasons do not span more than four months. Night temperatures below 170 °C prevent pollen grain germination and ultimately the fruiting of kapok; therefore, it cannot be grown in regions above 20 N or S or higher than 1500 m above sea level [4]. Kapok fibres are natural cellulosic and are typically used for technical textile applications rather than yarn and clothing manufacture due to their brittleness and high natural wax content [5].

Fig. 1 Kapok fruit contains fibres [8]

The kapok fibre is a soft, silky fibre, but with a homogeneous hollow tube shape. The kapok fibres constitute about 64% cellulose, 13% lignin and 23% pentose [6]. The kapok tree does not require a lot of pesticides and generally does not have mould due to its high quantity of lignin, wax and bitterness. Kapok fibres are easier to process compared to other natural fibres as they have low trash and foreign contaminants [7]. There has not been sufficient research into the use of kapok fibres in various applications, including on absorbent non-woven materials. The manufacture and disposal of synthetic fibres is not environmentally friendly and contributes to global pollution [9]. There is a need for environmentally sustainable fibres, which include natural fibres such as kapok.

1.1. Structure of Kapok fibres

The structure of the kapok fibre wall is significantly different to that of cotton. The fibres are characterized by having high levels of acetyl groups (13%) [9, 10, 11]. Kapok fibres are significantly super-hydrophobic due to low amounts of hydroxyl groups in the fibre. Furthermore, crosslinking of polysaccharides by lignin creates a barrier to water and other fluids from the kapok fibre cell wall [11]. The Scanning electron microscopic images of the kapok fibres shown in Figure 2 indicate a homogeneous circular cross-section with a hollow lumen, which is filled with air. The fibres have a wall thickness of about 1.2 micrometres; the homogeneous hollow wall thickness ranged from 0.8 to 1.0 micrometres, making it very difficult for water to penetrate [12, 13]. The fibre lumen constitutes about 64% of the fibre [13].

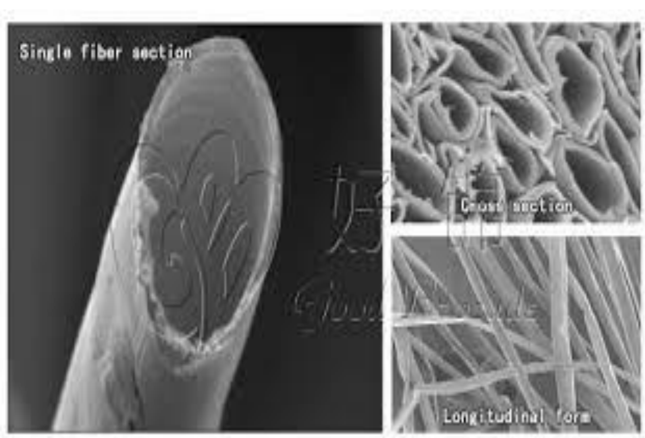

Fig. 2 The cross-section and longitudinal form of the Kapok fibres [13]

1.2. Applications of Kapok Fibres

Kapok fibre is not suitable as a textile-grade fibre for spinning as it is too smooth, brittle and slippery. The kapok fibres have been used in the bedding industry as a backing material due to their comfort properties and good shape retention after deformation [5, 14]. The kapok fibre is also used for upholstery and in materials suited for thermal and acoustic insulation. Kapok fibre has also been found to be useful in lifebuoys due to its naturally low water absorption and high buoyancy [15]. Kapok fibres have good oil-absorbency properties, making them suitable for use in membrane technology in oil-soiled fluids. Furthermore, kapok is very durable in this application [16]. It is important to note that hollow kapok fibre lumen brings a significant disadvantage of allowing flame propagation due to the availability of air pockets within the fibre. Flame propagates quickly in material made from kapok fibre [17]. This requires a flame-retardant finish to be applied to the kapok fibre to cater for this problem [18].

1.3. Advantages of Kapok Fibres

Kapok fibres have numerous advantages, which include the following [7, 18].

- The hollow structure gives the material a low density.
- The high wax content on the fibre’s surface reduces its tendency to soil.
- Kapok fibre has good comfort properties due to its flexibility and ability to retain its original form after deformation.
- The hollow lumen aids the fibre in having good thermal and acoustic insulation properties.
- The kapok fibre does not require a lot of chemical treatment as it is naturally resilient to pests and fungi due to its waxy layer on the fibre surface.

1.4. Limitations of Kapok Fibres

Kapok fibres have some limitations, which include:

- The kapok fibres tend to be brittle and break easily, therefore making them unsuitable for weaving or spinning into textile fabric. The high wax content on the surface makes the fibres slippery, and it is difficult to subject them to spinning, knitting and weaving.
- The kapok fibres have low density and can be easily inhaled, causing irritation to the lungs, and therefore, care must be taken when processing the fibres.
- The air content within the hollow lumen allows easy flame propagation through the fibre [18].

1.5. Non-Wovens

Non-woven materials are fabrics that include felt, which is consolidated by mechanical, thermal or chemical methods [19][20]. Non-woven materials are produced by consolidating fibres into a web and binding them. The consolidation methods include mechanical methods by interlocking the fibres with serrated needles, with an adhesive or thermally by applying binder to the fibres in the form of powder and melting it into the web [21]. The use of a chemical binder is regarded as one of the cheapest ways of manufacturing a non-woven since it does not require complicated machines [22].

1.6. Chemical Bonding Process

Chemical binders, which are the adhesive that holds together the fibres, are used in this process [23]. The most popular chemical binders are waterborne latexes. These latexes can be applied in numerous methods, as they can easily penetrate the non-woven structure by emulsion [24]. The binder used forms an adhesive film, binding the fibres. This study, therefore, seeks to extract and use kapok fibres to form a non-woven material and investigate its mechanical properties.

2. Research Methodology and Design

The methodology involved the collection and extraction of kapok fibres. These fibres were then formed into a web and bonded chemically, forming the non-woven material. These materials' mechanical properties were then tested.

2.1. Extraction of the Kapok fibres

Kapok fibres were extracted from the kapok tree (cieba pentandra (L.) Gaertn). The kapok seed pods were hand-harvested; this method ensured reduced damage to the fibres. The Kapok capsules were collected, and the pods and seeds were removed manually by opening the pods by hand. The opening of the pods was done using a knife, and a cut was made along the seams of the pod prior to prying it open for fibre extraction. The fibres were carded using wire brushes to remove any clinging impurities on the fibres, giving the fibres shown in Figure 3.

2.2. Web Formation

A fibre web was produced by spreading the fibres uniformly. A roller was used to compact the fibres to the required height of the web. Combining the web was done to increase uniformity and alignment of fibres to give the unconsolidated web shown in Figure 4.

Fig. 3 Extracted kapok fibres containing trash

Fig. 4 Kapok fibre web

2.3. Web Bonding

The web was bonded using the chemical bonding technique, and the saturation method was used to deploy the chemicals on the non-woven structure. The procedure involved firstly the preparation of the bonding paste and secondly the application and curing of the paste. 40 ml of distilled water, 5ml of mineral oil, and 5ml of merpol surfactant were used. The mixture was continuously stirred using a magnetic stirrer. 50 ml of the latex binder was added and stirred for 2 minutes, then finally 25 ml of aluminium hydroxide was added. The chemical binding paste was then applied to the fibre web by immersing the web in the bonding paste. The excess paste was squeezed out using rollers. Thereafter, the non-woven material was cured in an oven at 60 °C for about 30 minutes to give samples, as shown in Figure 5. The experimental design based on prior research varied the binder ratios between three levels 30%, 40% and 50%.

Fig. 5 Non-woven samples

2.4. Testing the Non-Woven

The manufactured non-woven was tested to ascertain its physical and mechanical properties.

2.4.1. Tensile Testing

The test was done according to the ISO 9073-18: 2007 using a Universal Testing Machine. The procedure for testing the non-woven was that sample sizes of 150 mm by 30 mm were prepared and mounted on the top and bottom jaws of the testing machine. The gauge length was set at 75 +/- 1 mm. A trace mark on the specimen at the front inner jaw was made to check for slippage.

2.4.2. Water Absorbency Testing

The assessment of the absorption capacity of each sample was carried out according to Standard 13726-1 testing method [23]. To determine the amount of fluid taken up, each sample was first weighed to get the initial weight. The samples were submerged in a solution of Calcium Saline, a representative of a very high level of exudates, for five minutes and were placed between a metal grid and a glass plate with a weight on top of it. Each sample was then subsequently rolled 3 times with a

2.5 Kg roller to determine the proportion of free and bound fluid. Weight measurements were taken again to get the final weight of the samples. The absorption capacity was then calculated using the weights of the samples before and after.

2.4.3. Antimicrobial Testing

The Agar test was carried out in accordance with AATCC 100: 2004 standard testing against the Staphylococcus aureus bacteria. The steps involved were the preparation of sample swatches with a size of 4.8 cm in diameter and placing them in a 250 ml jar with a screw cap. An application of 1.0 ml of a 24-hour broth culture of the test organism was carried out. The dilution of the test organism was made in a nutrient broth. The sample was subjected to shaking with the culture for 24 hours and then allowed to stand for 15 minutes before inoculation. 100 ml of neutralizing solution was added to each sample. Incubation was carried out over contact periods at 37±2°C for 18-24 hours.

The degree of contamination on each sample was computed as shown in Equation 1.

$$\text{CFU}\,\frac{\text{s}}{\text{ml}} = \frac{\text{Number of colonies on plate}}{\text{Amount plated equation}}\,\text{X dilution factor} \quad (1)$$

2.4.4. Fire Retardancy Testing

This was done using the cigarette test according to ASTM E1353- 16. The fabric was conditioned for 48 hours at room temperature and maintained a relative humidity of less than 55%. A burning cigarette was placed on top of the non-woven material, and observations were recorded.

3. Results and Discussion

3.1. Tensile Strength

The tensile strength results are shown in Figure 6.

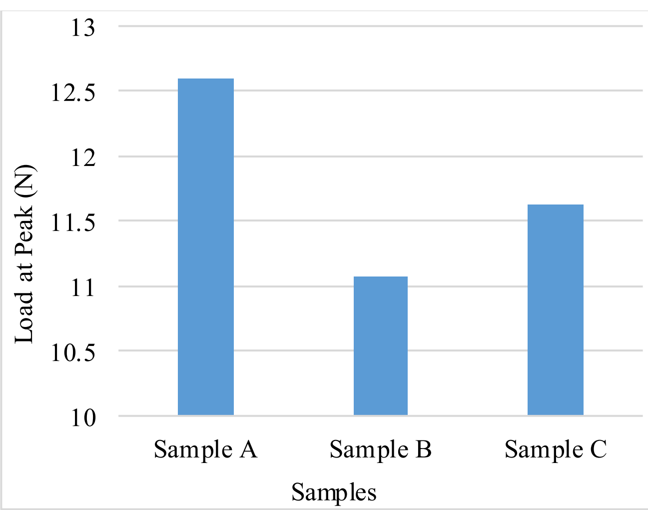

Fig. 6 Tensile strength of the samples

Sample A (30% binder) recorded a mean value of 1.32 kgf (12.593 N) load at peak and an elongation at peak averaging 4.326 mm. This corresponded to an elongation percentage of about 28.84%. The strain at peak had a mean value of 2.14%. The strain at break was 17,82% with an elongation at break averaging 36.33 mm.

Sample B (40% binder) showed a much lower mean of 1.13 kgf (11.08 N) load at peak, while also recording a lower mean value of elongation at peak of about 2.73 mm, which is about 18.2%. The strain at peak highlighted a mean average of 1.33% and an elongation at break of 27.97mm, which corresponds to 186.46%. The strain at break indicated a mean of 13.61 %.

Sample C (50% binder) recorded a mean value of 1.18 Kgf (11.62 N) load at peak. The elongation at peak recorded 3.441mm, corresponding to 22.93% and the strain at peak was 1.68%. The elongation at break averaged 35.68 mm, which relates to 237.86%. The strain at break for sample C was 17.44%.

When comparing the samples, sample A showed higher values than the other two samples. These tests show that the amount of binder has an insignificant effect on the ultimate tensile strength of the non-woven material. The tensile strength of all the samples was relatively low when compared to polyurethane foam and other previously used mattress protectors.

3.2. Absorption Capacity

The absorption capacity of the samples is shown in Figure 7. The graph shows that sample B showed slightly higher values of absorbency than the other two. Sample C had the lowest absorbency of the three samples.

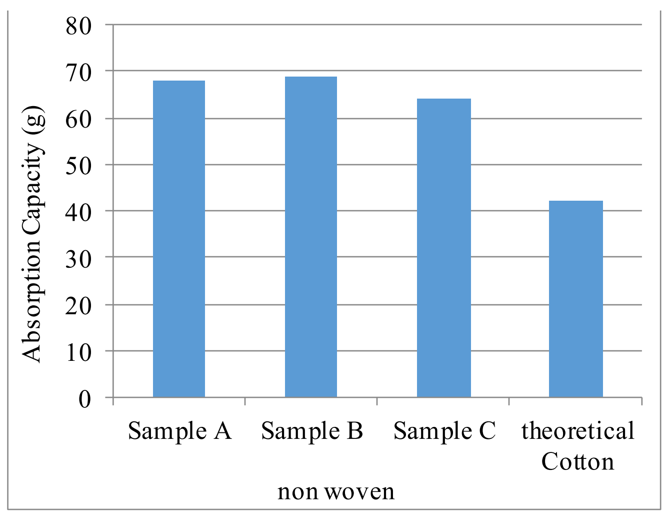

Fig. 7 Absorption capacities of the samples and theoretical cotton non-wovens

This was attributed to their hydrophilic-oleophilic properties, which make them absorb metal ions and oils effectively. The low cellulosic content of kapok fibre, which implies low hydroxyl groups, makes the fibre hydrophobic. However, the presence of a waxy hollow structure makes the kapok fibres absorbent to metal ion-based solutions.

3.3. Antimicrobial Results

The results shown in Figure 8 indicate that all the samples have some antimicrobial properties.

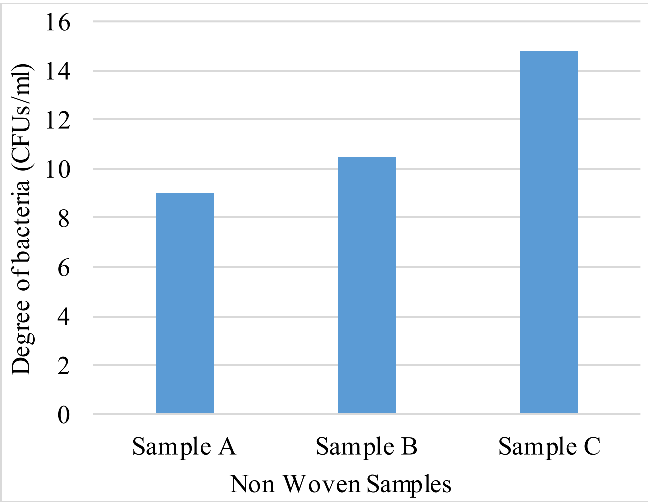

Fig. 8 Degree of bacterial contamination of samples after the Agar test

Sample A showed the lowest degree of contamination compared to the others, while sample C highlighted the highest degree of contamination. From the experiments, it can be concluded that the amount of binder has a very low impact on the antimicrobial property of the non-woven samples. The antimicrobial activity of the kapok non-woven material is due to the presence of lignin and wax on the fibres. This also impacts anti-soiling properties and resistance to microbial attack.

3.4. Flame Retardancy

All the samples with binder ratios between 0 and 50% failed the flame retardancy test, indicating a strong need for a flame-retardant finish. Each sample could not sustain the burning cigarette test and ignited upon contact with a flame. This could be due to the high wax content in kapok fibre and air trapped in its hollow structure, which makes it highly inflammable [26]. The flame retardancy of the kapok fibre can be improved by chemical treatment. This treatment process can include treating the fibre with phosphorus-containing compounds such as ammonium dihydrogen phosphate.

4. Conclusion and Recommendation

The non-woven showed good antimicrobial properties, which indicate it can be used as a protective material against dust and micro-organisms. High absorption capacity shows that the non-woven can be used as an absorption material, removing metal ion solutions and oils. Due to the low tensile strength, the non-woven material cannot withstand washing. Sample A was the most economical among the three samples tested. It proves that the binder's cost-effectiveness is 30% of the solution. There is a need for further study into hybridizing kapok with other natural fibres in non-woven materials to improve its mechanical properties.

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