

Influence of Mercerization on Micro-structure and Properties of Kapok Blended Yarns with Different Blending Ratios

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ABSTRACT

To investigate the effect of mercerization on micro-structure and the properties of kapok/cotton blended yarns. FTIR spectra and x-ray diffraction (XRD) results, moisture regains and mechanical properties of blended yarns were compared before and after mercerization. The results show that mercerization treatment did not have an obvious effect on chemical compositions of cellulose, but did lead to decreasing on crystallinity of blended yarns, and transformed certain portion of cellulose I into cellulose II. When the NaOH concentration increased from 180g/L to 250 g/L, the strengths of blended yarns increased and elongations at breaking declined, and the extent of changes were lessened gradually with the increase of kapok fiber content, when the NaOH concentration further reached 280g/L, the strengths of blended yarns with high content of kapok fiber dropped dramatically, and elongations at breaking increased gradually, while hygroscopicities of blended yarns increased significantly. Different from cotton fiber, a more moderate alkali treatment condition should be chosen in mercerization process for kapok fiber.

INTRODUCTION

Kapok fiber is a type of natural cellulosic fiber with the unique structure of void content as high as 80~90% as shown in *Figure 1*¹⁻². The high hollowness of fiber makes it possess excellent moisture absorption and warmth capability³. Kapok fibers are traditionally utilized as packing materials, sorbent materials and non-woven fabrics in Southeast Asian countries⁴. Recently, these fibers have been blended with cotton fibers to apply as clothing fabrics⁵. Earlier study of the kapok has been limited to the characterization of the fiber. The present investigation is focused on kapok fiber spinning,

batting and composite material containing kapok fibers, also little on the chemical processes of kapok fiber⁶⁻⁹. This paper studies the influence of mercerization on micro-structure and performance of kapok fiber in order to improve the wearability of fabric made of kapok fibers. Because it is difficult to separate kapok fiber in alkali condensation¹⁰, and in addition, it is also hard to spin pure kapok yarns due to shortcomings of kapok fiber such as low strength, short length and smooth surface¹¹, the research is based on kapok/cotton blended yarns with different kapok fiber ratios.

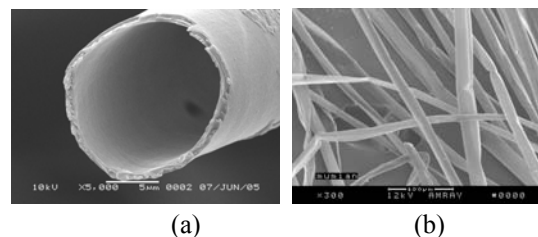


FIGURE 1. SEM of kapok fiber. (a)Kapok fiber's cross section, (b) Kapok fiber's surface

EXPERIMENTAL METHODS

Materials

The 28tex Kapok/cotton blended yarns contained 70%, 60%, 40% kapok fiber respectively, and 28tex 100%cotton yarn, supplied by Shanghai Panda Industry (group) Co. LTD. Shanghai, PR China.

Alkalization Mercerization of Samples

The samples were treated for 200s at 25°C with 180, 220, 250 and 280 g/L NaOH aqueous solutions at tension situation respectively. Samples were then removed, washed, with distilled water containing 1% acetic acid, to neutralize excessive NaOH, and then thoroughly rinsed with distilled water, rinsed and air-dried at 40°C.

Instruments for Appearance Measurement

SEM images of the samples surfaces were taken using a scanning electron microscopy Model JSM-5600LV. Fourier transform infrared spectroscopy (FTIR) was carried out on a NEXUS-670 instrument using an total transmission Fourier transform, in a range of $4000\sim 400\text{cm}^{-1}$. Diffraction data was obtained by using the X-ray diffractometer made in Japan at the operating condition of Cr Target, Ni filtered, 40 kV voltage, 40mA current, and $8^\circ/\text{min}$ scanning speed.

Physical Properties

Tensile properties of yarns were tested using YG061 tester. The length of the sample was 500mm in average and operating speed was 250m/min in standard air condition.

Moisture Sorption

Moisture absorptions of yarns were determined according to standards (GB/T398-93, China). Yarns were exposed for 24h in standard atmosphere: temperature at $20 \pm 2^\circ\text{C}$, relative humidity at $65 \pm 2\%$. (ASTM D 1776-74, 1974).

RESULTS AND DISCUSSION

Morphology Changes of Kapok Blended Yarns before and after Mercerization Treatment

Alkali-scouring blended yarns were treated respectively by mercerization at different NaOH concentration: 180g/L, 220g/L, 250g/L, and 280g/L. The surfaces of untreated and treated yarns were observed under SEM as shown in *Figure 2*.

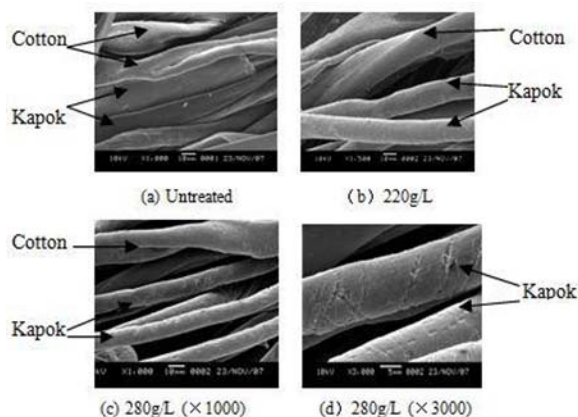
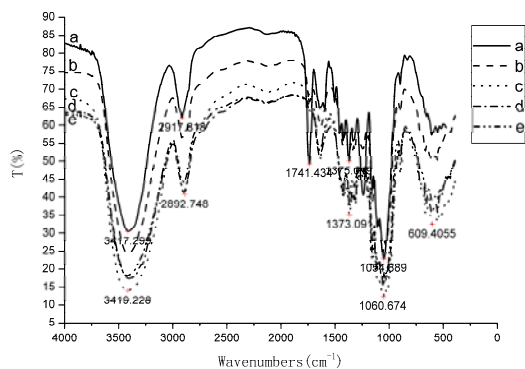


FIGURE 2. SEM of surface feature of 70/30 kapok/cotton blended yarn before and after mercerization treatment.

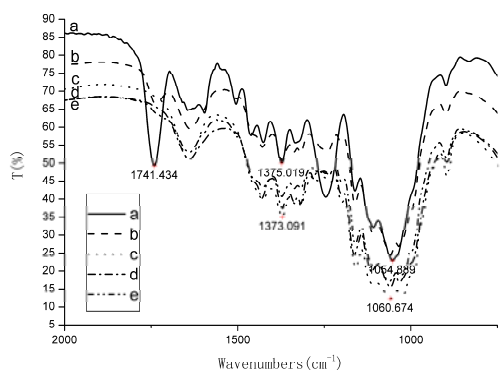
Figure 2 (a) shows that the untreated cotton fibers exhibit natural crimps, and the microfibrillar structure of cellulose could be observed obviously in the surfaces with a angle of $20^\circ\sim 25^\circ$ along the fiber axis. The untreated kapok fibers are flat, straight and the surfaces of fibers are very smooth. Due to high lignin and hemi-cellulose content of kapok fiber¹², the microfibrillar structure of cellulose do not present on the surfaces of kapok fibers. *Figure 2 (b)* shows the surface of blended yarn treated by 220g/L NaOH concentration, both fibers still remain smooth and fibers rounded up due to swell effect. Besides, for the cotton fibers, the twists reduce from the image. However, *Figure 2 (c)* ($\times 1000$) and *(d)* ($\times 3000$) show the surfaces of blended yarn treated by 280g/L NaOH concentration, compared with that of the cotton fibers, much more apparent spots and pits appear on kapok fibers surfaces, some of which are even ruptured. It is revealed that the alkali resistance of kapok fiber is not good as that of cotton fiber, which might mainly be attributed to the loose structure of kapok fiber with lower degree of crystallinity. In case of higher NaOH concentration treatment, OH- possessed higher diffusion and hydrolysis catalysis ability¹³, which could lead to alkali hydrolysis and ablation of macromolecules in non-crystalline regions or crystalline defect regions of kapok fiber. Finally, spots and pits would be formed on the surfaces of kapok fibers and even caused surfaces rupture of fibers. Therefore, much moderate alkali treatment conditions should be preferred in alkali mercerization process for kapok fiber than that of cotton fiber.

Microstructure Changes of Kapok Blended Yarns before and after Mercerization Treatment

FTIR spectra of fiber and blended yarns before and after treated with 250g/L NaOH are presented in *Figure 3*.



(a) 4000~400 cm⁻¹



(b) 2000~750cm⁻¹

FIGURE 3. FTIR spectra of fibers and blended yarns before and after treated with mercerization. a, 100%kapok fiber; b, 70/30kapok/cotton yarn; c, 100%cotton yarn treated with alkali; d, 100%cotton yarn; e, 70/30kapok/cotton yarn treated with alkali.

From Figure 3, it can be seen that FTIR spectra of kapok fiber (Curve a) and kapok blended yarn (Curve b) have the same characteristic absorption spectrum bands as that of cotton yarn (Curve d), such as the characteristic absorption peak of cellulose near 3417cm⁻¹ (O-H stretching), the cellulose cluster peak near 1060cm⁻¹ in the fingerprint area, and the peak near 2917cm⁻¹(C-H stretching)¹⁴. However, different from the spectrum of cotton yarn, there exist the peaks near 1595 cm⁻¹(aromatic skeleton vibration) and 1741 cm⁻¹ (non-conjugated C=O vibration) in FTIR spectra of kapok fiber and kapok blended yarn, which are the characteristics absorption peaks of lignin molecular structure. It indicates that the lignin exist in kapok fiber and yarn containing kapok fiber.

The Figure 3 also shows changes in characteristic peak positions of cellulose that was not observed on cotton yarn (Curve, c) or kapok blended yarn (Curve.

e) after alkali mercerization treatment, indicating that mercerization treatment does not have an obvious influence on the chemical composition of the cellulose. However, for treated cotton and kapok blended yarn, characteristic peak intensity of cellulose near 3417cm⁻¹(O-H stretching) increase, as well as the width and area, resulting in an increased number of free hydroxyl groups located in C₆H₁₀O₅ unit of cellulose¹⁴. While Compared the FTIR spectra of kapok blended yarn (Curve b) with that of treated blended yarn (Curve e), some changes were observed after mercerization, 1741cm⁻¹ and 1245cm⁻¹ peaks disappear because of the acetyl hydrolysis, and the peaks near 1600cm⁻¹ and 1500cm⁻¹corresponding lignin characteristics of the backbone benzene rings reduce significantly and almost disappear in original positions, indicating that the lignin in kapok fiber could be dissolved in alkali solution.

X-ray diffractograms of fibers and blended yarns treated with 250g/L NaOH concentration are given by Figure 4. Figure 4 shows that the peak positions of untreated fiber and yarns (Curve. a, Curve. c, Curve. e) are basically identical, 2θ at around 22.76°,15.02° and 16.34° respectively, corresponding to crystal indices of (002), (101)and (101)¹⁵, it indicates that both untreated samples have the same unit cell in shape and size, the same crystal form of cellulose I. But the peak intensities and FWHM (Full Width Half Maximum) of cotton fiber are much higher than that of kapok fiber, resulting in crystallinity of kapok fiber (38.43%) is well below that of cotton fiber (72.7%), which was calculated by sub-peak calculation method, as shown in Table I.

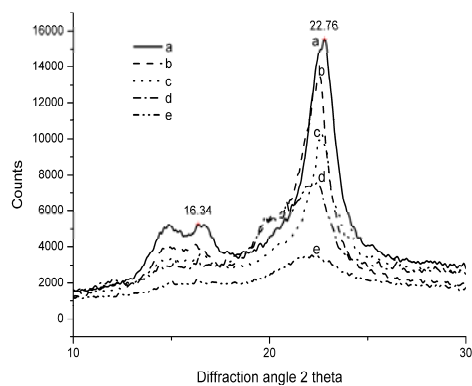


FIGURE 4. XRD spectra of fibers and yarns before and after treated with mercerization. a, 100%cotton yarn; b, 100%cotton yarn treated with alkali; c, 70/30kapok/cotton yarn d.; 70/30 kapok/cotton yarn treated with alkali e, 100%kapok fiber.

TABLE I. Crystalline Structure of Samples before and after Mercerization.

Samples	Crystallinity (%)	Crystalline structure
100%kapok fiber	38.43	cellulose I
100%cotton yarn	72.74	cellulose I
70/30 k/c yarn	51.94	cellulose I
100%cotton yarn (treated)	62.08	cellulose I + cellulose II
70/30k/c yarn (treated)	43.5	cellulose I + cellulose II

Figure 4 also reveals the changes of crystal structure of yarns after mercerization with 250g/L NaOH. For treated kapok blended yarn (Curve. D) and cotton yarn Curve. b), besides characteristic diffraction peaks of cellulose I, another two new diffraction peaks 2θ at 12.36° and 20.84° appear, which are the characteristics peaks of cellulose II¹⁵, that could be due to parts of cellulose I transforming to cellulose II after mercerization treatment. This is because that cellulose swells in aqueous alkali solutions where ionized H⁺ in hydroxyl groups are replaced by Na⁺ to combine into stable compounds, and the lattice of cellulose I changes considerably after removal of reagent, resulting in a great changes in crystal structure of treated yarns. While the peak shape, peak intensity and diffraction angle of treated yarns alter in different degrees, indicating the amorphous regions increasing and the crystallinities decreasing of treated yarns as shown in Table I. In addition, the rate of crystallinity change of the kapok blended yarn before and after mercerization treatment is about 16.2% but that of cotton yarn is about 14.6% in accordance with data of Table I, indicating the kapok blended yarn has greater change in crystallinity after mercerization treatment than that of cotton yarn. It further proves that alkali has more fiercely effect on kapok fiber. This is because the kapok fiber has a lower degree of crystallinity and loose structure, making it easier for -OH diffusing and catalysis hydrolyzing in the process of higher NaOH concentration treatment.

Mechanical Properties of Kapok Blended Yarn before and after Mercerization Treatment

Figure 5, 6 show the changes of breaking strengths and elongations of kapok blended yarns with

different blending ratios treated by different concentrations of NaOH.

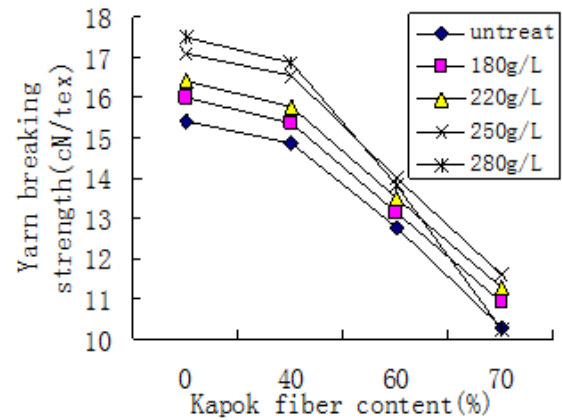


FIGURE 5. Effect of mercerization on breaking strengths of yarns with different kapok ratios

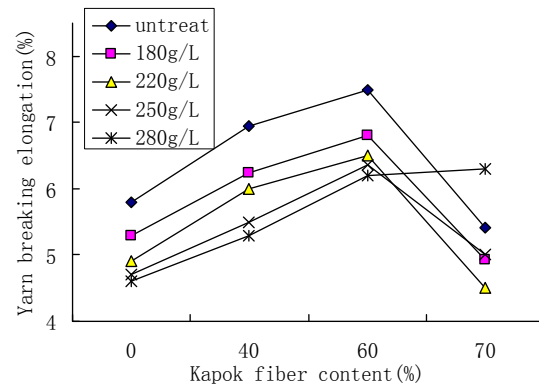


FIGURE 6. Effect of mercerization on breaking elongations of yarns with different kapok ratios

From Figure 5 and Figure 6, it can be seen that the breaking strength of untreated blended yarns decrease gradually with increase of kapok fiber contents, because the length of kapok fiber is relatively shorter and the strength is lower than that of cotton fiber¹⁶. However, the breaking elongations of untreated blended yarns increase gradually when the blended ratio is under 60%, but the breaking elongations drop dramatically when the blended ratio achieved more than 60%, it is mainly due to uneven yarn induced by high short kapok fiber content¹⁷. All treated yarns exhibit higher breaking strengths than that of untreated yarns under the suitable mass concentration of NaOH conditions, that is to say alkali mercerization could improve yarn strength. This is because alkali treatment could alter oriented arrangement and helical angle of fiber, harden weakness along the length of fiber, and remove the

cellulose with lower degree of polymerization¹⁸. In Figure 5, 6, when the mass concentration of NaOH increase from 180g/L to 250 g/L, the strengths of treated blended yarns increase and the elongations at breaking decline, and the extent of changes lessen gradually with the increasing content of kapok fiber. Otherwise, when the mass concentration of NaOH is up to 280g/L, the strengths of blended yarns with high content of kapok fiber drop dramatically, and the elongations at breaking increase gradually. This is because high concentration of alkali could impact intensively on kapok fiber with loose structure, resulting in violent cellulose degradation and consequently damaged fiber strength.

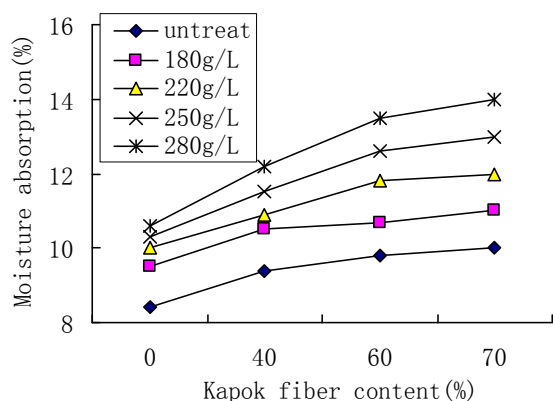


FIGURE 7. Effect of mercerization on moisture absorptions of yarns with different kapok ratios

Figure 7 shows moisture regain changes of kapok blended yarns after alkali mercerization process. It can see all treated yarns exhibited larger moisture regains and better moisture absorption properties than that of untreated yarns, especially for the yarns with high content of kapok fiber. The reason is that once the alkali concentration reached to some extent, fiber would swell and crystalline form would transform from cellulose I to cellulose II, this would lead to the decrease of degree of crystallinity and structure loosening, thus a greater number of free hydroxyl groups in water would be able to participate in reaction, so enhance fiber hygroscopicity capability¹⁸. In addition, kapok fiber has a high lumen, higher internal void ratio and more loosening structure than that of cotton fiber, so more water molecules could enter the amorphous regions and void spaces or could be adsorbed onto fiber surfaces. So the higher kapok fiber content of blended yarns, the more absorption regains of blended yarns.

CONCLUSION

From this study, we concluded that there was no apparent change of chemical compositions of cellulose, instead the crystallinity of blended yarns decreased due to the destruction of crystalline structure, and parts of cellulose I were transformed into cellulose II by mercerization with 250g/L NaOH concentration. When the alkali concentration increased from 180 g/L to 250 g/L, the strengths of treated blended yarns increased elongations at breaking declined and hygroscopicities improved gradually. When alkali concentration reached to 280 g/L, the strengths of blended yarns with high content of kapok fibers decreased, elongations at breaking increased and hygroscopicity improved significantly due to intense reaction between alkali and kapok fiber. Alkali mercerization under proper mass concentration of NaOH conditions could improve blended yarn strength. Kapok fiber has rather poor alkali resistance than that of cotton fiber, and high mass concentration of NaOH could result in a grooved serrated surface for kapok fiber. Therefore, relatively mild alkali treatment conditions for kapok fiber are recommended in finishing processes.

ACKNOWLEDGMENTS

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