**Stretch Properties of Cotton Hollow Yarns Made by Hybrid Open-End Rotor Spinning Frame**

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**Abstract**

Many yarns are made from chemical fibers with various kinds of functional properties, and filament yarn surpasses spun yarn in terms of mechanical properties. However, in this century, “comfort”, “safety”, “user-friendly” and “green” are key concepts. The Food and Agriculture Organization of the United Nations (FAO) officially launched the International Year of Natural Fibers (IYNF) 2009 to celebrate the virtues of cotton, flax, sisal and hemp, and also those of wool, alpaca, camel hair and angora. In order to make effective use of natural fibers and reduce carbon dioxide emission, it is worthwhile to design and develop new spun yarns from vegetable fibers.

It is also known that, in comparison with ring spun yarn, open-end spun yarn is inferior in quality. So, to produce open-end rotor spun yarn with novel functional properties, we investigated how to give it greater extension (and/or stretch), as in synthetic filament yarn. Thus, 100% cotton hollow yarns were produced using a hybrid open-end rotor spinning frame and an experimental covering machine, and the resulting mechanical properties were assessed.

**Key Words:** Hollow spun yarn, Cotton open-end rotor-spun yarn, Core spun yarn, Covered yarn

1. **Introduction**

To differentiate textile products from each other, many yarns are made from chemical fibers with various functional properties, and the mechanical properties of filament yarn are acknowledged to be greater than those of spun yarn. However, as we are all aware, one important way to prevent globe warming is the reduction of carbon dioxide emission. Therefore, as textile production with the key concepts of “comfort”, “safety”, and “user-friendly” have become firmly established, the production of regenerated fibers and the utilization of natural materials have increased accordingly. Additionally, the Food and Agriculture Organization of the United Nations (FAO) officially launched “The International Year of Natural Fibers (IYNF) 2009” to celebrate the virtues of cotton, flax, sisal and hemp, and also those of wool, alpaca, camel hair and angora [1]. From 1960 onward, as the market share of natural fibers has decreased with the increase of chemical fiber products, it has become crucial to insure a steady income for poor farmers and to enhance awareness of natural fibers by emphasizing their benefits to general consumers. In order to make effective use of natural fibers, it is worthwhile to design and develop new spun yarns from vegetable fibers.

In producing spun yarn, the most prevalent method is using the ring spinning frame, followed by open-end and jet spinning machines. In the 2007 statistical report of the International Textile Manufacturers Federation (ITMF) [2], the total number of ring frames worldwide is about 210 million spindles, with China having 99 million spindles, India having 35 million. Thus, these two countries alone have 60 - 70% of the global count. On the other hand, the total number of open-end rotor machines is about 80 million rotors through the world. However, it is well known that, in a comparison with ring spun yarn, open-end spun yarn is superior in terms of speed of production, but also is inferior in quality.

Moreover, to diversify and improve the yarn properties, it is necessary to develop new techniques and devices for combining different fibers in a layered yarn structure.
Hybrid yarn, composite yarn, fancy yarn, and hollow yarn are produced using not only the ring spinning frame, but also the open-end, the jet, the friction spinning machines, among others [3-12]. We also have produced the four kinds of new hybrid yarns: the rotor-spun core yarn, the rotor-spun folded yarn, the rotor-spun wrapped yarn, and the rotor-spun loop yarn, using the newly-developed open-end rotor hybrid system [12-14]. However, in producing of hollow spun yarn, it is necessary to produce a hybrid yarn combined with two fiber materials and to remove the material as core yarn.

In order to produce open-end rotor-spun yarn with novel functional properties, we investigated how to provide greater extension and/or stretch, as in synthetic filament yarn. Thus, 100% cotton hollow yarns were produced using the newly-developed hybrid open-end rotor spinning frame and an experimental covering machine, and the resulting mechanical properties were assessed.

2. Production Methods and Evaluation

2.1 Materials and Methods

Raw materials were cotton sliver [mean fiber length = 22.0 (mm), and sliver size = 3.6 (ktex)] and PVA spun yarn [cut length of fibers = 40 (mm), and yarn count = 12.4 (tex)].

Figure 1 shows schematic diagrams of the machines for yarn production. The hollow yarns were produced using the following procedures: (1) First, five kinds of rotor spun yarns with different twist factor of 4 - 10 (× 0.105 turns per cm ∙ tex)\(^{1/2}\), Z and a count of 59.1 [tex, (10 Ne)] were produced using the newly-developed open-end rotor spinning frame; (2) Secondly, under the spinning condition, the core spun yarn were produced by combining the staple fibers with an insertion of the PVA spun yarn controlled at a core tension of 50 ± 5 (cN); (3) On the other hand, in the experimental covering machine, six kinds of covered yarns with different covering level of 500 – 2,500 (turns/m) were produced by combining the rotor spun yarn and the core spun yarn with a twist factor of 10 (× 0.105 turns per cm ∙ tex)\(^{1/2}\) and Z as the covering yarn and a PVA core yarn with a core tension of 50 ± 5 (cN); (4) The PVA core yarn is removed by dipping the yarn samples in ether a hot water bath at 80°C for 30 minutes, or a 20% sodium hydroxide solution at 70°C for 3 minutes followed by neutralization with a 1% acetic acid solution at 20°C for 10 minutes; (5) The yarn samples were naturally dried in a room with a controlled temperature of 20 ± 2°C and a humidity of 65 ± 5% R.H.

2.2 Model and Stretch of Hollow Yarn

Figure 2 shows the structure models of various spun yarns. Model (A) shows longitudinal and cross-sectional views of rotor spun yarn as simple yarn. Model (B) shows those of core spun yarn or covered yarn with a core yarn. Model (C) illustrates hollow yarns without the core yarn: Model (C)-(i) is a hollow yarn from core spun yarn or covered yarn with the rotor spun yarn as covering yarn. The hollow yarn from rotor core spun yarn is denoted by “Hollow yarn I” and the hollow yarn from simple rotor spun yarn as covering yarn.
is denoted by “Hollow yarn II”; Model (C) - (ii) is a hollow yarn made by combining two production methods of the core spun yarn and the covered yarn. The hollow yarn with the rotor core spun yarn as covering yarn is denoted by “Hollow yarn III”. So, the hollow yarn is a covered yarn with the core spun yarn as covering yarn. These yarns have a coiled structure composed of a staple fiber strand or covering yarn with a hollow structure in the center.

Figure 3 shows models of hollow yarn in an extension process. When it is assumed that hollow yarn extends to the points of breaking during the process of (A), (B), and (C), an elongation from a coiled structure in the initial step to a straight condition in the final step can be allowed. Accordingly, the hollow yarn has not only the elongation capacity of rotor spun yarn but also a greater elongation as yarn stretch. Where the stretch of yarn is defined as follows:

\[
\text{Stretch of hollow yarn (mm)} = EHY - ERY \quad (1)
\]

\[
\text{Stretch percentage (%) } = 100 \times \frac{SHY}{ERY} \quad (2)
\]

where \(EHY\) = Elongation of hollow yarn, \(ERY\) = Elongation of rotor spun yarn, and \(SHY\) = Stretch of hollow yarn.

2.3 Evaluation

The mechanical properties of the sample yarns were examined using an Instron constant rate of elongation tensile tester with a test length of 250 (mm), an extension rate of 300 (mm/min), and 50 tests per yarn. Longitudinal and cross-sectional views of the yarns were observed under a microscope (OLIMPUS SZH-151), in which each observation was repeated 10 times with different parts of the sample yarns. The experiment was carried out in a room with controlled a temperature of 20 ± 2°C and a humidity of 65 ± 5% R.H.

3. Results and Discussion

Figure 4 shows longitudinal and cross-sectional views of various 100% cotton yarns. Photo (A) shows the rotor spun yarn. It can be seen that the yarn displays the most characteristic structure of open-end rotor-spun yarn, i.e. a difference between the arrangements of the staple fibers in the inner and outer layers of the yarn, and a stuffed fibers condition in the center of the yarn cross-section. Photo (B) shows hollow yarn I made from the rotor core spun yarn as illustrated in Model (C)-(i) of Figure 1, Photo (C) is hollow yarn II made from the covered yarn with simple rotor spun yarn as illustrated in Model (C)-(i) of Figure 1, and Photo (D) is hollow yarn III made from the covered yarn with the rotor core spun yarn. In comparison with the single yarn, these yarns have less disarrangement of the staple fibers in the yarn appearance, a hollow structure in the center of the yarn cross-section, and a wrapped structure as illustrated in Model (C)-(ii) of Figure 1.

Figure 5 shows the typical strength-extension curves of the hollow yarns and the simple yarn. It reveals that, in spite of its inferior strength, the extension of each hollow yarn is greater than that of the rotor spun yarn. And the yarn extension varies with the structure of hollow yarn. However, the curves of hollow yarns are difficult to distinguish visually and the hollow yarns break down at the condition of extension before the full length of the component yarn.

Table 1 lists the mechanical properties of the sample yarns. In the rotor spun yarn within the range of experiment, the breaking strength increases with increase of the twist factor. In Hollow yarn I, although the extension at yarn breaking point increases with increase of the twist factor, the breaking strength has a tendency to increase and decrease in a convex quadratic curve. In comparison of the rotor spun yarns, Hollow yarn I has an increase of extension and a decrease of strength. Thus, it can be seen that the hollow yarn has greater stretch under appropriate tension as illustrated in Figure 2. Regarding the decrease of yarn strength, one main
Fig. 4 Longitudinal and cross-sectional views of 100% cotton yarns

(A) Rotor spun yarn (Twist factor = $10 \times 0.105$ turns per cm $\cdot$ tex$^{1/2}$, Z)

(B) Hollow yarn I from rotor core spun yarn (Twist factor = $10 \times 0.105$ turns per cm $\cdot$ tex$^{1/2}$, Z)

(C) Hollow yarn II from rotor spun yarns as covering yarn
(Twist factor = $10 \times 0.105$ turns per cm $\cdot$ tex$^{1/2}$ and Z, Covering level = 2500 tpm and Z)

(D) Hollow yarn III from rotor core spun as covering yarns
(Twist factor = $10 \times 0.105$ turns per cm $\cdot$ tex$^{1/2}$ and Z, Covering level = 2500 tpm and Z)

(--- yarn axis, ----- fiber axis, ........ strand axis)
Table 1  Mechanical properties of various sample yarns.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Twist factor (Covering level)</th>
<th>Yarn Count (tex)</th>
<th>BS (cN/tex) Mean</th>
<th>CV%</th>
<th>BE (%) Mean</th>
<th>CV%</th>
<th>SP (%) Mean</th>
<th>CV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor spun yarn</td>
<td>4</td>
<td>55.2</td>
<td>7.1</td>
<td>9.9</td>
<td>7.0</td>
<td>8.1</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>5.5</td>
<td>55.2</td>
<td>9.5</td>
<td>6.9</td>
<td>8.5</td>
<td>6.2</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>56.2</td>
<td>10.0</td>
<td>6.3</td>
<td>9.6</td>
<td>6.0</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>8.5</td>
<td>55.7</td>
<td>10.5</td>
<td>4.7</td>
<td>10.0</td>
<td>4.8</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>60.3</td>
<td>10.5</td>
<td>4.9</td>
<td>9.6</td>
<td>4.6</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Hollow yarn I</td>
<td>4</td>
<td>59.1</td>
<td>8.1</td>
<td>9.6</td>
<td>9.0</td>
<td>5.7</td>
<td>27.7</td>
<td>26.3</td>
</tr>
<tr>
<td></td>
<td>5.5</td>
<td>52.9</td>
<td>8.0</td>
<td>10.0</td>
<td>11.0</td>
<td>5.0</td>
<td>31.3</td>
<td>20.1</td>
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<tr>
<td></td>
<td>7</td>
<td>59.6</td>
<td>9.3</td>
<td>9.0</td>
<td>16.0</td>
<td>6.3</td>
<td>62.7</td>
<td>16.2</td>
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<tr>
<td></td>
<td>8.5</td>
<td>57.2</td>
<td>8.6</td>
<td>7.1</td>
<td>20.0</td>
<td>4.3</td>
<td>95.7</td>
<td>8.7</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>53.8</td>
<td>7.5</td>
<td>8.8</td>
<td>24.0</td>
<td>5.5</td>
<td>152.5</td>
<td>9.2</td>
</tr>
<tr>
<td>Hollow yarn II</td>
<td>10 / 500</td>
<td>66.7</td>
<td>5.9</td>
<td>12.9</td>
<td>43.6</td>
<td>9.4</td>
<td>353.3</td>
<td>12.1</td>
</tr>
<tr>
<td></td>
<td>/ 1000</td>
<td>101.3</td>
<td>3.4</td>
<td>10.8</td>
<td>71.9</td>
<td>7.2</td>
<td>648.4</td>
<td>8.3</td>
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<tr>
<td></td>
<td>/ 1500</td>
<td>138.7</td>
<td>2.5</td>
<td>9.5</td>
<td>121.4</td>
<td>8.3</td>
<td>1163.1</td>
<td>9.0</td>
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<tr>
<td></td>
<td>/ 2000</td>
<td>174.0</td>
<td>1.9</td>
<td>9.5</td>
<td>165.3</td>
<td>7.9</td>
<td>1619.8</td>
<td>8.4</td>
</tr>
<tr>
<td></td>
<td>/ 2500</td>
<td>182.4</td>
<td>1.6</td>
<td>8.4</td>
<td>187.3</td>
<td>8.8</td>
<td>1848.2</td>
<td>9.3</td>
</tr>
<tr>
<td>Hollow yarn III</td>
<td>10 / 2500</td>
<td>189.5</td>
<td>1.5</td>
<td>9.9</td>
<td>266.7</td>
<td>5.6</td>
<td>2674.6</td>
<td>5.9</td>
</tr>
</tbody>
</table>

where Twist factor = \( \times 0.105 \) turns per cm \( \cdot \) tex\(^{1/2}\) and Z, Covering level = turns per meter and Z, BS = Breaking strength, BE = Breaking extension, SP = Stretch percentage.

![Fig. 5 Typical strength-extension curves of yarns (Twist factor = 10 \( \times 0.105 \) turns per cm \( \cdot \) tex\(^{1/2}\) and Z, Covering level = 2500 tpm and Z).](image)

reason might be expected to be the influence of the twist level of the staple fiber strand. Namely, in the production of open-end rotor core spun yarn, the twist level of staple fiber strand decreases because a mechanical twist is applied in order to cover the core yarn with the staple fibers. In a comparison of Photos (A) and (B) in Figure 4, although the angle between the axes of the core spun yarn and the fiber strand in Photo (B) is nearly equal to the angle between the axes of the rotor spun yarn and the fibers in Photo (A), the angle between the axes of the fiber strand and the fibers in Photo (B) is about zero. When the hollow area in the yarn center becomes extinct with increase of the yarn extension, the thickness of yarn decreases greatly and the covering level of the core spun yarn converts to the twist of the fiber strand. Furthermore, in Hollow yarn II, although the strength decreases with increase of the covering level, the stretch increases greatly with increase of the covering level. As this yarn is covered by the rotor spun yarn with a twist factor of 10 \( \times 0.105 \) turns per cm \( \cdot \) tex\(^{1/2}\) and Z, the effect on the covering level of the yarn is simply added to the original extension capacity of the simple yarn. However, regarding the decrease of yarn strength, one main reason might be expected to be the influence caused by superimposing the twist and the covering levels of the yarn. Namely, as the angle between the axes of the fibers and the yarn increases with increase of the covering level, the contribution of the fiber strength to the yarn strength decreases with making a greater fibers oblique with respect to the yarn axis. In comparison with Hollow yarn II with a covering level of 2,500 tpm, although the strength of Hollow yarn III does not decrease greatly, the stretch does increase significantly. This yarn is covered by the rotor core spun yarn with a twist factor of 10 \( \times 0.105 \) turns per cm \( \cdot \) tex\(^{1/2}\) and Z, and then it has two hollow areas in the center and in the spiral of the yarn. Accordingly, to improve the breaking strength of these yarns, it will be necessary to make Hollow yarns II and III under a controlled spinning condition as follows: (1) A lower twist level and a higher covering level of the yarns; (2) A higher twist level and a lower covering level of the yarns; (3) Or an inverse relationship between the twist directions of the rotor spun and the covered yarns. Simultaneously,
Table 2  Mechanical properties of yarns after NaOH treatment.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Twist factor / Covering level</th>
<th>BS (cN/tex)</th>
<th>BE (%)</th>
<th>SP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean CV%</td>
<td>Mean CV%</td>
<td>Mean CV%</td>
</tr>
<tr>
<td>Rotor spun yarn</td>
<td>10</td>
<td>10.2 9.3</td>
<td>12.2 4.7</td>
<td>26.9 22.2</td>
</tr>
<tr>
<td>Hollow yarn I</td>
<td>10</td>
<td>7.4 4.8</td>
<td>20.0 4.2</td>
<td>108.3 4.8</td>
</tr>
<tr>
<td>II</td>
<td>10 / 2500</td>
<td>1.8 6.2</td>
<td>179.4 9.3</td>
<td>1766.3 9.7</td>
</tr>
<tr>
<td>III</td>
<td>10 / 2500</td>
<td>1.6 6.1</td>
<td>256.9 6.4</td>
<td>2572.7 6.7</td>
</tr>
</tbody>
</table>

where Twist factor = $\times 0.105$ turns per cm · tex$^{1/2}$ and Z, Covering level = turns per meter and Z, BS = Breaking strength, BE = Breaking extension, SP = Stretch percentage.

Fig. 6  Typical strength-extension curves of yarns before and after NaOH treatment (Twist factor = $10 \times 0.105$ turns per cm · tex$^{1/2}$, Z).

as the extension of the textile products may be less than about 30% in normal clothing, there is no need to provide the greater stretch as in these yarns. However, it will be necessary to control the increase of the yarn thickness by varying the yarn structure.

Figure 6 shows the typical strength-extension curves of yarns before and after NaOH treatment. In comparison of the mechanical properties of the yarns before treatment, the strength of the rotor spun yarns after treatment is almost equal and the extension increases. Table 2 lists the mechanical properties of the sample yarns after chemical treatment. In comparison with the hollow yarns before treatment as listed in Table 1, the strengths of the treated hollow yarns are nearly equal. The extensions of Hollow yarns I, II, and III barely decrease by means of the mercerization as chemical treatment. However, it is well known that the strength and gloss of textile products from cotton fibers can be improved by the mercerization.

4. Conclusion

In order to make effective use of vegetable fibers and produce cotton yarn with novel functional properties, 100% cotton hollow yarns were produced and the resulting mechanical properties were assessed. The results were as follows: (1) Cotton hollow yarns can be produced using the newly-developed hybrid open-end rotor spinning frame and the covering machine; (2) In comparison with simple rotor spun yarn, hollow yarns have the characteristics of greater extension and/or stretch percentage; (3) The stretch of cotton open-end rotor spun yarn can be improved by means of the yarn structure.

Further study is needed to investigate fabrics woven from hollow yarns and to improve the warmth retention and air-permeability of those products.

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References