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Date: 7-6-19
The Ratio of Ply Twist to Spin Twist in a Balanced Yarn: Variations by Fiber Type

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Submitted to Olds College

15 September 2014
Abstract

Twist turns fiber into yarn. Twisted fibers store potential energy which gives the yarn a tendency to untwist. Plying two or more yarns together with an opposite twist relaxes the fibers and releases the potential energy. A balanced yarn has the spin and ply twist equalized so the yarn has no tendency to twist. There is a relationship between the amount of ply twist and the amount of spin twist in each ply in a yarn. The widely accepted formula for this relationship is \( P = \frac{n}{n+1} S \), where \( P \) = ply twists per inch, \( S \) = spin twists per inch, and \( n \) = number of plies. For a two-ply yarn, this is \( P = \frac{2}{3} S \). According to this formula, the number of plies is the only relevant factor in the ratio of ply twist to spin twist in a balanced yarn.

This study investigates a variety of fiber types to measure the P:S ratio in balanced sample yarns. Twenty different fibers were spun with the same parameters for the singles, plied to balance, and measured for ply and spin twist. Data shows that there is a variance in the balance ratio by fiber type, and all yarns have a lower balance ratio than the predicted \( \frac{2}{3} \). The fibers show a loose grouping by fiber characteristics. Balance ratio is also proportional to elasticity.

Further avenues of study include other yarn properties and their potential impact on ply to spin twist ratio of a balanced yarn, including grist, twist amount, fiber preparation, and yarn structure.
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Introduction

Twist turns fiber into yarn. Twist influences almost every aspect of yarn: hand, drape, size, elasticity, strength, durability, and stability of the yarn and finished fabric. Twist compresses fibers together, causing them to hold together into yarn (Amos, 2001, p. 313). However, the natural state of fiber is not twisted. Twist becomes potential energy in the yarn.

Plying (folding) twists two or more strands together. When ply twist is in the opposite direction of the singles, plying removes twist from each strand, releasing the potential energy and relaxing the compression on the yarn. The singles wind around each other in a helical shape with the ply structure providing the coherence to the yarn. Individual fibers within the yarn are straightened.

A balanced yarn has no potential energy left; the stored twist energy in the singles has been released by the plying twist.

Why care about balance?

Extra twist energy in yarn will affect the performance of the yarn and finished fabric. Most notably, unbalanced or twist-active yarns will cause knitted fabric to bias, and cause woven fabrics to display diagonal texture lines called “tracking” (Alderman, 2009, p. 201). Excessive twist can be used as a design element; textile artists Katheryn Alexander and Anne Field use twist-active yarn very successfully to create knitted and woven fabrics that distort into three-dimensional surfaces (Alexander, 2002; Field, 2008). However, smooth fabrics are more successfully produced with balanced yarn. In
addition, unbalanced yarn can be difficult to handle because of a tendency to kink or tangle.

How to achieve balance?

Twist is measured as the number of twists per unit length in a yarn, whether it is a singles, plied, or compound structure. It is expressed as twists per inch (TPI), or twists per 2.5cm.

According to Mabel Ross in The Essentials of Yarn Design for Handspinners (Ross, 1983, pp. 53-57), the amount of ply twist per inch required for a balanced two-ply yarn is 2/3 the amount of spin twist per inch, assuming the plies are equivalent. For a three-ply yarn, the ratio is 3/4. The formula can be extrapolated to a balanced yarn of any number of plies as:

$$P_{tpi} = \frac{n}{n+1} S_{tpi}$$

Where P = ply twist in TPI, S = singles twist in TPI, and n = number of plies.

This is a widely accepted formula used by many spinners.

Judith McKenzie McCuin suggests there is no formula for exactly determining the balancing ply twist (McCuin, 2009, p. 88). Alden Amos works through calculations on several examples, noting the complexity of the calculations, and the deviation of sample yarns from predicted results (Amos, 2001, pp. 314-324). Furthermore, Amos describes fiber rigidity as a particular fiber’s resistance to being twisted. Torsional reaction, defined as the force of the yarn trying to untwist itself, is related to rigidity,
amount of twist, and amount of fiber; as any of these increase, the yarn's tendency to untwist also increases (Amos, 2001, p. 316).

Torsional stiffness is a property of material, and constant for a given material. The torque generated by twisting a material is the product of this constant and the angle of twist, expressed as $M = \kappa \theta$, where $M =$ torque, $\kappa =$ the stiffness constant for the material, and $\theta =$ the angle of twist (Meriam, 1986, p. 373). Balancing the torque of the ply twist and of the aggregate of the remaining spin twist will reduce to Ross's formula. (Appendix A.)

Working with a variety of fiber types, a spinner will notice a difference in the handle of fibers, and how readily one will accept a great deal of twist, for example Merino or cashmere, while another, such as longwool, accepts only a comparatively slight amount of twist before forming corkscrews in the yarn from excessive twist. Stiffness means that fibers are suited to a range of yarn design; fine fibers work with fine, high-twist yarns, while coarser, stiffer fibers require thicker, lower twist yarns.

Questions

Many factors affect the properties of a finished yarn: fiber choice, amount of fiber, amount of twist, fiber alignment, and yarn structure. Many yarn properties also affect each other; grist and TPI affect angle of twist, fiber and twist amount affect elasticity, etc. Spin and ply twist influence the handle, thickness and elasticity of a yarn. Fiber type affects these properties as well. Does it affect the twist required to balance the yarn?
A simple mathematical derivation suggests that the general formula $P = \frac{n}{n+1} S$ works for any yarn, and the only factor in the ratio of ply to spin twist in a balanced yarn is the number of plies. Empirical evidence suggests otherwise.

The author observed that some fibers balance at a lower ratio of ply twist to spin twist than other fibers. Furthermore, almost all fibers balance at a lower ply to spin twist ratio than 2/3.

This study examines one of the properties of yarn and its influence on balance: does fiber type affect the balance ratio of spin and ply twist in a two-ply yarn? Can the fibers be grouped according to their behavior?

**Checking for balance**

Individual fibers in a balanced yarn align longitudinally with the yarn. This geometry is noted by many sources, including Geraldine Hubbard (Sutton, 1983, p. 25), Peter Teal (Teal, 1976, p. 159), and Jane Fournier (Fournier, 1995, p. 205).

However, individual fibers are not completely straightened; they wind through a ply, which takes a helical path through the yarn. Fibers observed near the center of the yarn will appear straight from a viewing angle tangent to the yarn. Fibers at the sides of the yarn, as seen from the viewing angle, will appear to curve along the outside edge of the yarn.

![Figure 1: Fiber alignment in plied yarn.](image)
The internal geometry of the yarn influences the character of the yarn, but it is also possible to check balance by the behavior of the yarn.

A yarn with extra twist energy will release that energy whenever possible. A cut yarn will twist to release the extra. A folded yarn will ply back onto itself. A skein of yarn will twist in the skein. A relaxed, balanced yarn or skein will hang in a flat loop, with no tendency to twist in either direction.

Figure 2: Testing for balance by observing twist in a strand of yarn

Figure 3: Testing for balance by observing twist in a skein
Twist energy will go dormant in yarn as it sits in a particular package. Singles yarn wound on a bobbin, finished yarn wound into a ball, even yarn stored in a tightly wound skein will begin to set the twist in a fairly short amount of time – even an hour on a bobbin will mask some twist energy in a yarn.

The energy is reactivated when the yarn or fabric is wet finished. To ensure there is no latent energy, checking for balance should be done on a wet finished (washed) yarn, air-dried without any tension, weights, or blocking of any kind. If allowed to twist freely, the yarn will display any latent twist energy.
Method of Study

The purpose of this study is to identify the ratio of ply to spin twist in a balanced two-ply yarn, and variations among fiber types. All other variables (preparation, yarn size, spin TPI, yarn structure) are kept as uniform as possible.

Fibers

The following fibers are tested:

<table>
<thead>
<tr>
<th>Group</th>
<th>Fiber type</th>
<th>Typical fiber size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long Wools</td>
<td>Wensleydale</td>
<td>30-46µ</td>
</tr>
<tr>
<td></td>
<td>Swalesdale</td>
<td>36-40µ</td>
</tr>
<tr>
<td></td>
<td>Cotswold</td>
<td>34-40µ</td>
</tr>
<tr>
<td>Medium Wools</td>
<td>Coopworth</td>
<td>35-39µ</td>
</tr>
<tr>
<td></td>
<td>Romney</td>
<td>33-37µ</td>
</tr>
<tr>
<td></td>
<td>Shetland</td>
<td>23-30µ</td>
</tr>
<tr>
<td>Fine Wools</td>
<td>Corriedale</td>
<td>26-33µ</td>
</tr>
<tr>
<td></td>
<td>Cormo</td>
<td>21-23µ</td>
</tr>
<tr>
<td></td>
<td>Merino</td>
<td>18-24µ</td>
</tr>
<tr>
<td>Animal, coarse</td>
<td>Mohair (adult)</td>
<td>23-38µ</td>
</tr>
<tr>
<td></td>
<td>Alpaca</td>
<td>18-27µ</td>
</tr>
<tr>
<td>Animal, fine</td>
<td>Cashmere</td>
<td>&lt;19µ</td>
</tr>
<tr>
<td></td>
<td>Bombyx silk</td>
<td>10-13µ</td>
</tr>
<tr>
<td>Plant, bast</td>
<td>Flax</td>
<td>12-16µ</td>
</tr>
<tr>
<td></td>
<td>Ramie</td>
<td>25-30µ</td>
</tr>
<tr>
<td>Plant, lint</td>
<td>Cotton</td>
<td>11-22µ</td>
</tr>
<tr>
<td>Manufactured</td>
<td>Viscose Rayon</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tencel</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soysilk</td>
<td></td>
</tr>
<tr>
<td>Synthetic</td>
<td>Nylon</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4: Fibers tested

1 Fournier, 1995
2 McCuin, 2009
3 Natural Fibers, 2009
Preparation

Commercial roving was used for all samples. Fiber preparation is another potential variable for study, so this was kept constant. Compacted rovings were split and pre-drafted just enough to loosen the fiber.

Spinning

Each fiber was spun into a similar singles yarn, -30 wraps per inch (WPI) using short forward draw, Z-twist, $1\frac{1}{2}''$ per treadle on 11.5:1 ratio using an Ashford Traditional single treadle, scotch tension spinning wheel with the standard flyer. One exception is cotton; $1\frac{1}{2}''$ forward draft is not practical for the $1 - 1\frac{1}{4}''$ staple length. Cotton was drafted using short backward draw with four small drafts totaling $1\frac{1}{2}''$ per treadle so the final twist/drafting rate was the same as for the other fibers. A sewing gauge set at $1\frac{1}{2}''$ was a guide for drafting. The nominal value for the singles twist using this setup is:

\[
TPI = \frac{\text{Ratio} \times \text{no. treadles}}{\text{Draft length}} = \frac{11.5 \frac{tw}{tr} \times 1 \frac{tr}{in}}{1.5 \text{ in}} = 7.7 \frac{tw}{in}
\]

The nominal value for ply twist using \( P = 2/3 \ S \) is:

\[
P = \frac{2}{3} S = \frac{2}{3} \times 7.7 \ tpi = 5.1 \ tpi
\]

Method of sample production:

I spun a singles using the set drafting length and ratio, until the singles began wrapping around the bobbin. I marked the singles with a pen just in front of the drafting zone. Yarn spun before this mark is discarded, to eliminate any irregularity from the start of spinning. I spun three to four yards of each yarn. I marked the singles again and kept
spinning until the mark was wound onto the bobbin. Yarn spun after this mark is discarded to eliminate any irregularity as the last length of yarn is wound on. From this singles, I pulled the yarn from the bobbin, folded it back on itself to make a self-plied sample of at least one yard, hanging a drop spindle from the fold. Keeping the folded end under tension creates a more even twist throughout the sample than allowing the end to twist freely (Patsy Zawistoski workshop notes, “Understanding Spinning Size and Twist” workshop notes, Convergence, Grands Rapids, MI, 6/29/2006). I kept a grip on the opposite end of the single, not allowing any twist out, until the cut ends were tied in a knot. Two reference samples were made. The most evenly spun was used as the reference.

I measured the ply twist in the sample yarn, stretched, and used that as the guide of determining the drafting length and number of treadles for the plying operation of the larger sample skein. Samples measured 2.6 to 4.0 TPI.

I then spun the larger sample skein, marking the leader and last yard. Ending marks were matched up to begin plying. Plying was done from two bobbins, using two treadles per draft length. Again, the portions outside of the marks on the singles were discarded.

I skeined the yarns and checked for balance by hanging the skein. Most skeins required adjusting the finished ply twist from the calculated value. Skeins were washed and hung to dry without weight or blocking. They were checked again for balance and adjusted if necessary.
**Adjusting twist in a plied yarn:**

Skeins that are unbalanced after washing can be adjusted by adding or removing ply twist to get them to the balance point. Yarn can be run through the spinning wheel again in the direction it was plied to increase twist, or in the opposite direction to reduce twist (McCuin, 2006). A drop spindle can also be used to adjust the twist in a plied yarn. It is convenient for small skeins, especially those that need minor adjustment. Any excess adjustment is corrected with a few turns of the drop spindle in the opposite direction. This adjustment was done to ensure the yarn exhibited balance throughout the sample.

To adjust the ply twist, I mounted the washed skein on a swift and attached the yarn to a drop spindle. I suspended one to two yards at a time into a hanging loop. If the loop twisted, I adjust it by turning the drop spindle and re-checked the loop until it hung straight. I then wound that portion onto the drop spindle shaft. I repeated checking and adjusting the next one to two yard length until the entire skein was balanced. I re-skeined the yarns by winding from the side of the spindle onto a one yard reel. Winding from the end of the spindle would add or remove one twist in the yarn for each pass around the spindle (Amos, 235). Side-delivery from the spindle to side-winding on the reel avoided any further alteration to the twist.

**Method of yarn measuring:**

- Cut 1 to 1½ yard samples from each 10-15 yard skein for testing. Take a sample from each end of the skein. Rinse these samples in warm water, squeeze out the excess, and hang them to dry from one end. This releases any latent twist energy in the yarn sample.
- Take macro photograph to view fiber alignment in the sample. Photos presented are approximately 12x magnification.
- From these samples, cut a 6-7" piece of yarn, tie a knot at one end, and secure it to a rigid card. Mark the card at 5.0" from the attachment point.
- Lay the relaxed yarn on the card. Mark the yarn with a pen at 5.0".
- Stretch the yarn. Measure and record the stretched length.
- Count the twists in the plied yarn. Count the number of ply bumps in the yarns and divide by two to get two-ply TPI.
- Clamp the yarn into a fringe twister at the pen mark. Untwist the yarn until the two plies separate. Count the twists. Record this as the ply twist over 5". If this number varies from the counted bumps, use this counted twist value as ply twists. (It varied by \( \frac{1}{2} \) twist on a few samples). (Method taught by Patsy Zawistoski, “Understanding Spinning Size and Twist” seminar, HGA Convergence, Grand Rapids, MI 6/29/2006).

![Figure 5: Counting ply twist](image)

- Grab the untwisted yarn right at the clip and release the end. Comb out the tail. Do not release the yarn until it has been re-secured.
- Secure one of the singles to the card with tape. Measure the stretched length of the singles from the secured end up to the pen mark.
• Secure the other singles back into the fringe twister clip right at the pen mark. The fringe twister will not grip securely on the singles for some of the slicker yarns. For those yarns, add a small tab of tape past the pen mark. The clip will catch this tab.

• Carefully untwist the singles while counting the number of turns. Use very light tension on the singles as it untwists. Start with 20-30 turns. Spread out the unspun fiber, dividing it slightly to show the twist has been removed. Use two long needles to assist separating the fiber. Walk remaining twist up towards the fringe twister. Continue to untwist and lay out the singles until all of the twist has been removed from the singles and the roving lies flat. Record the number of twists. Secure the untwisted roving with tape.

![Figure 6: Counting spin twists](image)

• Record data on two samples, using yarns from either end of the skein. If the yarn is dropped or count is lost, discard the sample and start with a new sample.

**Collected data**

For each sample, record the following:

- Fiber
- Relaxed length (5.0”)
- Stretched length
- Ply twists over 5" (counted during untwisting)
- Unplied singles length
- Spin twists over original 5" ply length (counted during untwisting)

**Calculations (shaded)**

For each sample, calculate the following from the measured values:

- Elasticity = (stretched length - relaxed length) / relaxed length
- P: Ply TPI = ply twist count / relaxed sample length
- S: Spin TPI = spin twist count / relaxed sample length
- P:S ratio = ply twist count / spin twist count = ply TPI / spin TPI
- P<sub>str</sub>: Stretched ply TPI = ply twist count / stretched ply length
- S<sub>str</sub>: Stretched spin TPI = spin twist count / stretched singles length
- P<sub>str</sub>:S<sub>str</sub> ratio = stretched ply TPI / stretched spin TPI

**Samples presented**

Each fiber sample is presented with:

- Macro photo of yarn showing fiber alignment, approximately 12x magnification
- Sample of unspun roving
- Two deconstructed yarn samples used for measuring
- 10-15 yard sample skein. Measuring sample was taken from this skein.
- List of findings for that skein
Findings

The measurements and calculations for two samples of each fiber type are as follows. Shaded fields are calculated values.

<table>
<thead>
<tr>
<th>Fiber type</th>
<th>Plied Sample</th>
<th>Ply</th>
<th>Spin</th>
<th>Relaxed</th>
<th>Stretched</th>
<th>P-S</th>
<th>P' tpi</th>
<th>S' tpi</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Relaxed</td>
<td>Stretched</td>
<td>elasticity</td>
<td>tw/5' # twists</td>
<td>P tpi tw/in</td>
<td>len</td>
<td>tw/5' # twists</td>
<td>S tpi tw/in</td>
</tr>
<tr>
<td>Wensleydale</td>
<td>5.0</td>
<td>5.1</td>
<td>2.8%</td>
<td>16.0</td>
<td>3.2</td>
<td>5.1</td>
<td>30.0</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>5.1</td>
<td>2.0%</td>
<td>15.0</td>
<td>3.0</td>
<td>5.1</td>
<td>35.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Swalesdale</td>
<td>5.0</td>
<td>5.3</td>
<td>6.0%</td>
<td>16.0</td>
<td>3.2</td>
<td>5.2</td>
<td>32.0</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>5.3</td>
<td>6.0%</td>
<td>18.0</td>
<td>3.6</td>
<td>5.1</td>
<td>35.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Cotswold</td>
<td>5.0</td>
<td>6.7</td>
<td>34.0%</td>
<td>25.0</td>
<td>5.0</td>
<td>6.4</td>
<td>42.0</td>
<td>8.4</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>6.4</td>
<td>28.0%</td>
<td>25.0</td>
<td>5.0</td>
<td>6.3</td>
<td>42.5</td>
<td>8.5</td>
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<td>Coopworth</td>
<td>5.0</td>
<td>5.7</td>
<td>14.4%</td>
<td>17.5</td>
<td>3.5</td>
<td>5.7</td>
<td>34.0</td>
<td>6.8</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>5.5</td>
<td>10.8%</td>
<td>18.0</td>
<td>3.6</td>
<td>5.5</td>
<td>36.0</td>
<td>7.2</td>
</tr>
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<td>Romney</td>
<td>5.0</td>
<td>5.4</td>
<td>8.0%</td>
<td>17.5</td>
<td>3.5</td>
<td>5.4</td>
<td>32.5</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>5.6</td>
<td>12.0%</td>
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<td>3.3</td>
<td>5.5</td>
<td>33.5</td>
<td>6.7</td>
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<td>Shetland</td>
<td>5.0</td>
<td>5.4</td>
<td>8.8%</td>
<td>17.5</td>
<td>3.5</td>
<td>5.5</td>
<td>38.0</td>
<td>7.6</td>
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<td></td>
<td>5.0</td>
<td>5.4</td>
<td>8.8%</td>
<td>16.0</td>
<td>3.2</td>
<td>5.3</td>
<td>36.5</td>
<td>7.3</td>
</tr>
<tr>
<td>Corriedale</td>
<td>5.0</td>
<td>5.7</td>
<td>14.4%</td>
<td>21.0</td>
<td>4.2</td>
<td>5.6</td>
<td>39.0</td>
<td>7.8</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>5.7</td>
<td>13.6%</td>
<td>19.5</td>
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<td>45.0</td>
<td>9.0</td>
</tr>
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<td>37.6%</td>
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<td>5.4</td>
<td>6.9</td>
<td>44.5</td>
<td>8.9</td>
</tr>
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<td>36.0%</td>
<td>27.5</td>
<td>5.5</td>
<td>7.0</td>
<td>48.0</td>
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</tr>
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<td>5.7</td>
<td>38.0</td>
<td>7.6</td>
</tr>
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<td>14.0%</td>
<td>23.5</td>
<td>4.7</td>
<td>5.7</td>
<td>39.0</td>
<td>7.8</td>
</tr>
<tr>
<td>Alpaca</td>
<td>5.0</td>
<td>5.0</td>
<td>0.4%</td>
<td>16.5</td>
<td>3.3</td>
<td>4.9</td>
<td>40.0</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
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<td>2.0%</td>
<td>18.0</td>
<td>3.6</td>
<td>5.1</td>
<td>32.0</td>
<td>6.4</td>
</tr>
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<td>1.2%</td>
<td>15.0</td>
<td>3.0</td>
<td>5.0</td>
<td>33.5</td>
<td>6.7</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>5.1</td>
<td>1.6%</td>
<td>15.5</td>
<td>3.1</td>
<td>5.1</td>
<td>37.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Cashmere</td>
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<td>6.5</td>
<td>30.0%</td>
<td>24.0</td>
<td>4.8</td>
<td>6.5</td>
<td>40.0</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>6.2</td>
<td>24.0%</td>
<td>21.5</td>
<td>4.3</td>
<td>6.3</td>
<td>37.0</td>
<td>7.4</td>
</tr>
<tr>
<td>Bombyx silk</td>
<td>5.0</td>
<td>5.1</td>
<td>2.0%</td>
<td>22.5</td>
<td>4.5</td>
<td>5.1</td>
<td>37.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Flax</td>
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<td>5.0</td>
<td>0.4%</td>
<td>13.5</td>
<td>2.7</td>
<td>4.9</td>
<td>27.5</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
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<td>1.2%</td>
<td>13.0</td>
<td>2.6</td>
<td>5.0</td>
<td>31.0</td>
<td>6.2</td>
</tr>
<tr>
<td>Ramie</td>
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<td>1.2%</td>
<td>16.5</td>
<td>3.3</td>
<td>5.0</td>
<td>30.5</td>
<td>6.1</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>5.1</td>
<td>1.2%</td>
<td>16.5</td>
<td>3.3</td>
<td>5.0</td>
<td>36.0</td>
<td>7.2</td>
</tr>
<tr>
<td>Cotton</td>
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<td>5.5</td>
<td>10.0%</td>
<td>20.5</td>
<td>4.1</td>
<td>5.4</td>
<td>33.5</td>
<td>6.7</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>5.4</td>
<td>8.8%</td>
<td>18.5</td>
<td>3.7</td>
<td>5.4</td>
<td>30.5</td>
<td>6.1</td>
</tr>
<tr>
<td>Viscose Rayon</td>
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<td>5.1</td>
<td>1.6%</td>
<td>16.5</td>
<td>3.3</td>
<td>5.1</td>
<td>38.0</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>5.1</td>
<td>1.6%</td>
<td>15.0</td>
<td>3.0</td>
<td>5.0</td>
<td>35.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Tencel</td>
<td>5.0</td>
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<td>1.2%</td>
<td>18.5</td>
<td>3.7</td>
<td>5.1</td>
<td>43.0</td>
<td>8.6</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>5.1</td>
<td>1.2%</td>
<td>16.0</td>
<td>3.2</td>
<td>5.1</td>
<td>33.0</td>
<td>6.6</td>
</tr>
<tr>
<td>Soysilk</td>
<td>5.0</td>
<td>5.1</td>
<td>2.0%</td>
<td>18.5</td>
<td>3.7</td>
<td>5.0</td>
<td>35.0</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>5.1</td>
<td>2.8%</td>
<td>15.5</td>
<td>3.1</td>
<td>5.1</td>
<td>39.0</td>
<td>7.8</td>
</tr>
<tr>
<td>Nylon</td>
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<td>5.2</td>
<td>4.0%</td>
<td>23.0</td>
<td>4.6</td>
<td>5.1</td>
<td>51.0</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>5.1</td>
<td>2.8%</td>
<td>25.5</td>
<td>5.1</td>
<td>5.2</td>
<td>47.0</td>
<td>9.4</td>
</tr>
</tbody>
</table>

Table 7: Measured and calculated sample values
Charts

This chart shows the measured ply:spin twist ratios for two samples of each fiber. The fibers are sorted by the average P:S value.

No samples reach the predicted 2/3 (0.67) ratio. Soft fine fibers cotton, Merino, Cormo, silk, and cashmere are closest, with values 0.57 - 0.61. Cotswold, classified as a longwool, falls among these fibers. All other fibers have lower values, with longwools, springy medium wools, bast fibers, and manufactured fibers not falling into neat groups.
This table shows the relationship between the ply:spin twist ratio in the relaxed yarn vs. elasticity in the yarns.

The most elastic of the tested yarns, Cormo, Cotswold, and cashmere, all balance at P:S twist ratios close to 0.6. The least elastic fibers, flax, mohair, Tencel, and Rayon all balance at a ratio of 0.5 or less. Other wools fill in the middle of the chart, with a range of elasticity and balance ratio.
There is no significant difference in the P:S ratio in the relaxed yarns vs. stretched yarns.
This chart shows a general trend that elastic yarns have a higher TPI than inelastic yarns, for yarns that are spun with the same drafting length, ratio, and number of treadles, equivalent to the same target TPI.
Twist Mechanics

The amount of twist put into a yarn is predicted by the formula:

\[ \text{TPI} = \frac{R \times N}{D} \]

Where TPI = Twists per Inch,

\( N \) = Number of Treadles, equivalent to one turn of the drive wheel. For double-treadle wheels, this is one press of both treadles. \( N = 1 \) for short forward draft.

\( R \) = Ratio of the wheel, or number of turns of the flyer per turn of the drive wheel.

\( D \) = Draft length

To spin a specific target TPI, the spinner adjusts the other values. \( R \), ratio, is fixed by the design of the wheel. Many wheels offer multiple ratios, but they are usually discrete values; no intermediate ratio is possible. Number of treadles per draft is easily adjusted to any whole number. Partial values are impractical. Drafting length has the most flexibility, limited only by length of the fiber and comfortable reach for the spinner.

For an Ashford traditional, standard flyer with ratios 6.5:1, 11.5:1, and 15.5:1, using short forward draw (\( N=1 \)) this chart gives the nominal TPI produced for different draft lengths for all three flyer ratios:

\[ \text{TPI} = \frac{R \times 1}{D} \]

<table>
<thead>
<tr>
<th>Short draw tpi</th>
</tr>
</thead>
<tbody>
<tr>
<td>in/treadle (D)</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>6 1/2</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>4 1/2</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>3 1/2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>2 1/2</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>1 3/4</td>
</tr>
<tr>
<td>1 1/2</td>
</tr>
<tr>
<td>1 1/4</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>3/4</td>
</tr>
<tr>
<td>1/2</td>
</tr>
</tbody>
</table>

Figure 12: Short draw TPI table
Short backward draw and long draw drafting styles use multiple treadles per length of yarn. This chart shows the nominal TPI for long draw produced by a certain number of treadles over a 12" draft length, using all three ratios. Similar charts for other draft lengths give the spinner more options for finding a comfortable and efficient draft.

\[
TPI = \frac{R \times N}{12''}
\]

When solved for \(D\), the formula gives the drafting length required to achieve a specific TPI for a set ratio and number of treadles.

\[
D = \frac{R \times N}{TPI}
\]

This formula is used to generate a convenient chart, showing the required draft length in inches for a specific TPI and number of treadles. One chart is defined for one ratio. The following three charts are an example for the Ashford Traditional standard flyer. To spin to a target TPI, find a comfortable drafting length and number of treadles.

For example, 6 TPI is obtained with a 2" draft per 1 treadle on the 11.5:1 ratio, suitable for worsted spinning, or with 7 treadles per 18" draft on 11.5:1, suitable for long draw spinning.

Lengths are rounded to the nearest \(\frac{1}{8}''\), or to \(\frac{1}{8}''\) for shorter lengths. Draft lengths over 24" are omitted since they are impractical.
<table>
<thead>
<tr>
<th>TPI</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6 ½</td>
<td>13</td>
<td>19 ½</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3 ¼</td>
<td>6 ½</td>
<td>9 ¼</td>
<td>13</td>
<td>16 ¼</td>
<td>19 ½</td>
<td>22 ¼</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2 ¼</td>
<td>4 ½</td>
<td>6 ½</td>
<td>8 ¼</td>
<td>10 ¼</td>
<td>13</td>
<td>15 ¼</td>
<td>17 ¼</td>
<td>19 ½</td>
<td>21 ¼</td>
<td>23 ¼</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1 ½</td>
<td>3 ¼</td>
<td>5</td>
<td>6 ½</td>
<td>8 ¼</td>
<td>9 ¼</td>
<td>11 ½</td>
<td>13</td>
<td>14 ¼</td>
<td>16 ¼</td>
<td>18</td>
<td>19 ½</td>
</tr>
<tr>
<td>5</td>
<td>1 ½</td>
<td>2 ¼</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1 ¼</td>
<td>2 ½</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>13</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>7</td>
<td>¾</td>
<td>1 ½</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>9</td>
<td>10</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>8</td>
<td>⅞</td>
<td>1 ⅞</td>
<td>2 ¾</td>
<td>3 ¼</td>
<td>4 ¼</td>
<td>5 ¼</td>
<td>6 ½</td>
<td>7 ½</td>
<td>8 ¼</td>
<td>9 ¼</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>9</td>
<td>⅞</td>
<td>1 ⅞</td>
<td>2 ¼</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>9</td>
<td>10</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>10</td>
<td>⅞</td>
<td>1 ⅞</td>
<td>2 ¼</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>9</td>
<td>10</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>11</td>
<td>⅞</td>
<td>1 ⅞</td>
<td>2 ¾</td>
<td>3 ¼</td>
<td>4 ¼</td>
<td>5 ¼</td>
<td>6 ½</td>
<td>7 ½</td>
<td>8 ¼</td>
<td>9 ¼</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>12</td>
<td>⅞</td>
<td>1 ⅞</td>
<td>2 ¼</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>9</td>
<td>10</td>
<td>12</td>
<td>13</td>
</tr>
</tbody>
</table>

**Figure 14: Draft length table for long draw**
In practice, the TPI produced by this formula is lower than predicted. In a single-drive, flyer-lead system, also known as scotch tension, some of the turning action of the flyer is used to wind the length of yarn onto the bobbin. The number of turns used depends on the circumference of the bobbin core, so the effective ratio of the flyer changes as the bobbin fills. According to Alden Amos, the effective ratio is 85 to 95% of the base ratio as the bobbin fills. (Amos, 2001, p. 389) The exact values will depend on the size of the bobbin and its capacity. A flyer-lead system also winds the yarn from the end of the bobbin, imparting one additional twist in the yarn for each wrap around the bobbin. Twist is still being added to the yarn until it is securely wrapped around the bobbin.

In a bobbin-lead system, all of the flyer and bobbin rotation is imparted to the yarn as twist. There is no change in the effective drive ratio of the wheel as the bobbin changes. (Amos, 2001, p. 390) No further twist is added to the yarn as it is wound onto the bobbin. Exact calculations for the twist produced by a double-drive wheel are more complex.
**Elasticity**

Twist is expressed per unit of length in a yarn. When a yarn is stretched, the number of twists remains constant while the length increases. The apparent twist per inch is therefore lower. When yarns are relaxed, they thicken and shorten.

![Elastic Yarn Diagram]

Figure 15: Apparent change in TPI between relaxed and stretched yarn.

For example, cashmere sample #1 measured 5” relaxed, and 6.5 inches stretched, with 24 ply twists over the length of the sample. The relaxed ply twist is $\frac{24}{5} = 4.8$ TPI. Stretched, the ply twist is $\frac{24}{6.5} = 3.7$ TPI. Wensleydale sample #2 measured 5” relaxed, and 5.1” stretched, with 15 ply twists. The relaxed ply twist in this yarn is $\frac{15}{5} = 3$ TPI, and the stretched ply twist is $\frac{15}{5.1} = 2.9$. The Wensleydale is an inelastic yarn and the difference in TPI is negligible.

Elasticity affects the accuracy of twist calculations with regard to drafting length, ratio, and treadles. Yarns are held under tension while they are spun and plied, so they are stretched. The resulting TPI will be higher.
Conclusion

Measurements of the ply and spin twist in sample yarns show that the ply twist to spin twist ratio in a balanced yarn is less than 2/3 and varies by fiber type. Instead of a standard value, each fiber exhibits a particular range of ratios. The formula relating ply and spin twist in a two-ply yarn can be expressed as \( P = f \times S \), where \( f \) is the empirically determined ratio of ply twist to spin twist in a balanced two-ply yarn.

Furthermore there is a slight tendency for similar fibers to exhibit similar balance ratios. Finer fibers with a high crimp, loft and elasticity have the highest ply:spin twist ratio, clustered around 0.6. Cotton shows a similar balance factor as fine wools. Stiff, resilient fibers mohair and flax were among the lowest ratios, at 0.41-0.45. Synthetic and manufactured fibers all measured low, 0.40-0.45. The remaining wools and animal fibers are scattered around the middle of the range. Clearly, fiber type comes into play in the amount of ply to spin twist in a balanced yarn.

Variations in values between the samples within each fiber type indicate that the balance point is not an exact value, but a range. Fiber properties vary between sources and even within a fleece, which would also be expected to cause variations in the balancing ratio. The values are not strict numbers. Sampling is the best way to determine how a yarn will perform. However, using a balance ratio appropriate for the fiber type will give a more accurate starting point for sampling.
Using the P:S ratios

Using the P:S ratio of a specific fiber type will suggest a lower ply twist to balance a specific singles than the widely accepted P = 2/3 S. The general form is P = f * S, where f is the balancing ratio calculated from the measured ply and spin twist (P:S).

For example, using the original value P:S = 2/3, a singles yarn spun at 6 TPI is predicted to balance in a two-ply yarn at 2/3 * 6 = 4 TPI, regardless of fiber type or other factors. Using the measured balance ratios, the 6 TPI singles yarn spun from Merino (P:S = 0.60) will balance at 0.60 * 6 TPI = 3.6 TPI. This same yarn spun from viscose rayon (P:S = 0.43) will balance at 0.43 * 6 TPI = 2.6 TPI.

The spinner can also work backwards from a target ply TPI to find an appropriate spin twist for the singles yarns.

Further questions

Balancing twist is affected by fiber type. Other properties of yarn are additional avenues of investigation, to reveal how P:S balance ratio varies. Other properties to check include:

- Grist/thickness: the amount of fiber in the singles.
- Twist: the amount of twist per unit length, i.e. does a tight twist balance differently than a soft twist?
- Twist angle: does the ratio relate to twist angle more closely than TPI?
- Fiber density: A tighter twist yarn will have a higher density with less air space, likewise, a smooth fiber or parallel preparation will pack more densely than a crimped or jumbled preparation.
- Fiber alignment: woolen vs. worsted structure.
- Yarn structure: number of plies. The number of plies is known to affect the balance ratio. Is there a general formula accounting for number of plies and the balancing factor of the fiber type?
- Environmental factors: is the balance ratio a stable value for an individual yarn, or does it vary with age, temperature, or humidity?
References


Appendix A

Deriving the basic balance formula

\[ M_P = n \cdot M_S \]  
Balance torque of ply twist with total torque of spin twist

\[ M = \kappa \cdot \theta \]  
Values of torque

\[ \kappa \cdot \theta_p = n \cdot \kappa \cdot (\theta_S - \theta_P) \]  
Substitute values for torque in the first equation. The angle of spin twist of each ply is the difference between the original spin twist \( \theta_S \) and the ply twist \( \theta_P \).

\[ \theta_P = L \cdot P, \quad \theta_S = L \cdot S \]  
Total angle of twist is the twist rate times length

\[ \kappa \cdot L \cdot P = n \cdot \kappa \cdot (L \cdot S - L \cdot P) \]  
Substitute into the third equation

\[ \kappa \cdot L \cdot P = n \cdot \kappa \cdot L \cdot (S - P) \]  
Reduce

\[ P = n \cdot (S - P) \]  
Solve for \( P \)

\[ P = nS - nP \]

\[ P + nP = nS \]

\[ (n+1)P = nS \]

\[ P = \frac{n}{n + 1} S \]

| \( M_P \) = torque of ply       |
| \( M_S \) = torque in one ply   |
| \( n \) = number of plies      |
| \( \theta \) = angle of twist   |
| \( \kappa \) = torsional stiffness, constant for all members |
| \( L \) = length of yarn       |
| \( P \) = ply twists per inch  |
| \( S \) = singles twist per inch, assumed the same for all singles |
Samples

1. Wensleydale
2. Swalesdale
3. Cotswold
4. Coopworth
5. Romney
6. Shetland
7. Corriedale
8. Cormo
9. Merino
10. Alpaca
11. Mohair
12. Cashmere
13. Bombyx silk
14. Flax
15. Ramie
16. Cotton
17. Viscose Rayon
18. Tencel
19. Soysilk
20. Nylon
Wensleydale

#1 Wensleydale

Angela K. Schneider
Master Spinner L6

-commercial roving
2's. 1 lb.
3.5 tpi, 21 wpi
Weight of 1000 yds.
8.66 oz.
4 ply

SHI

Weight of 1000 yds.
8.66 oz.
4 ply

Wensleydale Wool
<table>
<thead>
<tr>
<th></th>
<th>Sample 1 (Left)</th>
<th>Sample 2 (Right)</th>
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<tbody>
<tr>
<td>Relaxed Len</td>
<td>5.0'</td>
<td>5.0'</td>
</tr>
<tr>
<td>Stretched Len</td>
<td>5.1'</td>
<td>5.1'</td>
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<tr>
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<td>2.8%</td>
<td>2.0%</td>
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<tr>
<td>Ply twists/5&quot;</td>
<td>16.0</td>
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<tr>
<td>Ply tpi</td>
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<td>7.0</td>
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<tr>
<td>P:S</td>
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<td><strong>0.43</strong></td>
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**Stretched**

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<td>P:S'</td>
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<td>0.43</td>
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</table>
Angela K Schneider  Master Spinner L6

#2 Swalesdale

commercial roving
short fwd draw Z, 1½" / tr, 11.5:1
2-ply: zzS
13.5 yd, 17.3 g, 350 ypp, 1s/2 worsted ct.
3.75 tpi, 14 wpi, 21° ply angle
### Swalesdale

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<th>Sample 1 (Left)</th>
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<tbody>
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<td><strong>Relaxed Len</strong></td>
<td>5.0'</td>
<td>5.0'</td>
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<td><strong>Stretched Len</strong></td>
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<td>5.3'</td>
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<td><strong>Elasticity</strong></td>
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<td>6.0%</td>
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<td><strong>Ply twists/5”</strong></td>
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<td>18.0</td>
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<td>3.6</td>
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<tr>
<td><strong>Singles length</strong></td>
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<td>5.1</td>
</tr>
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<td><strong>Spin twists/5”</strong></td>
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<td><strong>P:S</strong></td>
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<td><strong>P':S'</strong></td>
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#3 Cotswold
commercial roving
short fwd draw Z, 1½"/tr. 11.5:1
2-ply: zzS
14.4 yd, 8.0 oz, 820 ypp, 2s/2 worsted ct.
4.5 tpi, 12 wpi, 27* ply angle
### Cotswold

<table>
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<tr>
<th></th>
<th>Sample 1 (Left)</th>
<th>Sample 2 (Right)</th>
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<tbody>
<tr>
<td>Relaxed Len</td>
<td>5.0'</td>
<td>5.0'</td>
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<tr>
<td>Stretched Len</td>
<td>6.7'</td>
<td>6.4'</td>
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<td>34.0%</td>
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#4 Coopworth

commercial roving
short fwd draw Z, 1½" / tr, 11.5:1
2-ply: zzS
12.5 yd, 5.4 g, 1050 ypp, 3s/2 worsted ct.
4 tpi, 12 wpi, 20° ply angle
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<th>Sample 1 (Left)</th>
<th>Sample 2 (Right)</th>
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<td>5.0'</td>
<td>5.0'</td>
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<tr>
<td><strong>Stretched Len</strong></td>
<td>5.7'</td>
<td>5.5'</td>
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<td><strong>Elasticity</strong></td>
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<td>3.5</td>
<td>3.6</td>
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<tr>
<td><strong>Singles length</strong></td>
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<td>5.5</td>
</tr>
<tr>
<td><strong>Spin twists/5”</strong></td>
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<td><strong>P:S</strong></td>
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<td>0.50</td>
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<td><strong>Stretched</strong></td>
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<td><strong>P:S’</strong></td>
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</table>
Romney Wool

Romney

Angela K. Schneider  Master-Spinner L6
commercial drawing
2 ply 1x2 1/2 in 11.5 ratio
8 ply 14 pl 18 ply angle

#5 Romney
commercial drawing
2 ply 1x2 1/2 in 11.5 ratio
8 ply 14 pl 18 ply angle
<table>
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<tr>
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<th>Sample 1 (Left)</th>
<th>Sample 2 (Right)</th>
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<tr>
<td>Relaxed Len</td>
<td>5.0'</td>
<td>5.0'</td>
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<tr>
<td>Stretched Len</td>
<td>5.4'</td>
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<td>12.0%</td>
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**Romney**
#6 Shetland

commercial roving
short forward draw Z, 1 1/2" / tr, 11.5:1
2-ply; 22 S
12.5 yd, 7.9 g, 720 ypp, 28/2 worsted ct.
3.75 tpi, 12. wpi, 20" ply angle
<table>
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<tr>
<th></th>
<th>Sample 1 (Left)</th>
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<td>5.0&quot;</td>
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<td>Stretched Len</td>
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<td>5.4&quot;</td>
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<tr>
<td>Elasticity</td>
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<td>8.8%</td>
</tr>
<tr>
<td>Ply twists/5&quot;</td>
<td>17.5</td>
<td>16.0</td>
</tr>
<tr>
<td>Ply tpi</td>
<td>3.5</td>
<td>3.2</td>
</tr>
<tr>
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<td>5.3</td>
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<td>Spin twists/5&quot;</td>
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<td>0.44</td>
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<td>Stretched</td>
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<td>Ply tpi</td>
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<td>2.9</td>
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<tr>
<td>P':S'</td>
<td>0.46</td>
<td>0.43</td>
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</table>
Angela K Schneider  Master Spinner L6

#7 Corriedale

commercial roving
short fwd draw Z, 1½” / tr, 11.5:1
2-ply: 2z5
12.5 yd, 7.2 g, 790 ypp, 2s/2-worsted ct.
4 tpi, 18 wpi, 26° ply angle

Corriedale Wool
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<tbody>
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<td>5.0&quot;</td>
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<td>5.7&quot;</td>
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<td><strong>0.43</strong></td>
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<tr>
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#8 Cormo
commercial roving
short fwd draw Z, 1½" / tr, 11.5:1
2-ply: zzS
10.0 yd, 4.3 g, 1060 ypp, 3s/2 worsted ct.
4.5 tpi, 13 wpi, 27° ply angle
## Cormo

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<td>36.0%</td>
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<tr>
<td>P':S'</td>
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Merino Wool
### Merino

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<td>5.0'</td>
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<td>Stretched Len</td>
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<td>0.61</td>
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#10 Alpaca

commercial roving
short fwd draw Z, 1½" / tr, 11.5:1
2 ply: zzS
13.9 yd, 7.4 g, 850 ypp, 3s/2 worsted ct.
4 tpi, 18 wpi, 15° ply angle
<table>
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<th>Sample 1 (Left)</th>
<th>Sample 2 (Right)</th>
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</table>
#11 Mohair

commercial roving
short fwd draw Z, 1½”/tr, 11.5:1
2-ply: 2x2
129 yd, 9.2 g, 640 ypp, 2s/2 worsted ct.
35 tpi, 18 wpi, 20° ply angle
<table>
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<th>Sample 1 (Left)</th>
<th>Sample 2 (Right)</th>
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<td>5.0'</td>
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<td>Stretched Len</td>
<td>5.1'</td>
<td>5.1'</td>
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<tr>
<td>Elasticity</td>
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<td>3.1</td>
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</table>

Mohair

**Note:** The data presented is for experimental purposes and may vary based on specific conditions and factors.
#12 Cashmere

commercial roving
short fwd draw Z, 1½" / tr, 11.5:1
2- ply, zzS
11.9 yd, 5.5 g, 980 ypp, 3s/2 worsted ct.
5 tpi, 11 wpi, 30° ply angle
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<td>5.0'</td>
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<td>6.5'</td>
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<td>Ply twists/5&quot;</td>
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<td>Singles length</td>
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Cashmere
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<td>5.1'</td>
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Flax

commercial roving
short fwd draw Z, 1½" / tr, 11.5:l
2-ply: zz5
12.5 yd, 7.5 g, 760 ypp., 5s/2 hca
3.5 rov. 18 wpi, 10-ply angle
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<td>5.0”</td>
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<tr>
<td>Stretched Len</td>
<td>5.0”</td>
<td>5.1”</td>
</tr>
<tr>
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<td>0.4%</td>
<td>1.2%</td>
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<td>4.9</td>
<td>5.0</td>
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<tr>
<td>Spin twists/5”</td>
<td>27.5</td>
<td>31.0</td>
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#15 Ramie

commercial roving
short fwd draw Z, 1½" / tr, 11.5:1
2-PLY: zzS
17.7 yd, 4.9 g, 1640 ypp, 1ls/2 lea
4 tpi, 26 wpi, 9° ply angle
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<td>5.1'</td>
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<td>1.2%</td>
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<td>16.5</td>
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#16 Cotton

commercial roving
short fwd draw Z, 1½" / tr, 11.5:1
2-ply: zzS
11.6 yd, 3.2 g, 1650 ypp, 4s/2 cotton ct.
4 tpi, 18 wpi, 13° ply angle
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<td>Stretched Len</td>
<td>5.5'</td>
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<td>10.0%</td>
<td>8.8%</td>
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Viscose Rayon
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Stretched

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#18 Tencel

commercial roving
short fwd draw Z, 1½"/tr, 115:1
2-ply: ZzS
15.8 yd, 6.3 g, 1140 ypp, 4s/2 worsted ct.
3 tpi, 25 wpi, 12° ply angle
## Tencel

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<tr>
<td>Stretched Len</td>
<td>5.1'</td>
<td>5.1'</td>
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<tr>
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<td>1.2%</td>
<td>1.2%</td>
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## Stretched

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#19 Soysilk

commercial roving
short fwd draw Z, 11/2 in, 11.5:1
2-ply, zzS
13.1 yd, 3.6 g, 1650 ypp, 4x2 synthetic ct.
4 tpi, 25 wpi, 14° ply angle
<table>
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Stretched

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<td>P':S'</td>
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Soysilk
Angela K Schneider  Master Spinner L6

#20 Nylon

commercial roving
short fwd draw Z, 1½" / tr, 11.5 to 1
2-ply, 22 S
11.9 yd, 4.0 g, 1350 ypp, 3s/2 synthetic ct.
5 tpi, 22 wpi, 20° pply angle
### Nylon

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<td>5.1&quot;</td>
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<tr>
<td>Elasticity</td>
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