16. Effect of Fibre Properties on Processing
Greasy Wool into Worsted Yarn

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Learning objectives

On completion of this topic you should be able to:

• explain how and why greasy wool fibre properties affect topmaking
• explain how and why top properties affect yarn properties and spinning performance
• explain of the key drivers of the specifications for tops and greasy fibres
• describe the relative importance of fibre properties in early stage processing

Key terms and concepts

Diameter and length distributions, diameter profile, crimp and curvature, TEAM regression fits, yarn properties, spinning performance, topmaking prediction, spinning prediction, relative importance of fibre properties

Introduction to the topic

This topic describes the effect of fibre properties on performance in the conversion of greasy wool through to top, and into worsted yarn. The spinner’s requirements drive the specification of top properties and ultimately what wool is purchased and, together with supply and demand, the price relativities. The potential performance in spinning and the yarn properties are determined or limited by the fibre properties and so it is possible to predict expected performance and establish a firm basis for the relative importance of fibre properties. The worsted processing route was outlined in Topic 1.

16.1 The requirements of the ‘customer’

In the worsted system of yarn manufacture, the topmaker is the ‘customer’ for the seller of greasy wool while the spinner is the ‘customer’ of the topmaker. Each customer has specific requirements in the raw material provided by their respective suppliers.

The topmaker’s requirements

The topmaker receives consignments of greasy wool to produce a quantity of top to a given specification. Except for very fine wool the topmaker prefers that consignments exceed 10 tonnes and charges a higher commission to process smaller consignments. About 15 tonnes of top can be packed into a 6 metre shipping container and it is convenient to deal in whole containers of either greasy wool or top. Given that the average sale lot is 4 to 5 bales of 200kg there will be typically 20 or more sale lots in a consignment.

Part of the art of the topmaker is to purchase the set of sale lots of the lowest total price that can be processed to just meet the specification in terms of quantity and properties. If the top does not meet specifications, particularly in terms of diameter, length and cleanliness, then it may be rejected by the customer. Most contracts conform to the terms set out in the IWTO (International Wool Textile Organisation) Blue Book with the measurement methods and standards set out in the IWTO Red Book. The topmaker does not want to produce top that significantly exceeds specifications because this generally means that too high a price was paid for the wool. Instead, the topmaker will build in a “margin of error” to protect against failure to meet specifications or the risk of a subsequent claim if contamination is found in the top, yarn or (most seriously) the fabric. “Contamination” can include pesticides, dark fibre, plastics, metal...
objects, unscourable brands, pack material, twine etc. The topmaker's key demands of the fibre relate to the wool performing as expected, no surprises, and having the measured attributes.

The spinner's requirements

Spinners require a top to meet a list of technical specifications, as well as a price. These specifications are designed to ensure that the top will perform as expected in the spinning mill and also downstream in weaving or knitting, ultimately to give the desired fabric at the best price.

Because they are the prime determinants of spinning performance, the fibre properties, diameter (D) and length (hauteur H), are always specified and wools chosen according to the yarn being spun. Most mills specify limits on the length distribution in terms of hauteur distribution (CV_H) or short-fibre content. Limits on diameter distribution (CV_D) are becoming routine but are not usually stringent.

Fibre strength of undyed top and curvature of top are not normally specified. Limits are set for colour and on the level of faults such as nep and pieces of vegetable matter (VM) and, for critical light-coloured fabrics, dark fibre levels will sometimes be specified. Limits on other contaminants, for example plastics, are not usually specified but when unacceptable levels are found in the fabric a claim is made against the spinner who will then make a claim against the topmaker. Evenness, regain and total fatty matter will usually be specified but some top attributes such as the quality of scouring and combing, and suitable lubricant and antistat, are difficult to determine from measurements of the top. Therefore, the spinner relies on a good relationship with the topmaker.

Spinning performance and downstream yarn performance are critical because both spinning and weaving cost, typically, three to five times as much as all of topmaking. Yarn breaks are so expensive in terms of labour cost and lost productivity that it is common for less than one break every 50 km to be allowed (Plate 1990). For a fine worsted yarn being produced at 1 km/hr/spindle this equates to a maximum of 40 ends-down per thousand spindle hours.

16.2 Prediction formulae

Essentially all Australian wool destined for the worsted system is measured for diameter and yield, and most is measured for staple length, staple strength and position of break. There are standard procedures for taking samples and for making the measurements and the average errors are known. Most wool is sold through the auction system and a representative sample made up from grab samples is displayed and available for inspection prior to auction. All display samples will be given an AWEX type according to a set of subjective attributes. This and other information, which includes diameter distribution and curvature plus the amount of wool, wool growing area, brand etc., is presented in the auction catalogue.

Team formulae

The Trials Evaluating Additional Measurement (TEAM) formulae are the result of an attempt to achieve a robust set of prediction formulae for length, length distribution and romaine (noil) that apply to consignments of merino wool. They were initially developed to enable the processor to take advantages of the ATLAS measurements of staple length (SL) and strength (SS) and have been highly successful at enabling the sale of wool by sample (i.e. by measurement and display sample) and in improving the understanding and reliability of processing of Australian wool. The TEAM formulae are simple linear regression fits that take into account that the fibre length in the top will be related to the fibre length of the greasy wool minus the amount of breakage (which increases for longer, finer, weaker, thin-in-the middle and more heavily VM contaminated wool). The TEAM formulae were developed for consignments, not sale lots or special batches of fleeces, processed in a wide range of commercial mills and therefore reflect average properties processed under average conditions. The formulae allow for mills to add a constant (correction factor) to each formula to take into account that some mills perform better than others, e.g. by introducing less entanglement or by using different loadings.
The TEAM2 formulae are presented in Table 16.1. The regression variables are staple length (SL), staple strength (SS), fibre diameter (D), vegetable matter (VM), corrected percentage of mid-staple breaks (M*) and a mill correction factor (Mill).

Table 16.1 Co-efficients of regression variables fitted to TEAM2 formulas for Hauteur (H), Coefficient of Hauteur (CV_H) and Romaine (R). Source: Lamb, 2006.

<table>
<thead>
<tr>
<th></th>
<th>H</th>
<th>CV_H</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>SL</td>
<td>0.52</td>
<td>0.12</td>
<td>-0.11</td>
</tr>
<tr>
<td>SS</td>
<td>0.47</td>
<td>-0.41</td>
<td>-0.14</td>
</tr>
<tr>
<td>D</td>
<td>0.95</td>
<td>-0.35</td>
<td>0.94</td>
</tr>
<tr>
<td>VM</td>
<td>-0.45</td>
<td>0.20</td>
<td>0.94</td>
</tr>
<tr>
<td>M*</td>
<td>-0.19</td>
<td>0.94</td>
<td>-3.5</td>
</tr>
<tr>
<td>Mill</td>
<td>-3.5</td>
<td>49.3</td>
<td>27.7</td>
</tr>
</tbody>
</table>

Topmakers have considerable experience on how different wools process and some have developed their own prediction formula according to the type or diameter of the wool being processed. The inspection of the display sample can be seen as insurance against problems wools (tippiness, cotted, rotten, mildewed, discoloured, contaminated, difficult-to-remove VM types, second cuts etc.) and to take into account visual clues, e.g. crimp frequency, crimp definition and dust penetration, that are believed to influence processing. However, the evidence is that the processing performance of most wool lots can be reasonably predicted with the major discrepancies being related to variations in diameter along fibres due to varying nutrition, stress and feed requirements and to the accuracy of the measurements of greasy fibre length and strength.

16.3 Effect of greasy properties on top properties and topmaking performance

The key fibre properties of top are mean diameter (D), mean fibre length (H), the spread in lengths (CV_H) and/or the short-fibre content, the diameter distribution and the fibre strength.

The mean fibre length by number (hauteur, H) is typically measured by an instrument called the Almeter (See Topic 3). A beard of fibres with their ends aligned is prepared from the top then the mass distribution is measured from base to tip of the beard. A decrease in mass is interpreted as fibres finishing and in this way a distribution of fibre lengths is built up. The length distribution can also be determined by hand drawing out of fibres according to their length or by pulling out and measuring the length of individual fibres; an extremely laborious procedure. The spread in properties is normally presented in terms of a percentage co-efficient of variation (100 times the standard deviation divided by the mean) and hence we have CV_D (the co-efficient of variation of diameter) and CV_H (the co-efficient of variation of hauteur). The spread in greasy fibre lengths is relatively small prior to fibre breakage so CV_H is seen to increase with increasing breakage and hence with decreasing H.

The strength of the top can be measured by gripping a small section of fibres between two pairs of closely spaced jaws (typically 3.2mm apart), measuring the force to break and then weighing the fibre that was gripped by the jaws.

Losses in topmaking are usually presented in terms of romaine (comb noil as a percentage of top plus noil), tear (ratio of top to noil) or yield in terms of mass of top as a percentage of the mass of greasy wool. Performance is considered in terms of H relative to the expected length, total losses and the rate of production. It also covers meeting all specifications including upper limits to faults/contamination such as VM and neps. The various greasy wool properties will now be considered in terms of their impact on top properties and topmaking performance.

Yield

In general, the yield is just taken into account in terms of calculating the amount of top that will result after removing all grease, dirt, suint and VM. However, low yields mean that there is more dirt or grease which may require more severe scouring resulting in additional entanglement, or that there is more VM which results in additional wool loss and fibre breakage.
Lower yields are also associated with drier, dustier environments and imply that the sheep were exposed to harsher or more variable nutritional conditions.

**Diameter (D)**

The finer the fibre diameter the more easily fibres entangle and felt. Finer fibres are weaker (per fibre) and, on average, have higher bulk. Hence breakage and \(CV_H\) should be expected to increase and hauteur to decrease with decreasing diameter, and this is observed. Finer fibres also mean that there are more fibres by number per tooth or pin in processing and it seems that fibres are more easily individualised at low fibre loadings. It is typical to lower loadings for finer wool and to adjust scouring conditions. So production in terms of weight of top per unit time tends to decrease as diameter decreases.

Fibre diameter increases in the presence of moisture and the moisture content depends on how the wool has been treated so the diameter can only be compared when test conditions have been controlled. Most dyeings have negligible impact on fibre diameter as measured by the Laserscan.

**Diameter distribution (CV\(_D\))**

The average coefficient of variation of diameter CV\(_D\) observed for Australian wools for both commercial tops and sale lots has been found to conform to the relationship \(CV_D\% = \mu m/2 + 10.5\) (Naylor 1996). The similar mean values for tops and sale lots is because it is unusual to mix sale lots with significantly different values (>±1 \(\mu m\)) of mean diameter. For wools of 20 to 24 \(\mu m\), about 95% of sale lots have \(CV_D\) between 19 and 26%. It is therefore difficult for a topmaker to put a consignment with low \(CV_D\) together. A survey of the diameter distribution of 100 commercial tops from four different top makers gave an observed range of \(CV_D\) values in tops that was much smaller than in sale lots, only about ±1.5, in units of %, about the mean value for that fibre diameter.

The \(CV_D\) value of a sale lot arises from the \(CV_D\) values of individual fleeces and the range of fleeces in the lot. The range of mean fleece diameters present in a flock is probably larger than the range in diameter of sale lots blended in a consignment, so that binning of fleeces according to on-farm diameter measurement will slightly reduce the average \(CV_D\), but most of the variation is already present in a single fleece. The variation within a fleece is the result of diameter differences between fibres (genetic) and the variation in diameter along fibres (nutrition, environment and genetics).

A small effect on topmaking due to a wider range of diameter between fibres is expected because fibre strength is proportional to \(D^2\) and entanglement is likely to be dependent on a higher power of \(D\). There should then be terms in \(D^2\), or similar, in the TEAM formulae but so far a linear dependence on \(D\) has been sufficient and it has not been found necessary to introduce such terms. The effect of variation in along-fibre diameter is to reduce the breaking strength of fibres which might be expected to lead to more breakage in processing. Both TEAM3 and an earlier study of sale lots (Lamb 2000b) observed a similar and significant dependence of hauteur on \(CV_D\). The inclusion of a \(CV_D\) term also greatly reduced the significance and size of the staple strength (SS) term presumably because the two are related measures of fibre strength. The size of the \(CV_D\) term is significant in the sense that an increase of 5 units (%) is associated with a decrease in \(H\) of 5 to 7mm but it has not been observed to have a marked effect on noil.

**Staple length SL**

The ATLAS instrument measures the length of a sample of staples taken from a grab sample. The fibres within a staple are not straight and also have a range of lengths. On average the mean length of fibres within a staple has been measured to be 1.17 times the length of the staple but this ratio has been observed to vary between 1.0 and 1.35. It is likely that this variation is a significant cause of errors in prediction and belly wools, for example, in which the staples appear to get shortened by agitation on the sheep measure differently.

If there was no fibre breakage the hauteur would average 1.17 times the staple length. In reality the hauteur has a dependence of about 0.5 * SL. The necessary conclusion from this is that
longer staples suffer relatively more fibre breakage in processing although longer staples still give longer tops. The suggested reason is that it is relatively more likely that long fibres will be gripped strongly in two places during carding and get broken. Noil, however, which includes both entanglements and short fibre is observed (TEAM2) to decrease as SL increases. So, for topmaking performance, there is no reason to penalise longer SL.

**Staple length distribution (CV\(_{SL}\))**

CV\(_{SL}\) is a measure of the range of staple lengths found in the grab sample and then calculated for the whole wool consignment. A high value could indicate that sale lots with markedly different mean staple lengths were blended or that there was a big variation in staple length between sheep or within sheep which may even partly reflect the quality of shearing and of skirting. Given that the coefficient of variation of fibre length within a staple is likely to be larger than the variation of staple lengths but is not considered and that a non-linear term in SL has not been found necessary then it is inappropriate to consider a term in CV\(_{SL}\) as has been done in the TEAM3 analysis. The small correlation between H and CV\(_{SL}\) is more likely to reflect some artefact such as a correlation between the blending practices and topmaking performance of better and poorer mills!

**Staple strength SS**

The ATLAS measurement of staple strength determines the force required to break a staple at its weakest point, which is usually the point of minimum cross-sectional area. The peak force at break is normalised by the average linear density, determined from the weight of the staple corrected for the measured length and yield. Staple strength thus has units of tenacity (N/ktex) but the mean linear density rather than the minimum is used. The peak force results from the combined behaviour of a large number of individual fibres. Any variation in thickness along the fibre reduces the total load that can be supported and variation between fibres in thickness and length means that they can extend at different times and rates and so not share the load equally or not break at the same time, which reduces the peak force. Thus staple strength is a measure of the average strength of the weakest places in single fibres modified by their collective behaviour and normalised by the average linear density.

Most wools have fairly similar intrinsic tenacity but lower SS can also arise from trace element deficiencies, microbial damage and weathering.

**Mid-breaks and along-fibre diameter profile**

It has long been argued and observed that staples with higher levels of mid-breaks, as measured by ATLAS, will break more in processing and so give higher CV\(_H\) and shorter H. The position of break by itself does not influence H because the mean length of the two broken parts is independent of the position of break (except to the extent that a short component is removed in combing). It is postulated that a weak place near the middle of the fibre is more likely to be broken because it is more likely that the weak place will be between two places being gripped during carding.

Studies using the Laserscan or OFDA instruments to measure along-fibre diameter profiles of staples have found that thick-in-the-middle profiles give a longer H, lower CV\(_H\) and less short fibre than expected while thin-in-the-middle profiles have the opposite effect (Oldham & Peterson 2000). For southern Australia such profiles correspond to Autumn and Spring-shorn wool respectively. Recent analyses have discovered that most of the apparent effect can be explained as an artefact of the flaw in the way the Almeter determines H and CV\(_H\). When the fibres get thinner the Almeter sees a drop in signal and interprets this as fibres stopping. The correlation between M*, SS and along-fibre diameter profile means that these parameters on actual length needs to be re-examined (although they influence the existing Almeter values used in specifications).

**Vegetable matter VM**

The AWTA measurement reported in the sale catalogue divides vegetable matter into burre, seed/shive and hardheads. These three different vegetable matter types a shown in Figure 16.1.
In addition the AWEX-ID description carries some information about the major type of VM present. Burrs are relatively more easily removed in carding and combing until broken open. The most difficult to remove plant contaminants are the shive types such as barley grass because they have components that are fibrous (long and thin) and surfaces that grip fibres. Hardheads can jam in card wire but do not easily get through to the top. However, they present problems for carbonising in the woollen system. A certain percentage of each type of VM will get through to the top depending on the quality of equipment, settings and maintenance so the level and type of VM are of potential concern to the topmaker. Removal of VM also leads to loss of fibre attached to the VM and higher VM levels are, on average, associated with shorter hauteur and more fibre breakage. The TEAM2 formula implies that nearly 1% of combing noil results from each 1% increase in VM in the greasy wool even though >90% of the VM by mass will be removed at the card prior to combing.

**Crimp and curvature**

Historically, wools of high crimp frequency have been more highly valued and there is still a premium for higher crimp frequency in otherwise similar sound, superfine wools. This premium originally related to the fact that higher crimp frequency is associated with finer diameter. This is no longer true for different fleeces within one mob of fine-wooled sheep (Hansford & Humphries 1997) but there remains a marked correlation between mean diameter and crimp frequency for sale lots and, more so, for consignments.

Curvature, as measured by Laserscan or OFDA, has been shown to have a close relationship to crimp frequency, with low crimp frequency corresponding to low curvature. Curvature is the rate of change in direction (in degrees) a fibre bends per mm along its length.

It should be directly proportional to crimp frequency if the depth of crimp (amplitude) is the same for wools of the same crimp frequency. Unfortunately, curvature is not a fixed property and is gradually reduced by processing as the fibres are straightened. The curvature of top is not a very stable property but is typically about 70% of that of the greasy wool. However, a curvature value fairly similar to that of the greasy wool can be recovered by wet relaxation of the top, if it has not been dyed. The relationship, if any, between depth of crimp and curvature for constant crimp frequency has not been determined. Hence, there may be some crimp attributes that are not covered by a measurement of curvature. It has been observed that crimp frequency and curvature vary with the rate of growth of fibres so that the same sheep on a higher plane of nutrition will grow longer wool of lower curvature. There is also a marked correlation between fleece weight and curvature so that a selection on heavier fleece weight is a selection on lower crimp frequency (Purvis & Swan 1998). A measurement of resistance to compression is available, which is closely related to bulk, but it is also approximately proportional to the product of diameter and curvature.
Trials examining extremes of curvature in which the other fibre properties, including SL and along-fibre diameter profile, have been well-matched have found a small improvement in hauteur and noil with decreasing curvature. The effect on hauteur is small as evidenced by the regression fits above where a decrease of 12 to 16°/mm is associated with a 1mm increase in H. It is therefore not surprising that the effect was not statistically significant in the TEAM3 analysis where the diameter and curvature of consignments was strongly correlated. For noil it is consistently observed that an increase in curvature is associated with an increase in wastes (typically 0.5% for 10°/mm). This is a little surprising given that higher crimp tends to reduce felting in water but may arise from the increase in bulk and likely stronger interaction with pins and teeth in processing. It is interesting that breeding for increased fleec weight at constant fibre diameter will lead to wool that fetches a lower price (Curtis & Stanton 2000) but which performs slightly better in topmaking.

It has been claimed that wools of high crimp definition, a visual assessment of the clarity and uniformity of the crimp, give rise to longer hauteur. One trial (Stevens & Crowe 1994) claimed enormous effects for both crimp frequency and crimp definition. In the light of subsequent trials which have not seen large effects the results must be treated with considerable caution. Potential explanations for the suspect results include that the crimp frequency, crimp definition and fibre attributes do not seem to have been re-measured after the selection for extremes (which will introduce a bias in SL, for example), and that CVD and along-fibre diameter profiles may have been different but were not measured.

**Style and AWEX-ID**

Style characteristics are visual assessments of staple properties including density, character (crimp definition), length regularity, tip type, visual colour and dust penetration. The AWEX-ID (Australian Wool Exchange Ltd 2002) is a descriptor of these properties and other non-measured characteristics of greasy wool made by trained appraisers. The AWEX-ID Style does not necessarily imply any expected processing capabilities and there is little evidence that any of these attributes have a significant effect on processing beyond that attributed to the measured property (e.g. high dust penetration being associated with lower yield). The AWEX-ID can also distinguish weaners and fellmongered wool, fleeces and bellies, and VM type, and has qualifiers for unscourable colour, cotted wool etc., so can help prevent surprises if the buyer has not had a chance to visually inspect the wool. The AWEX-ID can label wool finer than 18.5µm as Australian Superfine (AS) or Merino (M) but it can only be labelled AS if it has high crimp frequency (traditional superfine appearance).

**Other greasy wool attributes**

There may be other attributes between fleeces that affect processing performance but their effects are small or averaged out within sale lots and consignments. A short square tip is a preferred style attribute but seems to have little effect. Weathered tips will tend to break off during processing and so lead to lower yields and shorter hauteur but a simple and reliable method of quantifying weathering is not available. Sheep coats, which reduce weathering, give longer hauteur and less waste but some of this is due to the lower VM. It has been claimed that some wools have better fibre ellipticity (roundness) but the only well established tendency is for finer diameter wools to be more nearly round. It has been observed that some wools felt more rapidly than others but most of the differences can be explained by differences in diameter and curvature with finer, lower curvature wools felting more readily. It may be that some wools have a less pronounced scale structure, particularly in water, but no one has shown this for otherwise similar wools. Greasy wool brightness and colour are poorly related to scoured colour so it is difficult to select wools which will provide a whiter substrate and so give brighter colours in dyeing. There are now test methods for pesticide levels and for dark fibre. Measuring a small sample cannot guarantee freedom from dark fibre but such tests may become economically attractive when freedom from pesticides (eco-labelling) or dark fibre (pastel shade fabrics) is required.
16.4 Effect of fibre properties on yarn properties and spinning performance

A very extensive review of the effects of fibre properties in processing was carried out in 1980 (Hunter 1980). Many of the publications reviewed went back to older spinning and drafting equipment, such as the Bradford system. Since that time the Continental system has dominated and the preparation route, the spinning frames, and their drafting arms have become very similar in all modern mills. However, the broad conclusions about the effect of fibre properties are thoroughly confirmed and quantified by more recent trials. The results presented below are solely for pure woolworsted yarns spun on modern ring frames. There are other systems available such as air-jet, friction and rotor spinning, but these have negligible market share for wool apparel yarns and the general conclusions should apply anyway. Recently there have also been some developments on the ring frame such as Sirospun, Solospun and compact spinning. These variants improve the binding of surface fibres, reduce yarn hairiness and can affect yarn tenacity slightly. However, the relative contributions of fibre properties are unchanged.

What has changed since 1980 is the better incorporation of physical modelling into the analysis of experimental data and the validation of the quality of the resulting prediction algorithms using data from commercial mills. It had become very common to carry out multiple regression analyses on data from large experiments where there were numerous correlations between yarn parameters and fibre properties and no physical insight used to constrain the fits. Some of the pitfalls of such an approach have been illustrated (Lamb 1988). More recent trials, such as those seeking to elucidate the effect of diameter distribution, have used wools matched for most fibre properties but with wider than normal variation in the property of interest, and with the trial repeated at several diameters and for different yarn parameters. The data has then been fitted based on a physical understanding of expected behaviour (Yang & Lamb 1998).

It is then found that the normal spinning performance and properties, of a yarn of specified twist and thickness (linear density), can be accurately predicted from knowledge of fibre properties (Lamb & Yang 1995b, 1996a, 1998). The reason for this ultimately lies in the fact that the broad limits are imposed by the statistics governing a finite average number of fibres, and that most mills have very similar spinning machinery. Therefore, it is possible to outline the effect of fibre properties with some confidence.

Diameter (D)

For a given yarn linear density, the mean number of fibres varies inversely as the square of the fibre diameter and it is the mean number of fibres (n) that determines yarn evenness and the number of thin places. Therefore, diameter is overwhelmingly important in determining the number of ends-down for a given yarn thickness and, hence, in determining the minimum fabric weight. The mean diameter is also the major factor controlling yarn bending stiffness and yarn strength and elongation.

Diameter distribution (CV_D)

The actual range of CV_D that occurs in tops is fairly limited (Naylor 1996). The effects of fibre diameter distribution have been carefully studied (Lamb, DeGroot & Naylor 1993; Lamb 2000a) using wools with a much wider than normal range of CV_D. The experimental results are in excellent agreement with theoretical expectations. If there is a wide distribution of fibre diameters, then the effect is as if the mean diameter were a little larger. The implication of this refinement, for typical Merino wools, is that a percentage change in coefficient of variation of diameter of 5 units is equivalent to a change of 1 µm in mean diameter. In other words, a 20 µm wool with CV_D=25% could be replaced by a 21 µm wool with CV_D=20% and the spinner will see negligible difference in yarn and fabric properties, spinning performance or, as it turns out, next-to-skin comfort. There is only limited recent data on the effect of CV_D on ends-down in spinning, but it is consistent with the expected effect.
Notes – Topic 16 – Effect of Fibre Properties on Processing
Greasy Wool into Worsted Yarn

It is likely that there will be a tendency for some wool buyers to put separate, and occasionally unreasonable, limits on both diameter and diameter distribution. Such a buyer will end up paying more than the astute buyer who is prepared to trade one attribute off against the other and end up with the desired spinning performance at a better price. Yarns from wools which have the same effective fineness, matched in terms of \( D \sqrt{1 + (5 CV_D/100)^2} \), as well as length and strength, will be indistinguishable. The above formula takes into account the fact that fibres with a wider range of diameters behave as if they had a higher mean diameter.

A given value of \( CV_D \) can arise due to along-fibre diameter variations or between-fibre diameter variations. In principle, when combined into a locked structure (yarn) the components are indistinguishable as the source of variation in yarn properties (except for the length scale of the variations). No studies have been made that try and distinguish effects on spinning from the two sources of diameter variation.

**Hauteur (H)**

The mean fibre length measured in top by the Almeter instrument is referred to as the hauteur H. However, since the average number of fibres in the yarn cross-section is the prime determinant of evenness, the evenness is almost independent of fibre length. Only a small improvement in yarn evenness is observed with increasing fibre length. Fibres cannot contribute to yarn strength until their ends are bound by other fibres. Therefore, longer mean fibre length gives rise to increased yarn tenacity.

Ends-down and unevenness increase markedly at mean fibre lengths below 55 to 60 mm when the wool becomes too short for good fibre control on worsted drafting systems. It has been found that the spinning performance continues to improve with increasing hauteur out to at least 95 mm (Lamb & Yang 1996b). The machine settings (ratches) on the drawing machinery, but not the spinning frame, need to be increased for the longer wools, but this is a simple procedure. The one proviso is that the tops should not have a significant fraction of fibres longer than the drafting zone of the spinning frame. With current spinning frames, this is normally around 200 mm. For most Merino wools, fibres as long as 200 mm do not seem to occur unless the wool is overgrown, that is, there is more than a year between shearings.

A consistent effect of evenness and hauteur on tenacity has been observed in experiments. For a fine yarn the effect of a 25mm increase in H on evenness is similar to that of a \( 1 \mu m \) reduction in mean diameter, while for tenacity and ends-down a 10 mm change matches \( 1 \mu m \), although the exact trade-off is dependent on the average number of fibres.

Results from the Pricemaker\® analysis of the premiums and discounts paid at auction, and other studies (Swan, Piper & Purvis 2000) have revealed a peak in the price paid as a function of staple length (with the peak being much more marked at finer fibre diameters and with the position of the peak increasing from about 83 mm for \( 16 \mu m \) to 95mm for \( 23 \mu m \) wools). In other words, the market has actually penalised "over-long" wools. A more recent study (Lamb & Curtis 2004) has shown that there is now a plateau rather than a marked turn down at long staple length except for superfine wools, particularly those of high staple strength. This appears to be partly due to a belief by some spinners that a wool can be too long. Recent trials have not found any evidence to support such a belief. In one trial (Lamb & Yang 1996b), an especially long top (98.4 mm hauteur) of \( 22 \mu m \) mean fibre diameter was processed. No troubles were encountered in drawing and spinning with only the ratches of gill boxes and rover being adjusted. The wool spun well, despite having an average of only 31 fibres in the cross-section. Moreover, it was possible to spin with a lower than normal twist level and still get good spinning and excellent weaving performance, thus improving production as well as making a marginal improvement to fabric softness. A commercial trial using two long tops processed in five mills around the globe gave performance in good agreement with the claimed advantages of longer hauteur (Lamb & Oldham 2000).

The negative belief in "overlong" wool seems to be strongest amongst fine wool spinners. The most likely explanation is that a spinner will set up the machinery settings for the standard short wool and when the longer wool is gilled or roved without adjustment the long fibres are too strongly held and do not draft well. Longer wool also needs different settings in re-combing.

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Length distribution (CV_H)
There is a widespread belief that there is an optimum distribution of fibre length in top, corresponding to a Coefficient of Variation of Hauteur (CV_H) of about 40%, in order to achieve minimum yarn unevenness and optimum spinning performance. However, a careful examination of the literature and recent trials shows no concrete evidence for this assertion (Lamb & Yang 1995a; Lamb & Oldham 2000). However, CV_H can also partly reflect the extent of fibre breakage in processing and the staple strength (SS) of the input wool. It is also strongly correlated with H, with high CV_H corresponding to shorter H. This lack of any substantial dependence of yarn properties on CV_H has been confirmed in results from leading Italian mills. However, the belief of an optimum CV_H of around 45% is very widely held and most topmakers will have difficulty in selling a top with a CV_H greater than 50%. It is possible that the belief may have arisen partly from mill experience when processing tops which had been put together from extremes of short fine and long coarse wools. These tops would have often had a high CV_H and would have processed more poorly than expected. However, a measurement of CV_D would have explained the poor performance. As stated, high CV_H is also associated with short hauteur and high short fibre content. These values are also likely to be relatively large if combing has been poor or the fibres have been particularly weak. Thus the conclusions about the lack of importance of CV_H assume that combing has been good and that differences in other fibre properties have been taken into account. A trial in five Indian spinning mills with two tops matched for fibre properties other than CV_H showed no differences in performance (Lamb et al. 2002).

A high CV_H occurs most readily in long (e.g. fleece) wools with a weak point about one-third of the way along the fibre. It also tends to be associated with low staple strength. Upper limits on CV_H may therefore contribute to the penalty for long length and low staple strength in superfine wools where a penalty for high mid-breaks has also recently appeared (Lamb & Curtis 2004). The CV_H limits also tend to prevent a wide range of fibre lengths being blended. It seems that there is currently a market opportunity for purchasing long staple length, low staple strength wools as these can be under-valued or over-penalised.

It has also been shown recently that the value of CV_H determined by the Almeter can be seriously in error when there is a marked variation in along-fibre diameter profile, such that very high values of CV_H are most likely due to thin-in-the-middle profiles and very low values due to thick-in-the-middle profiles.

Short-fibre content
A few mills specify an upper limit on short fibre-content, e.g. that the % (by number) of fibres <30mm be less than 10%. Short-fibre content is strongly correlated with CV_H and H and its Almeter-measured value can be substantially in error if the along-fibre diameter profile varies (Brims 2002, 2003; Lamb 2003; Lamb 2004). In principle, short-fibre content is a check on the quality of combing, which is designed to remove all short fibre, although some breakage will also occur during combing. Re-combing typically only reduces the Almeter-measured short fibre content (%<30mm) by about 20% e.g. from 10% to 8%, so at this stage the measurement must be considered as suspect. Short fibres are less well controlled in drafting but when their measured total by weight (shorter fibres being lighter) is so tiny (typically <2% for fibres <30mm) and they are randomly spread through the sliver, they should not have a significant effect on yarn evenness or yarn faults. Re-combing has been observed to improve yarn evenness and reduce yarn faults but this is believed to be due to improved fibre individualisation and improved fault removal.

Strength
Bundle strength in top, using a short gauge, is a measure of the mean strength of the fibre keratin complex. It should be distinguished from staple strength which measures the weakest point along the whole staple of greasy wool and whose value primarily reflects changes in diameter due to nutrition or environment. The variation in the bundle strength of ecru wool tops, made from single sale lots, has been observed to be small, with a co-efficient of variation of only about 10% although the variation is partly associated with mean diameter. Chemical treatments, such as severe dyeing or shrinkproofing can damage fibres, reducing bundle strength and yarn
tenacity and elongation. Such chemical damage appears to be much more important than differences between ecru (undyed) wools.

Yarn strength will vary directly with average fibre strength measured at a gauge over which fibres are bound by twist to share the load. This has been confirmed in trials using the same wool damaged to varying degrees by dyeing. Studies have shown that incorporating bundle tenacity (BT), as measured using Sirolan-Tensor (Yang et al 1996; Yang, Schütz & Lamb 1997), significantly improves the prediction of yarn tenacity. It is estimated that a 10% decrease in fibre bundle tenacity will increase ends-down, near the spinning limit, by about 50%. In rough terms, a 10% change in fibre bundle tenacity trades-off against a change of about 6 to 9 mm in hauteur. However, it has been found that intrinsic fibre strength (measured at the point of break) and staple strength do not relate closely to bundle strength (Lamb 2004) although very low SS was correlated with a small reduction in bundle strength. Apart from this small correlation it is not currently possible to select wools that will give inherently stronger tops.

**Crimp/curvature**

By lower crimp is meant lower crimps per cm or crimp frequency as opposed to depth of crimp or the clarity or definition of the crimp structure. More than half of the original crimp, in terms of fibre curvature, is lost in processing from raw wool to yarn, though relative rankings remain. However, until the fibres are dyed or locked in a fabric structure, most of the crimp can be recovered by a wet relaxation. On the other hand, crimp definition, which is primarily a measure of whether groups of fibres curve together, is largely lost in scouring and carding.

Lower curvature is associated with improved yarn evenness and better spinning (Lamb, Robinson & Mahar 1996; Lobb et al. 1997; Kurdo, Whiteley & Smith 1986; Lamb 2000b; Lamb, Purvis & Robinson 2000) but it is difficult to separate the effects of hauteur and curvature. Curvature only has a small effect on hauteur but, because faster growing wools have lower curvature, there is a marked relationship in most studies between hauteur and curvature. The effects of curvature have generally been found to be small once strong correlations with other fibre properties, such as diameter and hauteur, have been taken into account. One trial (Dolling 2002) has seen relatively large effects on yarn evenness and tenacity/elongation and improved spinning performance but this trial also found differences in hauteur of more than 12mm, which easily account for the observed differences in yarn properties and spinning performance. Some studies (Stevens & Mahar 1995; Haigh & Robinson 2002) have failed to see significant differences when only small quantities of yarns have been measured. The more thorough spinning studies have indicated that a decrease of 7°/mm in curvature of the top (equal to a reduction of 10°/mm in the greasy, or -1 crimp/cm) is equivalent, for evenness, to an increase of 8 mm in H.

The OFDA, but not Laserscan, provides a measure of CV(Curvature). It has been argued that this is a measure of whether all fibres have the same curvature and hence may be related to crimp definition, however, one study found that variation in curvature did not reflect crimp definition (Crook, Nivison & Purvis 1999). This is not surprising as the path of a single fibre snippet on a slide is roughly sinusoidal with the curvature oscillating either side of zero. As far as is known the measurement is not considered in top specifications.

**Neps, contaminants (VM, dark and medullated fibre), residuals, weathering**

Neps, small entanglements of fibre, mostly arise on the card and are pulled tighter in gilling. Their number increases as the wool becomes finer. The vast majority are removed in combing. Any remaining will be removed by a re-combing but new ones gradually appear in further processing. In general, they are too small to affect spinning performance but their level appears to be correlated with the number of faults cut out of the yarn, which suggests that the mechanisms that give rise to new neps are similar to those giving rise to larger thick places (Lamb 1996; Prins & Robinson 1996).

Large contaminants, such as pieces of eyelash burr, can probably cause a spinning break on occasions, but their major impact is in holes in knitting and the cost of removing them in mending. Poor scouring, shown by high residuals, and excessive fibre damage from strong...
alkaline scouring have been shown to degrade spinning performance. However, these are not properties inherent to the wool on the sheep. Weathering can lead to more losses during topmaking and it seems that most weathered tip does not get through to the top. UV damage to the whole fibre should show up in terms of reduced hauteur and bundle strength. All these properties are difficult to measure on the top. For example, it is difficult to distinguish between grease left after scouring and lubricants added in processing. Improved measures of cleanliness and lack of damage would be desirable but are not considered further here as they are not seen as inherent properties of the wool fibre.

16.5 The relative importance of fibre properties

The theoretical understanding of the expected effect of fibre properties together with results of CSIRO and commercial mill trials have led to a series of prediction algorithms within a user-friendly computer program (Sirolan-Yarnspec) (Lamb & Yang 1996a).

The relative importance of fibre properties for yarn properties and spinning performance, which is encapsulated in these algorithms, can be summarised in a few simple statements:

- mean diameter is overwhelmingly the most important top fibre property
- mean fibre length is the next most important and 10 mm of hauteur can be traded-off against 1 µm in mean diameter in terms of its effect on yarn tenacity and ends-down in spinning. For evenness, about 25 mm trades off against 1 µm. Neither trade-off applies to fabric handle because fibre diameter, rather than tenacity and evenness, affects stiffness and softness
- the importance of fibre length distribution CV_H, on yarn properties and spinning performance, is small and over-rated
- the importance of diameter distribution CV_D is as expected, with approx. 5% in CV_D trading-off against 1 µm, for yarn and fabric properties and spinning performance
- a 10% change in fibre strength, in the top, trades off against 6 to 9 mm of hauteur, for yarn strength and spinning performance, but average fibre strength in the top is hardly related to staple strength
- higher curvature is associated with slightly poorer yarn evenness.

These messages are not meant to imply that, for particular end-uses, other attributes such as dark fibre, contaminants, colour and even neps are unimportant, but, in general they do not directly affect spinning performance.

The above ranking for relative importance primarily ranks fibre properties in terms of their impact on costs in processing, and independent of any correlations between fibre properties e.g. between diameter, hauteur and curvature. A finer diameter fibre may entangle more in scouring and will lead to a shorter top and more neps. It may also be processed through drawing at a lower production rate and lead to a yarn with different bulk (after allowing for curvature) but, when matched with another top differing only in mean diameter, it will give a stronger, more even, and less stiff, yarn with better spinning performance.

In order to illustrate the trade-offs, some of the Yarnspec (Version 5.20) predictions for yarn evenness and ends-down are presented below. The exact trade-off will vary according to the actual yarn and spinning conditions and other fibre properties, but the examples used are fairly representative for a medium to fine weaving yarn. The yarn evenness (CV%) and ends-down in spinning of such a yarn are shown as a function of fibre diameter in Table 16.2.
Table 16.2 Yarn evenness (CV%) and ends-down in spinning as a function of fibre diameter. Adapted from: Lamb (1997).

<table>
<thead>
<tr>
<th>Diameter μm</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of fibres</td>
<td>44</td>
<td>40</td>
<td>36</td>
<td>33</td>
<td>30</td>
</tr>
<tr>
<td>CV% (evenness)</td>
<td>19.0</td>
<td>19.9</td>
<td>20.9</td>
<td>21.8</td>
<td>22.7</td>
</tr>
<tr>
<td>Ends-down/1000 sp. hrs.</td>
<td>27</td>
<td>38</td>
<td>53</td>
<td>77</td>
<td>111</td>
</tr>
</tbody>
</table>

(Using: Nm 59, 17 tex, 675 tpm, CV₀=21%, H=70 mm, Curv. =75°/mm, fibre tenacity = 10.51cN/tex, re-combed, spun at 9000 rpm with #29 traveller on 50 mm rings.)

The spinning performance varies very rapidly with mean diameter. Forty ends-down per thousand spindle hours is about what is just commercially acceptable in high labour cost countries such as USA, Japan and Europe. For the middle wool with a mean fibre diameter of 21μm, the effect of CV₀ is shown in Table 16.3

Table 16.3 Effect of CV₀ on yarn evenness (CV%) and ends-down in spinning. Adapted from: Lamb (1997).

<table>
<thead>
<tr>
<th>CV₀%</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22.5</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV% (evenness)</td>
<td>20.5</td>
<td>20.7</td>
<td>20.9</td>
<td>21.1</td>
<td>21.5</td>
</tr>
<tr>
<td>Ends-down/1000 sp. hrs.</td>
<td>47</td>
<td>50</td>
<td>53</td>
<td>59</td>
<td>67</td>
</tr>
</tbody>
</table>

The extremes, which cover 90% of the range observed in sale lots of 21μm wool, show an effect roughly equal to that which would be achieved by a shift of 1μm in mean diameter. However, a mill is unlikely to encounter values of even this range in consignments of 21μm wool, unless wools of grossly different diameter have been blended together.

The effect of hauteur is illustrated in Table 16.4 for the yarn of Tables 29.1 and 29.2 with D = 21μm and CV₀ = 21%. Longer fibres lead to slightly more even and significantly stronger yarns and so to substantially fewer ends-down in spinning.

Table 16.4 Effect of hauteur on yarn evenness (CV%) and ends-down in spinning. Adapted from: Lamb (1997).

<table>
<thead>
<tr>
<th>Hauteur mm</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV% (evenness)</td>
<td>21.5</td>
<td>21.2</td>
<td>20.9</td>
<td>20.5</td>
<td>20.2</td>
</tr>
<tr>
<td>Ends-down/1000 sp. hrs.</td>
<td>119</td>
<td>76</td>
<td>53</td>
<td>39</td>
<td>30</td>
</tr>
</tbody>
</table>

For the wool and yarn of Tables 28.3, 4 and 5 with D = 21μm, CV₀ = 21% and H = 70mm, the effect on ends-down of 10% changes in bundle tenacity is shown in Table 16.5. The evenness is not shown because it is unaffected by bundle tenacity.

Table 16.5 Effect of bundle tenacity on ends-down in spinning. Source: Adapted from: Lamb (1997).

<table>
<thead>
<tr>
<th>Bundle Tenacity cN/tex</th>
<th>9.5</th>
<th>10.5</th>
<th>11.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ends-down/1000 sp. hr.</td>
<td>71</td>
<td>53</td>
<td>43</td>
</tr>
</tbody>
</table>

Comparison with Tables 15.3 and 15.4 indicates that a 10% change in bundle tenacity (BT) has a similar effect to a 7.5 mm change in hauteur or a change of 3 in CV₀%. However, as already noted, it is not possible at present to select greasy wools on the basis of their bundle strength in top.

It is important to realise that it is not being recommended to spinners that a specification for a 21μm wool should have, for example, H > 90mm, BT > 11.5cN/tex and CV₀ < 19%. Such overtight specification necessarily leads to a higher-priced top as the topmaker has a more limited choice of wools and must insure against the increased risk. Instead, improved knowledge of the relative importance of fibre properties should allow the topmaker and spinner to optimise the top purchase for the desired product and performance.
The aim is not to buy the "best" wool but the most suitable. This probably equates to the cheapest top that will perform to requirements (Lamb 1997).

### 16.6 Residual effects of greasy wool properties on yarn properties and spinning performance

It has been well established that good predictions of yarn properties and spinning performance can be made on the basis of measured top properties. There do not appear to be residual effects from greasy wool properties other than via measured differences in top properties. A review of staple strength (Lamb 2004) has shown that there is little evidence for effects beyond topmaking other than that due to the differences in hauteur that are associated with differences in staple strength. Downstream effects of differences in intrinsic fibre strength are expected, it is just that variations in staple strength are primarily due to other factors. Staple length influences hauteur which can then be used as the key length property. $CV_H$ replaces $CV(SL)$ as a measure of length variation but $CV_H$ is not significantly influenced by $CV(SL)$. The percentage of mid-breaks has an effect on hauteur but the position of the thin place is not expected to have additional effects and any remaining effects due to the severity of the thin place should be accommodated by the dependence on $CV_D$. The fibre diameter and $CV_D$ of the top reflect the greasy wool input and remain unchanged by further processing as fibre losses are small. Crimp, as measured by fibre curvature, is further altered during spinning and the effects in spinning appear to be small. Other style attributes such as crimp definition, tippiness, weathering, and staple shape are removed in topmaking, or make small contributions via differences in hauteur or fibre strength. The evidence is that tops perform according to their properties, as measured in the top. The main areas of uncertainty are in the ongoing contributions of staple strength, reliable measurement of fibre damage, and there is disagreement between mill purchasing practices and the measured importance of $CV_H$.

### Readings

The following readings are available on the web learning management system:

Summary

The fibre properties and wastes in topmaking are primarily determined by the greasy wool properties, with some small scope for the topmaker to control quality. The diameter and diameter distribution are determined by the wool that is purchased except that a small part is lost in processing. The length is determined by the length of the input fibres degraded by breakage due to entanglement but slightly improved by the removal of short fibre in combing. The breakage and losses are related to the amount of entanglement introduced by scouring and to the fibre length, strength, diameter, position of break and vegetable matter content. Diameter distribution and along-fibre diameter profile also have significant effects while lower curvature is associated with slightly better length and less wastes. The topmaker can achieve longer length or less waste by scouring more gently, by good lubrication and lower card loadings and by settings in combing, but this is generally at the expense of production. The art of the topmaker is to put consignments together from the available sale lots at the lowest total price while meeting the spinner's specifications without problems or surprises in processing. These specifications include not only fibre properties but freedom from contamination and faults of any form.

In terms of improved quality of yarn and spinning performance, the key quality attributes of wool top are, in order of importance, fibre diameter, length, strength, diameter distribution and curvature. Because of its impact on processing and on the desirability of the products, diameter is overwhelmingly important. Longer length in the top is better up to mean fibre lengths of at least 95mm but settings in drawing may need to be adjusted. The length distribution has little or no effect but a wide distribution is associated with more breakage in topmaking, shorter hauteur, and greater along-fibre diameter variation and thin-in-the-middle profiles. For undyed wools the strength of the top is relatively constant and only a little weaker if the staple strength is very low. Diameter distribution has well-established effects which can be accurately summarised by 5% in CV_D being worth 1µm. Curvature is related to the crimp frequency of the greasy wools and it appears that high curvature gives rise to marginally poorer performance. In addition, the biggest non-wool quality attribute is freedom from contamination in all its forms. Contamination is still the greatest complaint of the processor.

References


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Lamb, P.R. 2003, Note on the effect of Almeter errors on the prediction of top properties, CSIRO Textile and Fibre Technology, Internal note.


Plate, D.E.A. 1990, 'What are the Wool Characteristics which are of Importance to Wool Processors and End Users? CSIRO Division of Wool Technology, Geelong.

Notes – Topic 16 – Effect of Fibre Properties on Processing

Greasy Wool into Worsted Yarn


Glossary of terms

<table>
<thead>
<tr>
<th>Bulk</th>
<th>Volume occupied per unit mass of fibre under given load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commission processing</td>
<td>Processing, e.g. topmaking, of wool owned and selected by another party e.g. spinning mill</td>
</tr>
<tr>
<td>Creel</td>
<td>To mount input packages (rovings) on spinning frame</td>
</tr>
<tr>
<td>Doff</td>
<td>To remove full bobbins of yarn from all spindles on spinning frame</td>
</tr>
<tr>
<td>Dust penetration</td>
<td>The extent to which dust has penetrated down into the staple (it is not the same as dirt content which measures the mass of dirt and may be held near the tip by grease)</td>
</tr>
<tr>
<td>Intrinsic tenacity</td>
<td>The inherent strength (peak load per unit of linear density) of the material (fibre)</td>
</tr>
<tr>
<td>Re-combing</td>
<td>A second combing, similar to the first, but usually carried out by the spinner after dyeing or for fine diameter wool</td>
</tr>
<tr>
<td>Weathering</td>
<td>Damage caused to the outer ends (tips) of the fibres mostly by UV radiation</td>
</tr>
</tbody>
</table>