3. Fibre Diameter, Staple Strength, Style, Handle and Curvature

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Learning Objectives

On completion of this topic you should be able to:

- demonstrate an understanding of fibre diameter and the economic importance of fibre diameter
- explain and calculate the difference between the standard deviation of diameter and the coefficient of variation of diameter
- define the relationship between mean diameter, diameter variation and “coarse edge” or “prickle”
- measure staple strength and describe its economic importance
- explain the sources of variation in staple strength within a mob of sheep
- describe localised vs generalised fibre weakness as determinants of staple strength
- define and quantify the relationship between staple strength and each of minimum diameter, along-staple diameter variation, rate of change in diameter, fibre length variation and intrinsic fibre strength
- relate raw wool style including the main component traits to economic importance
- explain the influence of fibre diameter and fibre crimp on wool handle
- describe fibre curvature and the value of curvature

Key terms and concepts

Fibre diameter; coefficient of variation of fibre diameter; prickle and coarse edge; micron blowout; staple strength; variation in staple strength; determinants of staple strength; style; handle; curvature.

Introduction to the topic

This topic will discuss the economic importance of and sources of variation in fibre diameter, staple strength, style; handle and curvature.

3.1 Fibre diameter

Diameter is defined as the length of a straight line through the centre of a circle or sphere and wool fibres are assumed to be circular. Mean fibre diameter is the average diameter measured in millionth of a metre. The unit is commonly called microns (μm).

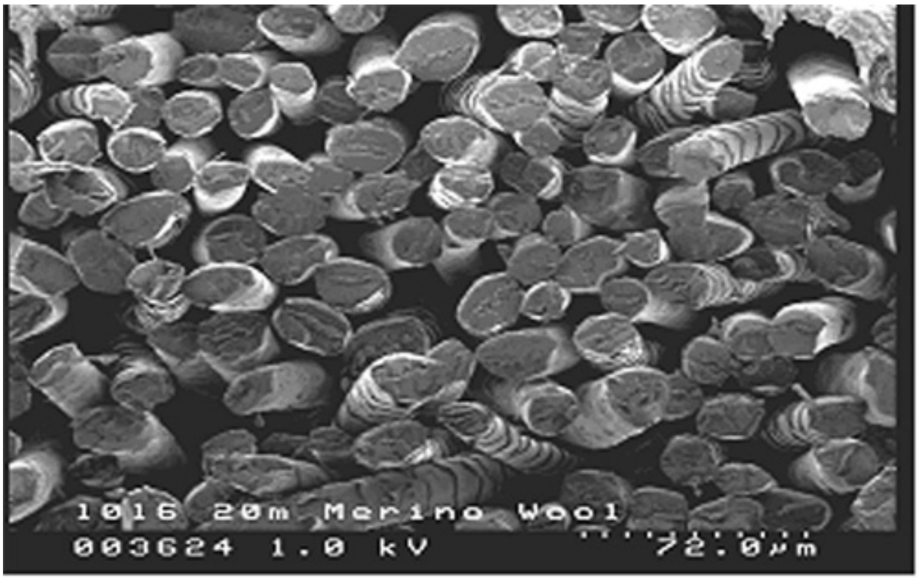
Statistically a mean is expressed as:

$$X=\sum Xi / N$$

(where Xi is the diameter of the ith fibre, N is the total number of fibres measured).

The variability of the measurement is also important and will be covered later.
However, not all wool fibres are circular in cross-section. Wool fibres are slightly elliptical as can be seen in Figure 3.1. While many fibres are circular in cross-section, the average ratio of the maximum width to the minimum width is 1.2:1, while a few fibres may reach 4:1. Modern fibre diameter testing equipment such as Projection Microscope, Airflow, Sirolan-Laserscan, or Optical Fibre Diameter Analyser (OFDA) does not measure the cross-section as viewed in Figure 3.1.

Figure 3.1 Cross-sections wool fibres show the variation ellipticity of the fibres. Source: Tony Schlink (2006).



The measurement of fibre diameter is perhaps best considered to be "equivalent diameter", i.e. no matter what the shape of the cross-section it can be converted to a circle and the diameter determined. As well as the non-circularity problem, the outer-surface of wool has scale edges are about 0.7 microns above the fibre, therefore moving fractionally on or off a scale edges could change a measurement by 5%. These problems of lack of circularity and fibre unevenness are addressed by taking a sufficiently large numbers of measurements of fibres to determine a statistical mean fibre diameter for the wool sample.

The importance of fibre diameter

Mean fibre diameter is the most important raw wool property measured and accounts for 75 - 80% of the value of the top. Hence, mean fibre diameter is a significant determinant of the price of greasy wool.

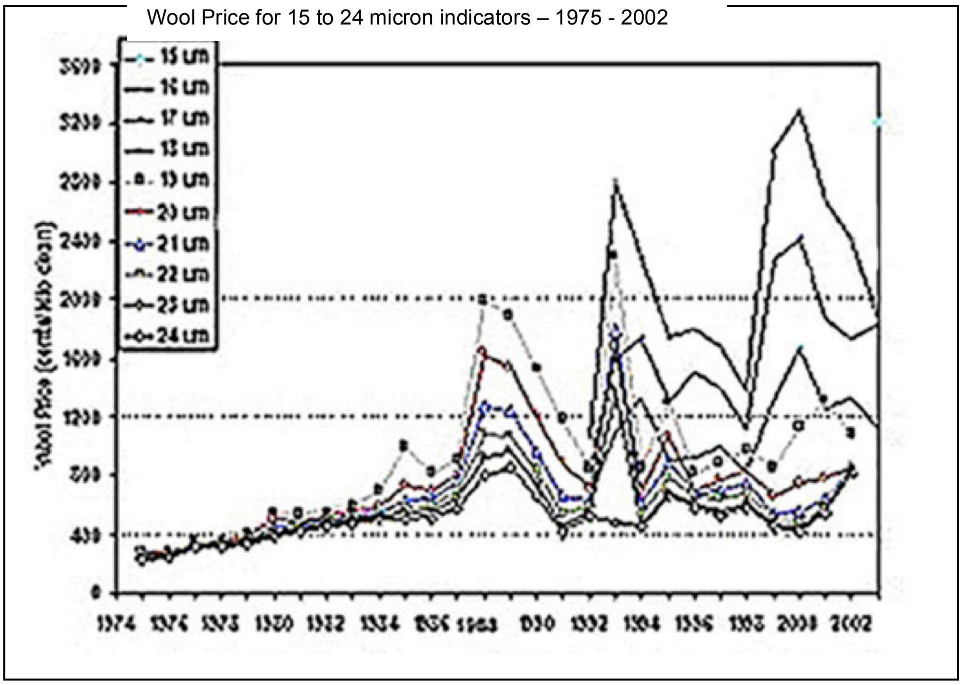
Following are a number of reasons for the importance of fibre diameter. It is worth noting that it is one of the few raw wool parameters that remain virtually unchanged during processing. Diameter limits the yarn thickness (count) that can be spun from a given raw material. A yarn requires a minimum number of fibres in its cross section. Yarn thickness or linear density is limited by both mean diameter and the diameter distribution (Martindale's theorem). For a given yarn count, various physical characteristics of the yarn such as bending rigidity and extension depend on the diameter of its constituent fibres, as well as the yarn twist and the spinning method. Yarns are woven or knitted into fabrics. Important fabric characteristics such as fabric weight, drape, handle, and comfort or "prickle" in next-to-skin wear (the mechanical effect of thick fibres poking into the skin) are dependent on the fibre diameter used.

While in most cases the finer the fibres the more attractive the material, there are two factors that work against the use of finer fibres. Sheep that grow fine wool generally grow less of it and the processing of finer wools is often difficult and more expensive. There is another important factor that governs the value of fibre diameter in the raw material and that is supply. In Australia, the world's major supplier of apparel wool, the greater mass of wool is about 22 to 23 mm, with supply reducing as the diameter becomes finer or coarser.

The effect of fibre diameter on wool price

Clean price increases as average fibre diameter declines. Thus there is a premium paid for finer wool types. In addition, there is an INCREASE in the price differential as fibre diameter DECREASES, i.e. the change from 20 μm to 19 μm is greater than the change from 25 μm to 24 μm. All prices for micron categories vary over the long term in value for each micron and in relation to micron categories as shown in Figure 3.2.

Figure 3.2. Long term prices for wool by micron categories. Source: Advanced Breeding Services, (2003), Schneider. http://www.gschneider.com/indicators/. Retrieved August, (2003).



3.2 Fibre diameter variation

Measures of fibre diameter variation are obtained from measurement of the fibre diameter distribution of a fibre sample. This involves the mini-coring of a fibre mass to obtain 2 mm snippets of fibre, of which approximately 2000 are then individually measured for mean fibre diameter using either the Laserscan (Charlton 1995) or OFDA100 (Baxter et al. 1992) systems or OFDA2000 using staples instead of using 2 mm snippets (Behrendt et al. 2002). The resultant distribution of fibre diameter is then used to derive the following parameters:

- **Mean fibre diameter** (μm) – the average diameter of snippets **measured**
- **Standard deviation of diameter** (SD, μm) – this indicates how narrow or wide the distribution of diameter is (ie. a measure of actual variation). Assuming normality, 68% of fibre diameters lay within 1 standard deviation either side of the mean diameter and 95% of fibre diameters lay within 2 standard deviations either side of the mean
- **Coefficient of variation of diameter** (CV%) – this expresses the standard deviation as a percentage of the mean diameter. It is a measure of variation relative to the mean.

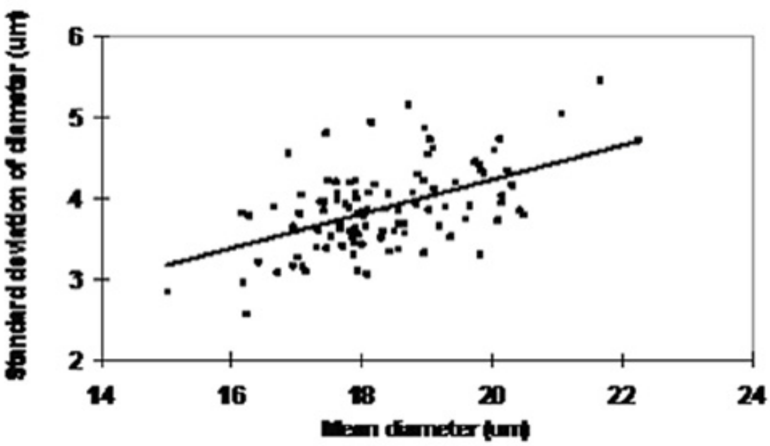
It is important to realise the difference between the two measures of variation. It is possible to have samples with the same spread in diameter but differing in CV% due to differences in mean diameter (Table 3.1, column 2). Also, it is possible to have samples similar for CV% but differing in actual spread of diameter (Table 3.1, column 3).

Table 3.1 The interaction between mean diameter, standard deviation of diameter (SD) and coefficient of variation of diameter (CV%). Source: Tony Schlink (2005).

Mean diameter (μm)	CV% when SD=3.5μm	SD when CV=20%
19	18.4	3.8
22	16.0	4.4
25	14.0	5.0

The trends suggested in column 3 of Table 3.1 are those typically observed within most flocks. That is, as mean fibre diameter increases, so too does the standard deviation of diameter (Figure 3.3), such that CV% provides a measure of variation that is relatively independent of mean diameter.

Figure 3.3 Phenotypic relationship between mean diameter and standard deviation of diameter within a Merino flock. Source: Crook et al. (1994).



Within-fleece gradients in diameter variation

Within-fleece gradients in mean diameter and the sources of variation in diameter were discussed in Lecture 2. In this section, the focus is on within-fleece gradients in diameter variation. In general, there is an anteroposterior increase in the standard deviation of diameter and a lesser increase dorso-ventrally. These gradients reflect those evident for mean fibre diameter, implying that gradients for CV% should be small. Thus the mid-side region is a suitable sampling site to measure diameter variation for flock testing purposes.

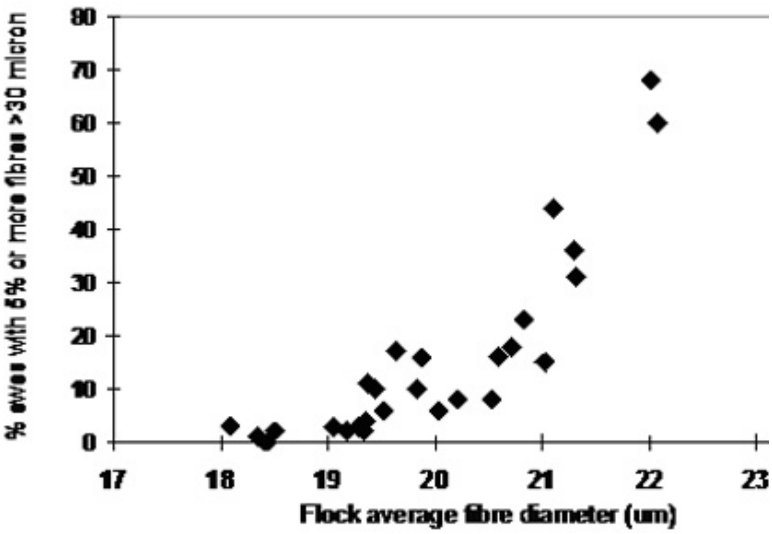
"Prickle" and "coarse edge"

Some wool fabrics, when worn next to the skin, can evoke a "**prickle**" sensation. This results from the mechanical irritation of fibre ends on the skin surface, rather than an allergic reaction to wool (which only occurs for a very small proportion of the population). When fibre ends, protruding from the fabric surface, come in contact with the skin, there are two possible outcomes. The fibre end can either deflect away from the skin surface, or it can press into the skin surface. The latter scenario activates pain receptors in the skin, which are interpreted as "prickle". Importantly, the main determinant of whether the fibre end deflects or not is the diameter of the fibre. Thus "prickle" is not a wool-specific phenomenon, but is more closely associated with wool due to comparative diameters of wool, cotton and synthetics.

Research has shown that "prickle" arises when a fabric to be worn next to the skin, has around 5% or more of fibres exceeding 30 μm. These coarser fibres show less tendency to deflect away from the skin surface. This proportion of coarse fibres is commonly referred to as the "**coarse edge**" of the diameter distribution. It should be noted, though, that many factors such as fabric construction and finishing techniques influence the actual threshold of coarse fibre required to generate "prickle".

As the average diameter of the flock increases, so too does the percentage of sheep within the flock that have 5% or more of fibres exceeding 30 μm (Figure 3.4). Once the flock average diameter exceeds 21 μm (approx.), the percentage of sheep in the flock with "coarse edge" of 5% or more increases rapidly and exponentially. Likewise, within a flock, the percentage of fibres in the fleece exceeding 30 μm rapidly increases once the fleece diameter exceeds 21 microns (Figure 3.5). Thus the higher the diameter of the fleece or the flock, the greater is the likelihood of high "coarse edge" and is usually reported as comfort factor, the percentage of wool fibres with a fibre diameter less than 30 microns.

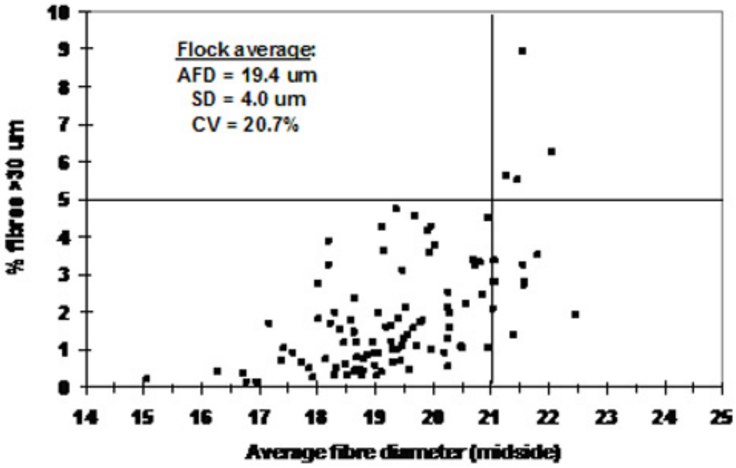
Figure 3.4 Flock average diameter and the percentage of ewes with ≥5% exceeding 30μm. Source: B. Crook, (Unpubl. data).

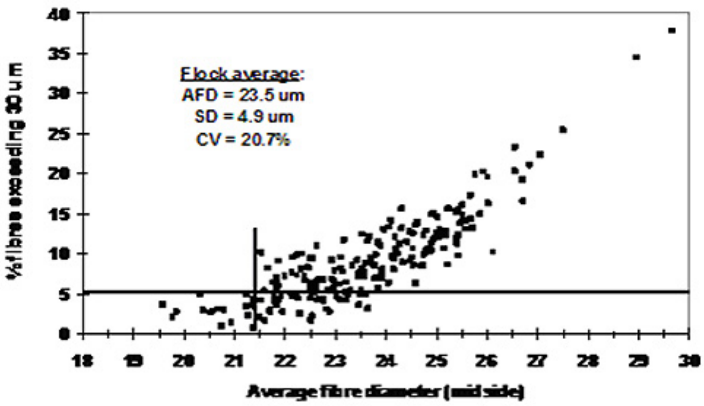


Micron “blow-out”

As sheep age, there is a general trend for average diameter to increase. But some sheep increase faster than the average, whereas some show slower change with age. **Micron “blow-out”** refers to a change in diameter with age, at a rate faster than the flock average rate. Another term sometimes used is **micron “stability”**, generally expressed as a difference in diameter between two ages (e.g. diameter measured at 10 months and 16 months).

Figure 3.5 Within-flock association between mid-side mean diameter and the percentage of fibres exceeding 30μm, in a fine wool flock (top) and a broad wool flock (bottom). Source: B. Crook, (Unpubl. data).





There is a perception within the industry that high diameter variation at a young age is an indicator of micron “blow-out” at a later age. Research results do not, however, support this (Table 3.2). In one study, hoggets with higher than average diameter variation were actually more stable in diameter as they aged.

Table 3.2 Phenotypic correlations between mid-side diameter distribution measurements and micron “blow-out”. Source: Taylor and Atkins (1992) and Ponzoni et al (1995).

	Taylor and Atkins (1992)	Ponzoni et al. (1995)
Mean diameter	-0.30	-0.24
SD of diameter	-0.20	0.05
CV of diameter	0.0	0.08

3.3 The measurement and economic importance of staple strength

Staple strength reflects the force required to break an individual staple when extended. Staple strength can be subjectively appraised by stretching the staple between both hands and "flicking" it with a finger. It is then allocated to one of four appraised strength categories - sound, part tender (W1), tender (W2) and rotten (W3) – based on the AWEX industry description system. However, appraised strength is strongly influenced by the thickness of staples assessed, with a thicker staple requiring more force to break than would a thinner staple, as there is more load-bearing material present within the staple. There are also biases arising from staple selection. For these reasons, objective measurement of staple strength has been developed.

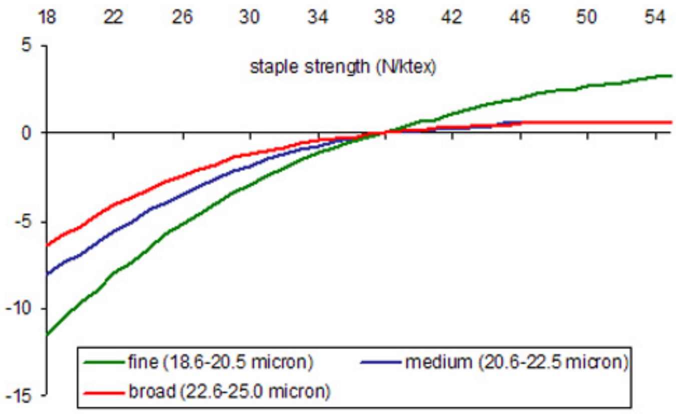
The measurement of staple strength involves a number of staples being individually gripped about 15 mm from the tip and base by two jaws, and extended until broken. The force required to break the staple is measured in Newtons (N), where 1N is approximately equal to 100 grams. The staple is also measured for length and weight so that measured force can be adjusted for staple thickness or staple linear density, expressed as grams per metre, or kilotex. This gives units of Newtons per kilotex (N/ktex) for the measurement of staple strength and is expressed as the average of the staples measured. Given that contaminants such as wax, suint, dirt and vegetable matter contribute to staple weight, the measurement must be adjusted to a clean fibre basis. For flock testing purposes, washing yield is used to make this adjustment and approximately 10 staples are measured. For sale lot testing of staple strength, 40 or more staples are measured and the adjustment factors are more complex.

The relationship between staple strength and clean price is not linear (Figure 3.6). There are threshold strengths above which there are only slight premiums paid per increment in strength, whereas below these thresholds, substantial penalties are incurred. These trends imply that the return from improving staple strength depends on where the flock average sits relative to the threshold. Unfortunately, these thresholds vary according to the market. It should also be noted that the premiums and discounts are greater for fine wool types compared to those for medium and broad wool types of the same strength (Figure 3.6). This implies that staple strength is economically more important for fine wool producers compared to broader types.

Figure 3.6 can also be used to show the general relationship between measured staple strength and appraised strength category, indicating that appreciable variation in strength is likely within similarly appraised wool types. The appraised categories are; tender with staple strengths of 15 to 20 N/ktex, part tender with staple strengths of 20 to 30 N/ktex, and sound with staple strengths of higher than 30N/ktex.

Staple strength measurement is required by the wool processing industry to predict the length of the fibre in the top. This prediction of fibre length (Hauteur) is made using the TEAM equation. The TEAM equation used the raw wool measurements of fibre diameter, staple strength, staple length, point of break and vegetable matter content to predict average fibre length in the top.

Figure 3.6 Staple strength premiums and discounts, relative to the threshold strength for fine, medium and broad wool types: 2003/2004. Tender wool is 15 to 20 N/ktex, part tender is 20 to 30 N/ktex and sound is higher than 30N/ktex. Source: Woolmark (2003).



When a staple is extended to breaking point, it usually breaks at the relatively weakest point of the staple, yielding a tip section and a base section. **The point or position of break (POB)** in the staple is measured via the relative weights of the two sections as a percentage of the staple weight. If the tip section accounts for <33% of the staple weight, then it indicates that the staple broke in the top third of the staple, (i.e. a tip break). Alternatively, if the base section accounts for <33% of the staple weight, then it indicates that the staple broke in the bottom third of the staple, (i.e. a base break). Otherwise, it is a middle break. There are currently no market signals indicating the influence of POB on clean price, however a tip or base break is generally preferable over a mid break from a top-making point of view.

Sources of variation in staple strength

Within a mob of sheep, the greatest source of variation in staple strength occurs between fleeces (Table 3.3), with a range of at least 40 N/ktex being observed between individual sheep. Variation in staple strength also exists within a single fleece, but mainly between staples within a site of the fleece. Fleece gradients in staple strength tend to be small and inconsistent, though the back-line may be slightly lower in strength due to the effects of weathering.

Table 3.3 Relative contributions to total within mob variation in staple strength. Source: Rottenbury et al. (1981).

Source of variation	% contribution
Within fleece	21
Within sites	18
Between sites	3
Fleece x site	14
Between fleeces	65

However, note the significant fleece by site component in Table 3.3, indicating substantial differences between sheep in the within-fleece gradients for staple strength. On average, measurements of staple strength taken from most sites of the fleece provide a relatively reliable estimate of the overall fleece average. Given that mid-side sampling is best for diameter, staple length and yield, this sample can also be used to obtain a reliable estimate of average staple strength for the fleece.

In terms of non-genetic handicaps for staple strength, age and birth-rearing status appear to have negligible effects. On the other hand, year to year variation in average flock staple strength can be high.

Determinants of staple strength

Variations in staple strength can arise from variations in the load-bearing material within the staple and variations in the intrinsic strength of the fibres in the staple. There may be an interaction between the two in that changes in the physical dimensions of the fibre may be associated with changes in the structural or chemical components of the fibre. Either way, any factor which influences the load-bearing capacity of wool fibres can impact on the strength of the staple.

Variations in load-bearing material

Variations in the load-bearing material are generally associated with a localised weak point along the staple, such as happens when fibre diameter diminishes, followed by an increase in diameter. In the measurement of staple strength, it is the average linear density of the staple that is measured even though it is the average linear density at the point of break that has the main influence on the force to break. A localised reduction in diameter will therefore reduce the force to break at the point of break (i.e. relatively less material present to bear the load) without greatly affecting the average linear density of the staple. The result is that measured staple strength must, by definition, decline. A relationship is therefore expected between staple strength, diameter at the point of break and diameter variation along the staple.

Figure 3.7 An example of a fibre diameter profile, showing the maximum (Max.) and minimum (Min.) diameters as well as the rate of change in diameter between the two. Source: With permission from B. Crook, (Unpubl. data).

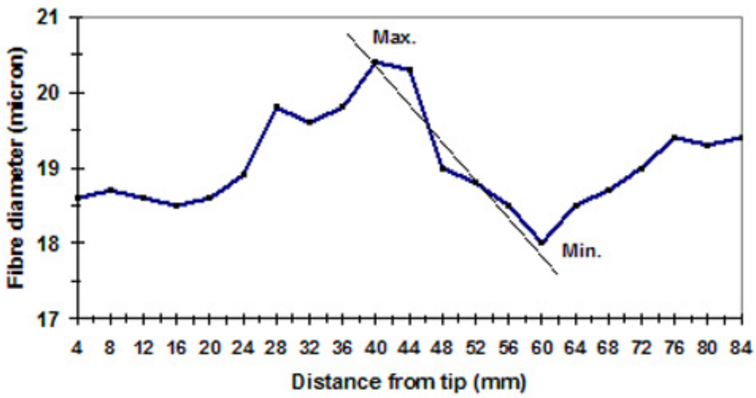
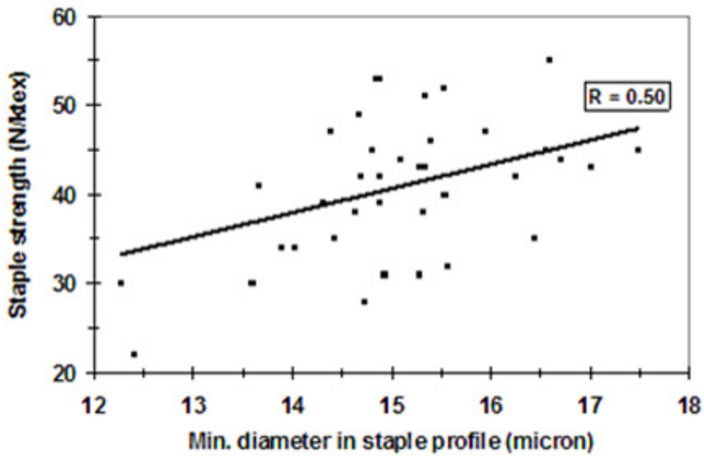


Figure 3.7 depicts a **fibre diameter profile** for a single staple, showing the average diameter of the constituent fibres at 2 mm increments along the length of the staple from tip to base. It reflects the changes in fibre diameter that occurred along the staple throughout the wool growth period. A number of parameters can be derived from such a profile, including the magnitude of the variation in diameter, the minimum and maximum diameters in the profile and the rate of change in diameter per mm of staple between the minimum and maximum diameters (Brown, D.J. & Schlink, A.C. 2002). These authors also found that the fibre diameter profiles generated from the OFDA2000 was similar to that produced from the 2mm snippet technique in Figure 3.7.

Minimum fibre diameter

The position of break generally equates to the point of minimum diameter. Within a mob of sheep, those individuals with a lower minimum diameter in the profile tend to be associated with lower staple strength. As there is a strong phenotypic correlation between minimum profile diameter and the average fibre diameter of the mid-side sample, those individuals of finer average diameter within a mob also tend to be those with lower staple strength. This indicates that any factor which reduces average fibre diameter at some point along the staple, and thus average diameter overall, will also tend to reduce staple strength. However, there are always individuals that do not conform to this trend. As an example, animals with a minimum profile diameter of approximately 15 microns in Figure 3.8 show a range in staple strength from 32 to 54 N/ktex. Obviously there are other determinants of staple strength in addition to the minimum diameter in the profile. The slope of the relationship between minimum fibre diameter and staple strength indicated that an increase in minimum fibre diameter of 1 micron was associated with an increase in staples strength of about 5 N/ktex (Thompson and Hynd 1998).

Figure 3.8 Phenotypic relationship between minimum fibre diameter and staple strength within a mob of Merino sheep. Source: With permission from B. Crook, (Unpubl. data).



Fibre diameter variation

Across a diverse range of environmental conditions, the total diameter variation measured within a mid-side sample has been shown to have a strong and negative *phenotypic* association with staple strength (Table 3.4). Environments that create high levels of variation in diameter throughout the year generally produce lower staple strength on average compared to less seasonal environments. But within any given environment, those individuals within a mob with higher levels of diameter variation are likely to have reduced staple strengths.

Table 3.4 Phenotypic correlations between staple strength and coefficient of variation of diameter within the mid-side sample, in a range of wool producing locations. Source: With permission from B. Crook, (Unpubl. data).

Location	Correlation	Reference
South west WA	-0.83	Ritchie and Ralph (1990)
Northern Tablelands, NSW	-0.29	Swan et al. (1995)
South east SA	-0.18 -0.40	Gifford et al. (1995)

The sources of variation in diameter that exist within any mob of sheep were discussed in Lecture 2. Table 3.5 shows that the relative contributions of these sources of variation differ between sound (>30 N/ktex) and tender (<25 N/ktex) wool types. With tender wool, the contribution of along-staple diameter variation is greater, accounting for a similar level of within-mob variation as that accounted for by between-fibre differences. This implies that **along-staple diameter variation** is greater in wool types of low staple strength. An estimate of –0.30 has been reported for the phenotypic correlation between the two traits (Denney 1990). Thus if two staples had a similar minimum diameter in their profile, strength is expected to be lower in the staple with more variation in diameter along its length.

Table 3.5 Relative contributions to total within-mob variation in fibre diameter for sound (>30 N/ktex) and tender (<25 N/ktex) wool types.
Source: With permission from B. Crook, (Unpubl. data).

	% contribution	
	Sound	**Tender**
Within staples	80	86
Between fibres	64	43
Along fibres	16	43
Within fleeces (between regions)	4	3
Between fleeces	16	11

Rate of change in fibre diameter

Consider two staples – A and B - each with the same minimum diameter in their profile and each with a 2 μm difference between the minimum and maximum diameter in the profile. Staple A has this difference spread over an 8 mm length of the staple while staple B has the same diameter difference spread over a 20 mm length of the staple. This gives a **rate of change in fibre diameter** from the minimum to the maximum diameter 0.25 μm per mm for staple A and 0.1 μm per mm for staple B. Both staples have the same minimum diameter and similar along-staple diameter variation, but staple B demonstrates a more gradual change in diameter over a given length of staple.

Rate of change in diameter does impact on staple strength. A study by Hansford and Kennedy (1988) showed that sheep with a high rate of change tended to produce lower staple strengths, with a phenotypic correlation of –0.43, and that rate of change exerted a greater influence on staple strength than did minimum diameter. This implies that if an individual is capable of buffering the change in diameter along the staple by spreading the change over a longer length of staple, it should theoretically achieve a higher staple strength.

An experiment cited by Thompson (1993) suggested that finer diameter sheep may be less responsive in diameter to an increase in the level of feed. For example, after changing to a higher plane of nutrition, an 18 μm animal increased in diameter to 21 μm, representing a 16% increase in diameter. A 28 μm individual, on the other hand, increased by 6.3 μm, representing a 23% increase. In other words, the broader wool type was more responsive in terms of diameter to an increase in feeding level. This raises some interesting questions about the role of fibre diameter as a determinant of staple strength. On one hand, a finer fibre diameter gives rise to a lower minimum diameter in the profile, potentially reducing strength. But on the other hand, it may lower the variation in diameter along the length of the fibre in response to nutritional changes, thereby improving strength.

A second experiment (Hynd 1992) demonstrated that sheep with a high L/D ratio – that is, the ratio of the length growth rate of fibres to the average diameter of the fibres - displayed greater length responsiveness to nutritional change compared to diameter responsiveness (Table 3.6). These results suggest that high L/D individuals may be able to buffer against nutritional change by responding via fibre length rather than fibre diameter, giving lower diameter variation and/or rate of change in diameter. This experiment also demonstrated again that animals of high diameter showed greater diameter re

Table 3.6 Phenotypic correlations between initial fibre diameter and L/D ratio with fibre diameter response (ΔFD) and fibre length response (ΔFL) to changes in nutritional level. Source: Hynd (1992).

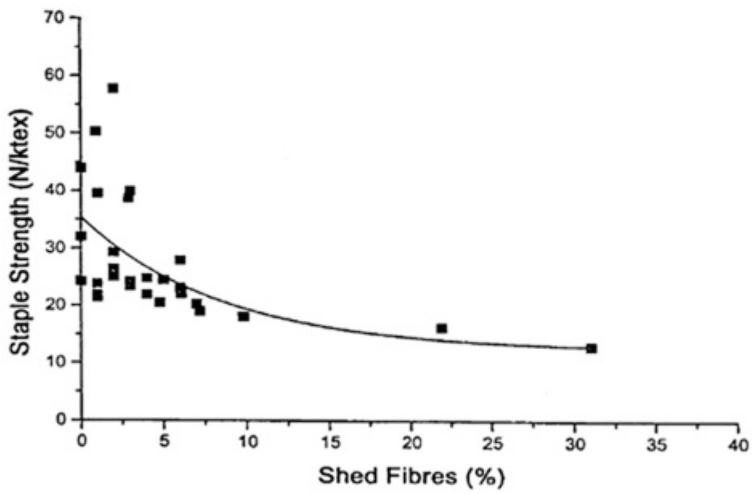
Trait	ΔFD	ΔFL
Initial fibre diameter	+0.53	-0.16
L/D ratio	-0.66	-0.08

Fibre length variation

Fibre length variation exists within all staples. But as this variation increases, so too does the potential for some fibres to be held by one clamp only while others are held by both. Those fibres that do not traverse the whole distance between the clamps will contribute to the linear density of the staple, but will not bear the load. So linear density overestimates the amount of load-bearing material in the staple and thus measurements of staple strength will, by definition, decline. Fibre length coefficient of variation was significantly correlated with staple strength (Schlink et al. 2001). In a fine wool flock fibre length coefficient of variation and minimum fibre diameter accounted for 84% of the variation in staple strength.

Another source of fibre length variation is **shed fibres**, resulting from **shut-down** of part of the follicle population while other follicles continue to produce a fibre. Shed fibres may or may not be held by a clamp during staple strength measurement. In Merino sheep, the incidence of shedding under normal grazing conditions is generally low (<1%) and linked more to seasonal changes in feed, physiological condition and stress. However, Schlink and Dollin (1995) found the incidence to range from 0 to 30% in adult Merino wethers in the Mediterranean environment of WA, under conditions resulting in body weight loss during late summer. Those wethers with high levels of shed fibres produced the lowest staple strengths (Figure 3.9). But note that at levels <5% shed fibres, staple strength still ranged from as low as 20 to as high as 60 N/ktex. So other causal factors are obviously involved.

Figure 3.9 Relationship between staple strength and the percentage of shed fibres at the point of break in Merino wethers. Source: Schlink and Dollin (1995).



Variations in intrinsic fibre strength

When considering the fibre diameter profile parameters and how in combination they relate to staple strength, it becomes apparent that there are other sources of variation in staple strength that have not been accounted for. At best, diameter profile parameters account for 60% of the variation in staple strength within a mob. At the individual fibre level, fibres identical with respect to minimum diameter, diameter variation and rate of change can still exhibit large differences in breaking load.

The **intrinsic strength** of the fibre refers to the strength of the actual fibre material. It is defined as the force required to break a fibre, divided by the cross-sectional area at the point of break. Variation in intrinsic strength implies that some fibres are composed of weaker material (i.e. a **generalised** weakness), such that they break at lower forces than other intrinsically stronger fibres, reflecting structural and/or chemical differences between fibres.

The focus of intrinsic fibre research has been on the cortex of the wool fibre, which consists of two main cortical cell types – the orthocortex and the paracortex - differing in their chemical composition and arrangement of structural components. Paracortical cells contain more disulphide cross-links, which may confer them with greater strength or may make them less elastic (i.e.

more brittle) under tension. Also, the relative proportions of the two can vary throughout the fibre growth period and can alter with changes in nutrition, emphasising that chemical and structural changes do exist along the length of normal wool fibres. Research cited by Thompson (1993) indicated that an increase in the proportion of the paracortex was associated with a reduction in staple strength. This provided a possible explanation for the relationship between fibre diameter and staple strength, given the higher proportion of paracortex cells in finer fibres. However, later work by Thompson (unpub.) showed no significant relationship between cortical cell type percentage and staple strength. Furthermore, a study by Hansford and Kennedy (1990) also found no significant associations between cortical cell type percentage and staple strength in Merino sheep. This subject is reviewed in greater detail by Hynd and Schlink (1992).

Interplay of the components of staple strength

Staple strength is a composite measurement of a number of raw wool parameters outlined above. In an investigation of the relative importance of some of the components of staple strength Adams et al (2000) studied 20 flocks of sheep, using between 30 and 200 fleeces per flock. Staple strength was related to staple length in 13 flocks, and the coefficient of variation of fibre diameter in 12 flocks, fibre diameter in 9 flocks, the proportion of mid-breaks in 7 flocks, the standard deviation of fibre diameter in 6 flocks and wool yield in 6 flocks. Thus staple strength is not a single biological trait and the measurement of wool traits in relation to staple strength should not be undertaken in isolation as potential predictors of staple strength.

3.4. Style

Raw wool **style** is a summation of those attributes of the wool that are considered to be of importance in some way to the processor, but are not measurable. That is, a composite of those traits that are assessed by eye and hand. By obtaining this information, processors expect to get a more accurate picture of the potential processing performance of the wool, beyond that indicated by measured traits.

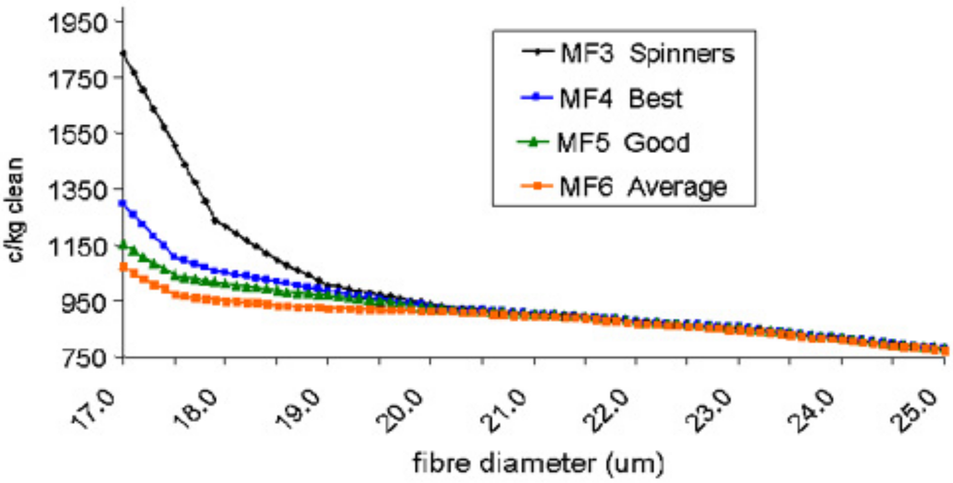
Subjective appraisal of style for fleece wool is based around a grading system as part of the AWEX-ID system, ranging from 1 (Choice) to 7 (Inferior). However, such a system is hampered by concerns over the repeatability of assessment and the agreement between different assessors. The technology capable of objectively measuring style traits is no longer being developed to objectively measure wool style.

The bulk of Australian sale lots fall into style grades 4 (best) and 5 (good), with less than 1% of bales falling into grades 1-3 combined. State differences in style reflect environmental differences as well as Merino type effects. In general, Victoria and Tasmania produce the largest proportions of the highest style grades, with Qld, SA and WA producing a higher proportion of lower style grades, reflecting in part the more arid nature of parts of their wool-growing environments.

Economic importance of style

Price differentials for style grade only start to appear below 21 microns (Figure 3.10). For broader wool types, style has relatively minor economic value, while for fine and superfine wool types, style contributes significantly to price variation. Style is therefore of greater economic importance to producers of fine wool compared to broad wool.

Figure 3.10 Fibre diameter premiums for Merino fleece style grades 3-6; Northern Region 2003/04. Source: Woolmark (2003).



The components of style

The major components of style relate to the formation of the crimp (crimp frequency, crimp definition), the structure of the fleece (tip shape, staple structure), dust content (amount of dust, colour of the dust and degree of penetration of dust down the staple), weathering (environmental damage to the staple tip) and greasy wool colour. Style therefore reflects an interaction between the fleece and the environment.

Crimp frequency relates to the number of staple crimp waves per unit length of the staple (e.g. 6 crimps per 2.5 cm). A high number of crimp waves is referred to as high frequency, while a low number indicates low crimp frequency.

Crimp definition, also referred to as **character**, indicates the degree to which the crimp wave of individual fibres within a staple, are in alignment, such that staple crimp is visible. High definition (or superior character) indicates a high degree of alignment between fibre crimp, while poor definition (or poor character) indicates poor alignment of fibre crimp.

Staple **tip shape** is thought to reflect the degree of variation in fibre length within the staple. A staple with a flat tip may have less variation in fibre length compared to a staple with the pointed tip. Also, it is postulated that there is an interaction between tip shape and exposure of the staple to UV damage, water and dust penetration, with more pointed tips facilitating greater exposure.

Research has shown that the major traits which assessors rely on to distinguish one assessed style grade from another are those relating to greasy wool colour, dust penetration and weathering, with crimp and fleece structural traits being secondary determinants. This is demonstrated in Table 3.7 which summarises the results of one study looking at the potential to correctly discriminate between different style grades on the basis of either measured dust penetration or assessed greasy wool yellowness only.

Table 3.7 Percentage correct discrimination between assessed style grades, when using either measured dust penetration or assessed greasy wool yellowness only. Source: Winston (1989).

		% correct discrimination		
	Style Grade	**4**	**5**	**6**
Dust penetration	3	70	98	100
	4		89	98
	5			98
Yellowness	3	70	77	86
	4		60	59
	5			53

Within-fleece gradients in style traits

The most distinct within-fleece gradients observed for style relate to those component traits that depend on environmental conditions, these being dust content and weathering. The area of the staple affected by dust or exhibiting weathering is usually greater for staples along the back-line, due to greater potential for exposure to the environment. The strength of the gradient, however, does depend on the severity of the environment in terms of dust and weathering. Tip shape tends to be most defined along the back-line, crimp definition may show a general improvement from back-line to mid-line and gradients for crimp frequency generally reflect those for mean diameter. Yellow discolouration of the fleece, when present, generally appears to affect most of the fleece, rather than specific regions.

Given the different gradients that exist for each of the component traits, no single sampling or inspection site is advocated for flock testing purposes. Rather, the component traits should be considered separately, based on their priority in the production objective. Thus the back-line should be inspected when considering dust, weathering and tip shape requirements, and the mid-side inspected or sampled for crimp related traits. Both back-line and mid-side regions will exhibit yellow discolouration when present within the fleece.

One strategy that has been considered for improving style, at least to reduce dust penetration and weathering, is the use of sheep coats (Hatcher et al. 2003). While improvements can be achieved, the value of this strategy depends on the improvements in wool value that result relative to the cost of using coats (including purchase and labour). Given that those environments in which dust content is likely to be greater are those environments generally associated with broader wool types, the increase in wool value may not outweigh the cost of using coats. The economic feasibility of using coats will depend on fibre diameter type and market differentials for style grade.

Associations between style traits and diameter variation

At the phenotypic level, some of the style traits are related significantly to diameter variation. Table 3.8 summarises some of the correlation estimates published based on fine, medium or strong wool genotypes. The consistent associations involve fleece structure. Higher variation in diameter (whether that be standard deviation or CV%) is associated with poorer crimp definition and poorer definition of staples. This may be mediated via fibre length variation. Associations between diameter variation and assessed dust penetration and wool colour appear to be negligible.

Table 3.8 Phenotypic correlations between mid-side diameter variation and components of style. All style traits were subjectively scored, with score 1 indicating more “favourable” performance. Source: Compiled from Lax et al. (1995); Crook et al. (1995); James and Ponzoni (1992).

Traits	Fine	Medium	Strong
Crimp definition	0.33	0.23	0.25
Staple structure	-	0.30	0.32
Staple thickness	0.31	0.23	0.32
Dust penetration	0.08	0.01	-
Greasy colour	0.12	0.03	0.10

3.5 Handle

Handle is a term used to describe the tactile aspects of fibre and fabric. It has both textural and compressional components. Fibre diameter exerts a strong influence on the textural properties of the fibre, with diameter variation, fibre surface properties, crimp and non-fibre contaminants being secondary determinants. Crimp frequency (or fibre curvature) exerts a strong influence on the compressional properties of the fibre, with diameter, grease content and staple pliability being secondary determinants. Handle is therefore a function partially of diameter and crimp.

The influence of fibre diameter and fibre crimp on wool handle can best be explained by considering a coiled spring. If we consider two springs with the same degree of coiling (i.e. turns per unit length), but one being of finer diameter than the other, the finer spring would require less force to compress it. If we consider two springs of the same diameter, but one having fewer turns per unit length compared to the other, then the less coiled spring will be the more easily compressed. So at similar levels of fibre crimp, finer fibres are more easily compressed. And at similar fibre diameters, lower crimped fibres are more easily compressed. Within a mob of sheep, finer fleeces tend to feel softer than higher diameter fleeces. At the same diameter, lower crimp frequencies tend to give a softer handle compared to higher crimp frequencies (Figure 3.11). Thus having finer diameter and lower crimp should confer improved handle to the wool. As a general trend, though, fibre crimp increases as fibre diameter decreases (Figure 3.11). So the “softer than average” individuals are those having a level of crimp lower than expected given their diameter.

Figure 3.11(a) The relationship between fibre diameter and fibre curvature in fine and medium wool sheep. Source: Stevens (1994).

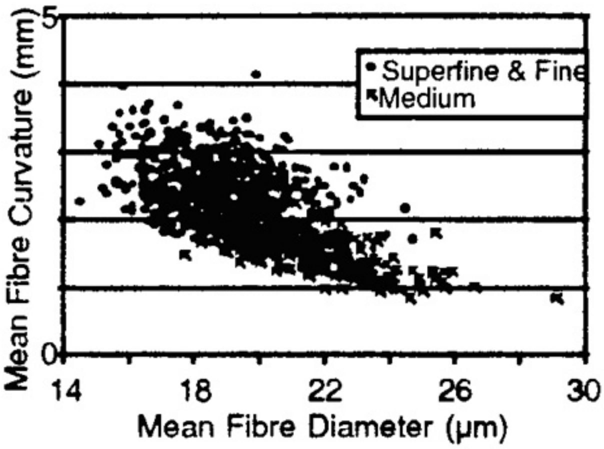
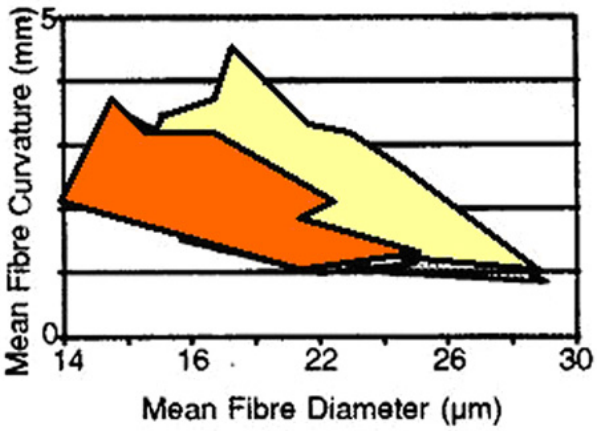


Figure 3.11(b) The impact of fibre diameter and fibre curvature on handle assessments of greasy wool in fine and medium wool sheep. The darker-shaded area denotes softer than average wool handle scores, while the lighter-shaded area denotes harsher than average wool handle scores. Source: Stevens (1994).



3.6 Curvature

Fibre curvature is one of the main components of crimp. Curvature has been found useful in predict crimp, spinning ability and wool bulk (Edmunds 1997).

The curvature measurement is measured on snippet using OFDA or Laserscan and is reported as degrees per mm. After a fibre has been tracked, recognised and measured, the software assumes that the clear length forms a circular arc and proceeds to calculate the curve of both sides of the fibre (Fish et al 1999). Figure 3.12 illustrates 2 mm snippets with a range of curvature outcomes shown.

The curve measurement result is presented as a mean curvature and a standard deviation of curvature. A straight fibre will have a curve of 0 deg/mm, a fibre that is 1mm long and forms a circle will have a curve of 360 deg/mm.

The relationship between measured crimp frequency and fibre curvature has been found to be high. A higher curve implies a higher crimp frequency. A lower standard deviation of curve implies that the curve or crimp is more uniform between fibre snippets. It should be noted that the distribution of curvature measurement does not follow a normal distribution.

Figure 3.12 A microscopic image of 2 mm snippets of wool showing a range in fibre curvatures. Source: Swan (1994).

Similar to fibre diameter and fibre diameter variation, fibre curvature also varies over the animal, between animals in a flock, and between flocks. In general, fibre curvature increases from the dorsal to ventral regions and from the anterior to posterior regions. The variance within an animal is not consistent between or within strains (Fish et al. 2002).

Economic value of curvature

An examination of Australian Merino sale lots between July 2000 and December 2001 found a significant price change between sale lots of differing curvature (Curtis and Stanton 2002). At 18 microns, the price change between wools with a curvature of 80º/mm and 140º/mm was 700 cents per kilogram of clean wool. The results showed that the price differential for curvature was consistent over the period examined suggesting that the price premiums were not a market abnormality but the price premiums were restricted to wools below 21 microns.

Readings

The following readings are available on CD:

1. Adams, N.R. and Kelly, R.W. 2000, 'Staple Strength', *Asian-Australasian Journal of Animal Science,* vol. 13C, pp. 20-29.
2. Brown, D.J. and Schlink, A.C. 2002, 'A Comparison of Fibre Diameter Profiles Generated Using 2 mm Snippet Techniques to Those Measured Using the OFDA2000', *Wool Technology and Sheep Breeding,* vol. 50(1), pp. 27-39.
3. Crowe, D. and Stevens, D. 1994, 'Style Appraisal', in *WOOLSPEC94: Specification of Australian Wool and its Implications for Marketing and Processing*. Proceedings of the Seminar held by CSIRO Wool Technology and International Wool Secretariat, Sydney 1994, (eds. R.A. Rottenbury, K.A. Hansford, J.P. Scanlan), D1.
4. Fish, V.E., Mahar, T.J. and Crook, B.J. 1999, 'Fibre Curvature Morphometry and Measurement', *ITWO, Commercial Technology Forum*, Nice, Report No: CTF 01.
5. Hansford, K.A. 1994, 'Fleece Specification and Processing Prediction', in *WOOLSPEC94: Specification of Australian Wool and its Implications for Marketing and Processing*. Proceedings of the Seminar held by CSIRO Wool Technology and International Wool Secretariat, Sydney 1994, (eds. R.A. Rottenbury, K.A. Hansford, J.P. Scanlan), J1.

Activities

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Assignment Questions

Choose ONE question from ONE of the topics as your assignment. Short answer questions appear on WebCT. Submit your answer via WebCT

Summary

Summary Slides are available on CD

Fibre diameter is the single most important parameter of raw wool accounting for 75 to 80% of the variation in wool price. Fibre diameter is now readily measured for auction and on-farm using Laserscan or OFDA technologies. Both these instruments also provide information on fibre diameter variation and fibre curvature. Fibre diameter variation plays a role in determining spinning fineness and wool comfort or prickle. Fibres with fibre diameters greater than 30 micron can result in a prickly sensation on the skin. If there are more than 5% of fibres with fibre diameter greater than 30 microns the wool fabric is likely to be prickly.

Staple strength is not as economically important as fibre diameter but can have a significant effect on price within micron categories. Staple strength is the summation of a number of raw wool properties in the staple. The relative importance of those staple parameters to staple strength depends upon the sheep's genetic and environmental background.

Style and handle are wool traits that are considered to be important but are not objectively measured. Style is assessed by hand and eye with wool being allocated to one of seven AWEX style grades for sale. There is a price differential for style for wools less than 21

microns. Handle refers to wool textural properties and is affected mainly by the fibre properties of diameter and curvature/crimp.

Curvature is the measurement equivalent of crimp. Curvature is readily measured by OFDA or

Laserscan devices. It affects wool spinning ability and wool bulk. Curvature has been shown to have an economic value for wools less than 21 microns.

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Glossary of Terms

Coarse edge	the proportion of fibres with fibre diameters of greater than 30 microns is commonly referred to as coarse edge
Coefficient of variation of fibre diameter (CV)	a statistical measure of the variability exhibited within measurements of fibre diameter in a wool sample. It expresses the standard deviation as a percentage of the mean; the higher the CV, the greater the variability
Comfort factor	the percentage of fibres with fibre diameters less than 30 microns
Crimp	the waviness of a fibre, expressed numerically as the number of complete waves per unit length; crimp is usually taken as an indicator of mean fibre diameter, the higher the number of crimps per unit length, the finer the wool
Curvature	a measure of crimp performed by OFDA or Laserscan and reported as degrees/mm
Fibre diameter profile	a measure of the variation in fibre diameter along the staple
Fibre length	the length of individual wool fibres in the fleece
Handle	term used to describe the tactile aspects of fibre and fabric. It is influenced by fibre diameter and curvature
Hauteur (H)	the average of the length-biased distribution of fibre length in the top. It is obtained by sorting a sample of the sliver into length classes and calculating the average of the number of fibres of each length class. Hauteur is usually regarded as a numerical average although this assumes no relationship between fibre length and fibre diameter
Intrinsic strength	is defined as the force required to break a fibre divided by the cross-sectional area at the point of break
Linear density	the mass of clean fibre per unit length of a staple at standard conditions
Martindale theorem	used to estimate spinning fineness micron – a decisive figure for processors. It is a calculation of mean fibre diameter and coefficient of variation of diameter into a single measure of fineness expressed in micron units. This formula means that a reduction in CV of diameter of 5% has the same effect on spinning fineness as a 1 micron reduction in mean fibre diameter
Mean fibre diameter	the arithmetic mean of all fibre diameter readings in a sample
Micron blow out	the degree of change in fibre diameter with age. The larger the increase in fibre diameter with age the more the sheep is considered to have blown out in micron

Minimum diameter	usually refers to the minimum fibre diameter along a staple and is the point where the staple is likely to break with staple strength testing
Newton	the unit of force in the SI system; a force of one kilogram is equivalent to about 9.8 newtons (N)
Point or position of break	an indication of where a staple breaks during extension, determined by comparing the masses of clean wool in the broken portions of the staple. It does not imply that a break exists in the staple
Prickle	mechanical irritation of the skin surface by fibre ends. Prickle arises when around 5% or more of fibres exceed 30 microns
Standard deviation of diameter (SD)	a measure of the dispersal of fibre diameter within a wool sample and expressed in the units of measurement
Staple strength	the maximum force required to rupture a staple per unit of linear density
Style	is a summation of the visual appearance of wool based on tip structure, crimp, colour and dust. Style is the basis for AWEX classifications of wool into type grades from 1 to 7
TEAM	Trials Evaluating Additional Measurements. Trials were conducted by the Australian Wool Corporation and CSIRO to establish the value of measurement data from additional parameters such as length and strength, to predict processing performance