7. Fibre Diameter

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Learning objectives

On completion of this topic you should have an understanding of;

- the relevance of Fibre Diameter to wool fibre value, processing performance and end product quality
- the difference between visual appraisal and measurement of Fibre Diameter
- the sources of variation in Fibre Diameter measurement
- sampling and sample preparation for the four (4) Standard methods of Fibre Diameter measurement, viz. Projection Microscope, Airflow, Laserscan and OFDA 100
- Fibre Diameter testing of top, slivers, core and fleece samples (including On-farm Testing)
- compare the precision levels possible with the various instruments used for measuring mean fibre diameter

Key terms and concepts

Fibre diameter, mean fibre diameter (MFD), standard deviation, coefficient of variation of diameter (CVD), fibre diameter distribution, International Wool Textile Organisation (IWTO), Projection Microscope, Airflow, Laserscan, OFDA, snippet, micron.

Introduction to the topic

This topic describes the measurement of fibre diameter of wool samples, slivers and tops and outlines the relevance of fibre diameter testing to determine wool value and to processing performance and quality of textile or apparel end product. Fibre diameter is arguably their most important property, because of the importance of fibre diameter in the efficient spinning of fine worsted yarns and in the manufacturing light, soft handling fabrics for apparel. The finer the fibres, and the fewer the number of fibres present in a cross section of a yarn produced from the fibres; the more flexible is the yarn. These factors are critical to the quality of wool fabrics.

A number of methods have been developed for measuring the fibre diameter of wool, notably the projection microscope, airflow, Laserscan and OFDA (Optical Fibre Diameter Analyser). The latter two methods utilising modern technologies have largely replaced the first two methods. However, the Projection Microscope provides the benchmark test by which the other methods are calibrated.

7.1 The relevance of fibre fineness

Wool quality, value and trading

Fibre fineness is the most important value-determining property of wool. The original subjective estimation of fibre fineness, which will be discussed in more detail in a subsequent section of this topic, used the term ‘quality number’ to describe wool fineness. It is the property of wool which is most closely identified with wool quality. As shown in Figure 7.1, Mean Fibre Diameter (MFD) has the strongest impact on wool price/kg of the measured raw wool properties. The strong dependence of greasy wool price on wool fineness is related to the overwhelming importance of diameter in the determination of the value of a wool top (70% to 80%). Since a top is the end product of early stage processing of wool, wool producers, traders and early stage processors value greasy wool largely in terms of the diameter of a top that the greasy wool will produce.

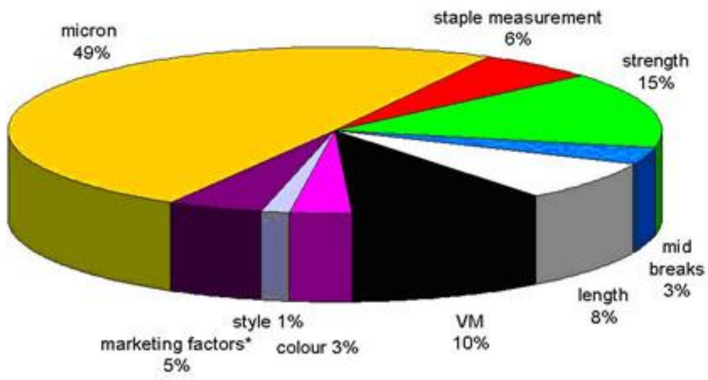


Figure 7.1 Value determining characteristics of Raw Wool for 2003/04, for Merino fleece wool from 18.6µm to 24.5µm. The relative influence of Mean Fibre Diameter on the price of Raw Wool is shown as "micron", a descriptor commonly used in the wool industry. Source: Stott, K. (2005, pers. comm.).

Not only is Fibre Diameter the main price determinant of raw wool, the price paid is highly dependent on the actual measured Fibre Diameter as shown in Figure 7.2. Note that a small change in MFD is responsible for a large change in price for Raw Wool which has an MFD less than approximately 20µm. For wool lots coarser than approximately 20µm the price is far less sensitive to small changes in MFD.

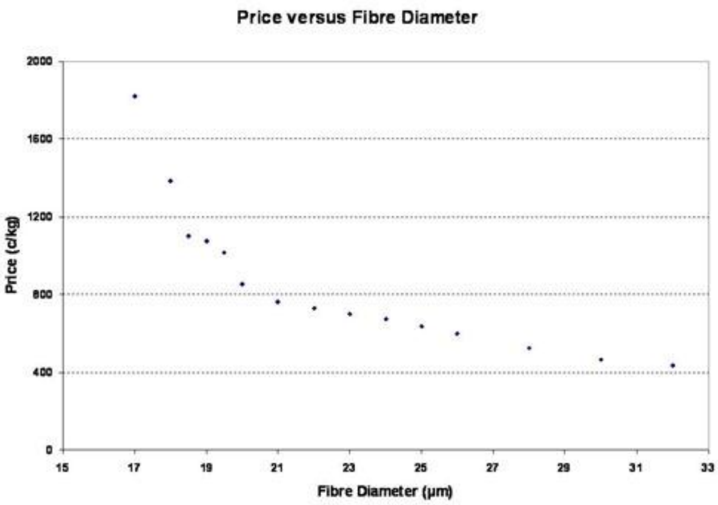


Figure 7.2 Average price paid at auction in Australia from July, 1998 – April, 2005 for sale lots of different mean fibre diameter. Source: DAWA and AWTA Ltd.

7.2 Relationship to processing performance and end product quality

The vast majority of Australian wool is manufactured into woven and knitted fabrics and garments. In the course of manufacturing these products, the steps required to manufacture a wool thread, or yarn, are often the most expensive.

A minimum number of fibres is required in the cross section of a yarn to ensure suitable evenness and strength in the yarn for conversion into a woven or knitted fabric. In general, the higher the number of fibres in the yarn cross section the more even, and thus the stronger, is the yarn. A greater number of finer than coarser fibres can be incorporated into a yarn of a given weight, or linear density. The greater number of finer fibres result in a more even stronger yarn than a yarn of equivalent linear density composed of a fewer number of coarser fibres. Stronger, more even yarns are more efficient to spin and to weave into fabrics.

Given that a commercially acceptable yarn consists of a minimum number of fibres, the fineness of the yarn is directly related to the fineness of the fibres. In turn, the fineness of the yarn largely determines the 'fineness' or weight per unit area of the fabric. This means that the only way to manufacture a fine, strong yarn from wool, is to use fine fibres. And thus fibre fineness has a direct relationship to the minimum weight per unit area into which a fabric can be converted.

As well as fabric weight per unit area, Fibre Diameter is also a major determinant of the aesthetic fabric characteristics which are strongly associated with the perception of fabric quality, e.g. fabric handle and drape. Within any given fabric structure, Fibre Diameter is a major determinant of fabric handle, with finer fibres giving a softer, smoother feel to a fabric than coarser fibres. In a similar way Fibre Diameter affects the drape of a fabric, with finer fibres being associated with fabrics having smooth, figure-hugging drape compared with the stiffer drape of similar fabrics made of coarser fibres.

7.3. The determination of fibre fineness

Subjective appraisal

The visual appraisal of greasy wool was based mainly on the crimp frequency seen in the staples, i.e. the number of crimp waves per cm along the length of the wool staple. An illustration of the Bradford Quality Numbers for two pairs of staples is given in Figure 7.3. The broader crimp frequency of the 64's quality can be compared with the finer crimp of the 74's quality.

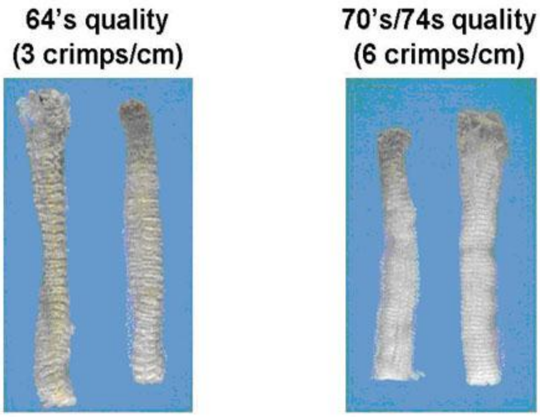


Figure 7.3 Wool staples of different Bradford quality number. Source: Mahar (2006).

When reliable measurement of Fibre Diameter became available, a number of studies showed the benefits of objective measurement over the subjective approach. Firstly, as greasy wool and wool tops were traded extensively and internationally, it was apparent that disputes between traders about wool quality were better settled by objective means than by the subjective assessment of experts. Also, studies of the quality number systems in different countries showed differences in interpretation with respect to crimp frequency and to measured Mean Fibre Diameter (MFD).
The quality number concept is still used to describe wool today, e.g. in the Australian Wool Exchange (AWEX) Code of Practice for Wool Classing, classers are directed to class wool within 3 neighbouring quality numbers into the same line. Also, the International Wool Textile Organisation (IWTO) Code of Practice 2/102, Identifying Fine Wool Fabric uses the standards

7.4 Mean fibre diameter

Wool fibres are not uniform cylinders – the cross-section can range from roughly circular to highly elliptical or kidney-shaped (See reading – AWTA 2002a.pdf). Furthermore, the thickness can vary substantially along the fibres. And in a sample of wool the constituent fibres will vary widely in their thicknesses. While a number of options are available to define the fineness of wool fibres, the industry has chosen to define fibre diameter in terms of the average thickness of a two-dimensional projected image of a large number of short fibre sections (or snippets). These are measured using a Projection Microscope (or Lanameter). The unit used for measuring fibre diameter is the micron (or micrometer), where 1 micron (1μm) = 10^{-6} meter. The very finest wools have mean fibre diameters of around 13 μm while the coarsest wools can exceed 40 μm.

Fibre snippets are generally 0.8 – 2 mm long, cut from fibres at random positions along their length. Snippets are obtained from a wool sliver using a guillotine or microtome. These are spread on a glass slide in a mounting fluid under a glass cover slip. They are magnified using a projection microscope and the widths of the magnified images are measured using a graduated scale. Care is taken to ensure that the snippet being measured is in focus and that each snippet is measured only once.

Calculating the mean fibre diameter (MFD) from distribution data is quite simple. For each class interval select the middle of the range d and multiply this by the total number of fibre snippets n. Add the products then divide by the total number of fibre snippets. For these data:

$$\text{MFD} = \frac{\Sigma\, d \times n}{n} = \frac{80150}{4000} = \mathbf{20.03\ \mu m}$$

Calculation of the standard deviation and the coefficient of variation

The standard deviation of fibre diameter (SD) measures the dispersion (or spread) in the fibre diameter distribution. Calculation of the standard deviation from the distribution data is a little more complicated because it involves a further calculation – multiplying the square of the diameter by the number of fibre snippets in each class interval.

$$\text{SD} = \sqrt{\frac{\Sigma\, n \times d^2 - \dfrac{(\Sigma\, n \times d)^2}{\Sigma\, n}}{\Sigma\, n - 1}}$$

$$= \sqrt{\frac{1640744 - \dfrac{(80150)^2}{4000}}{4000 - 1}}$$

$$= \mathbf{2.95\ \mu m}$$

If we assume that the fibre diameter distribution is bell-shaped, i.e. normal (which is usually approximately true), 68% of the fibres fall within one SD of the MFD and 95% of all fibres fall within two SDs of the MFD. For example, for a sliver with MFD = 20 µm and SD = 4 µm, 68% of all fibres are in the range 9-24 µm and 95% of all fibres are in the range 12-28 µm.

While the standard deviation is useful in describing the dispersion of a fibre diameter distribution, it is less useful in comparing different lots of wool unless the fibre diameters are very close or equal. As the MFD increases so does the SD.

For commercial purposes, a measure of dispersion that is comparable for different mean fibre diameters is preferable. This is the coefficient of variation (CVD).

$$CVD = \frac{SD}{MFD} \times 100 = \frac{2.95}{20.03} \times 100 = \mathbf{14.7\%}$$

Because the Standard Deviation is linearly related to the mean fibre diameter, the coefficient of variation is generally independent of the mean fibre diameter.

Although the mean fibre diameter is the major price determinant for wool, the degree of fibre diameter variation is also important. Wools with higher MFDs and lower CVDs have been found to produce yarns with properties similar to wools with lower MFDs and higher CVDs. The so called "5% rule" says that a 5% change in CVD is equivalent to a 1 micron change in MFD. For example, a wool with a MFD of 21 µm and a CVD of 20% will produce yarns with properties similar to 20 µm wool with a CVD of 25%.

7.5 Sampling requirements

Where test results for a consignment of sliver or top are to be issued on an IWTO test certificate, the IWTO regulations require that:

1. Samples are to be taken from bales of sliver distributed equally throughout processing of the consignment
2. Only one sample is to be taken per bale, with a minimum of 5 samples per consignment
3. At least one sample must be tested per 5,000kg of conditioned sliver
4. Samples drawn for testing must weigh at least 10g.

Instrument calibration

Instruments used for measuring the fibre diameter of wool are usually calibrated using Interwoollabs IH Standard Tops. These comprise 8 specially prepared combed slivers which have been measured by many laboratories by Airflow and Projection Microscope in repeated round trials. Interwoollabs, based in the UK, supply the tops together with their standard mean fibre diameter values. Where a test result is to be issued on an IWTO test certificate, instrument calibration using the Interwoollabs tops is mandatory. The calibration procedures and calculations for each instrument are outlined in its relevant IWTO test method.

7.6 Testing instruments and methods

1) Projection microscope

The Projection Microscope (PM) method is the basis of all commercial Fibre Diameter measurement. Other methods are linked back to the PM through a calibration process which will be discussed in detail when describing the other three (3) methods.

The projection microscope, as the name implies, projects a magnified image of the fibres onto a measuring screen which has a calibrated scale used to measure the diameter of the fibres (See reading – AWTA 2002b.pdf). It is a manual operation (Figure 7.4).

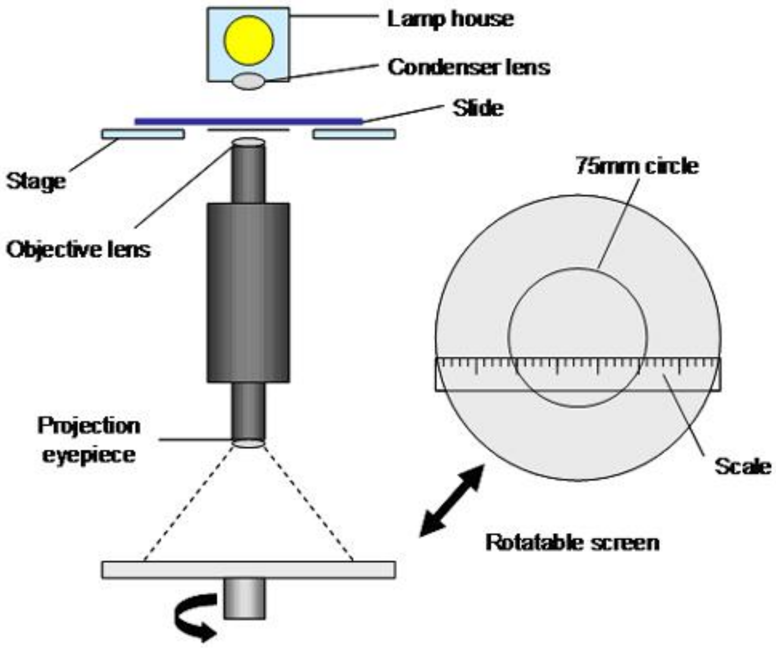


Figure 7.4 Projection Microscope. Source: Canesis Network (2006).

Any microscope that can project the image onto a screen may be used, but the two most widely used are the WIRA microscope and Reichart Lanameter. The magnification required is 500X and the instruments are calibrated by a graticule.
Snippets are cut from the conditioned fibre snippet or sample of sliver, at random positions. They are mounted on a standard microscope slide in a suitable medium and a cover slip is applied.

The slide is placed under the microscope lens and the slide moved across and down (in 0.5mm steps) during measurement so that its area is covered uniformly, but no fibre is measured twice. After each movement the fibre images are focussed and their widths measured and placed into 2mm classes. Fibres are not measured if:

- more than half their width is outside the 75mm measurement circle
- their end(s) lie within the measurement circle
- fibres that cross each other in the measurement circle.

The frequency distribution formed from this operation is used to calculate mean fibre diameter and fibre diameter distribution.

Sampling

The PM can be used to measure the Mean Fibre Diameter (MFD) of samples taken from all stages of processing from Raw Wool to fabric. Raw Wool samples are cleaned, and either hand carded or Shirley Analysed (a Shirley Analyser is a mechanical card which opens wool and removes the majority of any vegetable matter contamination from the sample) to form a uniform blend of randomised fibres. Small portions of fibre are then sampled from the mass and placed into the slot of a microtome. For sliver, roving, yarn and fabric samples a suitable thickness of material is simply placed into the slot of a microtome.

Three important factors affect results obtained using this method:

- It is very slow and labour intensive (a rate of approximately 600 snippets in two hours is achievable for a good operator)
- It is operator dependent. Standard wool tops are provided to calibrate operators. This means that this method is not directly traceable to the International Standards Organisation (ISO) standard metre
- It is dependent on sample preparation. If the snippets are cut too short the result will be biased toward a larger diameter. This is because the more elliptical fibres lie on their

major axis on the microscope slide. Coarser fibres are considered to be more elliptical in their cross-sectional shape, therefore these fibres will measure as being thicker.

Also a PM measurement according to the IWTO Test Method stipulates that a minimum of 600 fibres mounted on at least 2 microscope slides be measured by at least 2 operators. As an example of another of the rules in detail, the operator is not permitted to take a measurement within 25mm (50µm) of the end of a snippet or within 25mm (50µm) of another snippet.

Strengths and weaknesses of projection microscope Measurement

The major advantages of the PM are that it is:
- a fundamental measurement with values traceable to a well defined unit of length
- relatively cheap, being labour, rather than capital, intensive, and
- relatively simple to perform.

The major disadvantages of PM are that the measurements:
- have a degree of operator dependence
- are slow and time-consuming to perform
- are operator-intensive and expensive in high labour cost countries, and
- require a relatively small sample (containing a relatively small number of fibres) which may be less representative than a larger sample, such as those used in the other three (3) more mechanised measurement systems.

2) Airflow

The Airflow instrument operates on the principle that the resistance to the flow of air through a plug of wool fibres of a given mass will increase as the mean fibre diameter decreases (and the surface area increases), for a given pressure drop (See reading – AWTA 2004.pdf).
Since the method is indirect, the instrument must be calibrated by international standard tops which have been measured by both projection microscope and Airflow devices.
In practice a conditioned and carded test specimen is placed in a fixed volume chamber and measurements are recorded in millimeters (the scale reading for the change in pressure). The mean value is converted to micrometers using the second order regression line of the calibration curve constructed from measurements on the Standard tops. A standard atmosphere is required as the method depends on the weight of the test specimen (2.5g ± 0.004g).

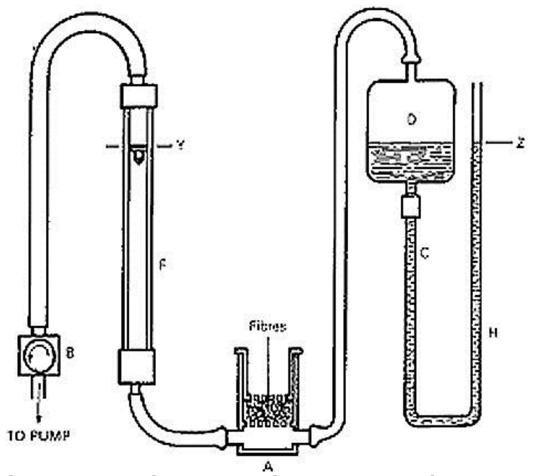
This method only measures mean fibre diameter and provides no information on the distribution of fibre diameter in the sample.

The major factors that affect results obtained from this method are:

- It is dependent on sample preparation. The calibration material and unknown samples must be prepared by the same method. Shirley Analysing is the most widely used method of carding
- It is affected by changes in fibre density. While changes in fibre density are difficult to quantify, they are a source of error. For example, medullation has a marked effect
- Being an indirect method it requires a supply of standard calibration tops.

An image of an Airflow Meter is shown in Figure 7.5 in which the following components are illustrated: air control valve (B in the diagram, and the black knob in the lower right of the image), the manometer (C in the diagram, and shown by the orange vertical column towards the middle of the backing plate in the image), the flowmeter (F in the diagram, and the glass tubing mounted between the metal blocks, which runs vertically along the left of the backing plate, in the image), and the chamber (A in the diagram, and the metal object with the (2) hoses (one (1) on each side) mounted on its base located in the lower right of the image). The pump is mounted away from the meter itself to minimise noise for the comfort of the operator.

a.



b.

Figure 7.5a Diagrammatic representation. Source: IWTO-28-00.
Figure 7.5b Image of an Airflow meter. Source: Mahar (2006).

Strengths and weaknesses of airflow measurement

Airflow is the most popular technique amongst members of Interwoollabs. One of the reasons for this popularity is the reliable performance of the instrument over many years. Also, Airflow measurement is much quicker to perform than PM, the equipment is relatively inexpensive to purchase, and simple and easy to maintain. The method uses a much larger sample than does PM and, on this basis alone, is likely to obtain a more reliable estimate of the MFD of a sample. The precision of Airflow measurement of top is much better than the equivalent precision of a PM measurement, according to IWTO-6-98 and IWTO-8-97.

3) Laserscan

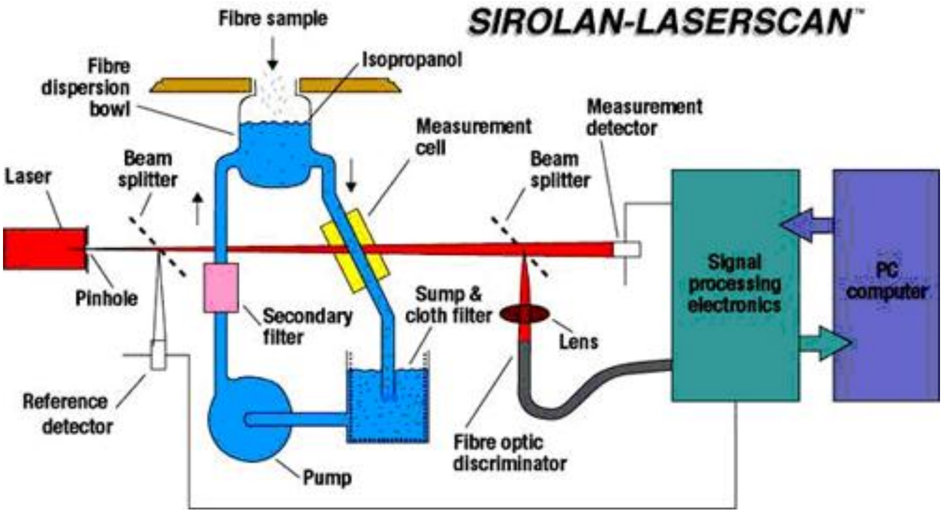


Figure 7.6 Laserscan system. Source: AWTA Ltd. (available from website - http://www.awta.com.au/).

Development of Laserscan by CSIRO commenced in 1971, and in the early 1980s its predecessor, the FDA (Fibre Diameter Analyser) was launched. The modern Laserscan evolved from FDA, and an IWTO test method for this instrument was approved in 1995. The instrument is now marketed and supplied by AWTA Ltd.

The process of acquiring the snippets by guillotining a sliver at random positions along its length, is the same as for the projection microscope and OFDA, but there is no need to mount the snippets on a glass slide for presentation to the instrument. It is required for 2 test specimens to be measured from each sliver subsample.

Figure 7.6 shows how LASERSCAN operates. Fibres snippets are dispersed into an isopropanol-water mixture, or alternatively a water/detergent mixture (Crowe et al. 2000). The suspension of snippets in the transport fluid passes through a measurement cell. While passing through the cell the fibre snippets intersect a fine beam of light from a laser which is directed at a measurement detector. The optical response in this instrument is not simply a shadowing of the fibre on the cell but a more complex diffraction pattern. An electrical signal is produced by the detector that is proportional to the amount of light falling on it. Hence, when a fibre snippet passes through the beam this electrical signal is reduced by an amount that is directly proportional to the projected area, and therefore thickness or diameter of the fibre. The relationship between the magnitude of the change in detector signal and the mean fibre diameter is determined by calibrating the instrument using standard wool tops.

It is important that only snippets that fully intersect the beam are measured. Also, only one snippet can be measured at any instant or else the signal from the detector will indicate the snippet is either finer or coarser than it really is. To ensure that (1) only single snippets are measured and (2) the snippets fully intersect the beam, the instrument uses a special fibre optic discriminator as the detector. The principle of this device is shown in Figure 7.7. It consists of a ring of fibre optic detectors surrounding a central fibre optic detector. The signal from each of these is continuously monitored. The Laserscan computer detects when decreases in signal from the central detector and two of the surrounding detectors occur simultaneously and it matches this event with the signal from the main detector. Events that do not match this selection criterion are rejected and the measurements are not recorded.

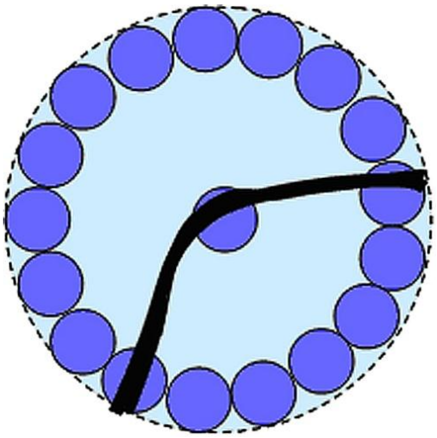


Figure 7.7 Laserscan fibre optic discriminator. Source: Canesis Network (2006).

By operating in this way Laserscan resembles the projection microscope, in that only measurements on individual snippets are used to produce the fibre diameter distribution. This requirement is particularly important in eliminating the bias resulting from selective sampling from the total population of snippets presented to the instrument.

The snippets are filtered from the liquid after passing the beam and the liquid re-circulated. The fibres have been shown to pass the laser beam in a random orientation in rotation about the fibre axis. The device can measure 2000 fibre snippets in approximately two minutes.

The individual measurements are collected in 1 mm classes (compared to 2µm classes for PM). The mean fibre diameter and fibre diameter distribution are calculated from the frequency distribution obtained from this operation. The measurement of mean fibre curvature is also possible with this instrument.

Laserscan results are less reliant on laboratory conditioning than other methods for measuring fibre diameter because the snippets are immersed in a mixture containing water at a known concentration which ensures even, rapid conditioning.

Figure 7.8 Commercial Laserscan (courtesy AWTA 2014)

Strengths and weaknesses of Laserscan measurement

Laserscan measurements are essentially operator independent, more precise than other methods (as highlighted in Table 7.5 and Figure 7.7), quick and simple to perform, and independent of conditioning if water is used as the fluid transport medium. Laserscan also provides an estimate of diameter distribution parameters other than the mean, i.e., Standard Deviation (SD), Coefficient of Variation (CV), and Comfort Factor (CF). Comfort Factor is simply the percentage of measured fibres with a diameter less than 30µm. Although Airflow Meters are the most popular measurement method amongst Interwoollabs members, more commercial wool tests are performed using Laserscan than any other instrument as it is the preferred method of the high-volume test Houses for certified testing of greasy wool, and greasy merino wool in particular.

On the negative side, Laserscan is relatively capital intensive compared to PM and Airflow, requiring computer processing and sophisticated optics and electronics in its manufacture.

Fleecescan

Fleecescan is a transportable sampling, cleaning and measurement system for Fibre Diameter of individual fleeces. The Fleecescan system, which was developed by CSIRO, can be used during shearing to obtain a sample of a skirted fleece. It comprises an Automatic Fleece Corer-Washer unit used in conjunction with a standard Laserscan instrument. The Corer-Washer unit automatically cores the fleece, then cleans and dries the sample for measurement on Laserscan. Washing and measurement are completed in less than a minute, providing real time results during shearing. This enables the classer to use the diameter (and Fibre Curvature) information in his classing decisions.

Fleecescan has been designed to fit onto a utility, or small flat-tray 4WD vehicle. The advantages of the Fleecescan system are: the immediacy of the results (instant feedback, compared with midside sampling and testing at a Test House); the constant conditions of the fibre snippets being tested (fibre snippets equilibrate based on the moisture content of the transport fluid; and, the fact that fleece weight is obtained as part of the system. A disadvantage of the Fleecescan compared with the OFDA2000 is its relative lack of portability.

4) OFDA 100 (Optical fibre diameter analyser)

The OFDA 100 system is essentially an automatic image analysis system (Figure 7.9). Magnified images of fibre snippets are captured by a camera, then processed to both determine the width (or diameter) of the snippet at a selected point along the image and to validate that the fibre image for measurement is a valid individual fibre.

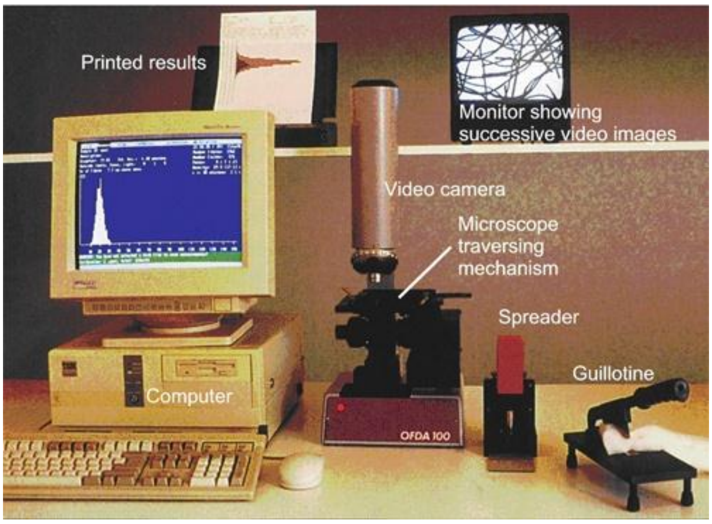


Figure 7.9 OFDA system. Source: BSC Electronics with permission

For measurement, snippets are sampled in a similar manner to Laserscan (i.e., minicore for Raw Wool and guillotine for top) with the addition of a snippet spreading step in which the sampled snippets are spread onto a hinged, 70mm x 70mm microscope slide. The guillotine is used to cut snippets of a standard length of 2mm. After spreading onto one of the hinged slides, the other hinged slide is closed over the snippets, and the whole slide mounted on an XY stage of the microscope. The motorised XY stage then traces out a predetermined pattern which allows for the capture of the images of the fibre snippets. As with the Laserscan, the processing of the information is performed very quickly using modern computer technology. A complete measurement cycle on a clean, conditioned sample takes less than 2 minutes.

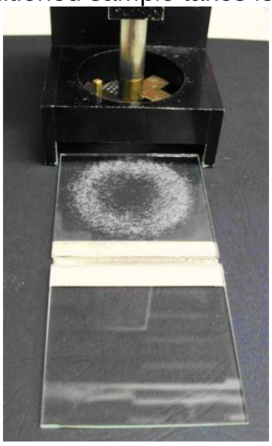


Figure 7.10 Snippets spread on a slide before closing. Source: Canesis Network (2006).

The slide is closed and placed on the stage of microscope, and the measurement process is commenced. During scanning up to 2000 or more images may be acquired and analysed. Each image, which covers an area of about 1mm by 1.5mm, is analysed in real time and between three and 50 fibres may be measured. Sixteen images are analysed each second. After a pre-set number of fibres have been measured the contents of the bins are analysed to calculate the mean fibre diameter, the fibre diameter distribution and other statistics.

Strengths and weaknesses of OFDA measurement

OFDA measurements are essentially operator independent, more precise than PM and Airflow and quick and simple to perform. OFDA also provides an estimate of diameter distribution parameters other than the mean, i.e., Standard Deviation (SD), Coefficient of Variation (CV), and Comfort Factor (CF). The OFDA is popular for both commercial and non-commercial measurement of Fibre Diameter. In fact, variations of the OFDA100 have been and are being developed both for On-farm measurement where the OFDA2000 is available, and for top measurement of both diameter and length, where the OFDA4000 is currently being used.

As with Laserscan, the OFDA100 is relatively capital intensive compared to PM and Airflow, requiring computer processing and sophisticated electronics in its manufacture.

OFDA 4000

In an ideal situation no correlation is expected between the length of a fibre and its mean fibre diameter. However, in practice tops can have a diameter profile where there is a relationship between the mean diameter of a fibre and its length. This can arise in wool tops if:

a) wools of different length and strength characteristics are blended for topmaking
b) fibres are selectively broken in topmaking, e.g. if finer fibres break more readily than coarser fibres so that the longest fibres in the top are the coarsest
c) blending wool from different sources, e.g. short fine wool blended with coarser, longer wool.

OFDA 4000 is a new instrument from BSC Electronics Pty Ltd that has been developed for simultaneously measuring fibre length, fibre diameter, diameter profile and fibre curvature in slivers and tops using a digital video microscope. Details of its operation are provided by Brims (2002).

OFDA 4000 has evolved from OFDA100 and from OFDA2000, which is a portable instrument for measuring greasy wool fibre diameter and having the additional capability of measuring the diameter profile along a wool staple. It has been developed primarily for quality control in topmaking and research use.

A fibre aligner device has been developed for preparing a beard of fibres from a top and presenting it to the microscope:

- Beards of density from 100 fibres to the full number of fibres across the top can be extracted
- The beard is lightly clamped to hold the fibres in the focal plane of the microscope while video images are captured every 1.2mm across the beard, and every 5mm along the beard
- The process continues until the number of fibres viewed falls below a threshold, indicating that the end of the beard has been reached
- If the number of fibres counted in the first scan has not reached a preset minimum value another beard is presented and measured, with all results being summed for analysis.

The diameter measurement software is identical to that used in OFDA 100, except that the maximum fibre count is extended to 300,000.

The diameter-related statistics provided by OFDA 4000 are:

- Mean, standard deviation and histogram of diameter
- Comfort factor
- Diameter profile along beard (graph of fibre diameter along, standard deviation along)
- Fibre end comfort factor (measured at aligned end of beard) to provide a measure of the risk of prickle in a fabric.

In addition measures of fibre length and curvature are also provided.

Brims (2002) provides a series of examples of fibre diameter profiles (i.e. micron versus length along a beard).

The manufacturers of OFDA 4000 claim that it can replace:

- Almeter Fibroliner and Measurement Unit (the well-established system for measuring the fibre length characteristics of slivers and tops)
- OFDA100 and Laserscan (the established instruments for fibre diameter measurement).

It is also claimed that the results on a sliver or top can be produced using one minute of operator time. Figure 7.11 has been derived from data on a top provided by Brims (2002).

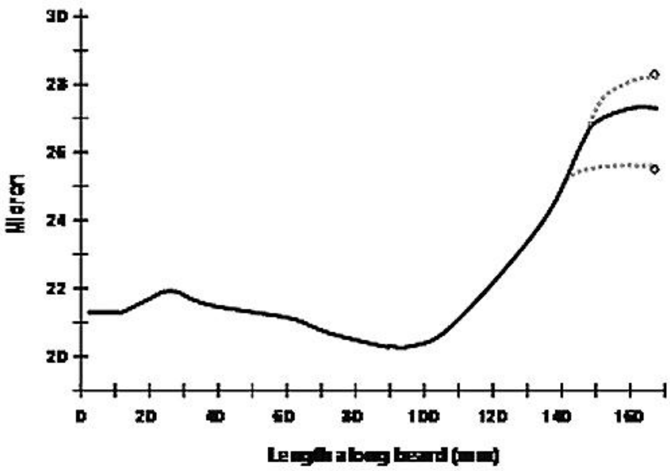


Figure 7.11 Diameter profile for a top. Source: Canesis Network (2006).

The profile curve is actually the average of 10 repeats measurements on the same top, with a minimum of 4000 fibres per measurement. It shows a significant increase in mean fibre diameter as the fibre length increases above about 120mm. The profile is less repeatable near the end of the beard due to the inevitable reduction in the number of fibres. The variation in this region is indicated by the dotted curves.
Based on the results provided by Brims there is considerable variation in the shape of the profiles of tops obtained from different sources. Some profiles show a steady increase in micron with length, while others show a distinct peak or dip in micron in the mid-length range.

OFDA2000

OFDA2000 is a modification of an OFDA100, which measures full length wool rather than 2mm snippets. It is also possible to measure the wool in either a greasy or a clean state. The actual samples measured by the OFDA2000 are microstaples. As well as MFD, SD and CVD, the OFDA2000 provides an estimate of the diameter profile of a staple. The OFDA2000 is portable, and comes in a specially constructed case with its own PC. OFDA2000 measurements can be performed while samples are being taken in a wool race or during shearing.

The advantages of OFDA2000 are: immediacy of results; greater portability than Fleecescan; and, provision of diameter profile data. A current limitation of the OFDA2000 data is the lack of information about the interpretation of diameter profile data. An image of an OFDA2000 is shown in Figure 7.12.

Figure 7.12 OFDA2000 instrument. Source: Mahar (2006).

7.7 Comparison of test house, Laserscan and OFDA2000 measurement

Australian Wool Innovation (AWI) sponsored a trial (Fish 2002) to compare the precision and accuracy of Test House, Fleecescan and OFDA2000 technologies in the measurement of the following characteristics: MFD; SD; CVD; CF; and, Mean Fibre Curvature (MFC). The trial involved sampling sheep on seven (7) properties, with samples drawn from midside and pinbone sites as well as minicoring of whole fleeces and manually coring fleeces to obtain core samples for estimating the characteristics of the whole fleece. 160 sheep were sampled and shorn at each property.

Results of this trial are summarized in Table 7.1 which shows the better precision (lower 95% Confidence Limits) for MFD measurement by Test House (1.04/1.05µm) compared to Fleecescan (1.17µm) and OFDA2000 (1.24µm). Average values of each parameter are included for information.

Table 7.1 95% Confidence Limits for testing individual fleeces using different technologies. Source: Fish (2002).

Parameter	**Fleece**	**Fleece**	**Midside Samples**		
	Whole Fleece Average	Fleecescan	OFDA2000	Lab OFDA100	Lab Laserscan
MFD (µm)	19.5	±1.17	±1.24	±1.05	±1.04
SD (µm)	4.1	±0.7	±0.5	±0.5	±0.6
CVD (%)	20.8	±3.4	±2.2	±2.4	±2.9
CF (%)	98.1	±1.8	±1.6	±1.5	±1.6

The results also show that the midside sample was, on average, 0.2µm – 0.4µm finer than the whole fleece average, and that the pinbone sample was 0.5µm – 0.7µm coarser that the fleece average. The precision of the pinbone sample was approximately 0.2µm worse than the precision of the midside for each technology.

The effect of differences in measurement precision on selection decisions on farm is discussed by Marler (2001) who pointed out that the deleterious effect of low measurement precision on potential genetic gain in a flock. These effects are shown in Table 7.2 for three levels of precision, with three different SDs of MFD between sheep in the mob, and two levels of culling.

Table 7.2 Percentage of incorrect selections for three different levels of precision of testing. Source: Marler (2001).

SD of Mob	95% CL	35% Cull	95% Cull
1.0µm	± 0.4µm	4%	12%
	± 1.0µm	11%	27%
	± 1.6µm	15%	47%
1.5µm	± 0.4µm	3%	13%
	± 1.0µm	7%	19%
	± 1.6µm	11%	33%
2.0µm	± 0.4µm	2%	8%
	± 1.0µm	5%	17%
	± 1.6µm	9%	31%

7.8. Variation in fibre diameter measurement

Discussion to this point has concerned the Mean Fibre Diameter of a sample of wool. But there is also variation about this mean diameter in every sample of wool. Variation in Fibre Diameter has been shown to influence processing and end-product performance, though to a lessor extent than the mean diameter. Three (3) of the commercial diameter measuring instruments, PM, Laserscan and OFDA, provide information about the variation in diameter as well as the mean value.

A frequency histogram, as shown in Figure 7.13, provides a full representation of the variation in diameter found in a sample of wool. Also highlighted in Figure 7.13 is the Standard Deviation (SD) of the Fibre Diameter distribution. A relatively narrow, tall frequency distribution is associated with a relatively small SD, 2.5µm; while a broad, short distribution is associated with a relatively high SD, 5.0µm. SD is a parameter used to describe variation in diameter and is a measure of the relative width of the distribution. Another parameter is the Coefficient of Variation of Diameter (CVD).

CVD = (SD x100)/Mean Fibre Diameter

CVD is the most popular measure of diameter variation used in the wool industry, as it has a relatively constant value for lots of wool with different MFDs. It has the drawback that, as the ratio of two (2) other parameters it is less precise than either of its components, MFD or SD.

A typical Fibre Diameter distribution is almost symmetrical, but has a slightly longer spread of diameters at the coarser than at the finer end. Because of their importance in determining the absence of 'prickle' in a wool fabric worn next to the skin, the presence of fibres greater than 30µm in diameter is also often reported in wool testing. The Comfort Factor of a sample is the percentage of fibres tested with a diameter less than 30µm.

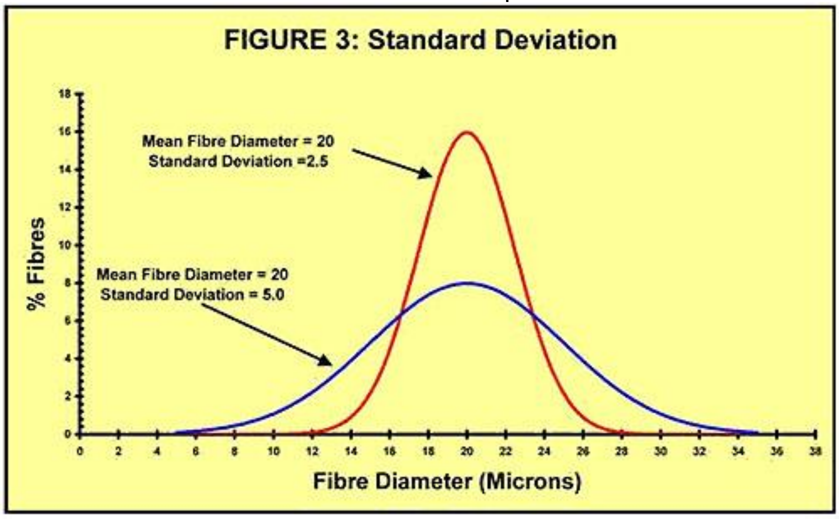


Figure 7.13 A Fibre Diameter distribution highlighting the effect of the shape of the distribution on Standard Deviation. Source: Mahar (2006).

7.9 Sources of variation in fibre diameter measurement

There is variation in every sample of wool which is measured because wool fibres are not identical cylindrical rods. In this section we will quantify the relative contribution of various sources of variation in a sample of wool.

Within a fibre

As illustrated in Figure 7.14 there is variation in the "diameter" of wool fibres simply because of their irregularly shaped fibre cross section. Clearly, if we use a ruler to measure the "diameter" of these images, the "diameter" we obtain for each image will depend where we place the ruler. If we measured a very large number of transects across each fibre cross section, we could calculate the average "diameter" of these fibre cross sections and also calculate the variance of all these transects. This variance is a measure of the variation in Fibre Diameter between fibres at one point along each fibre. For Merino wool, the ratio of the major to the minor elliptical axes (fibre ellipticity) typically ranges from 1.0 to 1.2, meaning that a Merino fibre can have its major axis 20% bigger than its minor axis. The effect on variation in measured Fibre Diameter of a fibre ellipticity of 1.2 is shown in Figure 7.15 for an elliptical fibre cross section with an average diameter of 21.9µm.

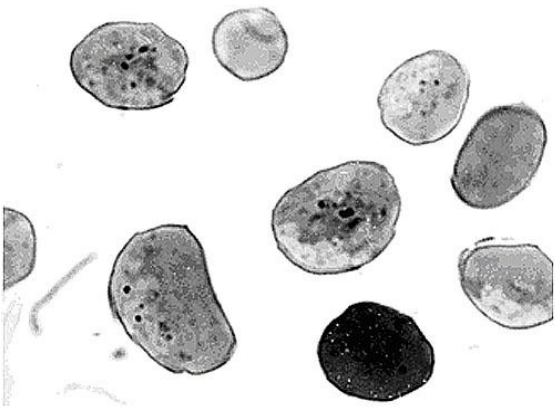


Figure 7.14 Cross sections of wool fibres extracted from a 19µm top. Source: Turner, P. (2005, pers. comm).

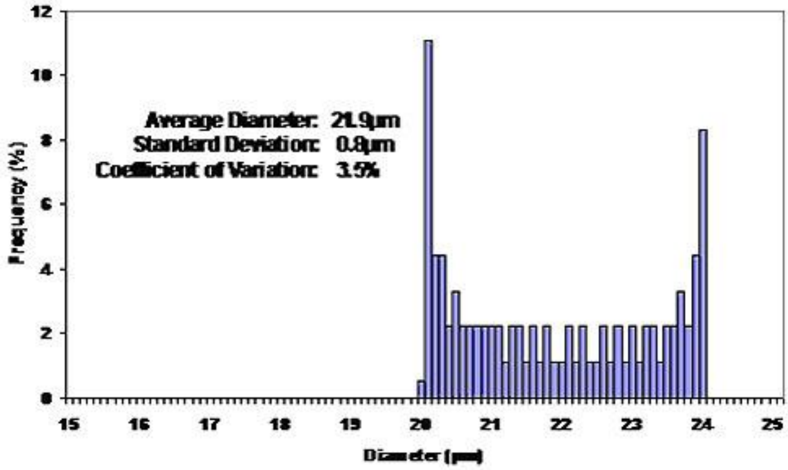


Figure 7.15 Variation in Fibre Diameter due to a fibre ellipticity of 1.2. Source: Mahar (2006).

It is also the case that wool fibres vary in diameter along their length in response to changes in food supply, the onset of pregnancy and lactation and other physiological stresses (e.g. disease). This along-fibre variation has been measured (Peterson 1997) using a SIFAN instrument to produce the diameter profile shown in Figure 7.16. This example shows that variations of over 12µm are possible between the finest and coarsest measured diameter within a fibre which has an average Fibre Diameter of approximately 24µm.

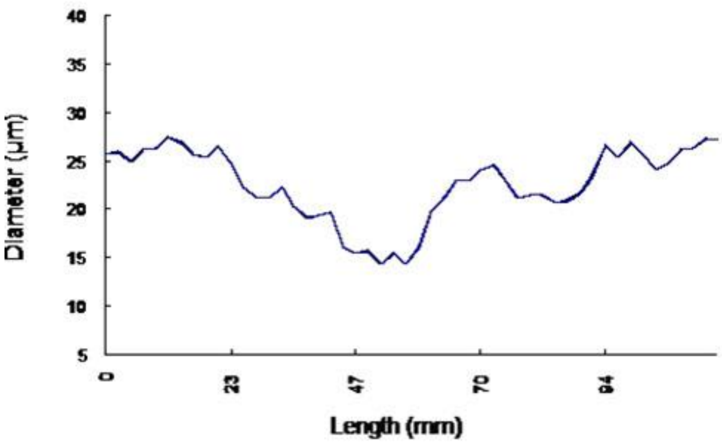


Figure 7.16 Diameter variations along the length of a single wool fibre. Note that each point on this graph is the mean of 53 consecutive measurements. Source: Peterson (1997).

The information contained in Figure 7.16 has been termed the diameter profile of that fibre. This profile highlights an extreme of variation along the fibre length, and is typical of wool from an animal which has been under stress during the middle of its growth period. In recent years, researchers (Hansford 1989; Baxter 2002) have developed means of obtaining an estimate of a Fibre Diameter profile based on measuring the average diameter of fibres at regular points along the length of a staple. Unlike single fibre measurement, these techniques offer the possibility of obtaining an estimate of a diameter profile on a commercial basis because the staple diameter profile can be measured much more quickly than the individual fibre profile. The OFDA2000 has become a popular measurement technique for On-farm measurement of individual animals and will be discussed in more detail under Testing Individual Sheep.

Between fibres in a staple

The sources of variation in Fibre Diameter already discussed are generally of far less significance than the variation between the fibres within a staple of wool. The ratio of the coarsest to finest Fibre Diameter in a staple can be over 4 to 1, providing a minimum of approximately 1,000 individual fibre measurements are made. Indeed, Whiteley (1972) demonstrated that, whether the wool was sound or tender, most of the variability of Fibre Diameter in a sample of wool occurs within a single staple, as shown in Table 7.3.

Table 7.3 Baxter, P. 2002, 'An evaluation of the performance of the OFDA2000 instrument operating in OFDA 100 mode,' *Proc. of IWTO,* Raw Wool Group Committee meeting, Report No. RWG03. Source: Whiteley, (1972)

Source of Variation	**Percentage of Variation (Variance for a mean diameter of 21.9µm - µm^2)**	
	Sound	Tender
Among Fibres within a Staple	64 (16)	43 (16)
Among Staples within a Fleece	4 (1)	3 (1)
Among fleeces within a Flock	16 (4)	11 (4)
Along the Staple	16 (4)	43 (16)
Total	100 (25)	100 (37)
Coefficient of Variation based on a Mean Diameter of 21.9µm:	22.8%	27.8%

Diameter differences between fibres growing from adjacent follicles in a narrow area of a skin on a sheep can be over 20µm. Sheep have primary and secondary follicles that are set prior to birth. Merino sheep have secondary to primary follicle (S:P) ratios of 15:1 or higher. No other breed has S:P ratios this high, indicating that the between fibre variation in diameter would be expected to be higher in non-Merino than in Merino sheep. The Fibre Diameter distribution of a 2mm guillotined section of a merino staple measured by Laserscan is shown in Figure 7.17. The measured SD and CVD for this example with an MFD of 19.1µm are: 3.6µm and 19%, respectively.

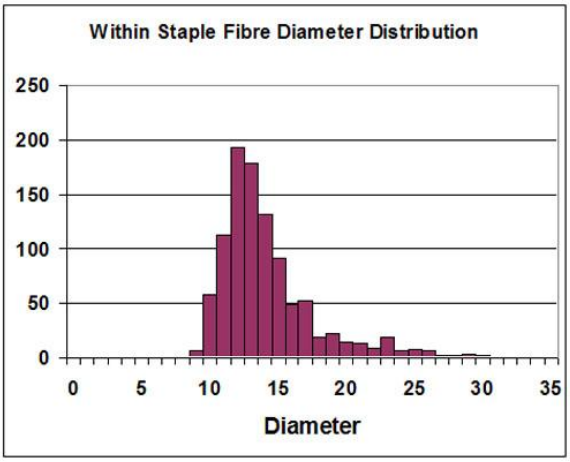


Figure 7.17 Fibre Diameter distribution of a 2mm section of a Merino staple showing the variation between fibres within the staple. Source: Mahar (2006).

Note that the greater contribution to overall diameter variation from along the fibres in the case of tender, or weak, wool in Table 7.6 demonstrates the effect that variation in along-fibre diameter has on the variation of diameter within a staple.

Between staples on a fleece

There is a pattern in the variation of diameter over a fleece. In one example (Fish 2002), diameter increases progressively from anterior to posterior (as expected), and decreases from the dorsal to ventral positions, as illustrated in Figure 7.18. As shown in Table 7.3, the variation over a fleece is relatively small compared with the other nominated sources of variation.

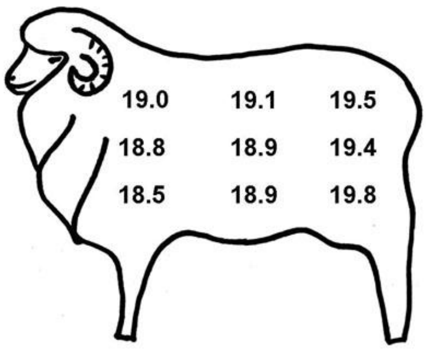


Figure 7.18 Diagram of a Merino sheep showing the average diameter of samples taken from different regions. Source: Fish (2002).

Pioneering work by Newton-Turner et al. (1953) demonstrated that, on average, a mid-side sample was most representative of the diameter (and some other properties) of the whole fleece compared to samples taken from other regions of the sheep. Trials reported by Marler and Baxter (2004) both highlighted the variation between sheep in the representativeness of the midside for diameter measurement, and quantified the deleterious effect on precision and representation of the fleece of substituting, an often more conveniently taken, sample from the pinbone (hip) instead on from the midside.

Among fleeces in a sale lot

The variation of diameter for fleeces within a sale lot would be expected to be marginally less than the variation between sheep in a mob, since the visual/tactile classing is expected to separate only the extremes of any diameter variation. As shown in Table 7.3, this source of variation can be expected to contribute approximately 11% to 16% of the variance in a lot. Figure 7.19 shows the variation in MFDs amongst approximately 160 fleeces taken from each of 2 mobs, based on trial work reported by Marler and Baxter (2004) and sponsored by Australian

Wool Innovation (AWI). The 2 mobs chosen for representation in Figure 7.19 were the extremes in between-sheep variation amongst the 7 mobs sampled in the trial. It is worth noting that the estimates of the MFD of each fleece reported in Figure 7.19 were obtained by coring each fleece and averaging the results of 4 measurements made from these core samples. As such, they represent extremely accurate estimates of the MFD of each fleece, and so the variation represented in Figure 7.19 would be expected to have relatively small sampling and measurement error, i.e. the variation depicted in Figure 7.19 is virtually all accounted for by the between-fleece variation amongst the 160 fleeces. In the mob with the lower CV between sheep, individual animals ranged in MFD from 16.0µm to 20.5µm; whereas the range in the other mob was from 16.0µm to 25.0µm.

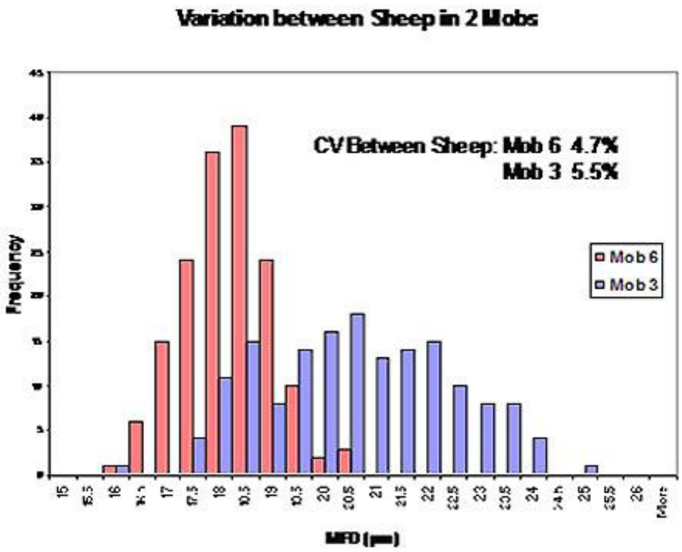


Figure 7.19 An example of the variation in Mean Fibre Diameter of fleeces in a mob. Source: AWI.

7.10 Precision of fibre diameter testing

In the testing of wool, repeated testing of a sample will not provide exactly the same result. Variation is associated with every measurement, arising from limitations of the instrument, the sample preparation and the sampling itself. Variation due to human intervention is also present, but modern automated measurement systems significantly reduce this contribution.

The precision of a measurement is an indicator of the magnitude of the expected variation in a result. It is usually defined as a range within which 95% of all repeated measurements should lie. Extensive testing trials with the four instruments used for measuring fibre diameter have been conducted, enabling the levels of precision achievable with them when testing wool sliver to be compared. The 95% confidence levels are shown in Table 7.4 (AWTA 1999).

Table 7.4 Precision levels for fibre diameter testing of slivers (MFD). Source: AWTA (1999).

Instrument	Precision (95% Confidence Level)	
	20 microns	35 microns
Projection Microscope	± 0.60	± 1.40
Airflow	± 0.41	± 0.55
OFDA	± 0.30	± 0.66
Laserscan	± 0.25	± 0.64

Where test results are to be included on an IWTO test certificate because they form part of a commercial transaction, procedures are in place to ensure that the inherent variability in wool testing does not compromise the quality of the data provided. Each instrument will require a certain number of subsamples and test specimens to be used, and where necessary additional tests may be required.

Critical range values

The critical range values enable decisions concerning how many additional test specimens or subsamples may need to be tested, depending on the range of the first set of results.

Requirements for OFDA

According to IWTO 47, for sliver testing using OFDA, determine the range in MFD between two slides from the same subsample. If the difference exceeds the value shown in Table 7.5 for the appropriate MFD, prepare and measure another slide. The test method outlines the subsequent steps to be taken, depending on whether new results are within the range. For example, if the range between 2 of the 3 results falls within the allowable range then discard the third result.

When all subsamples of sliver have been measured, and the mean fibre diameters calculated, calculate the range between subsamples. If this exceeds the allowable range in Table 7.5, test two further subsamples. If the appropriate range is still exceeded discard any result that may be regarded as an outlier, and calculate the range again. In the event of the range still not complying, combine the results from all subsamples.

Table 7.5 Critical ranges for OFDA. Source: IWTO-47.

Mean fibre diameter		**<26 µm**	**>26 µm**
Between two slides		0.4	0.7
	Number of subsamples		
Range between subsamples (µm)	2	0.3	0.5
	3	0.3	0.6
	4	0.3	0.6
	5	0.4	0.6
	6	0.4	0.7
	7	0.4	0.7
	8	0.4	0.7

Requirements for Laserscan

The corresponding test method for using Laserscan (IWTO-12) also includes a set of critical range values (Table 7.6).

Table 7.6 Critical ranges for Laserscan (99% level of confidence). Source: IWTO-12.

MFD (µm)	**SD (µm)**	**Number of test specimens**				
		4	7	8	11	12
Up to 15.0	0.1064	0.5	0.5	0.5	0.6	0.6
15-1 – 20.0	0.1736	0.8	0.8	0.9	0.9	0.9
20.1 – 25.0	0.2409	1.1	1.2	1.2	1.3	1.3
25.1 – 30.0	0.3081	1.4	1.5	1.5	1.6	1.6
30.1 – 35.0	0.3754	1.7	1.8	1.9	2.0	2.0
Greater than 25.1	0.4426	1.9	2.2	2.2	2.3	2.3

Four test specimens are measured and the range of the results calculated. If the range of the four readings is less than or equal to the critical range for 4 readings the testing process is complete.

However, if the range is exceeded, four additional test specimens are measured and the range re-calculated. Consult the test method for the subsequent steps required, depending on whether or not the range of the 8 readings exceeds the appropriate critical or not.

Retesting

According to the IWTO regulations, to allow for unusually high variability within a lot of sliver or top, the range of the results for MFD should not exceed 0.6 µm. If this limit is exceeded, the lot should re-sampled and re-tested. The regulations deal with the possibilities of the new results being either within or outside the required range.

See also round trial data comparing the different instruments (http://www.iwgofda.com/pdf/Performance of the OFDA 100 compared to other methods.).

Readings

The readings indicated with * are available on web learning management systems

1. *AWTA, 1999, Sirolan Laserscan™ - A new technology for the millennium, Australian Wool Testing Authority Ltd., Technical brochure, September 1999.
2. *AWTA, 2002a, Understanding fibre diameter measurement – Fundamental concepts, Australian Wool Testing Authority Ltd. Newsletter, January 2002, pp.10.
3. *AWTA, 2002b, Fundamentals of fibre fineness measurement – The projection microscope, Australian Wool Testing Authority Ltd. Newsletter, May 2002, pp.18.
4. *AWTA, 2002c, Fundamentals of fibre fineness measurement – Gravimetry, Australian Wool Testing Authority Ltd. Newsletter, October 2002, pp.18.
5. AWTA, 2003a, Using optical diffraction to measure fibre fineness, Australian Wool Testing Authority Ltd. Newsletter, February 2003, pp.24.
6. AWTA, 2003b, Direct measurement of fibre fineness, Australian Wool Testing Authority Ltd. Newsletter, July 2003, p.24.
7. AWTA, 2003d, Using conductivity to measure fibre fineness, Australian Wool Testing Authority Ltd. Newsletter, December 2003, p.18.
8. *AWTA, 2004, The Airflow instrument – Using porosity to measure mean fibre diameter, Australian Wool Testing Authority Ltd. Newsletter, March 2004, pp.18-21
9. *AWTA, 2005, Using photometry to measure mean fibre diameter (1950 – 1970), Australian Wool Testing Authority Ltd. Newsletter, April 2005, pp.23-24.

Summary

Summary Slides are available on web learning management systems
Many wool properties remain almost unchanged from raw wool through to top. These include mean fibre diameter and fibre diameter distribution where the only real change occurs because of any differences between the characteristics of the top and the noil. Other properties, such as base colour, are highly correlated from raw wool to top but anomalies can occur due to processing variability.

This topic covers the methods used to measure the fibre diameter characteristics of slivers and tops – sampling, specimen preparation, instrument operation and the analysis of the results. Fibre diameter is arguably their most important property, because of the importance of fibre diameter in the efficient spinning of fine worsted yarns and in the manufacturing light, soft handling fabrics for apparel.

A number of IWTO test methods have been developed for measuring the fibre diameter of wool, notably using the Projection Microscope, Airflow, Laserscan and OFDA (Optical Fibre Diameter Analyser). The latter two methods utilising modern technologies have largely replaced the first two methods for routine commercial testing. However, the Projection Microscope provides the benchmark test by which the other methods are calibrated.

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Brims, M A, 2002, 'Introducing OFDA4000 – A new instrument for simultaneous measurement of fibre length and diameter in tops,' *Proceedings. of IWTO,* Report No. SG 2, Barcelona.

BSC Electronics, OFDA System, BSC Electronics, OFDA100 Product Information Brochure.

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Crowe, D W and Marler, J W, 2000, Calibrating Laserscan for raw wool measurement and an evaluation of an alternative transport fluid, *Proceedings. of IWTO,* Technology and Standards Committee, Report No. RWG 03, Nice.

IWTO 6, Method of Test for the Determination of the Mean Diameter of Wool Fibres in Combed Sliver using the Airflow Apparatus, International Wool Textile Organisation test method.

IWTO 8, Method of Determining Fibre Diameter Distribution Parameters and Percentage of Medullated Fibres in Wool and Other Animal Fibres by the Projection Microscope, International Wool Textile Organisation test method.

IWTO 12, Measurement of the Mean and Distribution of Fibre Diameter using the Laserscan Fibre Diameter Analyser, International Wool Textile Organisation test method.

IWTO 47, Measurement of the Mean and Distribution of Fibre Diameter of Wool using an Optical Fibre Diameter Analyser (OFDA), International Wool Textile Organisation test method.

Marler, J W, Shepherd, G R and Barry, R G, 1999, 'A comparison of histograms from OFDA, Projection Microscope and Laserscan for wool tops,' *Proceedings. of IWTO,* Report No. SG 01, Florence.

Glossary of terms

Airflow	An indirect method of measuring the mean fibre diameter of wool using the rate of air flow, or the pressure drop when air is forced through a compressed sample of wool ain a standard chamber
Comfort factor	The percentage of fibres in a fibre diameter distribution which are less than or equal to 30 µm
Confidence limits	An expression of the precision of the mean of a set of values, usually associated with a stated probability such as 95%. It is the interval around the mean within which, with the stated probability, the true value is expected to lie
Diameter profile	A graph depicting how the mean fibre diameter varies with distance along a 'beard' of aligned fibres, as formed by the Almeter Fibroliner or OFDA4000
Fineness	Mean fibre diameter
Graticule	A glass plate with a series of accurate and closely-spaced lines ruled into its surface, for the calibration of microscopes
IWTO	International Wool Textile Organisation, the body responsible for developing and maintaining the test methods, regulations and other procedures involved with the measurement and marketing of wool
Laserscan	An instrument for obtaining the wool fibre diameter distribution and its associated statistics by the detection of shadows of fibre snippets in a laser beam
Mean fibre diameter	The average thickness of a sample of wool fibres, measured in microns (µm)
Micron	A unit of measurement of fibre diameter, correctly termed a micron (µm). 1 micron equals one-millionth of a metre
Microtome	A guillotine consisting of two parallel blades separated by 0.8 – 2.0mm, used to cut through a sample of top or sliver to obtain a sample of fibre snippets
OFDA	Optical Fibre Diameter Analyser – an instrument for obtaining the wool fibre diameter distribution and its associated statistics using an automated microscope and digital image analysis techniques
Projection Microscope	A manually-operated instrument for obtaining the wool fibre diameter distribution and its associated statistics. Magnified images of the profiles of fibre snippets are projected on a screen and their widths measured by using a graduated scale
Sample	The sliver drawn from, and representative of a lot
Sliver subsample	A randomly drawn portion representative of a sliver or top, from which guillotined snippets are cut
Snippet	Very short section of fibre, typically 0.8 – 2.0mm long which is cut to measure fibre diameter
Strobing	A light source switching on and off at a moderate to high frequency
Test specimen	The snippets taken from a sliver subsample, which are fed into the testing instrument
Top	A substantially parallel assembly of fibres, essentially free of short fibres, vegetable matter and neps