

9. Fibre Diameter

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Learning objectives

By the end 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 measurement of Mean and Coefficient of Variation of Fibre Diameter (CVD)
- 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, core and fleece samples (including On-farm Testing)

Key terms and concepts

Fibre Diameter, CVD, sampling, sources of variation, Projection Microscope, Airflow, Laserscan, OFDA, International Wool Textile Organisation (IWTO) Standard Test Methods, Interwoollabs.

Introduction to the topic

As well as describing the measurement of Fibre Diameter of wool samples this topic briefly outlines the relevance of Fibre Diameter testing to the determination of wool value and to processing performance and quality of the textile or apparel end product. The differences between visual appraisal and measurement of Fibre Diameter are discussed, along with the sources of variation in Fibre Diameter testing. The relevance and measurement of CVD are outlined. The strengths and weaknesses of the four (4) main techniques of measurement, Projection Microscope, Airflow, Laserscan and OFDA100 are analysed. The distinction is made between the different forms of wool which are commonly tested commercially for Fibre Diameter, i.e. fleece samples, core samples of Sale Lots and wool top.

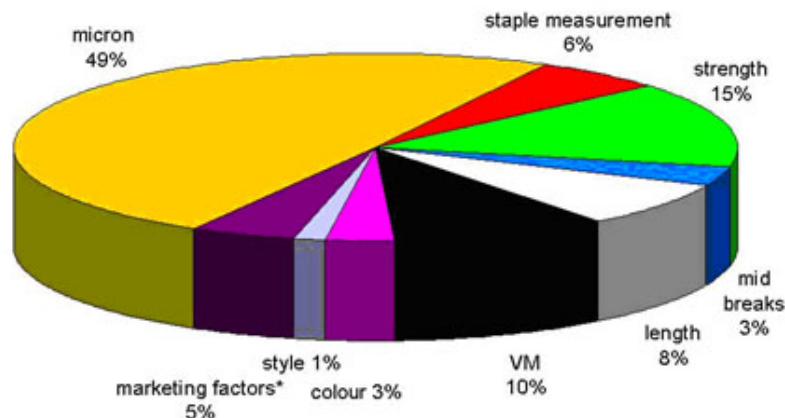
9.1 The relevance of fibre fineness

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 9.1, 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.

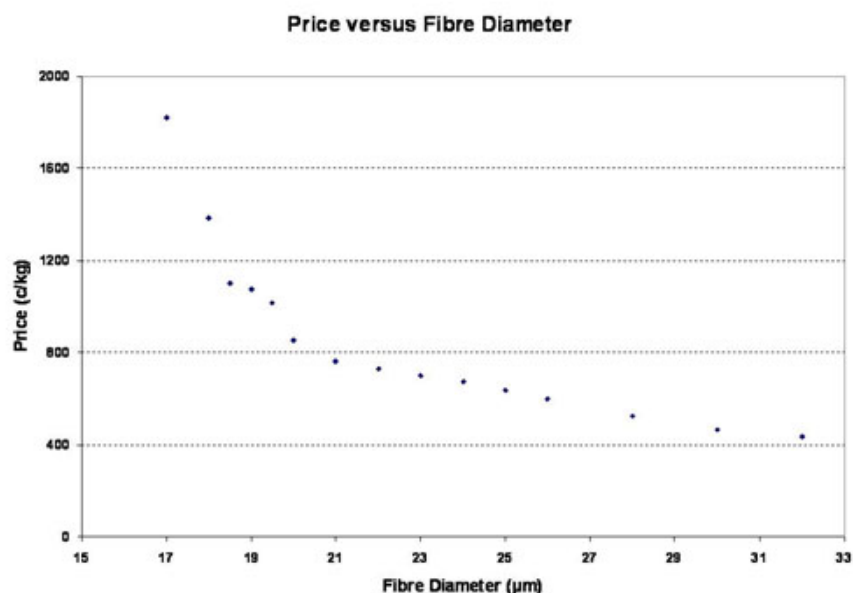
Since greasy wool is traded, often across international boundaries, prior to the production of a top, a system of testing standards for is required in order to provide certifiable measurement of Fibre Diameter. National and international standards exist for Fibre Diameter measurement. Since many International Wool Textile Organisation (IWTO) Standards for wool testing have been derived from Australian Standards, and Standards Australia/Standards/New Standards New Zealand now adopts IWTO Standards in place of Australian Standards, IWTO Standards will be used as the basis of techniques discussed in this topic. But it should be noted that other standards are available and are used within the international wool industry, e.g. American Society of Testing Materials (ASTM).

Figure 9.1 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 9.2. 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 9.2 Average price paid at auction in Australia from July, 1998 – April, 2005 for sale lots of different mean fibre diameter. Source: DAWA and AWTALtd.



9.2 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.

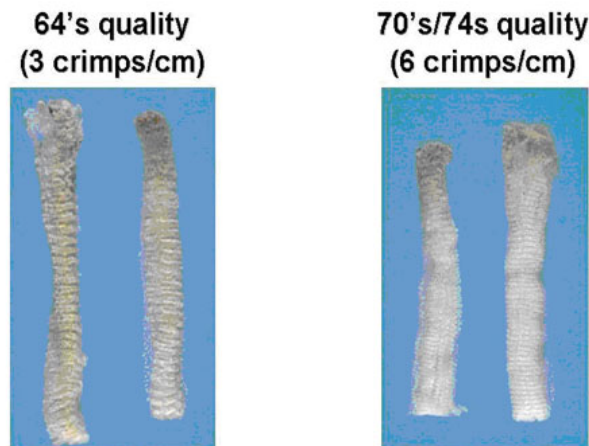
9.3. The determination of fibre fineness

Subjective appraisal

Before the advent of measurement of fibre fineness, and because of its overriding importance, systems developed for estimating wool quality based on visual, and to a lesser extent tactile, appraisal of wool. There was variation in these systems between geographical regions such as England, Continental Europe and the United States of America, but they relied on a quality number. In England these quality numbers related to the finest count (linear density) of yarn which could be spun from tops composed of a given wool quality number. Certain preferred quality numbers emerged through common usage such as, 80's, 74's, 70's, 64's, 60's, 58's 56's etc, and research (Barker and Winson 1931) suggested that the differences between these commonly used quality numbers were approximately equal steps of mean fineness.

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 9.3. The broader crimp frequency of the 64's quality can be compared with the finer crimp of the 74's quality.

Figure 9.3 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) as illustrated in Table 9.1.

Table 9.1 Quality number, crimp frequency and mean fibre diameter relationships for South African, Australian and Western Australian wool. Source: Mahar (2006).

Quality Number	South African wool (middle of Duerden limits)		Australia		Western Australia	
	Crimps/cm	Mean Fibre Diameter	Crimps/cm	Mean Fibre Diameter	Crimps/cm	Mean Fibre Diameter
80's	7.3	17.5	7.7	15.6		
70's	6.5	18.4	6.4	18.9	6.4	18.8
66's	5.7	19.5	5.6	19.7	5.5	20.3
64's	4.9	20.7	5.0		4.9	22.8
60's	4.1	22.2	4.0	21.0	3.4	27.0
58's	3.3	24.3	3.1	23.5	2.6	29.2
56's	2.6	27.5	2.4	26.5	2.1	32.4

Studies demonstrated that spinning performance and yarn strength and evenness were largely determined by fibre fineness, while staple crimp was seen to have a lessor importance. They concluded that staple crimp was not a good indicator of fibre fineness, either within or between breeds and strains of sheep. Staple crimp has been shown to have some influence on fabric thickness and possibly fabric handle and bulk.

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 set out in Table 9.2.

Table 9.2 Fabric standards for pure wool fabric descriptions as set out by IWTO.
Source: Onions (1962).

Fabric Description	Mean Fibre Diameter (µm)	Fabric Description	Mean Fibre Diameter (µm)
SUPER 80's	19.5	SUPER 150's	16.0
SUPER 90's	19.0	SUPER 160's	15.5
SUPER 100's	18.5	SUPER 170's	15.0
SUPER 110's	18.0	SUPER 180's	14.5
SUPER 120's	17.5	SUPER 190's	14.0
SUPER 130's	17.0	SUPER 200's	13.5
SUPER 140's	16.5	SUPER 210's	13.0

Objective measurement

Concept of fibre diameter

There are three obvious ways of specifying fibre fineness:

Measure the maximum width of the approximately circular cross section of the fibre, i.e. the fibre 'diameter'

Measure the surface area for a known mass of fibre and calculate the fibre diameter using the density of the fibre

If M = the mass/unit length of the fibre,

If ρ = the specific gravity (density) of the fibre,

If S = the surface area/unit length of the fibre, and,

If d = the diameter of the fibre

Then $M/S = \rho \pi d^2 / 4 \pi d$

Then $S = 4M/\rho d$

i.e. the surface area of a known mass of fibre is inversely proportional to fibre diameter)

Measure the linear density of the fibre, i.e. the mass of a given length of fibre. Although technically feasible, method 3 is not applied to wool fibres nowadays, but it is commonly used in the synthetic fibre industry where denier (or grams/9,000meters) or decitex (grams/10,000m) is the common parameter.

Both methods 1 and 2, which are used commercially in the wool industry, employ the concept of a Fibre Diameter. A cylindrically shaped object such as a fibre can have a circular cross section from which a diameter can be either measured or calculated. A wool fibre is an approximately cylindrical shape with a series of protruding scales on its surface, i.e. it is strictly not a cylinder. Also, measurements have shown that many wool fibres are generally elliptical in cross section rather than circular.

This means that, when testing wool, we are trying to measure the diameter of something of the approximate shape of a tree trunk by assuming it is a really a cylindrical pipe. It is as well to remember this approximation in relation to Fibre Diameter measurement of wool.

9.4. The measurement of fibre diameter

There have been many different principles used to measure Fibre Diameter over the years. Examples include:

- Direct measurement, e.g. using a micrometer calliper
- Optical diffraction, e.g. the Mikronmeter
- Gravimetry – the first unit of fibre fineness adopted by IWTO
- Photometry, e.g. Laserscan
- Radiometry, e.g. Liquid Scintillation system
- Harmonics, e.g. Vibrasscope, and
- Porosity, e.g. Airflow.

A comprehensive review of these techniques can be found in a series of articles in AWTA Ltd Newsletters (Sommerville, various issues).

The four (4) techniques which are the main methods used commercially, and for which there are IWTO Test Methods, are: Projection Microscope, Airflow, Laserscan and OFDA100. It is important to know the principles and operation of these techniques.

Wool fibres absorb moisture from the atmosphere, and their dimensions (diameter and length) are altered by absorption and desorption of moisture in a predictable manner. The dimensions of a wool fibre are also determined by the history of the moisture content (often defined as percentage fibre regain (= mass of moisture in fibre x 100/mass of dry fibre)) of the fibre, such that a fibre is broader (has a higher diameter) if it has come to moisture equilibrium from a moist state than if it arrived at that same moisture equilibrium from a drier initial state.

Thus, in all Fibre Diameter testing of wool both the equilibrium temperature and relative humidity of the testing and the pre-test storage environment are specified ($20 \pm 2^\circ\text{C}$ and $65\% \pm 3\%$ relative humidity), as well as the state from which the sample is equilibrated (specified as dry – $<10\%$ regain).

The unit of wool Fibre Diameter measurement is a micrometer ($= 10^{-6}$ meters) which is known in the wool industry as 'micron'.

Because of the irregular shape of wool fibres it is not unexpected that measurements of Fibre Diameter made using different principles may give slightly different results in some cases.

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.

As the name implies, the PM uses a microscope to directly measure the width of the profile of a fibre snippet (i.e. a short $<2\text{mm}$ (approx.)) length cut from a wool fibre – see following section for definition of snippets from PM testing). As shown in Figures 9.4 and 9.5, the PM has a screen onto which an image of a fibre snippet can be projected. There is a magnification of 500 times between the fibre snippet and screen, which means that a distance of $1\mu\text{m}$ is equivalent to 0.5mm on the screen. Individual fibre widths are measured and recorded. When a minimum number of fibre widths has been obtained and all the acceptable snippets on the microscope slide have been measured, the MFD is calculated based on the conversion of the snippet widths into diameters according to the magnification of the instrument.

There is a number of critical steps in the measurement of the Fibre Diameter of a sample using the PM. These include sampling, sample preparation, selection of snippets for measurement on the slide and the actual taking of a 'diameter' reading.

Figure 9.4 Diagram showing the major elements of a Projection Microscope.
Source: Teasdale (1995).

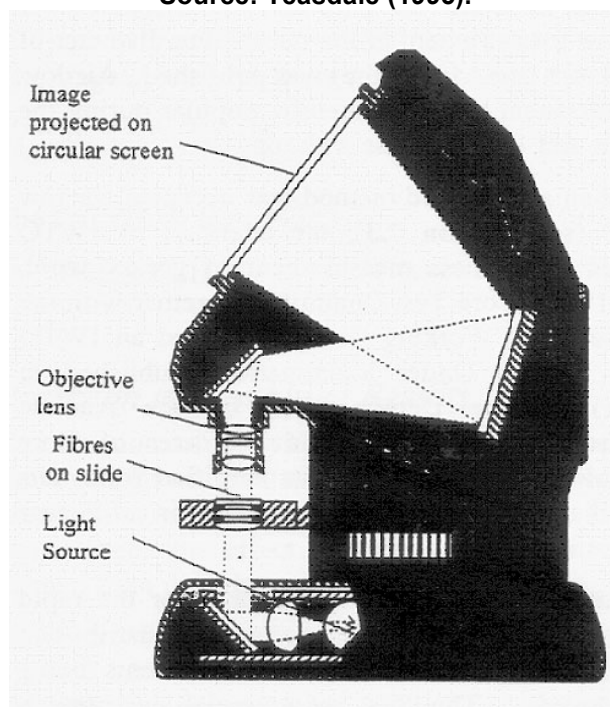
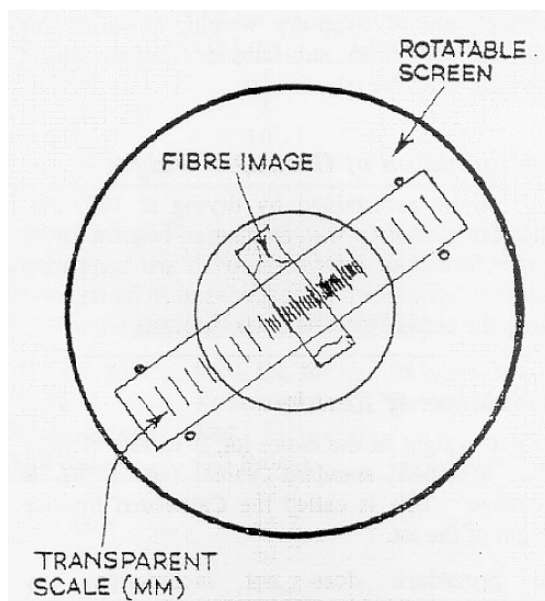


Figure 9.5 Diagrammatic representation of the screen of a Projection Microscope showing the rotatable calibrated scale aligned to measure the diameter of a fibre snippet.
Source: Teasdale (1995).



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.

Preparation for measurement

In all cases fibres in the microtome are sheared off leaving all fibres with one end flush with the microtome. The fibres are then advanced in the microtome by 0.8mm and sheared again flush with the face of the microtome. The resulting series of 0.8mm fibre are placed in a mounting medium on a glass microscope slide and randomised by stirring the medium. A cover slip is placed over the mounting medium.

Measurement

There are rigid rules for PM measurement which are designed to ensure that:

- a random sample of fibre snippets is measured
- no snippet is measured twice, and
- an operator has negligible or no opportunity to influence the measured result, e.g., allow the operator to choose which snippets to measure and which not to measure.

It is critical that a random sample of snippets is measured and that no snippet is measured twice.

The four (4) key elements of the measurement procedures are:

1. specific rules for defining the acceptable measurement areas on a slide, i.e. defined viewing fields, e.g. distances between centres of the viewing fields should be greater than the length of the snippets
2. a definition of procedures for bringing images into focus prior to measurement, e.g. refocusing if Becke lines are form on the fibre edge
3. measurement of the width of the focussed image, e.g. at right angles to the lengthwise direction of the image, and
4. recording individual measurements in 2µm classes, as shown in example depicted in Table 9.3.

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.

Table 9.3 An example of recording and some analysis of a Projection Microscope measurement. Source: Teasdale (1995).

Class Interval (µm)	Mid-point (µm) (d)	Number of Snippets (n)	d x n	d ² x n
0 - 2	1	0	0	0
2 - 4	3	0	0	0
4 - 6	5	0	0	0
6 - 8	7	1	7	49
8 - 10	9	8	72	648
10 - 12	11	111	1221	13431
12 - 14	13	204	2652	34476
14 - 16	15	177	2655	39825
16 - 18	17	71	1207	20519
18 - 20	19	24	456	8664
20 - 22	21	9	189	3969
22 - 24	23	3	69	1587
24 - 26	25	1	25	625
26 - 28	27	0	0	0
28 - 30	29	0	0	0
30 - 32	31	0	0	0
32 - 34	33	0	0	0
34 - 36	35	0	0	0
36 - 38	37	0	0	0
38 - 40	39	0	0	0
Totals		609	8553	123793

The mean and standard deviation of Fibre Diameter are then calculated from the resulting frequency distribution according to the following formulae which draw on the example shown in Table 9.3:

$$\begin{aligned} \text{Mean Fibre Diameter} &= \frac{\sum (d.n)}{\sum n} \\ &= 8,553/609 \\ &= 14.0\mu\text{m} \end{aligned}$$

$$\begin{aligned} \text{Standard Deviation} &= \sqrt{\frac{\sum d^2.n - \frac{(\sum d.n)^2}{n}}{(n-1)}} \\ &= ((123,793 - ((8,553)^2/609)/(609 - 1))^{1/2} \\ &= 2.5\mu\text{m} \end{aligned}$$

Details of these procedures are outlined in IWTO-8-97, Method of Determining Fibre Diameter Distribution Parameters and Percentage of Medullated Fibres in Wool and Other Animal Fibres by Projection Microscope.

IWTO-8-97 also includes details of the calculations required to determine the mean, standard deviation and coefficient of variation of Fibre Diameter.

Calibration and quality assurance

A certified graticule is used to ensure that the magnification of the PM system is 500±1. The procedure specifies that the magnification be calculated based on 5 measurements taken after refocusing the image of the graticule. In order for a valid calibration the range of individual values of magnification should be 10 units.

Users of PM's are also able to participate in Interwoollabs Round Trials which are a means of maintaining harmony in international Fibre Diameter measurement. Interwoollabs is a cooperative organisation linked to IWTO, which supplies wool top for measurement of Fibre Diameter and Length parameters by its members in biannual round trials. The organisation also supplies top of known diameter for calibration of instruments, such as Airflow, Laserscan and OFDA, which measure diameter indirectly. Members of Interwoollabs are thus able to both gauge how their measurement systems are performing relative to other members, and to ensure that their instruments are regularly calibrated to agreed international standards.

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.

Andrews and David (1978) showed that the between laboratory component of variation in PM measurement was the largest source of variance in a PM test of 400 or more fibres. This result was surprising as it was generally assumed that the major source of variation was between fibres, and it emphasised the major role played by the operators and the setup (including lab procedures) of the test method within a laboratory in determining the measured MFD. It is obviously difficult to remove the subjectivity from the PM method, although the procedure outlined in IWTO-8-97 removes the overwhelming majority of operator interpretation if the method is implemented rigorously.

It is instructive to examine the results of Interwoollabs Round Trials over recent years to gain insight into the trends in Fibre Diameter measurement. As shown in Table 9.4 there has been a significant reduction in the number of Interwoollabs members who use PM during the period from 1998 to 2004. There has been a 25% reduction in the number of PM participants in the Round Trials over this period, while the total number of participants has declined by only 8% - a clear indication that commercial measurement of Fibre Diameter is moving away from PM.

Table 9.4 Summary of Interwoollabs members participating in Fibre Diameter measurement Round Trials – 1998 – 2004. Source: IWTO (2005).

Year	Projection Microscope (IWTO-8)		Airflow (IWTO-28)		OFDA (IWTO-47)		Laserscan (IWTO-12)	
	Trial1	Trial 2	Trial1	Trial 2	Trial1	Trial 2	Trial1	Trial 2
1998	40	40	105	103	30	32	20	19
1999	37	38	98	94	32	33	20	20
2000	38	39	94	94	34	38	20	22
2001	38	37	92	89	40	41	25	27
2002	34	31	85	84	43	39	30	32
2003	30	30	79	83	40	41	29	31
2004	29	29	80	75	13	40	30	30

Despite this trend for reduced numbers of PM measurements of Fibre Diameter, the PM method remains the fundamental definition of wool Fibre Diameter. The measured PM results of at least two (2) Interwoollabs Round Trials are used to assign values to selected wool top samples which are then used as the basis for calibration of the other three (3) commercial Fibre Diameter measurement systems, Airflow, Laserscan and OFDA.

Airflow

Principle of measurement

The Airflow method of Fibre Diameter measurement is the most widely used of the commercial measurement technologies. As shown in Table 9.3 more Interwoollabs members use Airflow than any two of the other technologies combined.

The Airflow measurement uses the principle that when a current of air is passed through a compressed mass of fibres, the ratio of the rate of airflow through the wool to the pressure differential is primarily determined by the total surface area of the fibres. This relationship is predictable from the work of a number of researchers from the 19th and early 20th centuries, and was formalised by Kozeny (1927) who built on the earlier work of fluid flow through porous beds to derive his equation, a form of which is:

$$\mu = \frac{\varepsilon^3}{k\eta S^2} \cdot \frac{\Delta P g}{L_c}$$

where, μ = the face velocity

k = the kozeny constant

η = the viscosity of the fluid

S = the surface area of the particles per unit volume of the bed

g = acceleration due to gravity

ΔP = the pressure differential across the bed

ε = the porosity (free space per unit volume) of the bed

L_c = the depth of the bed

This general equation can be applied to wool and simplified by assuming all wool fibres are cylindrical rods as follows:

$$Q = K_b \cdot \frac{A_c}{L_c} \cdot \frac{\varepsilon^3}{(1 - \varepsilon)^2} \cdot \Delta P \cdot d^2$$

where, Q = average flow (cm³/sec)

d = the mean diameter

K_b = a constant

A_c = the cross-sectional area of the fibre bed

From this equation it can be seen that, for a predetermined shape and size of chamber (A_c is constant), mass of wool in the chamber (ε is constant, assuming wool has a constant specific gravity (density)), and pressure drop across the perforated ends of the chamber (ΔP is constant), the rate of airflow through the plug of wool is proportional to Fibre Diameter, or strictly to d^2 . A variation on this approach is possible using a constant rate of airflow (Q is constant) and varying ΔP , though it is the variable airflow (constant pressure drop), rather than this constant flow (variable pressure), apparatus which has gained popularity for commercial measurement of Fibre Diameter.

It should be pointed out that this relationship assumes that all the fibre rods in the sample are the same diameter, and that further derivation of the relationship indicates that the rate of airflow is related to the mean and coefficient of Fibre Diameter such that:

$$d = d'(1 + C^2)$$

where,

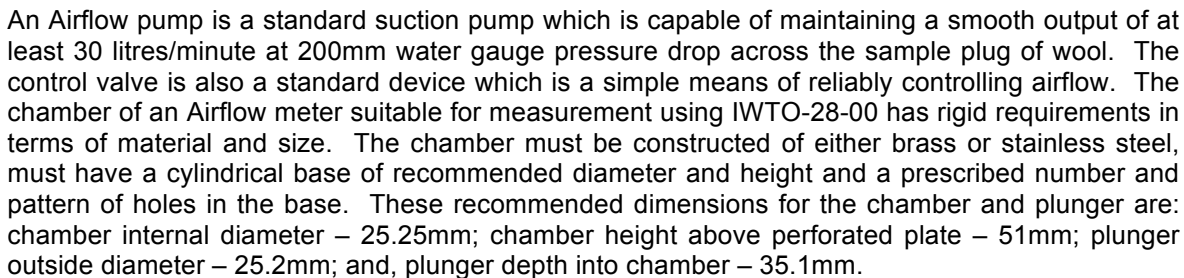
d = measured diameter,

d' = actual average diameter, and

C = the fractional coefficient of variation of d' .

There are five (5) major components of an Airflow Meter for measuring Fibre Diameter: a pump, and air control valve, a flowmeter, a chamber (including plunger and locking mechanism), and a manometer. These components are linked by a series of tubes and hoses. An image of an Airflow Meter is shown in Figure 9.6 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.

Figure 9.6b Image of an Airflow meter. Source: Mahar (2006).



The flow range of the flowmeter is specified as 4 – 24 litres/minute, and it should include a graduated scale approximately 350mm long, from which to take readings of the height of the rotameter.

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Airflow test procedure

Sampling and sample preparation

Samples for commercial testing by the Airflow method can be obtained from core samples extracted from bales of greasy or cleaned wool (IWTO-28-00, Determination by the Airflow Method of the Mean Fibre Diameter of Core Samples of Raw Wool) or from top samples (IWTO-6-98, Method of Test for the Determination of the Mean Fibre Diameter of Wool Fibres in Combed Sliver Using the Airflow Apparatus). Samples for testing are cleaned (degreased), if necessary, and then homogenised, opened (for core samples) and most contamination from vegetable matter and dust are removed if necessary. The opening, homogenising and contaminant removal commonly occur simultaneously by passing the sample through a Shirley Analyser, though hand carding is also often used for opening and blending. For top measurement a variation to this preparation method is also permissible. In this alternative approach, care is taken to maintain the parallelised orientation of the fibres in the top during the measurement. This alternative technique should only be used as a quality control procedure in commercial testing and is therefore not recommended for use when a certified test result is required.

Measurement

The steps in Airflow measurement are:

1. Weigh the Test Specimens: Test Specimens for Airflow testing are 1.5g $\pm$ 0.002g, for the constant flow method, and 2.5g $\pm$ 0.004g, for the constant pressure method. IWTO stipulates a minimum of 2 Test Specimens/ test and 2 measurements/Test Specimen
2. Pack the specimen into the chamber ensuring that the fibres are packed uniformly and that the sides of the chamber are not scratched
3. Insert the plunger and fix it in place for measurement
4. Adjust the air valve until either (i) the meniscus level of the manometer is 180mm and read the flow height on the flowmeter (constant pressure method) or (ii) the float height on the flowmeter reaches a predetermined mark and read the meniscus level on the manometer (constant volume method)
5. Remove the Test Specimen from the chamber and repack it in the reverse direction, being careful not to tease out the fibres in the plug, and repeat steps 3 and 4
6. Calculate the measured Fibre Diameter from each reading by reference to the calibration of the instrument.

Calibration

Airflow measurement uses an indirect method of obtaining the MFD of a sample – the flow heights or pressure differences are referenced to similar values obtained from wool which has a known, or assigned, value of MFD. As discussed in the Projection Microscope section, samples of wool tops are tested in many laboratories and diameter values are assigned to these tops through a process controlled by Interwoollabs. Calibration tops are chosen from amongst the tops tested in Interwoollabs Round Trials because of the relatively high levels of agreement amongst members about their diameter values, and also based on the agreement between the PM and Airflow values for these tops. Because the Coefficient of Variation of Fibre Diameter (CVD) affects the measured Airflow value it is considered important to choose for calibration of Airflow meters only those tops which have very similar measured values for PM and Airflow measurement. However, it is the MFD value assigned by Interwoollabs members using Airflow meters rather than PM's, which is used to calibrate Airflow meters.

The calibration procedure for Airflow meters involves the measurement of 8 calibration tops which range in diameter from approximately 17 μ m to 38 μ m. The flow heights (or manometer levels) for each top are fitted to their corresponding assigned MFD values using a least squares method to a relationship of the form:

$$h = a + bd + cd^2,$$

where,

h = flowmeter height,

d = assigned diameter, and

a, b, and c are constants of the curve fitting.

In order for the calibration to be acceptable, the Mean Square Error for the fit of the relationship to the data needs to be $< 0.05\mu\text{m}^2$. The procedure is similar for the constant flow method except that a log/linear relationship is used instead of the quadratic relationship discussed in the previous paragraph.

Strengths and weaknesses of airflow measurement

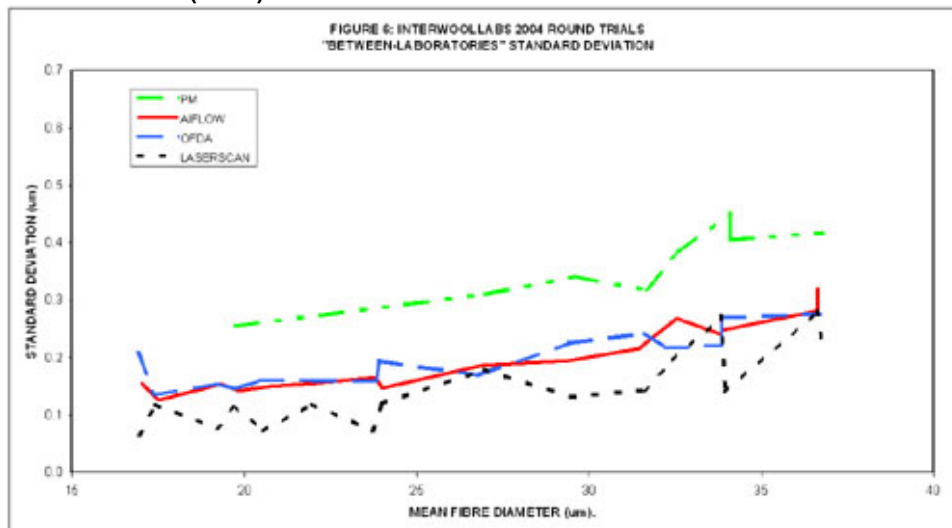
As can be seen from Table 9.1, Airflow is the most popular technique amongst members of Interwoollabs. One of the reasons for this popularity is the reliable performance of the instrument over many years. Also, Airflow measurement is much quicker to perform than PM, the equipment is relatively inexpensive 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. The precision estimates from these Standards for the measurement of top are compared in Table 9.4.

Table 9.5 Comparison of the precision of PM, Airflow, Laserscan and OFDA instruments for measurement of the mean fibre diameter of wool top. Adapted from: IWTO Test Methods.

Instrument	95% Confidence Interval for a Standard test on one (1) sample by one (1) Laboratory ($\pm\mu\text{m}$)					
	MFD (μm)					
Projection Microscope	15	20	25	30	35	40
	0.6	0.7	1.0	1.2	1.6	2.0
Airflow	<26 μm			>26 μm		
	0.52			0.72		
Laserscan	0.25			0.64		
OFDA	0.30			0.66		

There is also less opportunity for operators to affect the measured value in Airflow measurement compared to PM measurement, as evidenced by the smaller between laboratories standard deviation found in the Interwoollabs Round Trials for Airflow compared to PM. Results for the standard deviation between laboratories from the Interwoollabs Round Trials for 2004 are shown in Figure 9.7. The higher values for PM measurement compared to Airflow measurement illustrated in Figure 9.7 are indicative of the greater harmony in MFD measurement between laboratories for the Airflow method.

Figure 9.7 Between Laboratories Standard Deviation for Interwoollabs Round Trials in 2004. Source: IWTO (2005).



A disadvantage of Airflow is that it does not provide an estimate of the variation in Fibre Diameter about the mean value, i.e. there is no data about the distribution of Fibre Diameter about the mean – no estimate of the Standard Deviation (SD), CVD or Comfort Factor. Also, the measured value from the Airflow is not an accurate estimate of the mean unless the wool has a CVD equivalent to the CVD of the calibration tops which have a similar MFD as the sample being measured. If the CVD is different from the relevant calibration top, then the measured MFD will be different from the actual MFD of the sample. In practice, this 'limitation' of the Airflow is not responsible for significant errors in most samples of wool, since the CVD's of wool samples generally fall within relatively

narrow bounds. Another disadvantage of Airflow measurement is the specialised preparation required, i.e. the randomising of both top and core samples, and the opening and cleaning required for core samples. This preparation can introduce some operator dependence to the final result.

Laserscan

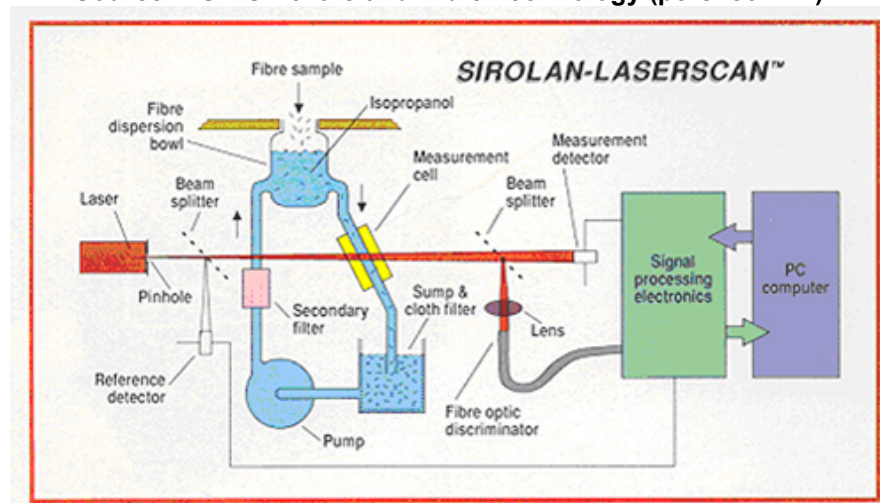
Principle of operation

The Laserscan uses a completely different principle of operation to either PM or Airflow. A fibre snippet intersects a laser beam (shown in red in Figure 9.8) which is directed at a measurement detector. The detector produces an electrical signal that is proportional to the amount of light which reaches its surface. When a fibre snippet passes through the beam (which occurs in the measurement cell, shown in yellow in Figure 9.8), the electrical signal is reduced by an amount proportional to the projected area, and thus the diameter, of the fibre. To ensure that only single snippets are measured and that the snippets fully intersect the laser beam, a fibre optic discriminator is used. A series of algorithms is able to interpret discriminator signals and thus discriminate between multiple fibres, incomplete fibres, non-fibre fragments and valid fibre snippets. The use of computer signal processing enables this discrimination to take place at very high speed.

Samples inserted into the Laserscan are obtained either by minicoring with a 2mm diameter core tube (for testing raw wool) or by guillotining a top using a 2mm spacing between the blades of the guillotine. The snippets are mixed in a slurry with either an isopropanol/water mixture or a water alone as shown in

blue in Figure 9.8. The slurry is mixed in the fibre dispersion bowl from where the slurry is transported into the measurement cell where some snippets pass through the laser beam. The transport fluid is recirculated back into the dispersion bowl after the fibre snippets are removed by filtration.

Figure 9.8 A schematic diagram of the major components of a Laserscan.
Source: CSIRO Textile and Fibre Technology (pers. comm.).



The Laserscan can measure 1,000 snippets in about 1 minute. The individual measurements are collected in 1µm classes (compared to 2µm classes for PM).

Figure 9.9 An image of a Laserscan. Source: Mahar (2006).



Calibration

Calibration for measurement according to IWTO-12- uses the same 8 x Interwoollabs tops as are used for Airflow calibration. The calibration algorithm for Laserscan is a more complex function than in the case of Airflow, viz.

$$\%occlusion = \frac{(\alpha + \beta d)}{(1 + \lambda d + \delta d^2 + \epsilon d^2)}$$

where, α , β , γ , δ and ϵ are calibration parameters, and d is the Fibre Diameter.

Because of the processing power of modern computers, the calculation of the calibration relationship is performed automatically by the Laserscan and does not require intervention by the operator. However, unlike other methods of diameter measurement, a Laserscan calibration requires a validation of the calibration using a separate set of Interwoollabs tops. The Mean Square Error (MSE) of validation measurements of a new calibration must be less than $0.1\mu\text{m}^2$. Figure 9.9 shows an image of a Laserscan.

Strengths and weaknesses of Laserscan measurement

Laserscan measurements are essentially operator independent, more precise than other methods (as highlighted in Table 9.5 and Figure 9.7), 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 $30\mu\text{m}$. 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.

OFDA

Principle of operation

The OFDA100 uses image analysis to measure the diameter of fibre snippets. 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.

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. 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.

An image of an OFDA is shown in Figure 9.10. A complete measurement cycle on a clean, conditioned sample takes less than 2 minutes.

Figure 9.10 Image of an OFDA. Source: Mahar (2006).



Calibration for measurement according to IWTO-47- uses the same eight (8) Interwoollabs tops as are used for Airflow and Laserscan calibrations. The OFDA uses a simple linear calibration and, as with Laserscan, the calculation of the calibration relationship is completed by the computer with no intervention required by the operator. The OFDA also comes with a preset factory calibration which can be checked against a reference slide that contains wires of a predetermined diameter. This wire-based calibration can be used to check the set up of the OFDA has not changed.

Strengths and weaknesses of OFDA measurement

OFDA measurements are essentially operator independent, more precise than PM and Airflow (as highlighted in Table 9.5 and Figure 9.6), 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 (refer Table 9.4) 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 trialled.

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

(See Section 9.7 for information on the OFDA2000).

9.5. 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 lesser 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.

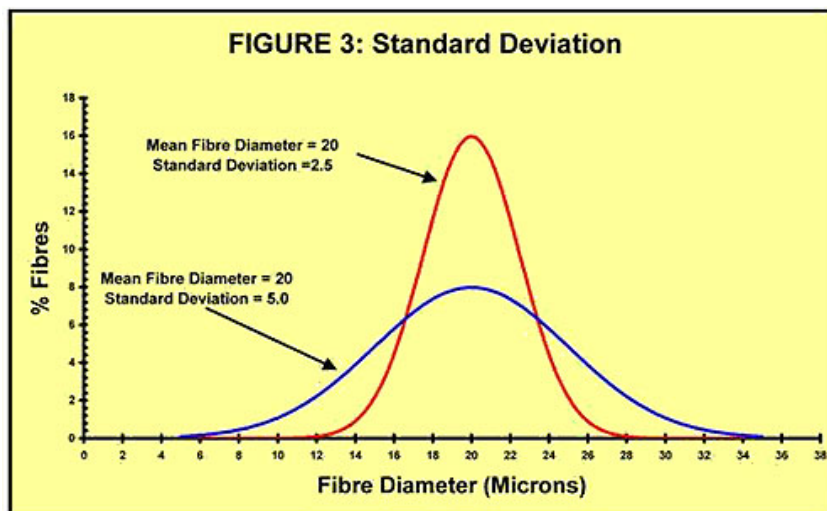
A frequency histogram, as shown in Figure 9.11, provides a full representation of the variation in diameter found in a sample of wool. Also highlighted in Figure 9.11 is the Standard Deviation (SD) of the Fibre Diameter distribution. A relatively narrow, tall frequency distribution is associated with a relatively small SD, 2.5µm in Figure 9.11; while a broad, short distribution is associated with a relatively high SD, 5.0µm in Figure 9.11. 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).

$$\text{CVD} = (\text{SD} \times 100) / \text{Mean Fibre Diameter}$$

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



9.6. 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 9.12 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 9.13 for an elliptical fibre cross section with an average diameter of 21.9 μ m.

Figure 9.12 Cross sections of wool fibres extracted from a 19 μ m top.
Source: Turner, P. (2005, pers. comm).

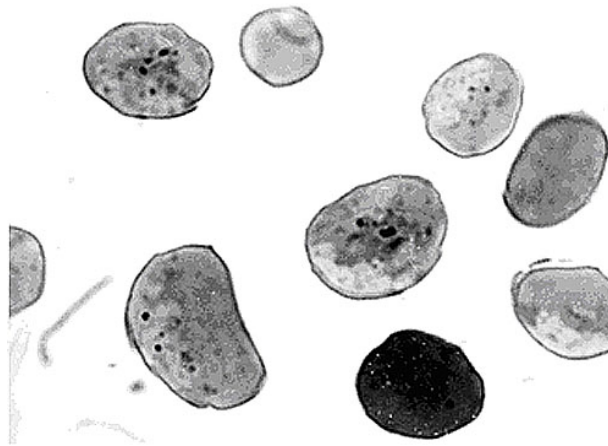
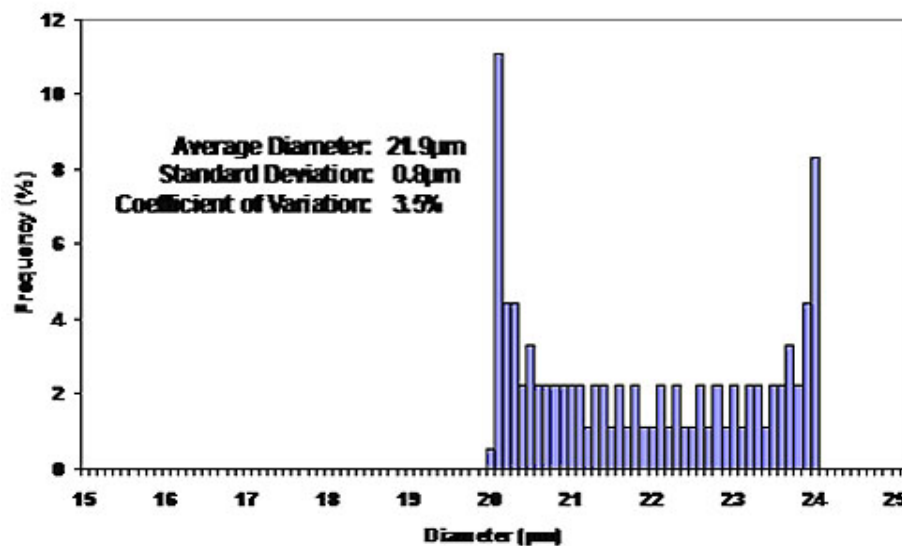
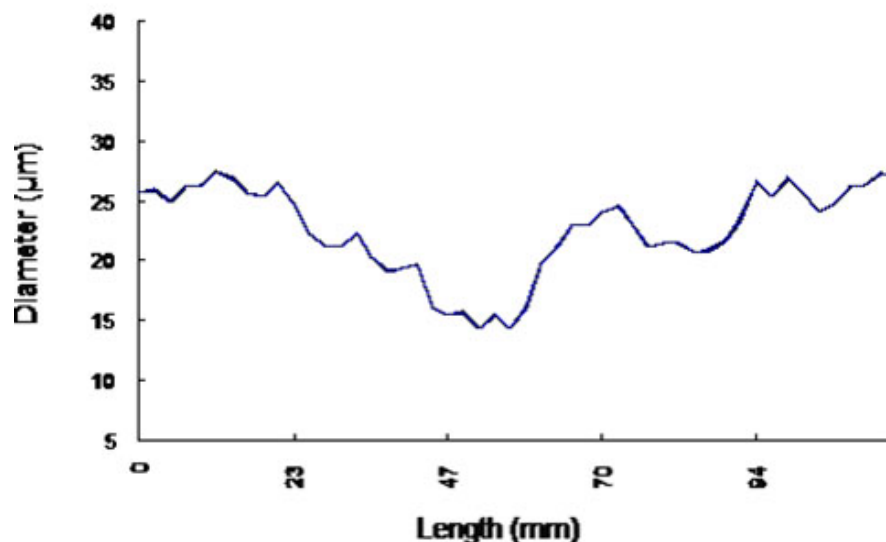


Figure 9.13 Variation in Fibre Diameter due to a fibre ellipticity of 1.2.
Source: Mahar (2006).



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 9.14. This example shows that variations of over 12 μ m are possible between the finest and coarsest measured diameter within a fibre which has an average Fibre Diameter of approximately 24 μ m.

Figure 9.14 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 9.14 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

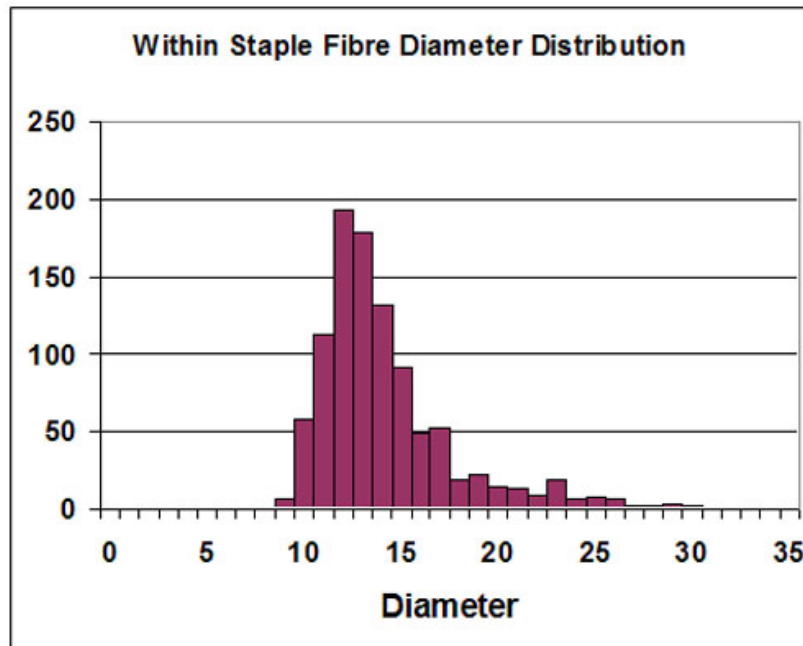
The sources of variation in Fibre Diameter already discussed are generally of far less significance than the variation between the fibres within a staple of wool. The ratio of the coarsest to finest Fibre Diameter in a staple can be over 4 to 1, providing a minimum of approximately 1,000 individual fibre 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 9.6.

Table 9.6 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 20 μ m. 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 9.15. The measured SD and CVD for this example with an MFD of 19.1 μ m are: 3.6 μ m and 19%, respectively.

Figure 9.15 Fibre Diameter distribution of a 2mm section of a Merino staple showing the variation between fibres within the staple. Source: Mahar (2006).

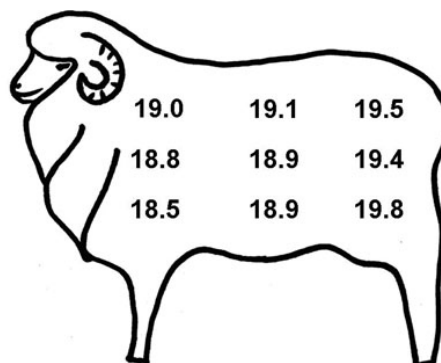


Note that the greater contribution to overall diameter variation from along the fibres in the case of tender, or weak, wool in Table 9.6 demonstrates the effect that variation in along-fibre diameter has on the variation of diameter within a staple.

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 9.16. As shown in Table 9.6, the variation over a fleece is relatively small compared with the other nominated sources of variation.

Figure 9.16 Diagram of a Merino sheep showing the average diameter of samples taken from different regions. Source: Fish (2002).

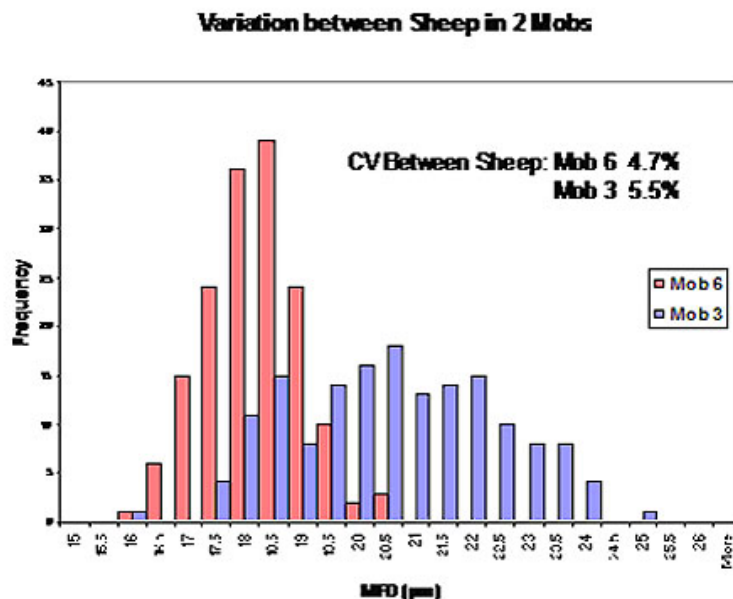


Pioneering work by Newton-Turner et al. (1953) demonstrated that, on average, a mid-side sample was most representative of the diameter (and some other properties) of the whole fleece compared to samples taken from other regions of the sheep. Trials reported by Marler and Baxter (2004) both highlighted 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 9.6, this source of variation can be expected to contribute approximately 11% to 16% of the variance in a lot. Figure 9.17 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 9.17 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 9.17 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 9.17 would be expected to have relatively small sampling and measurement error, i.e. the variation depicted in Figure 9.17 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 16.0 μ m to 20.5 μ m; whereas the range in the other mob was from 16.0 μ m to 25.0 μ m.

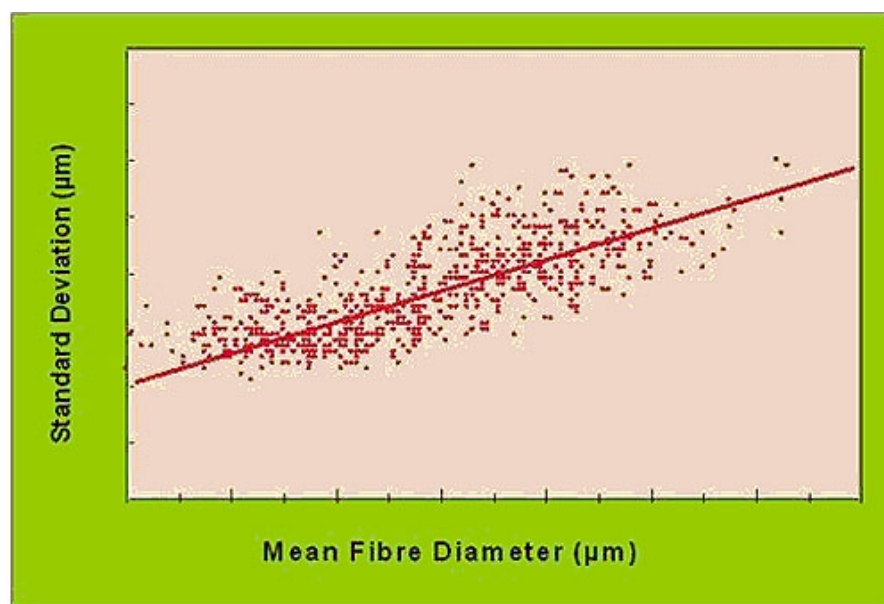
Figure 9.17 An example of the variation in Mean Fibre Diameter of fleeces in a mob.
Source: AWI.



Relationship between MFD and SD

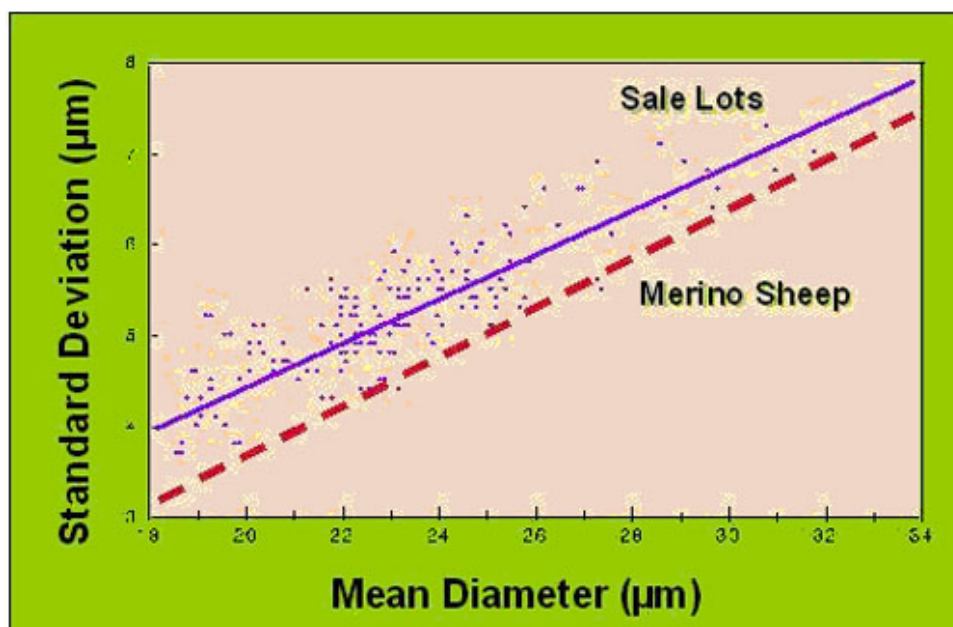
The relationship between SD and MFD for individual sheep is shown in Figure 9.18 for 737 Merino sheep from different flocks and environments (Bow and Hansford 1994). Note that there is an approximately linear relationship between MFD and SD in Figure 9.18.

Figure 9.18 Standard Deviation and Mean Fibre Diameter for 737 individual sheep from different flocks and environments. Source: Bow and Hansford (1994).



When fleeces are combined into a sale lot, the SD at each value of MFD increases relative to the value for an individual sheep because fleeces of different MFD are being combined. This effect is quantified in Figure 9.19 where measurements of SD and MFD are shown for a series of sale lots, collected from a number of sources. The dashed line shows the relationship for individual sheep from Figure 9.18. It can be seen that the combination of fleeces into a sale lot adds from 0.5µm to 1.0µm to the SD of an individual fleece for MFDs in the range from 32µm to 18µm.

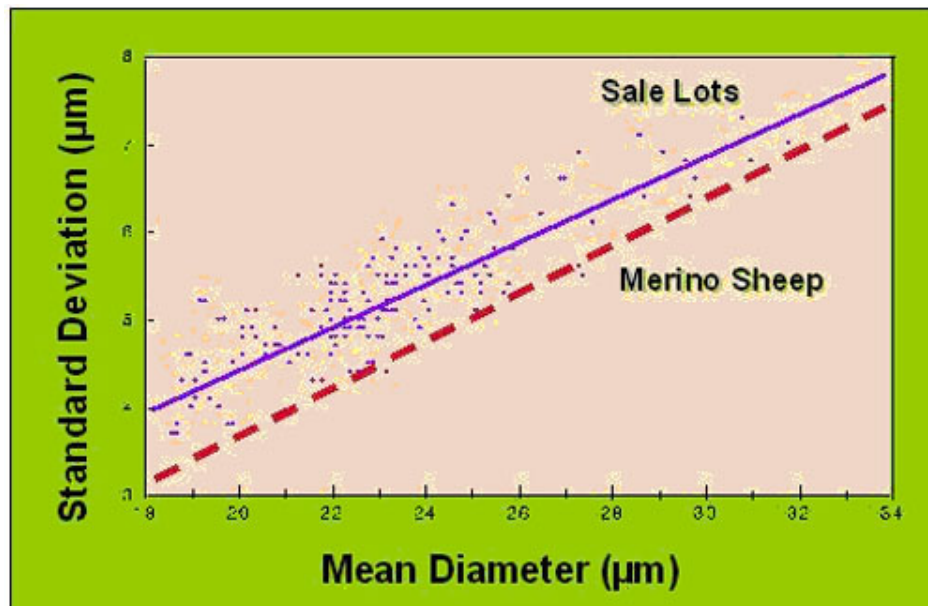
Figure 9.19 Standard Deviation versus Mean Fibre Diameter for a series of Sale Lots. Source: Bow and Hansford (1994).



Among sale lots in a consignment

Because processing consignments are generally assembled from sale lots under tight specifications for MFD and price, there is usually a very narrow range of MFDs among the sale lots which comprise commercial processing consignments. However, as in the case of the combination of fleeces into sale lots, there is also a small increase in SD for all values of MFD when the SD versus MFD relationship is plotted for commercial processing consignments. As can be seen in Figure 9.20 the difference between sale lots and consignment SDs is almost negligible for fine wool ($< 18\mu\text{m}$) and is still very small for coarse wool ($> 25\mu\text{m}$).

Figure 9.20 Standard Deviation versus Mean Fibre Diameter for 222 tops from TEAM 2.
Source: Bow and Hansford (1994).



9.7 Testing of individual sheep

Individual sheep can be tested for diameter characteristics to both assist in flock management (including breeding decisions, e.g., the selection of culls and rams) and in clip preparation when decisions are made about the number and content of different classed lines to make lots for sale. Testing can be performed either in a test house based on midside samples, or On-farm using either a Fleecescan (a Laserscan adapted for On-Farm work) or an OFDA2000, a portable instrument which uses a similar image analysis approach as the OFDA100. The two most important statistics in determination of the expected benefits of testing individual sheep are the variation in MFD between sheep in the mob, and the precision of testing.

Test house measurement of diameter of midside samples is generally made by Laserscan or OFDA100, though it is possible to use an Airflow Meter.

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. An image of a Fleecescan is shown in Figure 9.21.

Figure 9.21 An image of a Fleecescan system showing the Coring, Snippet Washing and Fleece Weighing unit and the separate Laserscan section. Source: CSIRO Textile and Fibre Technology (pers. comm) with permission.



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 similar to the fibre profile shown in Figure 9.14. 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 9.22.

Figure 9.22 OFDA2000 instrument. Source: Mahar (2006).



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 9.7 which shows the better precision (lower 95% Confidence Limits) for MFD measurement by Test House (1.04/1.05 μ m) compared to Fleecescan (1.17 μ m) and OFDA2000 (1.24 μ m). Average values of each parameter are included for information.

Table 9.7 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 (μ m)	19.5	± 1.17	± 1.24	± 1.05	± 1.04
SD (μ m)	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, 0.2 μ m – 0.4 μ m finer than the whole fleece average, and that the pinbone sample was 0.5 μ m – 0.7 μ m coarser than the fleece average. The precision of the pinbone sample was approximately 0.2 μ m 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 9.8 for three levels of precision, with three different SDs of MFD between sheep in the mob, and two levels of culling.

Table 9.8 Percentage of incorrect selections for three different levels of precision of testing. Source: Marler (2001).

SD of Mob	95% CL	35% Cull	95% Cull
1.0 μ m	$\pm 0.4\mu$ m	4%	12%
	$\pm 1.0\mu$ m	11%	27%
	$\pm 1.6\mu$ m	15%	47%
1.5 μ m	$\pm 0.4\mu$ m	3%	13%
	$\pm 1.0\mu$ m	7%	19%
	$\pm 1.6\mu$ m	11%	33%
2.0 μ m	$\pm 0.4\mu$ m	2%	8%
	$\pm 1.0\mu$ m	5%	17%
	$\pm 1.6\mu$ m	9%	31%

Readings ³

The following readings are available on CD:

1. Australian Wool Testing Authority Ltd. (AWTA), 2002, Glossary of Terms.
2. Marler, J.W. 2001, 'The Impact of Test Result Precision on On-Farm Decisions,' *Proceedings of IWTO*, Commercial Technology Forum, Report No. CTF 04, Nice.
3. Sommerville, P.J. 1998, 'Measurement of the fineness of superfine wool: Effect of the revised LASERSCAN calibration function on comparisons between Airflow, LASERSCAN and OFDA,' *Proceedings of IWTO*, Technical and Standards Committee meeting, Report No. CTF 04, Nice.

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Summary

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Fibre Diameter is the most important single value-determining property of wool. There are four techniques available to measure Mean Fibre Diameter (MFD) in accordance with IWTO Standards, viz. Projection Microscope (PM), Airflow, Laserscan and OFDA. PM is the only direct measurement system for Fibre Diameter measurement; the other three methods are calibrated systems, dependent (either directly or indirectly) on the value assigned by the PM.

Research has determined the sources of variation in MFD measurement, and sampling schedules have been developed to ensure that an accurate and precise estimate of MFD can be obtained for various samples of wool, e.g., presale core sample, top, midside.

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Movies

The following movies are available on CD:

1. Canesis Network Ltd., OFDA Fibre Diameter Measurements.

Glossary of terms

Airflow	A method of measuring the Mean Fibre Diameter of a sample of wool in which a test specimen (a measured mass of the scoured, dried and carded sample), after exposure to a conditioning atmosphere, is compressed to a fixed volume and a current of air is passed through it. The rate of flow is then adjusted so that the pressure drop across the sample equals a predetermined value. The rate of flow is an indicator of the mean fibre diameter of the wool in the sample. The instrument is calibrated to international standard wool tops of known fineness
Coefficient of variation (CV)	A statistical measure of the variability exhibited within a set of values. It expresses the standard deviation as a percentage of the mean; the higher the CV, the greater the variability. The coefficient of variation of a sample may be calculated from: $CV = S \times 100\% \div X$ where CV = coefficient of variation S= standard deviation of the sample X = mean of the sample Coefficient of Variation is often measured for Fibre Diameter and Staple Length
Fibre diameter	The thickness of individual fibres; it is customary to quote an average value (Mean Fibre Diameter or MFD) in micrometres
Laserscan	An instrument that detects shadows of fibre snippets in a laser beam as they are carried in solution through the beam, developed for improved performance in measuring Mean Fibre Diameter and fineness distribution

OFDA (Optical Fibre Distribution Analyser)	An instrument for measuring fibre diameter mean and distribution using automated microscope and image analysis techniques
Projection microscope	An instrument for measuring fibre diameter mean and distribution. Magnified images of the profiles of short lengths (snippets) of fibre are projected on a screen and their widths measured by using a graduated scale
Variance	The variance of a sample is the square of the standard deviation and is a measure of the distribution of values around the mean. It is expressed in the units of measurement squared (also see coefficient of variation)

