13. Fibre Curvature, Crimp Frequency, Resistance to Compression and Bulk

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Learning objectives

By the end of this topic, you should have:

- an understanding of the measurements of fibre shape
- an understanding of the principles of measurement of Bulk and Resistance to Compression
- an understanding of the relationship between Bulk and Resistance to Compression
- an appreciation of the measurement of Crimp Frequency, and
- an understanding of the commercial measurement of Fibre Curvature

Key terms and concepts

Fibre Curvature, Crimp Frequency, Resistance to Compression, Bulk

Introduction to the topic

This topic describes the relationship between the four different measurements of fibre shape, and explores the relationship between these measurements. The four measurements to be covered in this topic are fibre curvature, crimp frequency, resistance to compression and bulk.

Resistance to compression and bulk are measures of the characteristics of a mass of fibres, which are affected by the shape of the individual fibres. Their values are determined by the diameter and shape of the constituent wool fibres, and the interaction between wool fibres.

In contrast, crimp frequency and fibre curvature are directly related to the shape of wool. Crimp frequency is related to the shape of the staple, thus it is usually referred to as staple crimp frequency. Fibre curvature is directly related to the fibre's individual shape characteristics in situ.

There are three main reasons why fibre shape is measured:

- For breeding purposes – to attain uniformity of the clip from any one flock of animals. In the past, crimp frequency was also considered to be a reliable estimate of fibre diameter, though it has been demonstrated that this is not necessarily the case,
- For processing purposes – to determine how a particular wool will process to top or yarn. Work by CSIRO has shown that the crimp or curvature of a wool will have an influence on the type of yarn produced,
- To predict a product consequence – to determine if a particular wool will meet the requirements of a specific end product, for example, will the wool that is purchased be more suited to the manufacturing of men's suits, or wool jumpers.

13.1 Resistance to Compression (RtoC)

Introduction

"Resistance to compression is defined as the force per unit area required to compress a fixed mass of wool to a fixed volume. It is related to fibre diameter and the frequency and form of the wool crimp." (AS 3535–1988).

Resistance to compression is a uniquely Australian measurement, designed to distinguish differences amongst the majority of the wool types produced in Australia. For apparel purposes, the ability to compress wool into a given shape is far more important than the space filling capacity of the wool (see Section 13.2).

In Australia, the resistance to compression (RtC) measurement is not available as a commercial pre-sale core-testing measurement, except by special request. Resistance to compression measurements are available for fleece samples, but the majority of these tests are performed on research fleece samples. Approximately 750–1000 RtC tests are performed annually by AWTA Ltd, indicating there is very little demand for the measurement.

Units of measurement

Resistance to compression is measured in KPa (kiloPascals). For Merino wool, the expected range of values is between 8kPa and 12kPa. Cross-bred and other fibres (mohair and cashmere) can have RtC values outside of this range (AS3535–1988).

Equipment

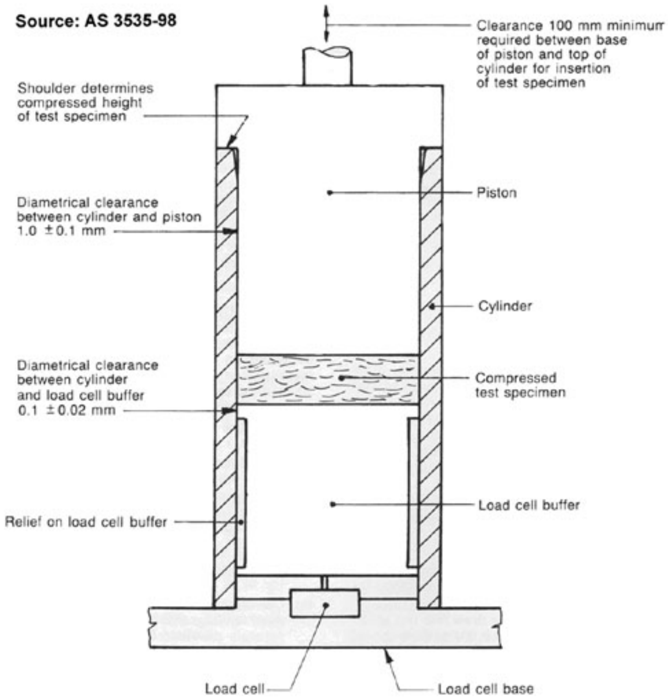
There are 2 main pieces of equipment used for the preparation and measurement of resistance to compression.

For preparation, a Shirley Analyser, or similar mechanical card-type devise is used to eliminate dust and most of the vegetable matter from the sample. The Shirley Analyser also opens the sample so that the individual fibres exist in their own space, allowing interaction between fibres (see Figure 13.1).

Figure 13.1 Shirley Analyser. Source: Fish, AWTA Ltd (2006) with permission

The resistance to compression instrument is automated; consisting of a measurement cylinder, a piston and measurement cell (see Figures 13.2).

(a)



(b)

Figure 13.2 **(a)** Resistance to Compression Instrument . Source: AWTA 2005, with permission.**(b)** Schematic of the Resistance to Compression Instrument Source: AS 3535 (1998).

Sampling

There are two main sampling methods for resistance to compression measurement, depending on the material to be measured.

Fleece sampling is usually performed on-farm, and is determined by individual growers. The most popular form of fleece sampling is by taking a mid-side sample, which is then sent to a laboratory. The mid-side sample needs to be taken from an area of the fleece approximately 10cm square, in order for there to be sufficient material to measure for resistance to compression.

Sale lots are sampled in accordance with IWTO Core Testing Regulations. These regulations govern the sampling of core material for Mean Fibre Diameter and yield measurement for IWTO standard testing, as well as sampling for additional measurements such as RtC.

Instrument principles

The material to be tested is opened and randomised, then a 2.5g mass is introduced into the measurement chamber in a specific manner, and compressed to a known volume (23.56cm^3). The force exerted to compress the wool is then recorded and converted to a pressure. The principle is that wool of a higher resistance to compression will require more pressure to compress to a given volume than wool of lower resistance to compression.

Procedures

The following procedure refers to core samples only; however it may be adapted for fleece measurement by chopping the fleece samples into 2cm lengths, then proceeding as for core measurements. These procedures are adapted from AS 3535–1988.

The core sample is scoured and dried, such that the ethanol extractable matter does not exceed 1.5%.

1. A 20g subsample is Shirley Analysed (carded), and allowed to reach equilibrium (conditioned) from the dry side
2. Two test specimens are withdrawn from the conditioned subsample. These test specimens are exactly 2.500 ±0.001g
3. The test specimen is shaped into a plug using tweezers, and eased into the cylinder
4. The piston compresses the wool into a plug of diameter 50mm, and a height of 12mm
5. The measurement cell reports the pressure exerted upon it in kPa two seconds after the piston has stopped moving
6. Repeat steps 4–6 on the second test specimen if the two measurements exceed a difference of 0.7kPa, the measurement is repeated on four more test specimens.

Limitations

The resistance to compression measurement is limited by the relationship between the precision of measurement and the range of expected values. The range for merino wool is 8–12kPa, however the between laboratory precision is 1.6kPa. This level of precision represents a significant proportion of the expected measurement range (40%), and therefore limits the usefulness of the measurement.

13.2. Bulk

Introduction

Bulk is defined as the amount of space that a given quantity of wool will occupy. Bulk is a measurement specific to the New Zealand wool industry, because it is mainly concerned with the space occupying capacity of wool, and in particular, carpet wool. However, less than 1% of the New Zealand wool clip is currently measured for bulk in any one year, and the majority of the demand for this measurement is from 1 broker.

Units of measurement

Bulk is the measurement of the space filling capacity of a known quantity of wool; therefore the unit of measurement used is cm^3/g.

Equipment

Wool is prepared for Bulk measurement using the Core Card, a small carding device used for the opening of a scoured core sample (Figure 13.3).

Figure 13.3 Core Card. Source: NZWTA Ltd. (2005) with permission.

Bulk is usually measured using the Bulkometer, an electrically powered device that consists of a cylinder, a plunger, and an electronic cell (Figure 13.4). The internal diameter of the cylinder is 50mm, and the cylinder height is 150mm. A nylon piston is guided into the cylinder using a piston guide.

Figure 13.4 Auto-Bulkometer. Source: NZWTA Ltd. (2005) with permission.

Sampling

Core samples taken from sale lots are scoured and dried in accordance with the IWTO Core Testing Regulations (1994). After conditioning (IWTO–52), samples are opened using a card-like machine, usually a core-card. Four 2.5g sub-samples are then weighed and placed into the four Bulkometer cylinders.

Instrument principles

The Bulkometer performs measurements by compressing the wool sample to 3 kPa twice, with a relaxation period (30 seconds) after each compression, before compressing the sample a final time under a pressure of 1kPa. The principle is that the initial compression cycles stabilise the fibre plug before the measurement is made.

Procedures

The following procedure for the measurement of bulk is adapted from NZS 8716:1994.

1. A core sample is scoured, dried and conditioned in a standard atmosphere (IWTO–52)
2. The conditioned sample is carded using the core card. This opens the sample
3. Four 2.5g subsamples are taken from the carded sample and placed into the four cylinders of the Bulkometer
4. The measurement cycle commences by exerting a pressure of 3kPa on the subsamples, which are then allowed to relax for 30 seconds. This cycle is repeated before the final measurement is made. During the final measurement, the sample is compressed with a pressure of 1kPa, the volume is recorded and the final bulk measurement is reported in cm3/g.

Similarities between bulk and resistance to compression

Bulk and resistance to compression are both derived properties, meaning they do not directly measure one physical property of a wool fibre. Rather, bulk and resistance to compression are expressions of the interaction between two physical properties of wool fibres, namely, fibre diameter and fibre curvature.

Resistance to compression and bulk have been shown to be highly related (Swan 1993). The space filling capacity of a wool sample is in proportion to the ability of a wool to withstand compression. The two measurements are essentially measures taken from different axes of the pressure versus volume relationship for a wool sample as seen in the Figure 13.5.

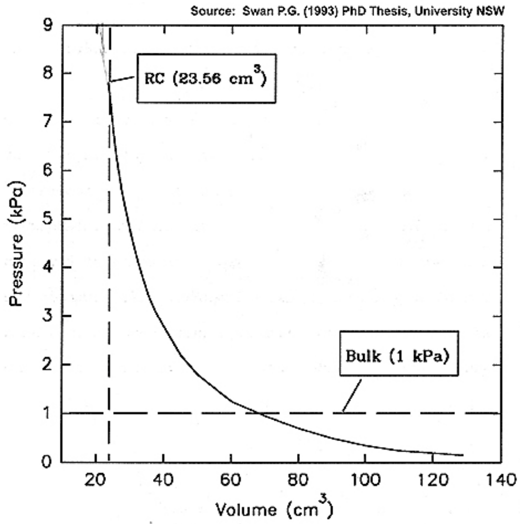


Figure 13.5 The relationship between pressure and volume for an initially random wool fibre assembly. The points at which Bulk and Resistance to Compression are determined are indicated. Source: Swan (1993).

13.3 Crimp frequency

Introduction
Crimp frequency is a measurement of fibre shape within the confines of the staple. Crimp frequency refers to the generally regular, or wavy pattern of ripples along the staple (Figure 13.6). It is a phenomenon of wool growth and is influenced by breed and nutrition. Automated crimp frequency measurement will be dealt with in detail under the next topic, Style, therefore manual crimp frequency will only be briefly discussed here.

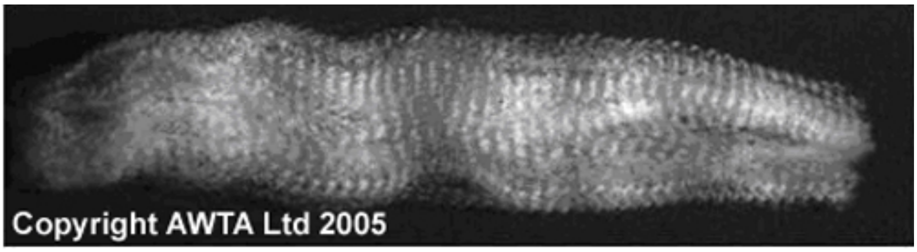


Figure 13.6 The Crimp of a Staple. Source: Fish, AWTA Ltd (2006) with permission

Subjective appraisal
The measurement of crimp frequency by subjective appraisal is covered in the next topic; please see this topic for details.

Units of measurement
Crimp frequency is measured and reported as crimps per centimetre (cr/cm); however, the traditional use of "Quality Counts" to represent crimp frequency still persists in some sections of the wool industry. This practice is fading out, and it is not used as a method of specification.

Crimp frequency is calculated as the number of full oscillations within a 1 cm length of staple.

Equipment and measurement procedure
Crimp frequency is measured manually using a crimp gauge; typically a small, metal comb-like device that has teeth on either side (Figure 13.7), or a metal disk with teeth of various frequencies around the outer edge. The teeth are in groups which represent crimp frequencies ranging from 1 cr/cm to 12 cr/cm. To make a measurement the crimp peak is lined up with the teeth of the gauge to find the appropriate crimp frequency. Sometimes the crimp frequency of a wool will not line-up precisely with either of 2 frequencies. In this case, it is given a half frequency, for example, if a wool sample had a higher crimp frequency than 6cr/cm, but it was not as high as 7 cr/cm, then it is estimated to be 6.5cr/cm, even though there was not an exact match between the actual crimp peaks and the crimp gauge teeth at a frequency of 6.5cr/cm

Figure 13.7 CSIRO Crimp Gauge. Source: Fish, AWTA Ltd (2006) with permission

Staples are measured in 2 places; firstly, at the imaginary boundary between the tip and middle thirds of the staple, and secondly, at the imaginary boundary between the middle and base thirds of the staple. These two measurements are then averaged.

Limitations

The limiting factor of crimp frequency measurement using the crimp gauge is the operator. People assess the frequency of wool slightly differently, and while training reduces this variability somewhat, it does not completely eliminate human error.

Manually measuring crimp frequency is also very time consuming, which is the main reason for the development of automated crimp frequency measurement (see the Style Topic for more details).

13.4 Fibre curvature

Introduction

The mathematical definition of curvature (K), as a geometric expression, is the inverse radius of a circle such that:

$$K = 1/r,$$

where r is defined as the radius of a circle, as shown in Figure 13.8.

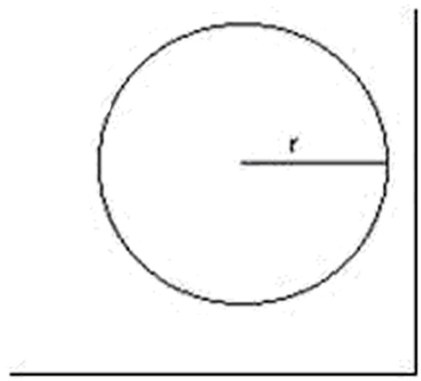


Figure 13.8 Radius of a circle.

Swan (1993) used this geometric expression of the curvature of a circle to explain the longitudinal shape of a wool fibre. Two assumptions are made for this definition:

- subsections form arcs of a constant radius along their entire length, and
- fibre subsections exist in a 2-dimensional plane only, which is known not to be the case.

Swan and Mahar (1998) further extended the original definition to express the fibre shape in more realistic terms. The term fibre curvature (FC) was used to express the shape of a fibre subsection that is randomly cut from a fibre, and exists such that it exhibits both geometric curvature (K) and torsion (T) (Brand and Scruby 1973). By suggesting that the fibre subsection exhibits both K and T in the one subsection, the existence of the 3-dimensional shape of a fibre is acknowledged.

Further investigation by Fish, Mahar and Crook (1999) has shown that the shape of a fibre subsection is influenced by all of the processes that the fibre subsection undergoes prior to measurement. As a consequence Fish, Mahar and Crook (1999) define fibre curvature as the inherent shape to which a fibre reverts when all external forces are removed.

Subjective appraisal

There is no method of subjectively appraising fibre curvature; however, crimp frequency may be an indicator of fibre curvature.

Units of measurement

The SI unit for curvature is mm^{-1}. However the wool industry, through instrument manufacturers and IWTO, has decided to use degrees per millimetre (^{o}/mm) as the units for measurement of fibre curvature. Both OFDA and SIROLAN-LASERSCAN report fibre curvature in ^{o}/mm. It should also be noted that $1mm^{-1}$ is equivalent to approximately 57^o/mm.

Throughout this topic, the term fibre curvature will be used to describe the shape of a scoured, dried and conditioned sample of greasy wool as tested using either LASERSCAN or OFDA, and reported in degrees per millimetre (°/mm), as adopted by IWTO in 1998 (Swan and Mahar 1998).

Equipment principles

OFDA (Optical Fibre Diameter Analyser)

The Optical Fibre Diameter Analyser (OFDA) is an automated image analysis instrument which is primarily used for the measurement of fibre diameter; however, fibre curvature values can be generated concurrently.

The OFDA operates by selecting the fibre snippet in the field of view. The software follows the edges of the fibre for a distance to determine if it is one fibre or two that have been captured in the image. An algorithm then determines the distance between the two edges, along with the angle of the arc that the fibre transcends. Both the arc of the angle, and the length of the fibre measured are used to determine the fibre curvature of the section of snippet being measured.

While mean fibre curvature can be measured concurrently on the OFDA with mean fibre diameter (MFD), selecting this option makes the measurement slightly slower than the standard measurement of alone.

Sirolan-LASERSCAN

The LASERSCAN is a fibre diameter measurement system based on illumination of approximately 2mm fibre snippets by a laser. Figure 13.9 shows a schematic of the Laserscan. Fibre snippets are dropped into the fibre dispersion bowl, which is filled with a transportation fluid. A snippet/fluid slurry is created, which moves from the dispersion bowl towards the sump and filter, passing through a measurement cell, with the laser from a pinhole passing through the measurement cell perpendicular to the flow of slurry.

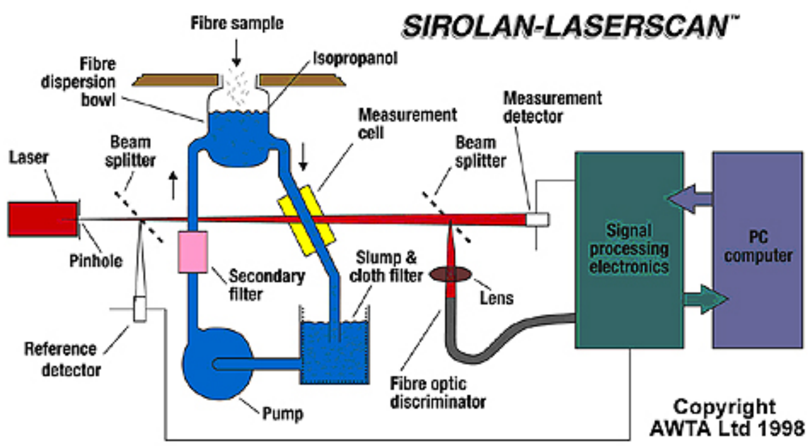


Figure 13.9 Schematic of the SIROLAN-LASERSCAN™. Source: Fish, AWTA Ltd (2006) with permission

Part of the beam going to the detector is split off and reflected to a discriminator. Figure 13.10 is a visual representation of the discriminator, which is composed of a ring of 16 optical fibres surrounding a central fibre optic. The LASERSCAN uses the image projected onto the discriminator to determine if the Diameter measurement of an individual fibre is a valid measurement. Measurements may be rejected if the fibre is too short, does not pass through the centre point of the discriminator, is misshapen, or if two fibres pass through together (Dabbs, van Schie and Glass 1994).

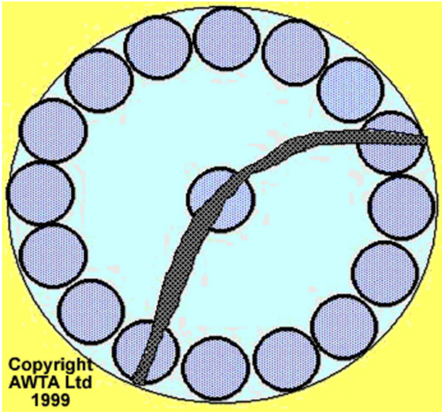


Figure 13.10 Illustration of Fibre Optic Discriminator with fibre shadow passing over. Source: Fish, AWTA Ltd (2006) with permission

The discriminator is also used to measure the fibre curvature of the snippets by allocating the fibres to a curve-bin based on which optical fibres that the fibre image is projected onto. A straight fibre, for example, has no curve and will pass through optical fibres that are opposite one another in the discriminator ring.

Measurement of FC on LASERSCAN involves an image of the 3-dimensional fibre being projected onto a 2-dimensional surface. The projected image is dependant on the orientation of the fibre in the slurry-stream.

Sampling

A wool producer will usually take fleece samples from the mid-side of the animal; however, the pin-bone is another popular site. Whichever site is chosen, the producer must be consistent across the flock.

Core samples are sampled as per the sampling requirements for the measurement of MFD and CVD. Sampling is governed by the IWTO Core Testing Regulations (1994).

The sampling of top for measurement is in accordance with IWTO–12 and IWTO–47 for Laserscan and OFDA, respectively.

Procedures

Preparation of sample

The fibre curvature of sale lots is usually measured at the same time as MFD. Sale lots are cored in accordance with the IWTO Core Test Regulations (1994). The core samples are blended, scoured and dried. Smaller sub samples of wool are then minicored and measured in the instrument of choice. In Australia, most core samples are measured on Laserscan, unless otherwise requested.

The preparation of top samples is governed by IWTO–12 and IWTO–47. A length of top is taken during production, and it is held without twist. The samples is then re-dried and conditioned in a standard atmosphere (IWTO–52), prior to measurement on the designated instrument.

In contrast, the preparation of fleece samples for measurement is dependant on the laboratory testing the samples, however AS/NZS4492.4:2000 and AS/NZS4492.5:2000 govern how Fleece testing is conducted for MFD measurement using Laserscan and OFDA respectively.

OFDA
The procedures for the measurement of mean fibre curvature (MFC) on OFDA are determined by the standard for MFD measurement, IWTO–47–00. OFDA measurements are performed using glass slides placed on the stage of the microscope. Slides are prepared using either scoured core or scoured full length fleece wool which is then placed into a mini-coring machine, an apparatus which samples snippets using 2mm diameter coring tubes. Alternatively, snippets are obtained by guillotining wool top.

The snippets are placed into a purpose-built spreading apparatus, which locates a slide underneath. The snippets are spread onto the slide so that they are evenly distributed across the slide.

The slide is gently closed and placed on the stage of the OFDA apparatus, and then the measurement phase begins. The stage moves back and forth in a continuous pattern, capturing and analysing snap-shots of the slide until the full slide is measured.

Sirolan-LASERSCAN
The measurement of sale lot material by Laserscan is governed by IWTO–12–00, the IWTO standard for measuring MFD on Laserscan. The Laserscan instrument usually uses a minicoring device located as per the OFDA to obtain fibre snippets which are placed into the dispersion bowl, where they are mixed into a slurry with the transportation fluid.

Limitations
As outlined in the introduction (Section 13.4), fibre curvature is affected by mechanical and hygral changes applied to the fibre throughout its measurement cycle. As a result, the measurement of fibre curvature is influenced by a number of factors, many of which are reported in Fish, Mahar and Crook (2000). The three main limitations are:

- The medium in which the fibre undergoes measurement, be it air, water or isopropanol/water. This will influence the degree of fibre curvature expressed by the wool. For example, using water as the transportation fluid in Laserscan will decrease the amount of fibre curvature expressed by the snippets, when compared with snippets measured in isopropanol/water
- The instrument used for measurement. There have been many reports in the wool technical literature which show that the MFC measurement differs greatly between instruments, and between instrument types. This makes it difficult to compare results obtained between different instruments, and especially between different test houses. It is strongly recommended that for comparisons of results between sheep or between years only one instrument type and one test-house should be used for all MFC measurements
- Unlike the measurement of mean fibre diameter, there is no calibration procedure for mean fibre curvature, for either the Laserscan or OFDA instruments. Attempts have been made to rectify this (Fish 2003; 2004). As a result, MFC data is currently being collected by Interwoollabs, which has the potential of being used as a calibration in the future.

Readings [3]

The following readings are available on web learning management systems

1. Australian Wool Testing Authority Ltd. (AWTA), 2002, Testing the Wool Clip, Glossary of Terms.
2. Fish, V.E., Mahar, T.J. and Crook, B.J. 1999, 'Fibre curvature morphometry and measurement,' *Proceedings. of IWTO,* Technology and Standards Committee, Nice December 1999, Report No. CTF 01.
3. Fish, V.E., Mahar, T.J. and Crook, B.J. 2000, 'The influence of preparation technique on the measurement of fibre curvature,' *Proceedings. of IWTO,* Technology and Standards Committee, Christchurch, May, 2000.

Summary

Summary Slides are available on web learning management systems
The most direct measurement of fibre shape is *Mean Fibre Curvature.* However, there are a number of factors, including lack of a calibration system or standardised preparation procedures, which limit the usability of Fibre Curvature Measurement. Alternative measurements, like Bulk and Resistance to Compression, are indirect measures of wool fibre shape, which appear to have little application in the commercial wool industry at present.

Glossary of terms

Check Test	A Check Test is verification of documentation and calculations forming the basis of the Certificate on which a doubt has been raised and, if possible, a set of additional measurements made, in accordance with the same standard IWTO Test Method as was adopted for the original test, on that portion of the sample material remaining after that original test. Where no sample material remains, a Recore Check Test may be carried out as part of the check testing procedures. Check testing is restricted to tests carried out by the Test House, which conducted the original test
Recore Check Test	This is a set of measurements made, in accordance with the relevant IWTO Test Methods and Regulations, on a further sample of raw wool drawn from the delivery as part of the check testing procedures. A Recore check test may only be conducted where a Certificate has not been delivered in relation to a contract. Where staple measurements are involved this definition applies to a fresh grab sample taken from the lot rather than a core sample
Retest	This is a set of measurements made, in accordance with the relevant IWTO Test Methods, on a further sample of raw wool drawn from a delivery for which the original Certificate is in doubt. This differs from a Recore Check Test in that duplicate core (grab) samples are drawn for possible testing by two separate Test Houses to resolve a disputed result. Such sample material must be obtained by recoring (regrabbing) and reweighing all bales, in accordance with the current IWTO Core (Staple) Test Regulations
Testing Error	A Testing Error is deemed to have occurred if the Maximum Retest Range is exceeded
Maximum Retest Range	The Maximum Retest Range (i.e. the difference between the values of a retest and the original Test Certificate or an earlier retest) is a statistically (and scientifically) determined upper and lower limit which, provided the test procedure has been rigorously adhered to, will very rarely be exceeded purely by chance. The Maximum Retest Range defines the maximum allowable difference between two test results