10. Staple Length, Staple Strength and Position of Break

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Learning objectives

By the end of this topic, you should have:

- an understanding of the limitations associated with subjective appraisal of Staple Length, Staple Strength and Position of Break
- an understanding of the relationship between Staple and Fibre properties e.g. Staple Length and Fibre Length, Staple Strength and Fibre Tenacity
- an understanding of the principles of objective measurement on an ATLAS instrument including the requirements of the IWTO Test Method

Key terms and concepts

Staple Length, Staple Strength, Fibre Length, Fibre Tenacity, Position of Break, Intrinsic Fibre Strength

Introduction to the topic

This topic describes the subjective assessment and objective measurement of Staple Length, Staple Strength and Position of Break. The principles of the measurements made on an ATLAS instrument are described as is the relationship between Staple and Fibre based measurements.

It should be noted that terms such as Staple Length and Staple Strength have specific meanings and are explicitly defined in IWTO-30-02.

10.1 Subjective appraisal of staple length and staple strength

This section outlines the difficulties of subjective appraisal of Staple Length and Staple Strength.

Staple length

Visual perception

Consider the following picture of two tables. Visually, they have seemingly different dimensions. But this is an illusion. The dimensions are exactly the same. Use a ruler and verify this if there is any doubt. This example is a classic illustration of how our eyes can play tricks on us, and where, if we relied on objective measurement using, in this case a ruler, instead of our visual senses we would obtain a different, though correct result. The science of psychology can provide numerous such examples where our visual senses are fooled by the way our brains interpret what our eyes see (Figure 10.1).

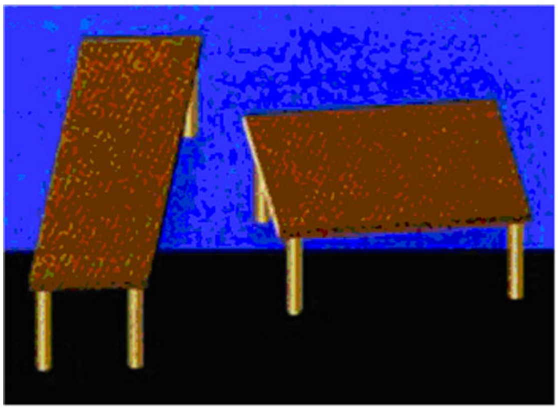

Figure 10.1 Example of our eyes playing tricks. Source: Holmes (1998).

It is equally possible to be confused when visually estimating the average Staple Length of wool. Within every sample of wool there is a distribution of Staple Length. For fleece wools this distribution is approximately normal (bell shaped). For skirtings and pieces lines the length distribution is often skewed. Figure 10.2 shows 3 distributions. The top distribution is a normal distribution. The others are skewed to the left and to the right.

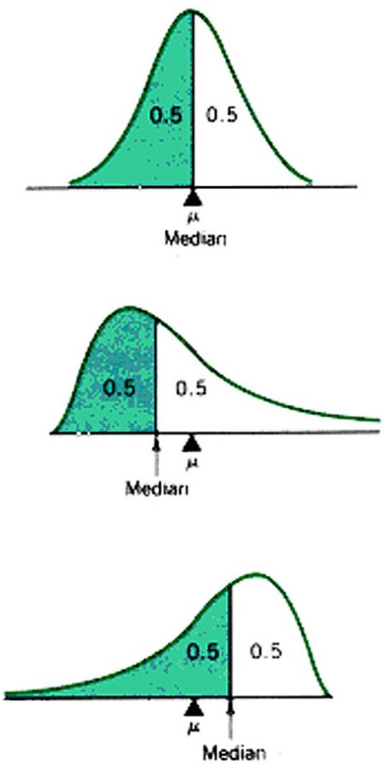

Figure 10.2 Normal and skewed distributions. Source: Crowe and Mahar, (2006).

These are idealised, but imagine them to be distributions of Staple Length. Such distributions have 3 statistical measurements that may represent the distribution with one 'typical' value of Staple Length. These are:

- Mean (μ)
- Median, and
- Mode.

The mean length is the arithmetic average and can be viewed as the balance point in these distributions. In this example, each distribution has the same mean length. The median length is the point that divides the distribution into 2 equal areas. The mode is the most popular or common length. As the skewness increases, the value of the mode will be increasingly greater than (or less than) the mean.

Objective measurement of Staple Length determines the mean length. But what has the most influence on subjective appraisal? Appraisal of Staple Length, where the length distribution is skewed, is very difficult. The human eye is drawn to the most common length – the mode. It is difficult to subjectively weight the shorter and longer staples in the correct proportions to achieve an accurate estimate of the mean length. In such cases, subjective estimates of length can be biased towards the most frequent length - the mode.

Sampling bias

To obtain an accurate measurement of Staple Length and Staple Strength, the distribution of the staples that are measured must be representative of the distribution within the lot. The sampling systems used for obtaining staples for measurement have been carefully designed to ensure that this is the case.

In 1992, an industry Working Group looked in detail at the possibility of any sampling bias, and was unable to demonstrate that this was occurring. However, AWTA Ltd did take steps to minimise the risk of bias in sampling of staples by doubling the number of operators involved in preparing the staples for each lot. This change was included in the IWTO Standard (IWTO-30-02 2003).

Furthermore, regular round trials involving fleece and pieces samples are carried out between the 3 AWTA Ltd Laboratories, to detect whether or not biases exist between the laboratories. Internal checks are also conducted to detect bias (if any) between operators.

Staple strength

Traditionally, the wool trade has assessed Staple Strength by gripping the ends of a staple and exerting a force on the staple by flicking the staple with the middle finger (Figure 10.3). There are several variables associated with this evaluation:

- the force exerted by the appraisers
- the thickness of staples selected
- and the number of staples evaluated.

The force exerted by this technique has been shown to range from 17 to 48 Newtons (Rottenbury 1979). The inconsistency of the force exerted makes it harder to compare between appraisals. Secondly, staples differ in thickness and its stands to reason that thicker staples will require more force to break them, so appraisal requires appraisers to select staples of equal thickness otherwise the appraised strengths will be different. The selection of staples of equal thickness is impossible to achieve. Finally, appraisers will typically sample a couple of staples and because of the variability in breaking force somewhere approaching 50 to 60 staples need to be assessed for a reasonable estimate of the breaking force to be made.

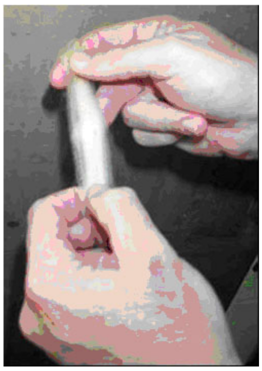

Figure 10.3 Manual appraisal of staple strength. Source: Crowe and Mahar AWTA (2006) with permission.

10.2 Relationship between staple and fibre properties

This section examines the relationship between the staple properties and the relevant fibre properties. For example, how do Staple Length and Fibre Length interact? Or what is the relationship between Staple Strength and Fibre Tenacity?

Staple length and fibre length

At a sale lot level, experimental data has indicated that some lots that do not predict well have a Fibre Length to Staple Length ratio significantly different from the mean ratio for merino wool. On average, the length of fibres within a staple is 20% greater than the staple length, so this ratio is 1.20. For extreme examples of merino wool, the ratio may be as low as 1.00 or as high as 1.35 (David 1992).

Superfine bellies are sometimes at the upper end of this range. While this might have a critical effect at a sale lot level, at the consignment level it is not as critical as the likelihood of putting a blend together with all the lots at the same extreme is small or negligible. However, if such a blend is constructed by design, then, in all probability, the consignment will comb shorter or longer than the TEAM formula will predict.

Staple strength and fibre tenacity

The term “strength” is used in the wool industry in an often loosely-defined way. Obviously, a coarser fibre will be stronger, i.e. a greater force required to break, than a finer fibre, all other things being equal. Strength needs to be normalised by the amount of material being tested. In general materials science, strength is normalised by the cross-sectional area of the material being tested, to provide a measure termed stress. In fibre and textile science, it is often extremely difficult to either measure or estimate the cross-sectional area of the fibre or fibres being tested, and so individual fibres and other fibrous materials such as filaments, yarns, fibre bundles and staples, are normalised by their mass/unit length, or linear density. The term specific stress is used in preference to stress to denote the use of linear density rather than cross-sectional area to normalise the amount of material being tested. The specific stress at break of a fibre is also called tenacity or specific strength.

Staple Strength is the maximum force of rupture per unit of average linear density (measured on the full span of the staple, apart from the portions gripped at each end), which should be the minimum length necessary for the purpose). It could also be termed staple tenacity. There is an important difference between the Staple Strength of a staple and the strength, or tenacity, of the individual fibres within the staple. In particular, Staple Strength is not the sum of the strength of each individual fibre in the staple.

Intrinsic fibre strength, or the fundamental strength of the (keratin) material, is only one component of Staple Strength; other fibre properties likely to be significant in the determination of Staple Strength include: the variation in decrimped length of fibres in the staple; variation in breaking strain of fibres within the staple; variation in cross-sectional area along the length of the fibres within the staple; presence of shed fibres in the staple; and, variation in crimp between fibres in the staple. The relative importance of these fibre properties in determining Staple Strength varies depending on the levels of the variation in amongst the fibres. For example, if fibres in the staple have very similar breaking strains, variation in decrimped fibre length becomes more important in determining Staple Strength than if there is a large between-fibre variation in fibre breaking strain.

Intrinsic fibre strength

Intrinsic fibre strength refers to the force required to break the fibre, normalised by the cross sectional area of the fibre at the point of break, i.e. it is the strength of the material from which the fibre is composed. In the context of this discussion about Staple Strength, we refer to the intrinsic fibre strength measured in air at 65% relative humidity and 20ºC. Note that it is reasonably common amongst researchers to measure properties of individual fibres in water.

It is difficult to obtain accurate data about intrinsic fibre strength because of the low levels of force required to break an individual fibre and the difficulties in measuring the cross-sectional area of the fibre at the point of break. Note that the break may not occur orthogonal to the applied force and that wool fibres are generally not circular so that measurement of the cross-sectional area is difficult, often requiring high magnification (electron microscopes used in some cases). An alternative to the single fibre approach is to measure the force required to break a bundle of parallelised fibres over a very short gauge length (e.g. 3mm, or even 1mm). Care is taken to ensure that the fibres are essentially decrimped and are all aligned in the direction of the applied force. It is assumed that there is a constant linear density of the fibres between the jaws of the bundle strength (or tenacity) tester. Details can be obtained of an instrument developed for this purpose, the CSIRO Sirolan Tensor (Yang, Schultz and Lamb 1997).

The difficulties of obtaining reliable data about intrinsic fibre strength has lead to conflicting published information about the existence of actual differences in intrinsic fibre strength of undamaged wool fibres above ±10% of the widely accepted mean intrinsic fibre strength of wool, 1.35cN.tex. This uncertainty leaves room for speculation as to whether or not differences in intrinsic fibre strength, e.g., exist between sound and tender portions of a wool fibre. Work by Gourdie et al. (1992) concludes that there is no difference within different portions of a partly tender fibre and that some previously observed differences may have been due to differences between sheep.

10.3 The principles of objective measurement

The name of the machine that measures Staple Length, Staple Strength and Position of Break is the Automatic Tester of Length and Strength (ATLAS). It was developed by the CSIRO, Division of Textile Physics in the early 1980's.

The ATLAS does three things. It measures the length of a staple, it measures the peak force required to break the staple in half, and it weighs the two broken portions of the staple.

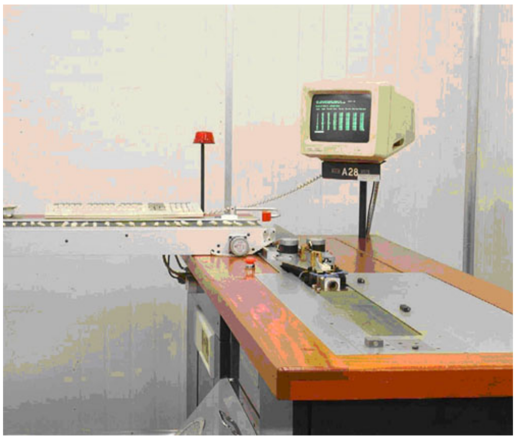

Figure 10.4 An automatic tester for length and strength (ATLAS).
Source: Crowe and Mahar AWTA (2006), with permission.

Other instruments have been designed and work on similar principals but in Australia all pre-sale testing for Staple Length, Staple Strength and Position of Break is conducted on ATLAS instruments. As at 1 May 2005 this testing represents approximately 76% of the Australian Clip (90% of Fleece wool Sale Lots).

Staple length measurement

The principle of length measurement on ATLAS (Caffin 1980, 1983; Thopson et al. 1986) is to convey the staple through a light beam at a fixed speed. The length of the staple is determined by relating the speed of the conveyor to the amount of time the light beam was interrupted by the staple.

The process is in fact a little more sophisticated than this explanation suggests because there are actually eight beams of light (Light Emitting Diodes) aligned vertically across the conveyor belt with eight photocells opposite them to detect the beam. These eight beams allow more accurate detection of the beginning and end of the staple. For example, there is often a few fibres protruding from either end of the staple and it would be clearly wrong to add these to the measured length of the staple.

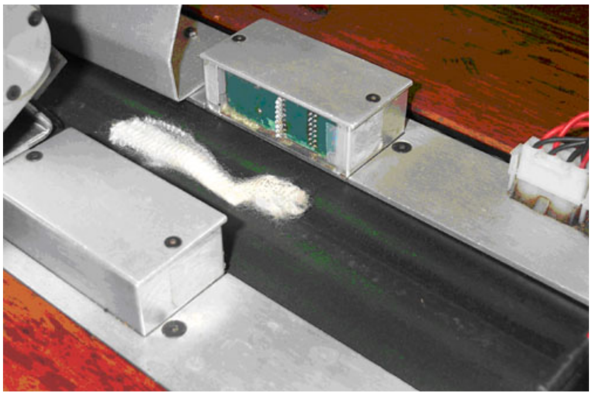

Figure 10.5 ATLAS staple length detector.
Source: Crowe and Mahar AWTA (2006), with permission.

When a staple moves between the light source and the photocells it reduces the amount of light falling on a number of them. Length measurement starts when at least one cell can detect less than 50% of the light from its corresponding beam. Similarly length measurement stops when all eight cells can detect more than 50% of the light from their corresponding beams.

Measurement of peak force to break and staple mass

Following length measurement, the staple is picked up between twin rubber belts and fed to the strength section.

The tip of the staple is gripped by one jaw and the base by another jaw and then the staple is broken and the peak force is recorded in Newtons.

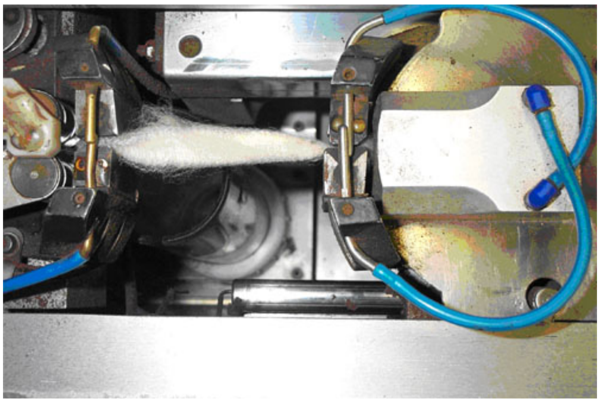

Figure 10.6 ATLAS staple force measurement system.
Source: Crowe and Mahar AWTA (2006), with permission.

The length of staple held by the jaws is approximately 20mm of the total length of the staple. Consequently any staple less than 50mm would have only 30mm of the staple free to break as the jaws moved apart. The peak force recorded in such a case would not be an accurate measure of the strength of that staple. A strength result is not reported for staples shorter than 50mm.

Each of the two broken portions of the staple is released from its jaw and blown down a tube to a balance where it is weighed. The sum of the two weights is used to calculate the Staple Mass.

Broken staples are weighed and then compressed air blows the portions to a collection vessel.

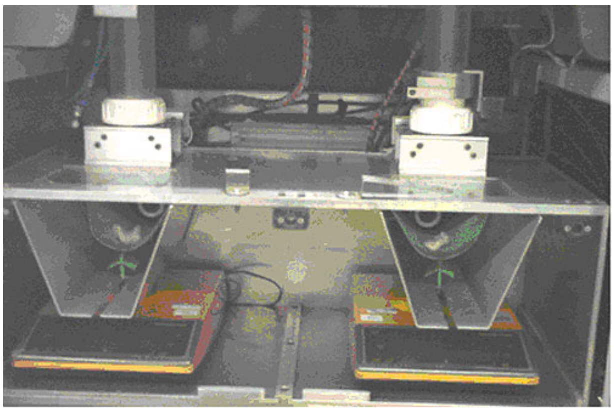

Figure 10.7 ATLAS tip and base mass measurement system.
Source: Crowe and Mahar AWTA (2006) with permission.

Calculation of staples strength (N/ktex)

The calculation of Staple Strength occurs in two parts. The first part corrects the Peak Force for the Greasy Linear Density.

The Greasy Linear Density is calculated by dividing the Greasy Staple Mass (mg) by the Staple Length (mm). This equation is presented below as equation 10.1

Equation 10.1

$$Greasy \quad Linear \quad Density_{(ktex)} = \frac{Greasy \quad Staple \quad Mass_{(mg)}}{Staple \quad Length_{(mm)}}$$

The Peak Force is then divided by the Greasy Linear Density to give the uncorrected Staple Strength. This equation is presented as equation 10.2.

Equation 10.2

$$Uncorrected \quad SS_{(\frac{N}{ktex})} = \frac{Peak \quad Force_{(N)}}{Greasy \quad Linear \quad Density_{(ktex)}}$$

Finally, the uncorrected Staple Strength is corrected for the Yield, Wool Type and Strength Factor using equation 10.3 (Kavanagh and Bos 1986; Allen and Bow 1985).

Equation 10.3

$$Corrected - SS_{(\frac{N}{ktex})} = \left[\frac{Uncorrected \quad SS_{(\frac{N}{ktex})}}{Strength \quad Factor \times Staple \quad Yield} \right] \times 100$$

where,

Strength Factor = 1.36704 – 0.006936 x WB + 0.06126 x Type

And

Staple Yield = 0.83 x WB + 0.314 x VMB – 6.18 x Type + 29.6
Type = 1 for Fleece and 0 for Skirting Wool
WB = Wool Base
VMB = Vegetable Matter Base
SS = Staple Strength

Calculation of Position of Break (POB%)

The Position of Break (POB%) is simply calculated by dividing the mass of the staple tip by the total mass of the staple (Tip and Base portions). This equation is presented as equation 10.4.

Equation 10.4

$$POB\% = \left[\left(\frac{Tip_{mass}}{Tip_{mass} + Base_{mass}} \right) \right] \times 100$$

Precision and variability of the test
Precision limits

Table 10.1 The 95% confidence limits for staple measurements using a single ATLAS. Source: IWTO-30-02 (2003).

Measurement	Wool Type	1 Operator	2 Operators	4 Operators
Staple Length (mm)	Fleece	±5.8	±5.3	±4.8
Staple Length (mm)	Non-Fleece	±6.7	±5.8	±5.4
Staple Strength (N/ktex)	Fleece and Non-Fleece	±6.0	±5.9	±5.9

For IWTO certification 4 operators are required to prepare staples.

Sources of variation

An important component of any measurement system is a thorough understanding of the sources of variation in the measurement system. In general instruments are designed and built to have relatively low between instrument variability. For wool testing it is generally the wool itself that is responsible for most of the variability.

Equation 10.5

$$v_{total} = \frac{1}{n_{staples}}\left[v_{staples} + 2.55v_{grabs}\right] + \frac{v_{ops}}{n_{ops}} + \frac{v_{labs}}{n_{labs}} + \frac{v_{inst}}{n_{inst}}$$

If a test was conducted only sampling a single staple for length and strength the largest source of variation would be due to the staple selected. This variance would swamp all other sources of variation.

Table 10.2 Variance components for a single staple test. Source: IWT0-30-02 (2003).

Sources of Variation	Staple Length $(mm)^2$	Staple Strength $(N/ktex)^2$
Between Staples	207.00	185.00
Between Grabs	38.00	49.00
Between Operators	3.26	0.54
Between Laboratories	0.1	1.65
Between Instruments	0.38	2.05
Total Variance	307.64	314.19

The relative size of the sources of variation for the case of a single staple test is presented graphically in Figures 10.8a and b.

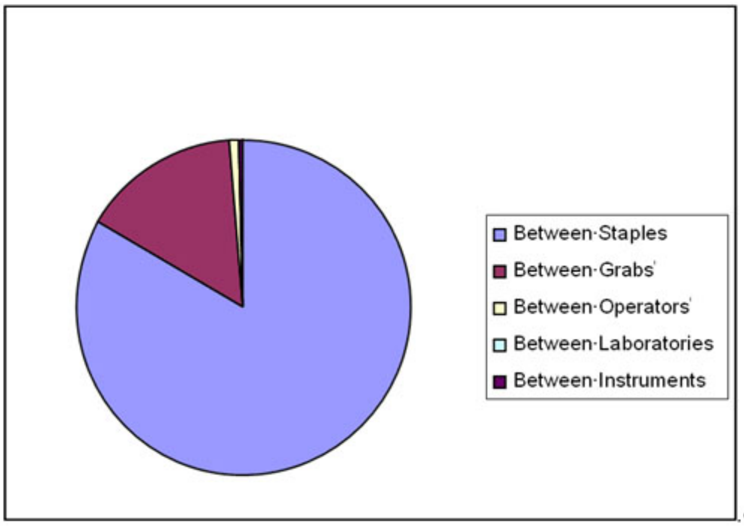

Figure 10.8a Sources of variation for a single staple length test.
Source: Crowe and Mahar AWTA (2006) with permission.

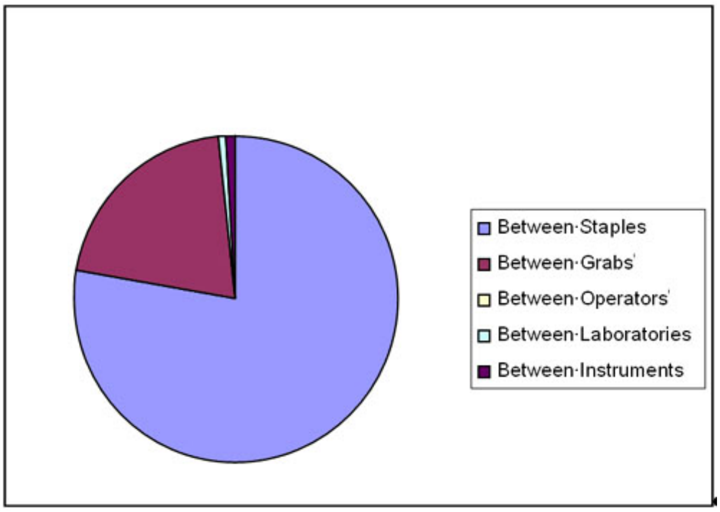

Figure 10.8b Sources of variation for a single staple strength test.
Source: Crowe and Mahar AWTA (2006) with permission.

To reduce the total variance a larger number of staples should be sampled. In a standard test for length and strength (IWTO-30-02 2003) on an ATLAS 60 staples are measured. The staples are prepared by 4 operators and measured on at least 2 instruments. Plugging these values into equation 10.5 reduces the total variance and the relevant components as shown in Table 10.3 and Figures 10.9a and b.

Table 10.3 Variance components for a standard ATLAS test.
Source: Thompson et al. (1996).

Sources of Variation	Staple Length (mm) ^{2}	Staple Strength (N/ktex) ^{2}
Between Staples	3.45	3.08
Between Grabs	1.62	2.08
Between Operators	0.82	0.14
Between Laboratories	0.10	1.65
Between Instruments	0.19	1.03
Total Variance	6.17	7.98

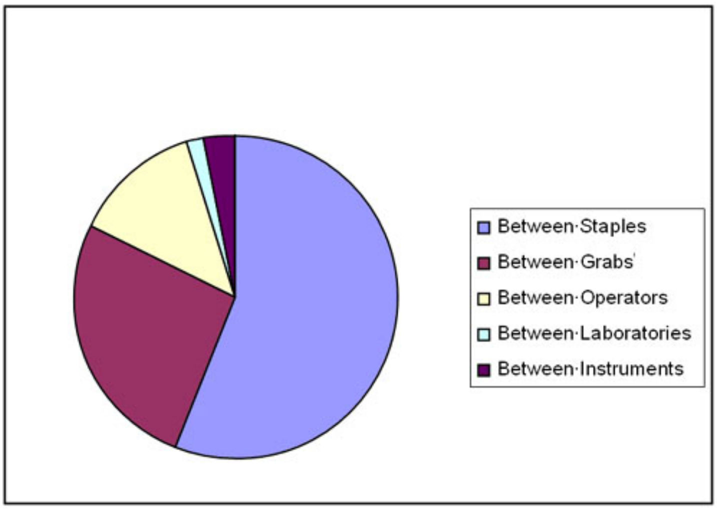

Figure 10.9a Sources of variation for a standard ATLAS staple length test.
Source: Crowe and Mahar AWTA (2006) with permission.

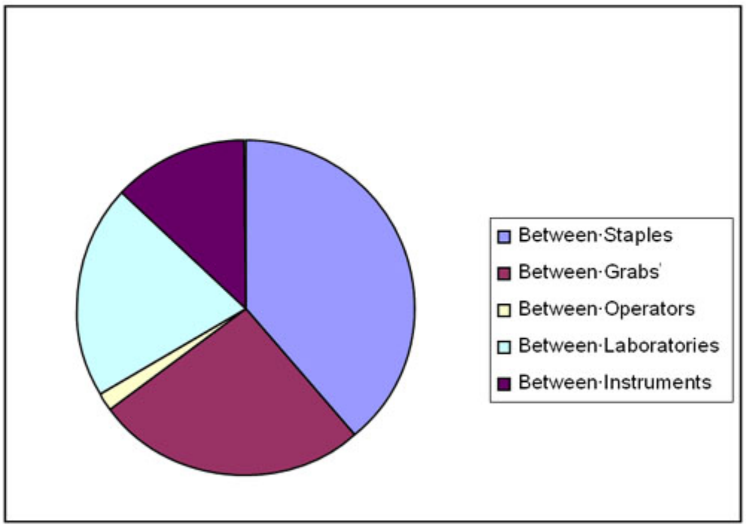

Figure 10.9b Sources of variation for a standard ATLAS staple strength test.
Source: Crowe and Mahar AWTA 2006 with permission.

Estimates of between staple variances for staple length and staple strength of mid-side samples

Recent work by Wang (2006) has calculated between staple variance estimates for Staple Length and Staple Strength of mid-side samples. It stands to reason that the differences for staple length and staple strength within a mid-side sample are likely to be smaller than the differences between staples in a Sale Lot. The between Staple Length variance for mid-sides was estimated as 36 mm^2 and the between Staple Strength variance for mid-sides was estimated as 34 $(N/ktex)^2$.

To calculate the total variance of a mid-side test you would substitute the value of 36 mm^2 or 34 $(N/ktex)^2$ into equation 10.5 and also set the v_{grabs} variance component to zero. An AWTA Staple Length and Staple Strength test on mid-sides is sampled by 1 operator and measured in 1 laboratory on a single ATLAS instrument and measures 10 staples.

New measurements

Recently a number of new measurements have been proposed to enable more information to be generated from the ATLAS instrument (Semmel 2003; Fish et al. 2003). These measurements include De-crimped Staple Length, De-crimping Ratio and Specific Work of Rupture.

De-crimped Staple Length (DSL)

De-crimped Staple Length is defined as the extended length of the staple not held by the ATLAS jaws corrected for the initial Staple Length:

$$DSL_{(mm)} = \frac{(SL - Jaw + Extension) \times SL}{SL - Jaw}$$

where,
DSL is the De-crimped Staple Length
SL is the ATLAS Staple Length
Jaw is a constant length (20mm) to account for the length of staple in the ATLAS Jaws
Extension is the distance the staple is extended before a extension force is registered.

De-crimping Ratio (DR)

De-crimping Ratio is the ratio of the mean de-crimped staple length divided by the mean staple length:

$$Decrimping - Ratio = \frac{Mean - DSL}{Mean - SL}$$

Specific Work of Rupture

In its simplest form the area under the force-extension curve can be considered the work of rupture. This value can then be corrected for the linear density of the staple to give the specific work of rupture:

$$Specific \quad Work \quad of \quad Rupture = \frac{\int_{\infty}^{0} SS * de}{SL}$$

where,
SS is the Staple Strength
SL is the Staple Length
e is the extension

10.4 Alternate measurement technologies

Agritest Staple Breaker Model 2 (SB2)

The Agritest Staple Breaker Model 2 (SB2) consists of three basic components, viz a staple length meter, a Staple Breaker (SB2) and a pair of electronic balances to measure the mass of broken staples. This enables the correction of force data for linear density and the calculation of position of break (Baxter 1996).

Due to the lower capital cost of these instruments they are used by Research and Education institutions in Australia, but the trade off is a higher labour cost. There is an appendix in the IWTO length and strength standard that describes the system in greater detail.

Readings [3]

The following readings are available on web learning management systems

1. Huson, M.G., Phair, N.L., Maxwell, J.M. and Turner, P.S. 2000a, 'Bundle Strength and Intrinsic Fibre Strength of Fine-Wools from Different Bloodlines,' Asian Australasian Association of Animal Production-Australian Society of Animal Production Conference, Sydney, July, 2000.
2. Huson, M.G, Bedson, J.B., Phair, N.L. and Turner, P.S. 2000b, 'Intrinsic Strength of Wool Fibres,' Asian Australasian Association of Animal Production-Australian Society of Animal Production Conference, Sydney, July, 2000.

Additional Reading (not on CD):

- IWT0-30-02, 2003, Determination of Staple Length and Staple Strength, International Wool Textile Organisation Standard.

Summary

Summary Slides are available on web learning management systems

This topic has been developed to enable students to gain an understanding of the limitations associated with subjective appraisal of Staple Length, Staple Strength and Position of Break, to be in a position to describe the relationship between Staple and Fibre Properties associated with Length and Strength. The development of objective measurements and how these measurements are made in Australia on an ATLAS Instrument are also described.

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Semmel, P.J. 2003, 'Deriving Additional Parameters from the Staple Force vs Extension Curve Measured by ATLAS,' *Proceedings. of IWTO,* Raw Wool Group committee meeting, Report No. 4.

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Glossary of terms

Staple Length	the length of a staple projected along its axis obtained by measuring the staple without stretching or disturbing the crimp of the fibres
Staple Strength	the maximum force required to rupture a staple per unit of average linear density (also see ATLAS)
Position of Break (PoB)	an indication of where a staple breaks during extension, determined by comparing the masses of clean wool in the broken portions of the staple. It does not imply that a break exists in the staple
Fibre Length	the decrimped length of an individual fibre
Fibre Tenacity	the breaking stress of a fibre, expressed as Pa or N/tex
Intrinsic Fibre Strength	the breaking stress of the material of which the wool fibre is composed
Peak Force at Break	the maximum force of rupture
Linear Density	the mass of clean fibre per unit length of a staple at standard conditions