The Measurement Precision and Evaluation of the Diameter Profiles of Single Wool Fibres

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ABSTRACT

A recent model of Single Fibre Analyser 3001 (SIFAN3001) was firstly employed to obtain the single wool fibre diameter profiles (S_fFDP's) at multiple orientations. The results showed that using SIFAN3001 to measure fibre diameter at four orientations for 50 single fibres randomly sub-sampled from each mid-side sample can produce average fibre diameter profiles (AS_fFDP's) of fibres within staples. Within the testing regime used, the precision estimates for the total samples were ±1.3μm for mean fibre diameter of staples and ±1.4μm for average fibre diameter of the AS_fFDP's at each scanned step in the diameter profile. The mean diameter ratio (ellipticity) obtained from the four orientations was 1.08±0.01, confirming that the Merino wool fibres under review were elliptical rather than circular. The elliptical morphology of wool fibres and the precision of fibre diameter measurement at each point along a fibre will be considered in the development of a mechanical model of Staple Strength testing.

Keywords: Wool, Ellipticity of Wool, Fibre diameter profile, Precision, SIFAN3001

1. Introduction

Wool fibre diameter and length are the most important properties used to determine the processing route and ultimate quality of the processed wool textile products (Downes 1971). The variance of fibre diameter further affects the processing performance (Dunlop and McMahon 1974; McKinley et al 1976). Fibre diameter profiles are used to describe the diameter changes along and across a staple and the locations of minimum and maximum diameter within the staple. Accordingly, the knowledge of single diameter profiles (S_fFDP's) is critical to the development of a mechanical model of Staple Strength (SS) (IWTO-30 1998). Extensive investigations into fibre diameter profiles along a staple (StFDP's) have been conducted in relation to farm management, Staple Strength and processing performance (Hansford and Kennedy 1990; Peterson 1997; Brown *et al*. 2000; McGregor and Toland 2002; Lamb 2004; Smith *et al*. 2005). However, the single fibre diameter profiles have not been thoroughly investigated in terms of its connection with the properties of a fibre staple.

Different technologies are available to measure the fibre diameter profiles or part thereof (Hansford 1989; Peterson 1997; Baxter 2001). The Optical Fibre Diameter Analyser 2000 (OFDA2000, BSC Electronics Pty Ltd., WA) has been used for testing StFDP's and is available for on-farm testing

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(Baxter 2001; Smith *et al*. 2006), whereas the testing reported by Hansford has been used for research purposes (Brown 2000). A limitation of these techniques is that fibre diameter is measured at one random orientation, and that it is not possible to trace the diameter profile of an individual fibre within the staple. In contrast, the Single Fibre Analyser (SIFAN, BSC Electronics Pty Ltd., WA) can measure S_fFDP's under a small pre-tension force and can provide the tensile properties of single fibres (Peterson 1997). In particular, the recent model SIFAN3001 is capable of measuring the S_fFDP's along a single fibre at different orientations by simultaneously rotating the upper and low clamps; hence the fibre ellipticity can also be evaluated along the fibre length.

The work reported in this paper is part of an investigation into the relationship between S_fDFP's and StFDP's. A SIFAN3001 instrument (one of two instruments currently available) was firstly employed to test the S_fFDP's at multiple orientations for single wool fibres which were sub-sampled from mid-sides of sheep. That is, the combined average single fibre profiles (AS$_f$FDP's) from the testing at four orientations were carefully examined for mid-side samples of three Merino flocks from different regions in Australia. Furthermore, the precision of the measurements within the testing regime was estimated for mean fibre diameter (MFD) of the samples and average fibre diameter of the AS$_f$FDP at each scanned step. In addition, the ellipticity (or circularity) of wool fibres was evaluated using the data from the measurements at four orientations.

2. Experimental

2.1 Fibre preparation

Mid-side samples were taken from three flocks (Flock H, Flock B and Flock T) which were run in major wool growing regions of Australia. Flocks B and T were run in the New England and in central areas of New South Wales, respectively, and Flock H in Western Australia. A small number of sheep that produced staples of typical SS (40.1N/ktex for Flock B, 25.8N/ktex for Flock H and 21.6N/ktex for Flock T) were selected from each flock (7 sheep from Flock H, 6 from Flock B and 3 from Flock T) and one greasy staple was selected from the mid-side sample of each sheep. The greasy staples were first cleaned by a mixture of alcohol and a non-ionic detergent (Teric) and then conditioned in a standard atmosphere of temperature of 20±2°C and relative humidity of 65%±3%. Then, 50 single fibres were randomly sub-sampled from the base of each staple and prepared for fibre testing.

The sub-sampled single fibres were prepared one by one on A4 sized transparent films as shown in Figure 1. The fixed length of the base end was 10mm. Each fibre specimen was manually de-crimped and the full fibre length was measured manually. The distance (D) between the fixed base and tip was calculated as the Staple Length minus 20mm. To simplify sample preparation and the setup of SIFAN3001, the same D was used for all fibres from a staple.

Once ten fibres were fixed on a film, the fixed fibre tip and base ends were each covered by a layer of adhesive tape. Before mounting a fibre onto SIFAN3001, the film and sticky tape fixing tip or base ends on both sides of the film were cut into a square shape approximately 8mm long in order to facilitate their mounting into the clamps of SIFAN3001.

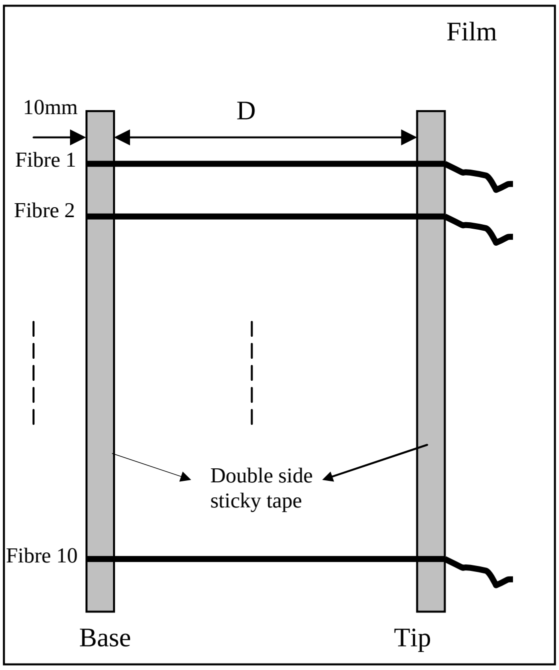


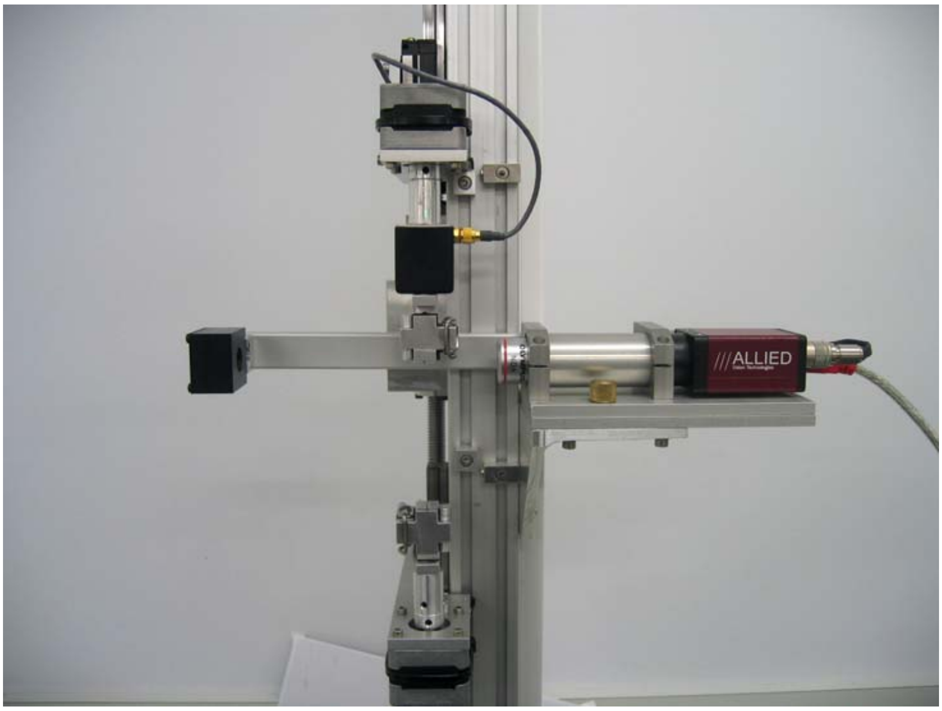
Figure 1.Schematic diagram of fibre preparation

2.2 Testing design and data processing

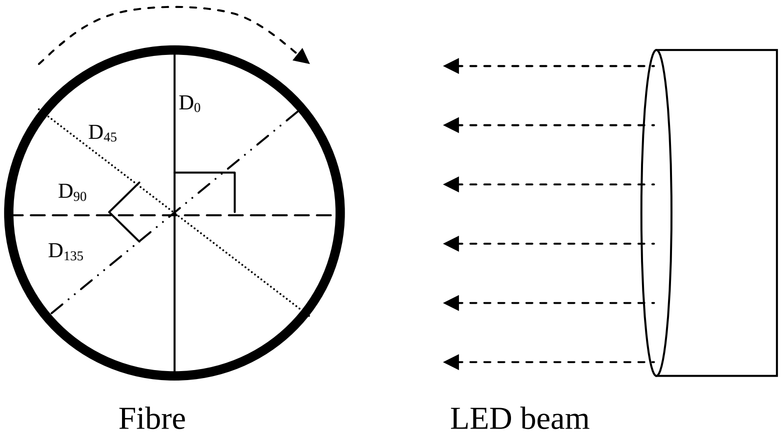
The S_fFDP's of each fibre were scanned at four orientations (i.e. 0^o, 45^o, 90^o, and 135^o), respectively, by SIFAN3001. The clamps and CCD camera system, as well as a diagram of the scanning principle, are shown in Figure 2. At each orientation, the fibre was firstly decrimped under a 1cN pre-tension force and the scanning was then conducted along the fibre at a speed of 8mm/s with a step of 0.2mm.

The raw diameter data were firstly smoothed by means of a moving average of five diameter results (in over 1mm length) to remove spurious measurements. Then, for each fibre, the mean diameter at each scanned point (at 0.2mm increment) was obtained by averaging the (four) measurements generated at the four orientations. Next, for each staple, the average fibre diameter at each scanned point (MFD_{step}) was obtained by averaging the values of 50 fibres from each staple. Finally, the values were compressed for 5mm increments by averaging the values in the corresponding 5mm interval.

In order to compare the AS_fFDP's of the staples from each flock, the fibre diameter at each point on the AS_fFDP's was normalised by mean fibre diameter. The nomenclature "%D" is used to denote the percentage change from the mean fibre diameter. Meanwhile, the scanned length from the tip end was also normalised by the mean decrimped fibre length, and the nomenclature "%L" is used to denote the percentage of the distance from the tip end. Because SIFAN is unable to test the full length of a fibre, the S_fFDP was obtained only over the tested length portion of a fibre. Schematic diagrams of the trial design and data processing are shown in Figure 3.



(a). The clamps and camera system of SIFAN3001



(b). Scanning model of four orientations

Figure 2. Scanning a single fibre by SIFAN3001 at four orientations

Taking advantage of measuring four orientations by SIFAN3001, the diameter ratios at each scanned point can be calculated as indicated in Figure 3, where the orthogonal diameters at 0^o and 90^o were used to calculate Ratio 1, and the orthogonal diameters at 45^o and 135^o for Ratio 2.

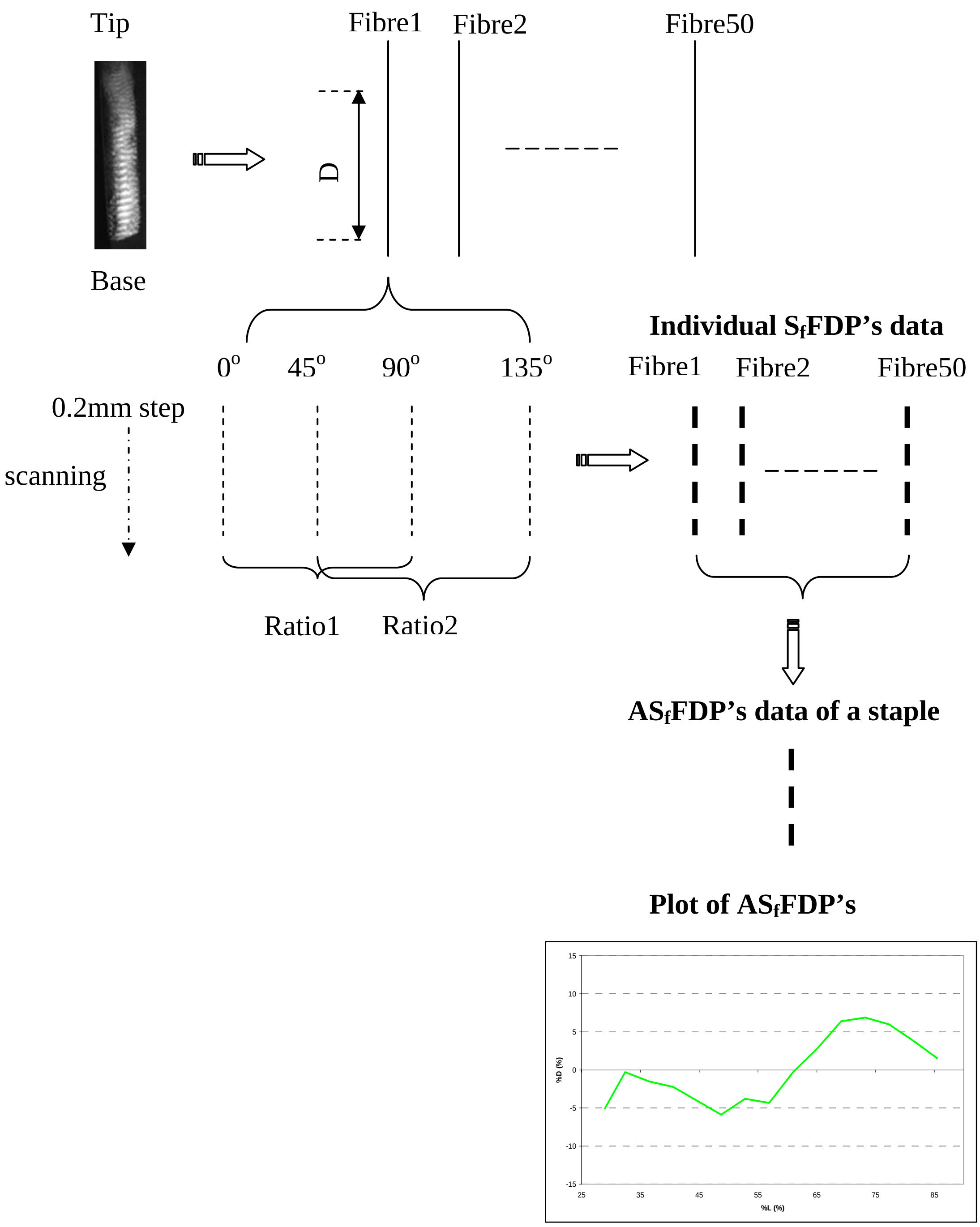


Figure 3. Schematic diagram of trials and data processing

2.3 Calibration of SIFAN3001

The SIFAN3001 was calibrated before testing, using standard tungsten wires of different diameters (10, 30 and 100 microns). Table 1 shows the uncalibrated diameters compared with the expected values. These three points were used to derive the slope and intercept of the calibration relationship.

Table 1 Measurement of diameter for the standard tungsten wires

	Tungsten wires		
Expected diameter (μm)	10.0	30.0	100.0
Uncalibrated diameter (μm)	10.1	29.5	101.0
SD (μm)	1.1	1.4	7.4
Testing points	14635	2614	5260

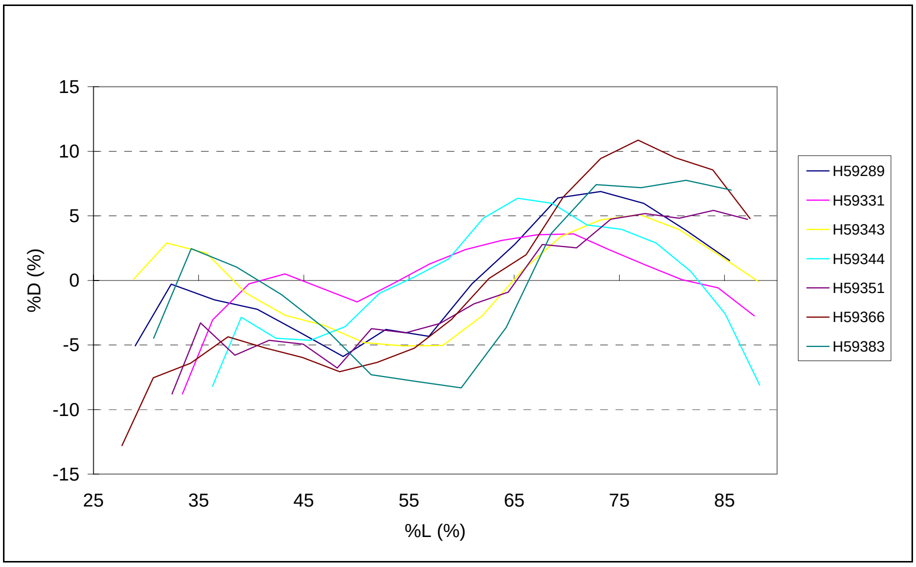
3. Results and discussion

3.1 Average of single fibre diameter profiles (AS_fFDP's) of staples

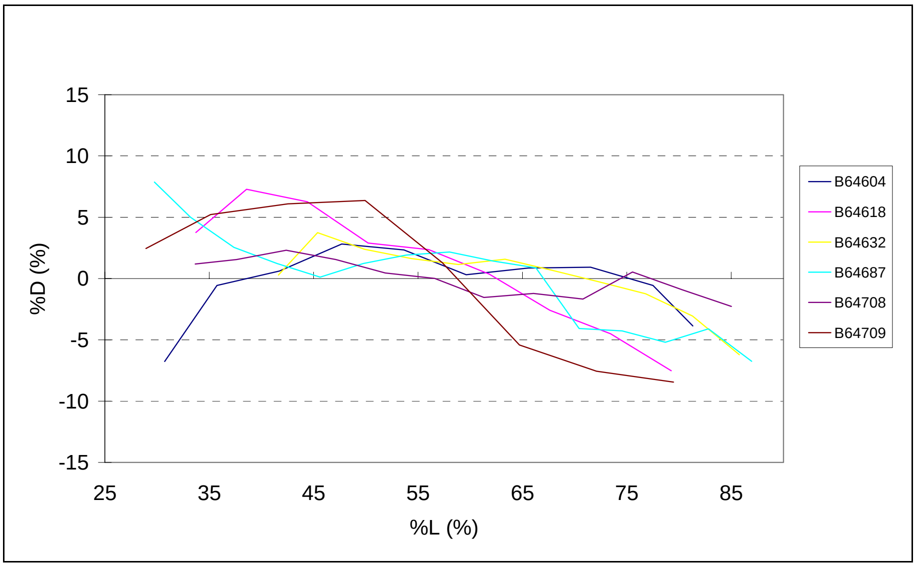
AS_fFDP's for a staple were created by the combination of individual S_fFDP's according to the procedure outlined in Section 2.2. The AS_fFDP plots are shown in Figure 4 for the three flocks. The discussion on the agreement of the S_fFDP's generated by SIFAN3001 and StFDP's by OFDA2000 is beyond the scope of this paper. Nevertheless, Figure 4 shows the typical characteristics of AS_fFDP's for each flock.

In Flock H, the staples (sheep) had very similar AS_fFDP's. In particular, from the tip to middle, the diameters were finer than the average, whereas from the middle to base, the diameters were broader than the average. The amplitude of %D at the tip and base was on a similar level (Figure 4 (a)). Both maximum and minimum diameters appeared in phase between the staples.

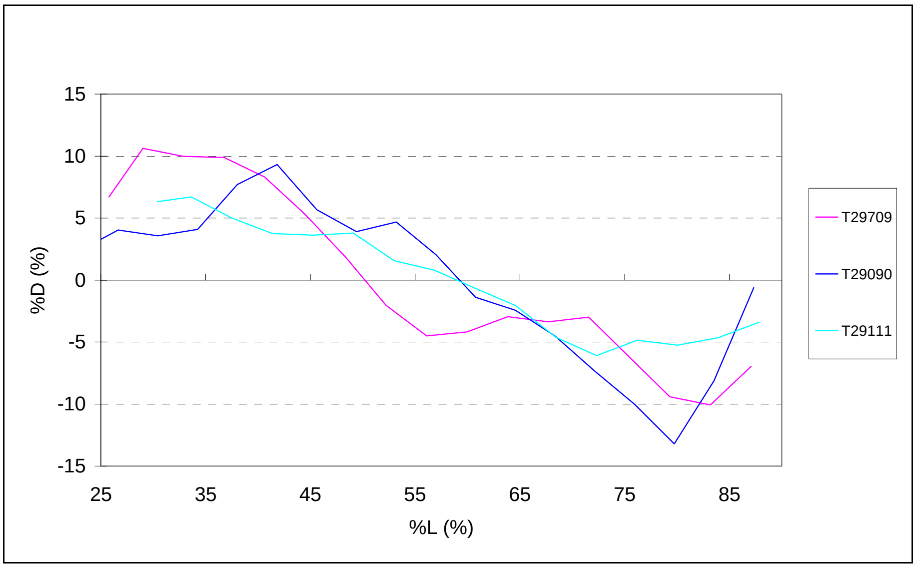
Flocks B and T demonstrated opposite characteristics in AS_fFDP's compared to Flock H. For both flocks, from the tip to middle, the diameters were broader than the average diameter, whereas from the middle to base, the diameters were finer than the average. The amplitude of %D for Flock B was lower than that of Flock T. In addition, the maximum or minimum diameter appeared slightly out of phase between staples (Figures 4 (b) & (c)).



(a) AS_fFDP's of Flock H



(b) AS$_f$FDP's of Flock B



(c) AS$_f$FDP's of Flock T

Figure 4. AS$_f$FDP's of three flocks.

3.2 Variance components of the measurements

3.2.1 Variance of diameter between orientations along fibres

For each fibre, the mean diameter at each scanned step was obtained by averaging the four measurements at different orientations (i.e. 0^o, 45^o, 90^o, and 135^o). Therefore, variance of diameter between orientations along fibres is a measure of dispersion of the diameters measured at the four orientations from the mean values at each scanned point. The mean, SD CV and variance of diameter between orientations are listed in Table 2 for each sheep tested.

Table 2 shows that staples from the three flocks had different average MFD's (19.0μm, 15.4μm and 21.8μm) and variances existed both within and between sheep. The average within sample variance for each flock was 1.3$(\mu m)^2$, 0.9 $(\mu m)^2$ and 1.6 $(\mu m)^2$, for Flocks H, B & T, respectively. Overall, the diameter variance between four orientations at each scanned step along fibres was level dependent as illustrated in Figure 5, that is, the broader wools had higher variance than finer wools.

Table 2. Variance between four orientations for each staple

Sample	Fibre diameter of 4 orientations			
	Mean (μm)	SD (μm)	CV (%)	Var $(\mu m)^2$
H59289	18.2	1.0	5.4	1.2
H59331	15.8	0.8	4.9	0.7
H59343	20.4	1.1	5.2	1.4
H59344	21.5	1.2	5.5	1.7
H59351	19.4	1.2	5.8	1.6
H59366	20.2	1.0	4.9	1.2
H59383	17.5	0.9	4.8	0.9
Average	19.0	1.0	5.2	1.3
B64604	15.3	0.8	5.6	0.9
B64618	15.4	0.8	5.5	0.8
B64632	15.5	0.9	5.6	0.9
B64687	15.4	0.8	5.4	0.8
B64708	15.5	0.9	5.9	1.0
B64709	15.2	0.9	6.0	1.0
Average	15.4	0.9	5.6	0.9
T29111	21.5	1.1	6.0	1.6
T29709	19.0	1.2	4.8	1.5
T29090	25.0	1.2	5.5	1.7
Average	21.8	1.2	5.4	1.6

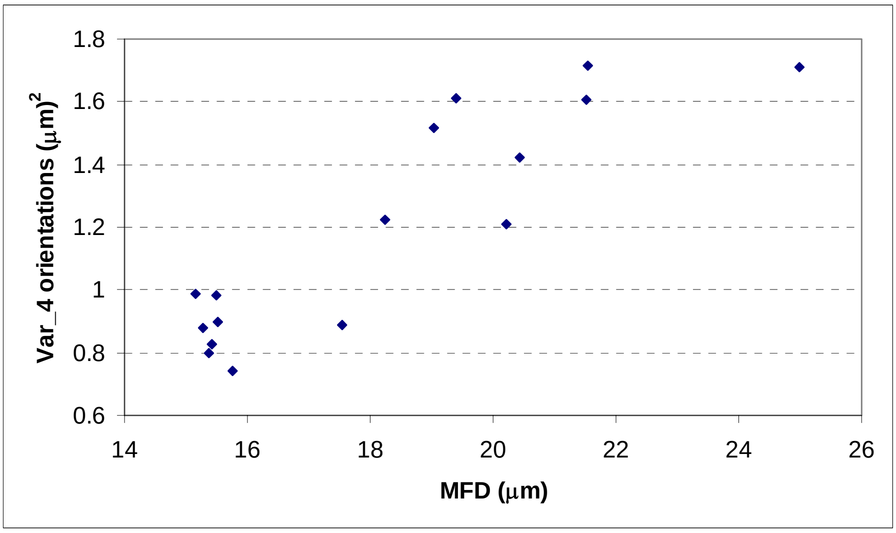


Figure 5. Level dependence of variance between orientations at each scanned step along fibres.

3.2.2 Variance of diameter between scanning steps along fibres

At each scanning orientation, the MFD of individual fibres can be obtained by averaging the fibre diameter measurements at each scanned step. The diameter variance between steps along fibres represents the variation of diameter along fibres. Along fibre diameter results are listed in Table 3. As in the case of between orientation variance, the variance was also level dependent as shown in Figure 6. The along fibre variance was higher than the variance between orientation within fibres, as would be expected.

Table 3 Variance of diameter between scanning steps along fibres

Sample	Diameter along fibres			
	Mean (μm)	SD (μm)	CV (%)	Var (μm)^2
H59289	18.2	1.9	10.4	4.0
H59331	15.8	1.3	8.0	1.8
H59343	20.4	2.1	10.4	5.2
H59344	21.5	1.7	7.9	2.9
H59351	19.4	1.6	8.6	2.8
H59366	20.2	2.0	10.2	4.4
H59383	17.5	1.8	10.2	3.3
Average	19.0	1.8	9.4	3.5
B64604	15.3	1.2	7.6	1.7
B64618	15.4	1.2	7.8	1.6
B64632	15.5	1.0	7.0	1.4
B64687	15.4	1.1	7.0	1.2
B64708	15.5	1.0	6.3	1.0
B64709	15.2	1.5	9.9	2.4
Average	15.4	1.2	7.6	1.6
T29111	21.5	1.7	7.9	3.0
T29709	19.0	1.9	9.8	3.6
T29090	25.0	2.3	9.4	5.7
Average	21.8	2.0	9.0	4.1

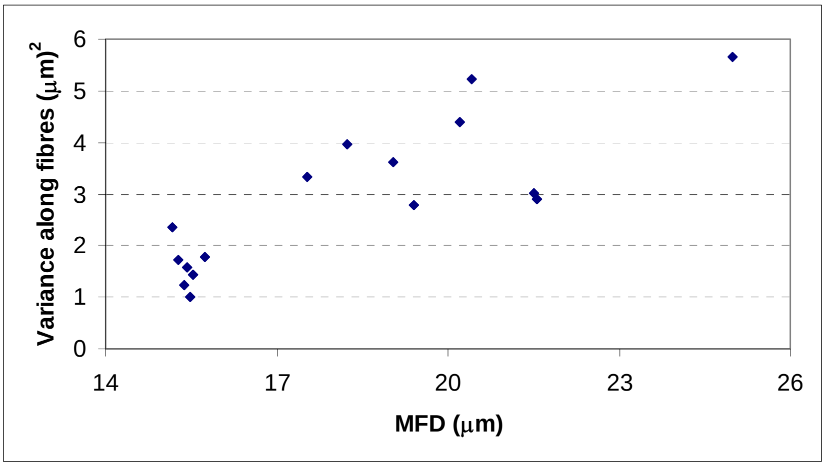


Figure 6. Level dependence of the diameter variance between scanning steps along fibres.

3.2.3 Variance of diameter between fibres within staples

After the S_fFDP was calculated as indicted in section 3.2.2, an AS_fFDP of each staple can be obtained by combining 50 fibres at each scanned step. Therefore, the diameter variance between individual fibres within staples and the diameter variance between fibres at each scanned step can be analysed. The results of this analysis are listed in Table 4. The variance between fibres at each scanned step was higher than the overall variance between individual fibres. If the divergent data from staple T29090 are regarded as outliers, the diameter variance between fibres within staples is level dependent (Figure 7).

Table 4. Variance of diameter between fibres within staples

Sample	Diameter between fibres				Variance between fibres at each scanned step (0.2mm)
	Mean (μm)	SD (μm)	CV (%)	Var (μm)^2	(μm)^2
H59289	18.2	2.5	14.0	6.5	9.8
H59331	15.8	1.8	11.4	3.2	5.1
H59343	20.4	3.1	15.0	9.4	15.0
H59344	21.5	4.0	18.6	16.0	19.1
H59351	19.4	2.6	13.2	6.5	9.0
H59366	20.2	4.3	21.4	18.6	22.0
H59383	17.5	1.3	7.7	1.8	4.2
Average	19.0	2.8	14.5	8.9	12.0
B64604	15.3	1.3	8.8	1.8	3.6
B64618	15.4	1.7	10.9	2.8	4.0
B64632	15.5	2.2	13.9	4.7	6.4
B64687	15.4	1.6	10.2	2.4	3.5
B64708	15.5	1.6	10.5	2.6	3.8
B64709	15.2	1.5	9.7	2.2	3.7
Average	15.4	1.6	10.7	2.8	4.2
T29111	21.5	4.0	18.7	16.2	19.9
T29709	19.0	1.9	10.1	3.7	5.9
T29090	25.0	2.4	9.7	5.9	9.4
Average	21.8	2.8	12.8	8.6	11.7

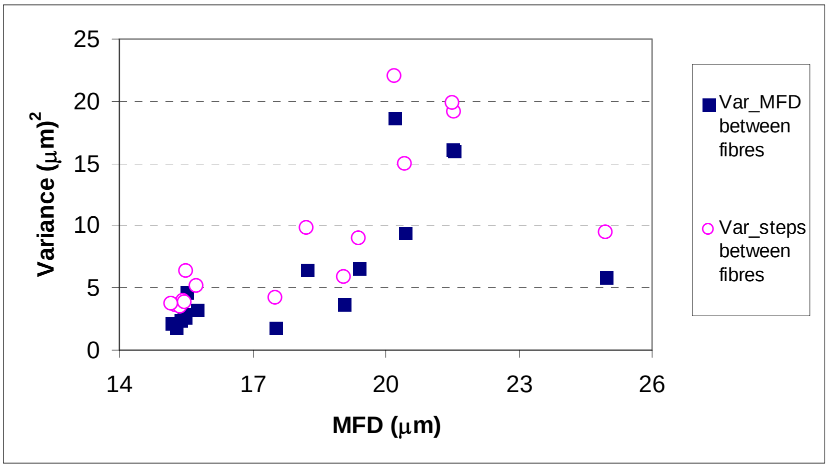


Figure 7. Level dependence of the variance between fibres within staples.
(Note: Var_MFD is the variance between mean fibre diameters of 50 fibres; Var_steps is the variance between fibre diameters of 50 fibres at each scanned step.)

3.2.4 Variance of diameter ratio between the orthogonal diameters

In order to examine the ellipticity of individual fibres, the mean fibre diameter ratio for each staple was calculated from the mean diameter ratio of its 50 fibres, which were obtained by averaging Ratio 1 and Ratio 2. The variance of the diameter ratio was estimated for both along fibres and between fibres. The results of these two analyses are listed in Table 5.

Table 5. Variance of diameter ratio along and between fibres within staples

sample	Ratio along fibres			Ratio between fibres		
	Mean	SD	Var	Mean	SD	Var
B64604	1.09	0.061	0.0042	1.09	0.033	0.0011
B64618	1.08	0.057	0.0035	1.08	0.030	0.0009
B64632	1.08	0.066	0.0074	1.08	0.041	0.0017
B64687	1.09	0.068	0.0051	1.09	0.029	0.0009
B64708	1.08	0.057	0.0036	1.08	0.032	0.0010
B64709	1.09	0.066	0.0048	1.09	0.035	0.0012
Average	1.09	0.063	0.0048	1.09	0.033	0.0011
H59289	1.08	0.063	0.0042	1.08	0.024	0.0006
H59331	1.07	0.055	0.0033	1.07	0.028	0.0008
H59343	1.08	0.079	0.0232	1.08	0.026	0.0007
H59344	1.09	0.069	0.0065	1.09	0.025	0.0006
H59351	1.09	0.070	0.0050	1.09	0.020	0.0004
H59366	1.08	0.060	0.0043	1.08	0.024	0.0006
H59383	1.07	0.060	0.0048	1.07	0.020	0.0004
Average	1.08	0.065	0.0073	1.08	0.024	0.0006
T29079	1.09	0.078	0.0117	1.09	0.032	0.0010
T29090	1.07	0.056	0.0032	1.07	0.018	0.0003
T29111	1.08	0.070	0.0097	1.08	0.052	0.0027
Average	1.08	0.068	0.0082	1.08	0.034	0.0013

The variances in Table 5 are relatively small for a number of reasons, including:

- Compared to the variation in diameter readings at each point, the ratio calculation includes two diameter readings.
- The average of two ratios was used at each point. It may also be expected that variation in ellipticity along a fibre would be less than variation in diameter along the fibre.

Furthermore, the variance between fibres is much lower than that along fibres. No strong level dependence was found for either the variance along or between fibres.

3.3 Precision estimates of measurements within the testing regime

3.3.1 Precision estimates of the measurement for MFD of staples

As discussed in Section 3.2, the variance components of the fibre diameter measurement for each staple are:

- Variance between 4 orientations within fibres (α^2)
- Variance between scanning steps (0.2mm) along fibres (β^2)
- Variance between fibres within staples (χ^2)

Therefore, the precision in terms of 95% confidence limit (95% CL) of the measurement for MFD of each staple can be estimated by Formula 1.

$$\text{95\% confidence limit of MFD} = \pm 1.96 * \sqrt{\frac{\alpha^2}{N_\alpha} + \frac{\beta^2}{N_\beta} + \frac{\chi^2}{N_\chi}} \qquad (1)$$

Where N_α is the number of orientations; N_β, the number of scans along fibres; N_χ, the number of single fibres sub-sampled from a staple.

According to the testing regime used, there were 50 single fibres from each staple scanned at 4 orientations with a 0.2mm step (meaning approximately 300 readings i.e. over approximately 60mm each fibre). The precision estimates of MFD for each staple are listed in Table 6. The precision for MFD measurement is level dependent. The finer wools had a tighter confidence limit than broader wools, as is often observed in MFD measurement of individual sheep, sale lots and processing consignments of wool.

According to the precision calculation, the variance between fibres is a major component contributing to the precision estimate. The result agrees with the findings by Quinnell et al (1973). These results mean that an improvement in precision (in 95% confidence limit) of MFD measurement of 14% can be achieved by an increase in the number of single fibres sub-sampled from a staple from 50 to 100.

Table 6. Precision estimates of MFD of staples (N_α = 4; N_β = 300; N_χ = 50)

Sample	MFD (μm)	95%CL (μm)
H59289	18.2	1.3
H59331	15.8	1.0
H59343	20.4	1.5
H59344	21.5	1.7
H59351	19.4	1.4
H59366	20.2	1.6
H59383	17.5	1.0
Average	19.0	**1.4**
B64604	15.3	1.0
B64618	15.4	1.0
B64632	15.5	1.1
B64687	15.4	1.0
B64708	15.5	1.1
B64709	15.2	1.1
Average	15.4	**1.0**
T29111	21.5	1.7
T29709	19.0	1.3
T29090	25.0	1.5
Average	21.8	**1.5**

3.3.2 Precision estimates of the measurement for MFD_{step} of the AS_fFDP.

According to the calculation of MFD_{step} for generating an AS_fFDP, the components of the diameter variance are:

- Variance between 4 orientations within fibres (α^2)
- Variance between fibres at each scanned step within staples (δ^2)

Therefore, the measurement precision of MFD_{step} can be estimated by Formula 2 and the results of this calculation are listed in Table 7. Although the variance between fibres at each scanned step is a major component in the total variance, its contribution to the precision estimate is relatively low, due to the relatively high number of fibres (50) tested. Therefore, an increase in the number of scanning orientations will increase the measurement precision for MFD_{step} of the AS_fFDP.

$$\text{95\% confidence limit of } MFD_{step} = \pm 1.96 * \sqrt{\frac{\alpha^2}{N_\alpha} + \frac{\delta^2}{N_\chi}} \qquad (2)$$

Table 7. Precision estimate of MFD_{step} of AS_fFDP ($N_\alpha = 4$; $N_\chi = 50$)

Samples	Variance between four orientations within fibres (μm)^2	Variance between fibres at each scanned step within staples (μm)^2	95% CL (μm)
H59289	1.2	9.8	1.4
H59331	0.7	5.1	1.0
H59343	1.4	15	1.6
H59344	1.7	19.1	1.8
H59351	1.6	9	1.5
H59366	1.2	22	1.7
H59383	0.9	4.2	1.1
Average	1.3	12.0	**1.4**
B64604	0.9	3.6	1.1
B64618	0.8	4	1.0
B64632	0.9	6.4	1.2
B64687	0.8	3.5	1.0
B64708	1.0	3.8	1.1
B64709	1.0	3.7	1.1
Average	0.9	4.2	**1.1**
T29111	1.6	19.9	1.8
T29709	1.5	5.9	1.4
T29090	1.7	9.4	1.5
Average	1.6	11.7	**1.6**

3.3.3 Precision estimate of the measurement for mean diameter ratio

The variance components of diameter ratio for a staple consist of the variance along fibre (ϕ^2) and the variance between fibres (ε^2). Therefore the precision of the mean diameter ratio of a staple can be calculated by Formula 3 and the results for this trial are listed in Table 8. The precision estimates all staples were the same at ±0.01.

$$\text{95\% confidence limit of mean diameter ratio } = \pm 1.96 * \sqrt{\frac{\phi^2}{N_\beta} + \frac{\varepsilon^2}{N_\chi}} \qquad (3)$$

Table 8 Precision estimates of mean fibre diameter ratio (N_β = 300; N_χ = 50)

Sample	MFD (μm)	Mean Ratio	95% CL
B64604	18.2	1.09	0.01
B64618	15.8	1.08	0.01
B64632	20.4	1.08	0.02
B64687	21.5	1.09	0.01
B64708	19.4	1.08	0.01
B64709	20.2	1.09	0.01
Average	17.5	**1.09**	**0.01**
H59289	19.0	1.08	0.01
H59331	15.3	1.07	0.01
H59343	15.4	1.08	0.02
H59344	15.5	1.09	0.01
H59351	15.4	1.09	0.01
H59366	15.5	1.08	0.01
H59383	15.2	1.07	0.01
Average	15.4	**1.08**	**0.01**
T29079	21.5	1.09	0.01
T29090	19.0	1.07	0.01
T29111	25.0	1.08	0.02
Average	21.8	**1.08**	**0.01**

3.4 Ellipticity of wool fibres

The morphological structure of wool cross-sections is important for the measurement of fibre diameter and the evaluation of fibre strength. The effect of ellipticity of wool fibres on the assessment of mean fibre diameter and its coefficient of variation has been investigated by some researchers employing different testing methods (Anderson and Benson 1952; Bona et al 1992; Downes 1975). Using SIFAN3001 in this paper, the ellipticity of wool fibres was examined by the average diameter ratio i.e. average of Ratio 1 and Ratio 2. It is expected that this technique would yield a lower value than using the ratio of major to minor axes as reported by the authors in the previous three references.

As shown in Section 3.3.3, the mean diameter ratio of the wool fibres is about 1.08±0.01. This mean value is relatively low, because the technique used to obtain the diameter ratio does not identify the major and minor axes but simply records the diameter ratio of two randomly selected orthogonal orientations. Nevertheless, this mean value still indicates that the cross-section of wool fibres appears to be elliptical rather circular as a normal assumption. The elliptical morphology of wool fibre cross-sections will need to be considered in the development of a mechanical model of Staple Strength testing.

4. Conclusion

The results reported here show that using SIFAN3001 to measure fibre diameter at four orientations for 50 single fibres randomly sub-sampled from each mid-side sample can produce average single fibre diameter profiles of staples. The average single fibre diameter profiles showed reasonable agreement between staples within flocks, and typified the major characteristics the fibre diameter profiles of the flocks.

The precision estimates within the testing regime used in this paper showed that the measurements for mean fibre diameter of staples and mean fibre diameter at each scanned step of the average single fibre diameter profiles were within reasonable confidence limits, ±1.3μm for mean fibre diameter profiles, and 1.4μm for the mean fibre diameter profiles at each scanned step in the fibre diameter profile. The variance between fibres within staples was a major component in the precision estimate for mean fibre diameter profiles. All variance components of the diameter within staples were level dependent.

The mean diameter ratio of 1.08±0.01 obtained from the four orientation testing confirmed that the Merino wool fibres under review were elliptical rather than circular. The elliptical morphology of wool fibres and the precision of fibre diameter measurement at each point along a fibre will be considered in the development of a mechanical model of Staple Strength testing.

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