INTERNATIONAL WOOL TEXTILE ORGANISATION **Nice Meeting**
Technical Committee Meeting **December 1998**

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Technical Coordinator **G. Mercier (France)** **CTF Report No. 1**

THE EFFECT OF FIBRE MEDULLATION ON LASERSCAN DIAMETER MEASUREMENT

D.J. Butler and M. Glass

CSIRO Telecommunications and Industrial Physics
Bradfield Road, West Lindfield, NSW 2070, Australia

SUMMARY

The effect of wool fibre medullation on diameter measurement in the expanding beam Laserscan has been investigated. A range of single fibres of diameter from 10 to 75 μm was used to investigate differences in the Laserscan optical response to normal and medullated wool. The concept of mean Fresnel diameter is introduced to account for the variation in diameter along the fibre axis. Measurements on unmedullated and highly medullated wool fibres show no discernable systematic differences and are in good agreement with Fresnel diffraction theory.

INTRODUCTION

Medullated fibres may be found in most samples of wool. Although relatively rare in superfine and fine wool, their presence becomes more conspicuous in coarser fleeces and tops. The hollow medulla within a single fibre is often uneven in diameter, discontinuous and in extreme cases may be present in more than 10% of the fibres within a sample[1].

Some recent investigations[1,2] have focused on the measurement differences between fibre diameter measurement technologies and in particular the role played by medullated fibres. Medullation is known to significantly affect airflow mean diameter measurement as a result of lower mean sample density[3]. Bow et al[4] have previously reported test results made using Laserscan to measure medullated wool fibres mounted on a rotating wheel in air and concluded that no significant effect could be attributed to medullation. The present study extends this previous work by measuring a range of mounted medullated and non-medullated (normal) single fibres immersed in an isopropanol bath.

EXPERIMENTAL METHOD

The optical response in Laserscan to normal and medullated wool fibres was compared by measuring the maximum occlusion, with each sample in the beam, in an experimental Laserscan type set-up shown in the schematic diagram of Figure 1. As a fibre is traversed across the beam, whose unobstructed power is $P_{0,}$ a minimum signal power P is measured at the detector and the percent occlusion is calculated from $(1 - P/P_0)$x100

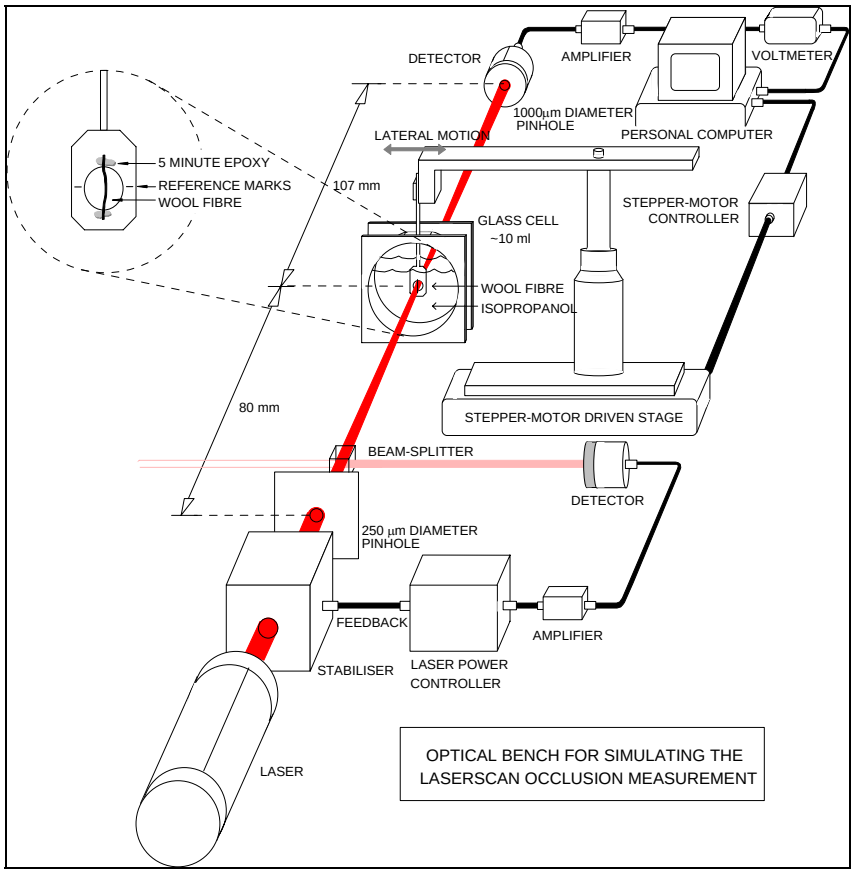


Figure 1. Experimental arrangement for the measurement of fibre sample occlusions.

After having its output power stabilised as shown, the beam from a 1.5 mW linearly polarised helium neon laser illuminates a 250 μm circular pinhole. Individually mounted samples are traversed perpendicular to the measurement beam, within an isopropanol filled glass walled measurement cell, by a computer controlled stepper stage with 2 μm resolution. The measurement detector is a silicon photodiode masked by a 1 mm circular aperture whose output is logged by a high precision digital voltmeter under computer control. Although the pinhole size, cell dimensions and pinhole-cell/cell-detector spacings are slightly different from the standard Laserscan optical bench the differences are small and do not affect the validity of the results presented later. Figure 2 shows for comparison the theoretical beam intensity profiles at the cell and the detector for standard Laserscan optics[5] and the experimental arrangement used here, while Figure 3 compares the theoretical calibration curves.

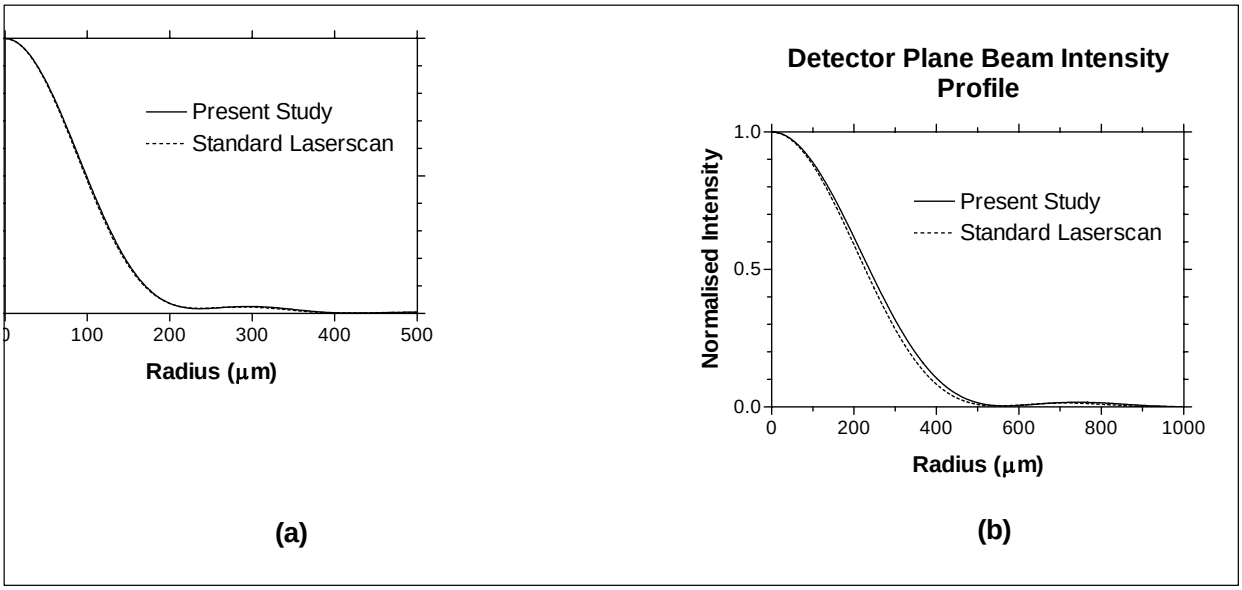
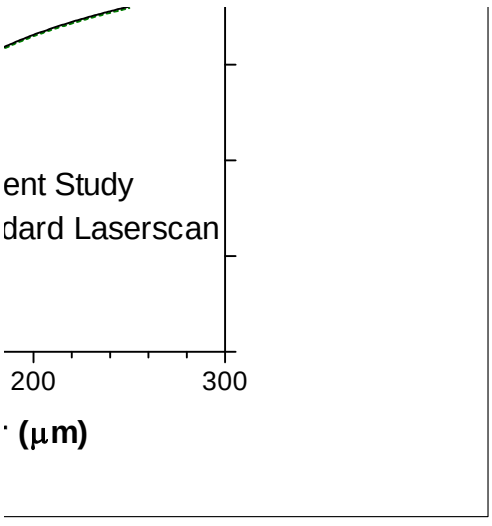


Figure 2. Comparison of the theoretical beam intensity profile for the present study and the standard Laserscan at (a) the cell plane and (b) the detector plane of each.

Figure 3. Comparison of the theoretical calibration curve for the present study and the standard Laserscan.

A range of individual fibres was selected mainly from the 1992 Interwoollabs series with the aim of choosing samples of reasonably uniform diameter along their length. The medullated fibres chosen were generally both heavily and uniformly medullated. The approximate diameter range for the normal fibre samples was 10-65 μm and 24-73 μm for the medullated samples thereby providing a good diameter overlap of the two sample types. Each of the fibre samples was mounted on its own sample holder that had a scored alignment mark indicating the center of the fibre. This alignment mark was subsequently used to center the fibre in the measurement beam and also used as a reference mark when measuring sample



diameters using a projection microscope. Using a projection microscope (PM) calibrated via a stage micrometer each of the fibre samples had its diameter measured, in the direction perpendicular to the Laserscan beam, at 50 μm intervals over a 1 mm length about the alignment mark. This length was chosen to be an adequate interaction region since, as indicated in Figure 2(a), the size of the measurement beam within the cell between the first minima is about 500 μm. Figure 4 shows the measured PM diameter along the length of each fibre sample used. Note that W12b is simply a repeat measurement of w12 and gives some idea of the precision of the PM data. Samples labeled "rem" were measured again after remounting on coming loose from their holders.

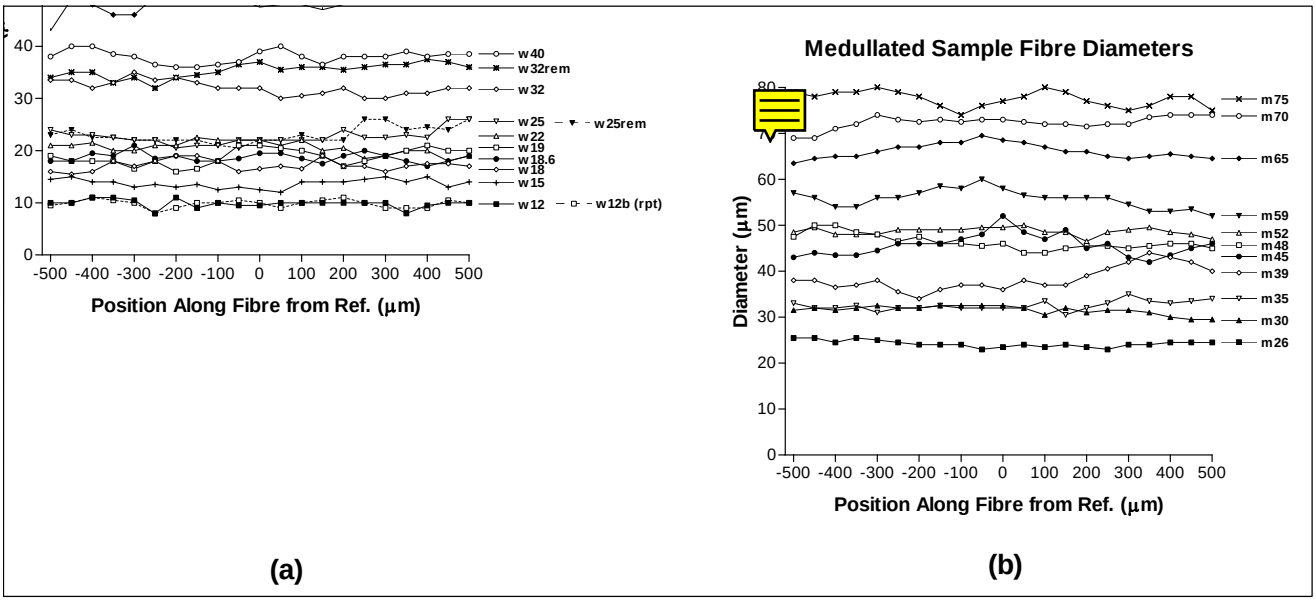


Figure 4. Profile of PM measured diameter along the fibre axis for each sample.

Occlusion measurements were made with the cell filled with spectroscopic grade isopropanol (propan-2-ol). Although in practice the Laserscan has 8% water added to the isopropanol, no water was added in the present experiments because resultant fibre swelling due to any added water would have made it difficult to reconcile "swollen" diameters within the cell with unswollen diameters measured using the PM.

At the start of each day the detector dark signal was logged so that correction for any offset could be made. With the sample moved out of the beam, the occlusion was measured by first logging the unobstructed signal for about 20 seconds and using the mode of the resulting distribution as a baseline power. The fibre sample was then traversed across the beam about 20-30 times and the mode of the resulting signal distribution was taken as the occluded power. The mode or peak of the distribution rather than the mean was used as, particularly for the baseline measurement, any spurious signal contribution due to small bubbles or dirt passing through the beam during measurement may significantly influence the mean but does not affect the mode of the distribution.

RESULTS AND DISCUSSION

Since neither the diameter nor the illumination intensity of each fibre sample is uniform along its length some appropriate average diameter must be determined to be able to plot measured occlusion against diameter. Diameter variations of the fibre near the intense part of the beam centerline will have a greater effect than any fibre diameter variation away from the beam centerline where the intensity is low and consequently using a simple calculation of mean diameter will be inadequate.

One appropriate average diameter, which combines the effect of longitudinal diameter variation with superimposed illumination intensity, is a mean diameter calculated using the beam intensity as an appropriate weighting function. Using this concept the mean "intensity diameter" can be calculated from

$$d_I = \frac{\int I(y)D(y)dy}{\int I(y)dy} \qquad (1)$$

where $I(y)$ is the intensity profile of the beam in the cell, as illustrated in Figure 2(a), and $D(y)$ is the diameter profile of the fibre sample along the fibre axis.

Although relatively simple and conceptually appealing, using the intensity diameter to plot occlusion results against is not strictly correct. With the hypothesis that the Laserscan optical response is governed by Fresnel diffraction one should strictly speaking calculate the theoretical occlusion seen by the measurement detector *due to a strip-like mask of varying width* corresponding to the diameter variation along the fibre axis. For any given diameter profile this gives the occlusion seen by the detector which can then be used to look up or infer a single equivalent Fresnel diameter, d_{Fr}, using the calibration curve of Figure 3. This mean "Fresnel diameter" would be the diameter of a uniform parallel-sided fibre giving the same occlusion as the variable diameter sample. Incorporating varying diameter profile into the previously used Fresnel models[5,6] is relatively straightforward. The PM measured diameter profile is used with computer interpolation to vary boundary limits on the Fresnel integration in the direction perpendicular to the fibre axis. For the diameter profiles used in this investigation this leads to mean Fresnel diameters which in most cases are not significantly different to their mean intensity diameter counterparts. The results of computing the mean intensity diameter and Fresnel diameter for the various samples are shown in Table 1.

Sample ID	Intensity Diameter (μm)	Fresnel Diameter (μm)	Sample ID	Intensity Diameter (μm)	Fresnel Diameter (μm)
W12	9.74	9.82	M26	23.64	23.76
W15	12.85	12.95	M30	32.1	32.27
W18	16.93	17.05	M35	32.16	32.34
W18.6	18.85	18.94	M39	36.98	37.14
W19	19.99	20.13	M45	48.61	48.79
W22	21.65	21.82	M48	45.25	45.41
W25	21.86	21.98	M52	49.30	49.51
W32	31.45	31.60	M59	57.67	57.94
W40	38.10	38.25	M65	68.10	68.39
W50	48.44	48.67	M70	72.66	72.88
W56	60.77	61.02	M75	77.09	77.31
W61	63.69	63.96			
W70	50.86	51.16			

Table 1. Comparison of mean Intensity Diameter and mean Fresnel Diameter values.

The data in Table 1 indicates that for the normal samples the Fresnel mean diameter is on average bigger than the intensity diameter by about 0.17 μm. For the medullated samples d_{Fr} is bigger than d_I on average by 0.20 μm. Hence although not strictly accurate the intensity weighted mean diameter can nevertheless be used as a rapidly computed reliable indicator of Fresnel mean diameter.

Figure 5 shows the measured percent occlusion for each sample plotted against inferred Fresnel

mean diameter with the theoretically generated Fresnel diffraction calibration curve shown for comparison. No discernable systematic difference between unmedullated and medullated fibre samples is evident and the data is in good agreement with Fresnel diffraction theory.

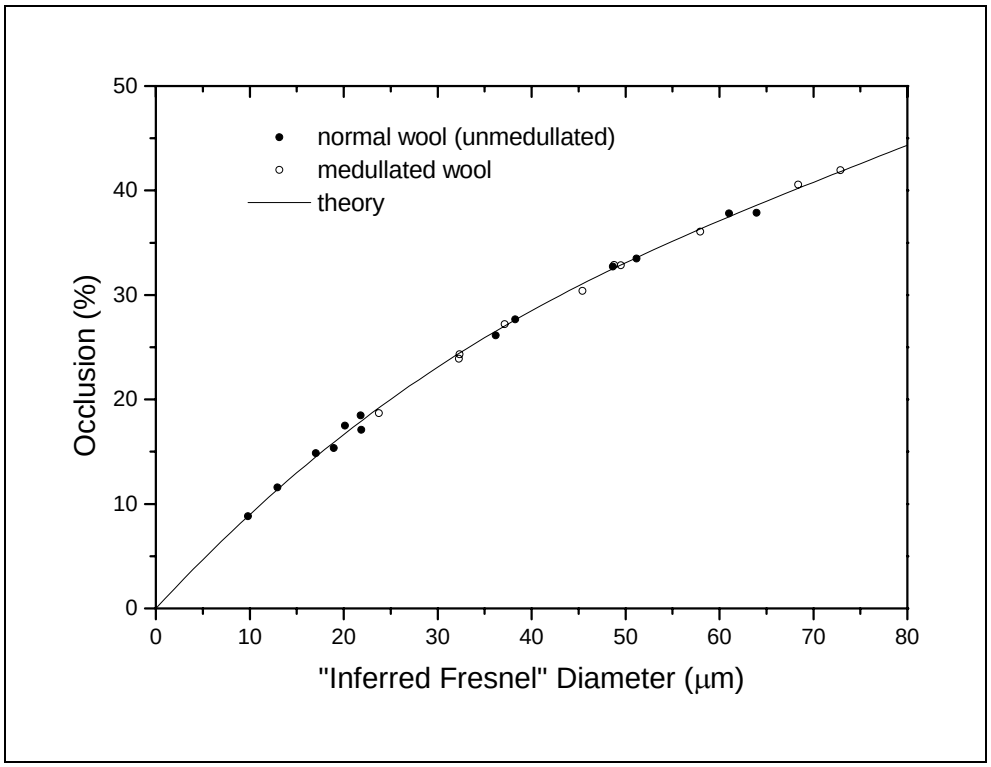


Figure 5. Measured % occlusion plotted against the Fresnel mean diameter of each sample. The theoretically generated Fresnel diffraction curve is shown for comparison.

A number of possible sources of error should be mentioned in connection with the data of Figure 5. These are as follows:

1. Variance in measured occlusions ~ ±0.1 in % occlusion. This gives small error bars in the vertical direction.
2. Longitudinal (along fibre) position error with respect to the reference mark when measuring PM diameters (~ ±10 μm) and when aligning each sample in cell with respect to the beam (~ ±100 μm). The size of this error can be estimated by calculating the worst case change in Fresnel mean diameter that results when a sample diameter profile is longitudinally offset with respect to the laser beam profile. Although different for each sample this results in worst case error bars in the horizontal direction ~ ±0.7μm.
3. Errors in PM diameter measurements using a 40X/0.65NA objective (~ ±0.5 μm). This can be expected to lead to horizontal errors of the same magnitude.
4. Wandering of sample fibre longitudinal axis with respect to the diametric beam axis (non-straightness of fibre samples). The magnitude of this error is difficult to quantify but in general bent fibres will have higher Fresnel mean diameter than straight ones (c.f. Reference 5).
5. Swelling of fibres due to moisture in the isopropanol after PM measurement. Experimental monitoring of fibre occlusion over several hours after immersion in the isopropanol shows this effect to be very small.
6. Ellipticity and fibre twisting due to aerodynamic forces during occlusion measurements as the sample is moved laterally back and forth through the isopropanol. Some of the samples appear to be quite elliptical. For example W70 which was measured at ~ 70 μm prior to mounting was

measured ~ 51 μm after mounting. Any twisting of the samples after immersion in the cell isopropanol may change the sample effective projected diameter.

7. Change in viewing angle for elliptical or irregular fibres. Differences in viewing/observation angle between measuring PM diameters and when measuring occlusions may change the sample effective projected diameter. This error, although difficult to quantify in practice, is expected to be small. For an elliptical fibre with a major to minor diameter ratio of 1.3 a 5° twist leads to a worst case change in observed projected diameter (at 45° to the major axis) ~ 2%. At 20 μm this is an error ~ 0.4 μm.

CONCLUSIONS

The effect of wool fibre medullation on diameter measurement in the expanding beam Laserscan has been investigated by measuring a range of mounted single fibres of diameter from 10 to 75 μm. The Laserscan optical response (occlusion) to normal non-medullated and medullated wool, when plotted against the characteristic diameter of each sample, show no discernable systematic differences and are in good agreement with Fresnel diffraction theory. This work supports the view that Laserscan measurements are not significantly affected by medullation.

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6. Dabbs, T.P., van Schie, H.F.M. and Glass, M., The effect of fibre curvature on Laserscan diameter measurement, IWTO Tech. Committee, Nice, Dec 1994.