1685 Inter-laboratory Evaluation of the Cottonscan Instrument for Determining Average Fibre Linear Density (Fineness) of Cotton Lint Samples

Dr. Graham J. Higgerson , CSIRO Textile and Fibre Technology, Belmont, Vic, Australia
Dr. Coung V. Le , CSIRO Textile and Fibre Technology, Belmont, Vic, Australia
Dr. Robert L. Long , CSIRO Textile and Fibre Technology, Belmont, Vic, Australia
Dr. Stuart R. Lucas , CSIRO Textile and Fibre Technology, Belmont, Vic, Australia
Dr. Geoffrey R.S. Naylor , CSIRO Textile and Fibre Technology, Belmont, Vic, Australia
Mr. Mark. M. Purmalis , CSIRO Textile and Fibre Technology, Belmont, Vic, Australia

The micronaire value for cotton is related to both fibre linear density (fineness) and maturity however it is desirable to have independent measures of both of these parameters as they are both important quality measures of cotton. The objective of this paper is to evaluate the technical potential of the Cottonscan instrument under development at CSIRO for measuring the average fibre linear density of cotton lint samples. A newly developed snippet preparation module for sampling lint is described and an inter-laboratory round trial (three laboratories) was used to assess the precision of the instrument. Results confirm that the new snippet preparation device is both effective and easy to use. The inter-laboratory trial of the complete Cottonscan system (incorporating the new snippet preparation device) found no significant difference between laboratories/instruments for samples with average fibre linear density values in the calibration region (within 50 mtex of the calibration cotton) and small statistically differences (typically 2-4 mtex) occurring only outside of this range. Overall the 95% confidence limits for a single measurement was estimated to be ± 10.4 mtex for average fibre linear density (fineness) and ± 0.047 units for average fibre maturity values. Further spinning trial results confirmed that unlike the micronaire value, average fibre fineness obtained from the Cottonscan correlate well with measured yarn properties. These data indicate that the Cottonscan instrument can be usefully employed to determine average fibre fineness, an important fibre quality parameter which can be a useful additional tool for the spinner in predicting yarn properties.

Keywords: cotton, fiber, quality, linear density, fineness, maturity, instrumentation

Introduction

The commonly used micronaire value for cotton is related to both fibre linear density (fibre fineness) and also fibre maturity. (For purposes of this paper, following the convention used elsewhere, eg Hequet et al,2006, fibre fineness is defined to be equivalent to fibre linear density ie mass per unit length and the two terms are used interchangeably throughout the paper.) However, in general it is not possible to accurately 'de-convolute' the micronaire value into separate linear density and fibre maturity values. For example fine mature cotton can have the same micronaire value as coarser immature cotton. Both fibre linear density and maturity have separate effects during textile processing. For example fibre linear density determines the numbers of fibres in the yarn cross section and so for a given yarn count, decreasing fibre linear density will increase the number of fibres in the yarn cross section which theoretically should lead to improved spinning efficiency, yarn evenness and yarn tenacity. On the other hand, the presence of immature fibres can (a) lead to increased nep generation during textile processing, (b) poor spinning performance and (c) reduced evenness in dyeing.

So micronaire is limited as a quality control tool for the textile industry and it is desirable to have commercially viable instrumentation and systems for measuring both parameters independently. Over the years a number of approaches have been proposed and explored, however to-date no systems have proved to be both technically sound and/or commercially viable, particularly for the demands of the rapid cycle time required by modern HVI instrumentation. The direct approach of measuring actual dimensions of fibre cross sections using optical microscopy and image analysis has been explored in recent years by Boylston et al (1993) and used extensively by Hequet et al (2006) to develop a series of reference cottons with specified fibre linear density (fineness) and maturity values. This direct approach is however very labour intensive and is unsuitable as a commercial test.

A number of indirect approaches have been investigated. One example is the Fineness and Maturity Tester (FMT) developed in the 1970's by The International Institute for Cotton (IIC) and The Shirley Institute, which was modified and upgraded by Montalvo et al (2002) and has also been further explored in our laboratory (Abbott et al 2004 and Naylor et al 2005). This test relies on two accurate determinations of the pressure drop across a plug of cotton fibres during an airflow test (similar to the micronaire test) measured under different experimental conditions. Average fibre maturity and fineness values are then determined from the small measured difference in these two observed pressure drops via empirical relationships. From a commercial perspective the speed of the FMT test puts it into the category of a low volume instrument, ie it is not fast enough to be compatible with HVI speeds.

CSIRO has been exploring two different technologies for measuring fibre fineness and maturity. The SiroMAT technology (Gordon and Phair, 2005 and Gordon et al, 2007) uses polarising microscopy to measure the maturity of individual fibre snippets using the established link between the cotton fibre's birefringent properties and fibre maturity as described in ASTM 1422-00. In essence, the SiroMAT technology automates this standard using modern colour digital cameras and computer image analysis techniques to produce a histogram of fibre maturity values for a given cotton sample.

This paper documents the recent progress in the development of the so-called Cottonscan instrument at CSIRO. This approach to measuring fibre linear density is based on the direct method of measuring the total length of a known mass of the fibre snippets to calculate directly mass per unit length. This technology has grown from preliminary work (Naylor and Sambell, 1999 and Naylor, 2001) which demonstrated that, when used in a novel mode of operation, an instrument previously developed for the wool industry, the Sirolan-Laserscan, was able to count the number of cotton snippets in a given sample. This preliminary work illustrated that when the fibre snippets were prepared at a fixed length (eg 2mm) then the average fibre linear density could be calculated from this data in combination with the mass of the snippets. Naylor (2001) also demonstrated that combining this measured average fibre linear density value with an independently measured micronaire value, an average fibre maturity value could be calculated using the well known Lord Equation (Lord, 1956). While this work demonstrated the approach, it is noted that the measurement time for this early work was in excess of 20 minutes per sample.

Following this preliminary work, a purpose built instrument, "Cottonscan" Version 1 (Gordon and Naylor, 2004a,b) was designed and manufactured to undertake this task more efficiently. Compared to the preliminary work with the Sirolan-Laserscan, where fibre snippets were counted one by one, Cottonscan used digital imaging techniques to photograph and analyse a large number of snippets in one image. This provided the

advantage of both increasing the speed of operation of the instrument and also allowing the instrument to measure directly the total length of snippets in the image ie removing the conditions of knowing that all snippets are of a known fixed length.

Cottonscan Version 1 used a mass of snippets typically 15 mg. Subsequent work (Abbott et al, 2004 (Bremen) and Naylor and Purmalis (2005) identified that the precision of the instrument was largely limited by the precision of the mass measurement for such a small mass. This lead to the development of Cottonscan Version 2 which enabled the sample size to be increased to 100mg or larger if desired.

Naylor and Purmalis (2005) reported comparative trials of three Cottonscan Version 2 instruments. Using well blended sliver samples, good agreement between instruments was observed (average between instrument difference were less than 4 mtex) and the observed 95% confidence limits for replicate measurement of average fibre linear density on a single instrument was ± 6.5 mtex (ie ± 3% for a typical 200mtex sample).

Up to 2005, most of the Cottonscan development trials had utilised well blended cotton samples in sliver form. This enabled fibre snippets to be readily cut from the pre-prepared sliver using the standard double bladed Sirolan-Laserscan guillotine. Naylor and Purmalis (2006) reported on the development of an automated lint preparation device for preparing fibre snippets for input to the Cottonscan from lint samples. Using this sample preparation device, trials on a range of cottons resulted in an observed 95% confidence limit for replicate measurements of average fibre linear density to be ±10 mtex. The underlying cause of the increase in the 95% confidence limits from the previously observed sliver data was not clear, but one suggestion was that it could indeed reflect the true variability within the cotton lint samples.

Over the last 18 months the focus of the ongoing development of Cottonscan at CSIRO has been (a) the development of a radical new design for the automatic lint snippet preparation device that simplifies the system from an operator perspective and (b) trials to validate the new approach and to illustrate the potential value of the technology to the spinning mill. These will be discussed in this paper.

Results and Discussion

(a) The New Lint Snippet Preparation Device

In the Cottonscan instrument, prepared and weighed fibre snippets are suspended in an aqueous medium within the instrument prior to the measurement cell. To improve the cycle time of the instrument, a premise of the instrument is that a suspension of fibre snippets can be formed so that it is reliable to sub-sample the suspension rather than measuring the total volume in order to determine the length of fibre snippets within the sample. Thus the calculation of the average linear density F of a sample is as follows

$$F = M*(v/V)/l \quad (1)$$

Where M is the total mass of the snippets, V the total volume of the suspension and *l* is the measured length of fibre snippets in the sub-sampled volume v.

Hence a technical requirement for the snippet preparation device is its ability to deliver snippets that can be readily mixed into a uniform suspension within the Cottonscan

instrument. From an operator perspective it is also important that all aspects of the Cottonscan instrument including the snippet preparation device be both easy to operate and generally 'user-friendly'.

Figure 1 illustrates the radical new snippet preparation device. A sample (approximately 10 g) of lint is manually inserted into chamber A. Movement of Piston B to a fixed pressure compresses the lint sample and then in a second action cylindrical cutters each approximately 2 mm in diameter extend from the face of the piston to collect a core of snippets from the cotton lint sample. In the current design a set of 8 cylindrical cutters are arranged in the piston assembly so that the total mass of snippets collected from one cycle of the preparer is approximately 80-100mg ie adequate for the Cottonscan instrument. The piston head assembly including the cylindrical corers/cutters has been used routinely for many years to prepare wool snippets for commercial testing in the Sirolan-Laserscan instrument. In the wool application, this engineering design has proved to be both robust and easy to operate. The snippet preparation device is driven by an external compressed air supply and appropriate safety interlocks are standard features.

Figure 2 summarises the results from a trial designed to evaluate the performance of four prototype snippet preparation devices manufactured at CSIRO to this new design. In this trial, using one well blended cotton, ten replicates from each of the four different snippet preparation devices were measured on the one Cottonscan instrument. No significant difference between the snippet preparation devices was observed.

(b) Inter-laboratory Trial of Three Cottonscan Systems.

Following the encouraging results from the above trial comparing the new snippet preparation devices, three complete Cottonscan systems (ie snippet preparation devices and Cottonscan measurement modules) were calibrated/harmonised at CSIRO in preparation for external trials.

In Equation 1, in principle, all the parameters to calculate the average fibre linear density are known and fixed. However, in practice, prior to instrument calibration/harmonisation, small differences (typically less than 15%) in the resultant fibre linear density values between instruments can occur due to difficulties in accurately determining the two volumes v and V and the effect of between instrument variations in the lighting systems affecting the observed length of snippets, *l*. A calibration cotton with an assigned average linear density value (157 mtex) was used to harmonise the results of each instrument for this particular cotton via the introduction of a small machine specific linear correction factor β. Equation 1 is thus modified as follows:

$$F = \beta M * (v/V) / l \quad (2)$$

Following this calibration procedure which was undertaken at CSIRO Textile and Fibre Technology in Geelong, two Cottonscan systems were shipped to cotton test laboratories interstate in preparation for an inter-laboratory trial to compare the operation of three different Cottonscan systems at three different locations within Australia (a commercial cotton classing house, the test laboratory at CSIRO's major Australian on-farm cotton R&D research station, and CSIRO Textile and Fibre Cotton Research Station). It is noted that on arrival at their destination, the instruments were installed and no further recalibration was undertaken prior to conducting the inter-laboratory trial. Thus the trial was designed to test the robustness of the instrument to both (a) the rigour of transport and also (b) their performance in different environments with different untrained operators.

For this trial 5 different cottons were chosen covering a range of fineness values from 160mtex to 250 mtex. These comprised the three well blended cottons samples used previously (Naylor and Purmalis, 2006), a one bale sample of a commercial Australian upland cotton that was blended and processed to sliver and then broken to form a loose fibre sample (Sample Ref No: SRL6000) and finally an unblended fibre sample of Australian Pima cotton (ie sampled directly from a commercial bale without any further blending). Nine replicate samples of each cotton (each approximately 10 g) were prepared centrally and supplied to each laboratory for the trial.

The results of the measured average linear density values from this trial are summarised in Figure 3. Figure 4 shows the partial residuals from an ANOVA of this data after removing the average between sample differences. Statistically significant but relatively small global differences between laboratories were observed as listed in Table 1. From this analysis the 95% confidence interval for a single measurement is ± 10.4 mtex. (Note this confidence limits includes the between laboratory/instrument component.)

Table 1. Summary of the Overall Differences Between Laboratories in Average Liner Density Values.

Laboratories	Global Difference (mtex)	Stat. Significance
Lab 1 – Lab 2	-2.47	*
Lab 1 – Lab 3	2.02	NS
Lab 2 – Lab 1	4.49	*

* Significant at the 95% level.

ANOVA's were performed with each cotton and the results are summarised in Table 2. It demonstrates that for each particular cotton, the within sample variation dominates ie it is much larger than the between laboratory effect. Further the between laboratory effects are not statistically significant for the finer cottons and the small statistically significant differences only appear for the coarser cottons ie small inter-instrument differences only appear as one moves 50 mtex or further away from where the instruments have been harmonised using the calibration cotton (157 mtex).

Table 2. Summary of ANOVA's for Individual Cotton Average Linear Density Values

Cotton	Mean Fineness (mtex)			Variance			[1]Between Labs Significance
	Lab 1	Lab 2	Lab 3	Within Cotton	Between Laboratory	Total	
5740	162.30	163.76	161.61	16.19	-0.60	16.19	NS
Pima	159.86	163.92	162.26	29.63	0.89	30.52	NS
5741	188.23	190.31	186.49	24.88	0.90	25.78	NS
SRL6000	199.64	199.97	193.92	23.38	8.97	32.35	*
5742	240.39	244.80	236.03	21.99	16.77	38.76	**

[1]NS = Not Significant; * = Significant at 95% level; ** = Significant at 99% level

Figure 5 illustrates the average within sample coefficient of variation (CV %) as a function of average linear density values. This illustrates that the CV for one particular sample (the Pima sample) is considerable larger than the others. This is consistent with the Pima sample being the only cotton taken immediately from the bale, ie without any further blending operation.

An average of three measurements of the micronaire of each of the 5 cotton samples was obtained from HVI testing. This value was used retrospectively in combination with each Cottonscan average fibre linear density data point, to calculate an average fibre maturity value (Lord, 1956). ANOVA's for each cotton of these maturity values are listed in Table 3. The 95% confidence limit calculated from the complete data set of maturity values is ± 0.047 units.

Table 3. Summary of ANOVA's for Individual Cotton Average Maturity Values

Cotton	Mean Maturity			Variance (x10^{-4})			[1]Between Labs
	Lab 1	Lab 2	Lab 3	Within Cotton	Between Laboratory	Total	Significance
5740	0.695	0.689	0.698	2.89	-0.977	2.89	NS
Pima	0.941	0.918	0.928	9.32	0.308	9.63	NS
5741	0.794	0.786	0.802	4.37	0.156	4.53	NS
SRL6000	0.956	0.954	0.984	5.39	2.14	7.53	*
5742	0.817	0.802	0.832	2.60	1.94	4.54	**

[1]NS = Not Significant; * = Significant at 95% level; ** = Significant at 99% level

(c) Value to the Spinner

A wider study into the role of varieties and agronomic factors to textile processing parameters is currently being undertaken at CSIRO and the results from this study will be published elsewhere in due course. A subset of this trial, involving one bale samples of a range of upland varieties grown in controlled large scale field trials has been processed at the CSIRO textile mill into 20tex ring spun singles yarn. Cottonscan measurements were made on seven lots forming this trial and Figure 6 demonstrates the relationship between the measured yarn tenacity values and (a) the micronaire value and (b) the average fibre linear density values. It is clear from the mill's perspective that the average cotton linear density values are a much better predictor of yarn tenacity than the micronaire value. A specific example relates to the two cottons circled in each graph. Both these cottons have the same measured micronaire value but are quite different in terms of yarn properties ie based only on micronaire values, a mill would be unable to identify the different potential of these two different cottons. The availability of the Cottonscan average fibre linear density data, is however able to clearly distinguish these two cottons and correctly predict the difference in yarn properties. Note that the observed correlation with average fibre linear density (fineness) is indeed in line with the established understanding of the spinning process where the use of finer fibres, increases the number of fibres in the yarn cross section leading to improved yarn evenness, and hence higher yarn tenacity values.

Conclusion

This work indicates that the Cottonscan instrument can indeed be used to reliably determine average fibre linear density (fineness) of cotton samples and further that this important fibre quality parameter can be a useful additional tool for the spinner in predicting yarn properties.

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Figure 1. The new automatic snippet preparation device highlighting A the sample chamber, and B the piston, C the cylindrical punches and D the sample collection cup.

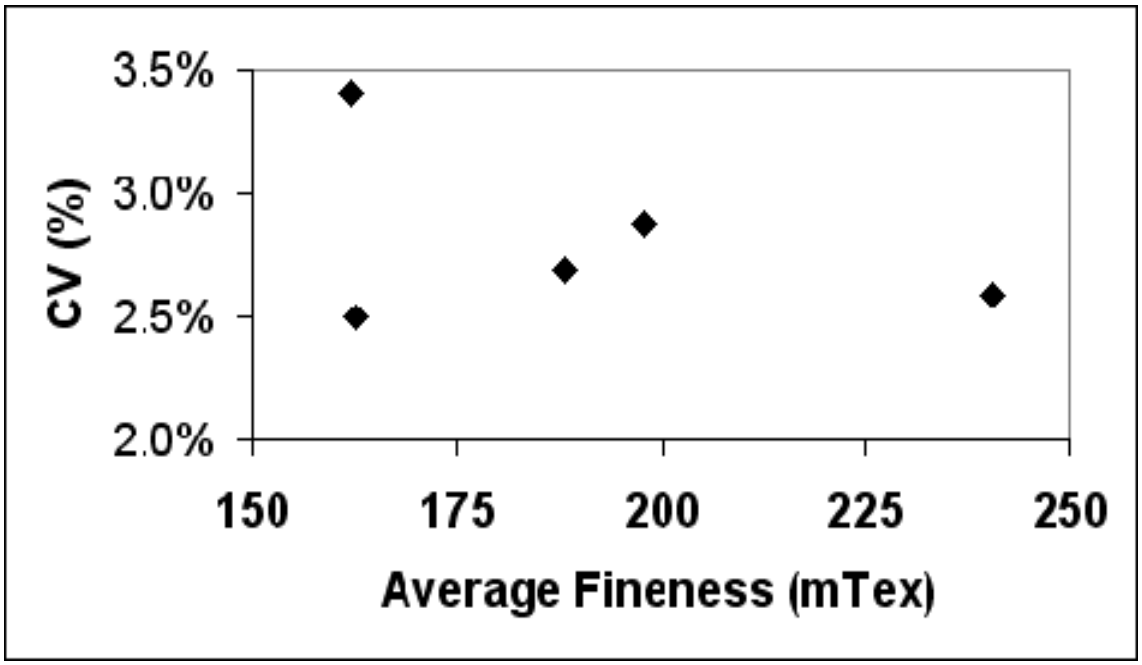

Figure 2. Individual Cottonscan results from a trial comparing four replicates of the new prototype snippet preparation device.

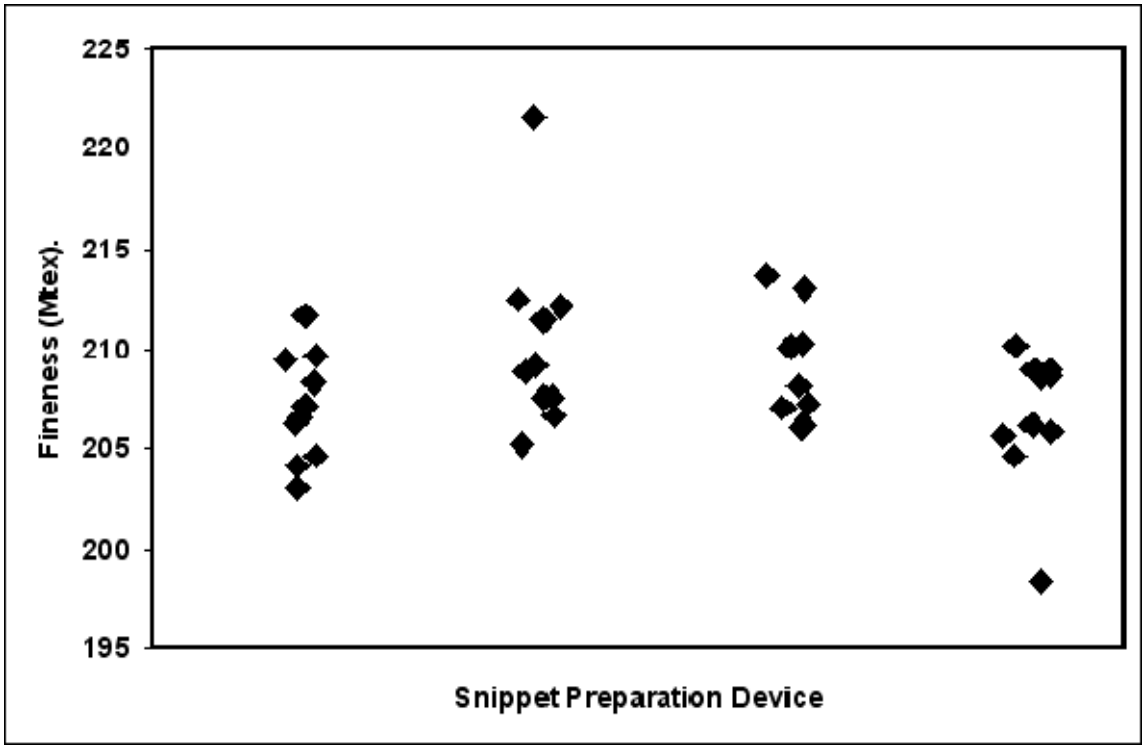

Figure 3. Results of the Inter-laboratory Trial Comparing Three Cottonscan Systems. (The Different Symbols represent the Three Different Laboratories.)

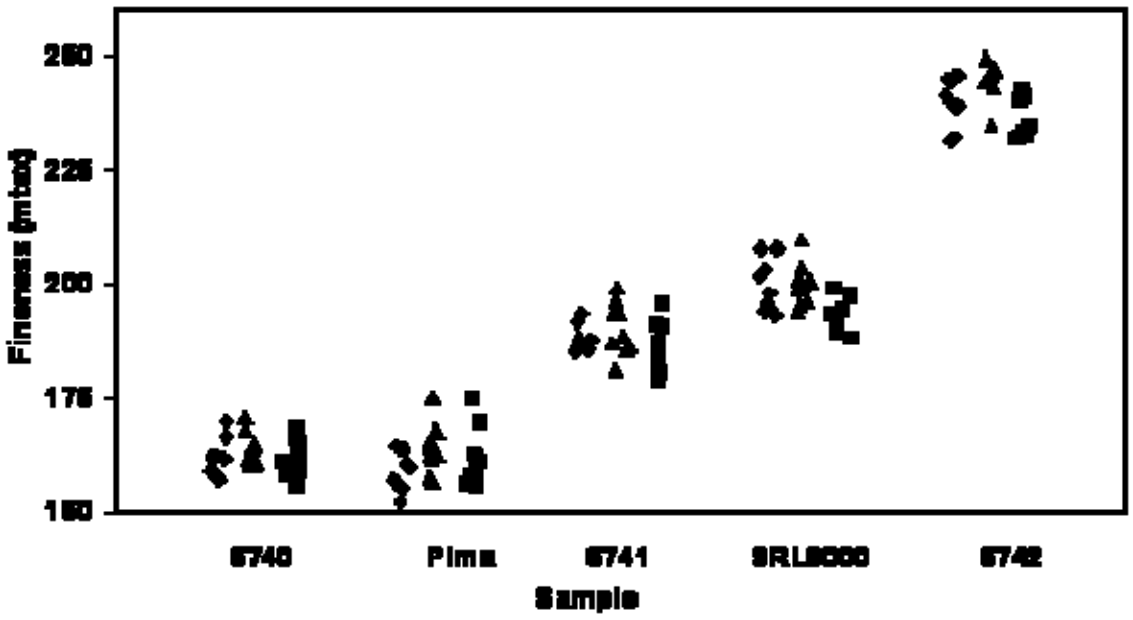

Figure 4. Partial residuals from an ANOVA of the data in Figure 3 taking account of the between sample variation. (The Different Symbols represent the Three Different Laboratories.)

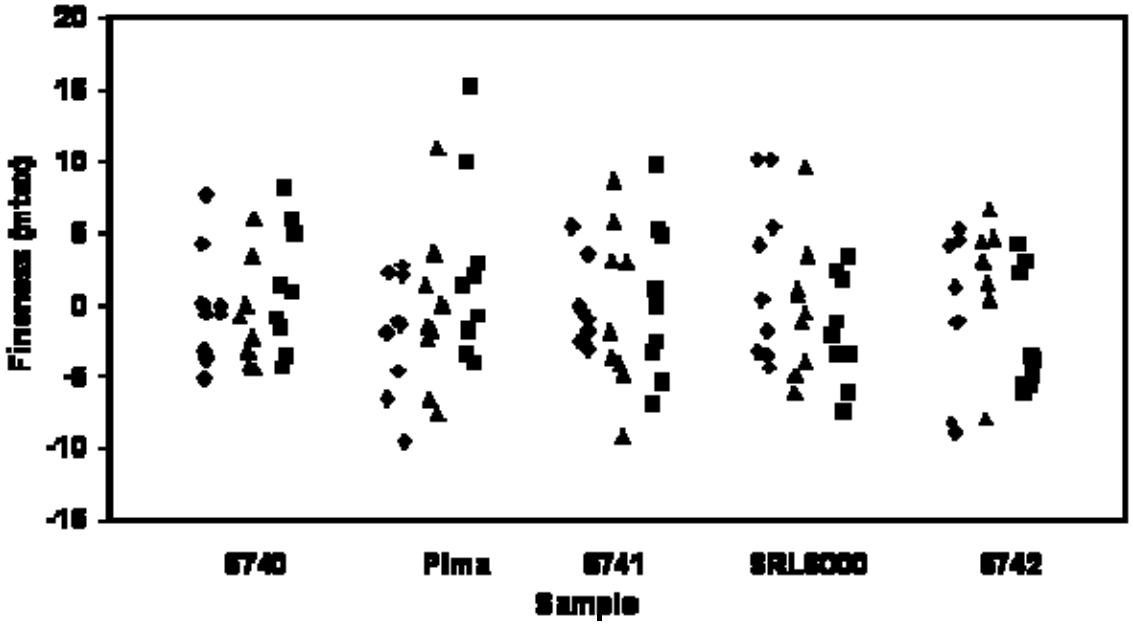

Figure 5. The Observed Total Variance from the ANOVA Analysis of the Average Fineness For Each Cotton (from Table 2) plotted as a CV (ie √(Variance)/Average Fineness) as a function of the Average Fineness.

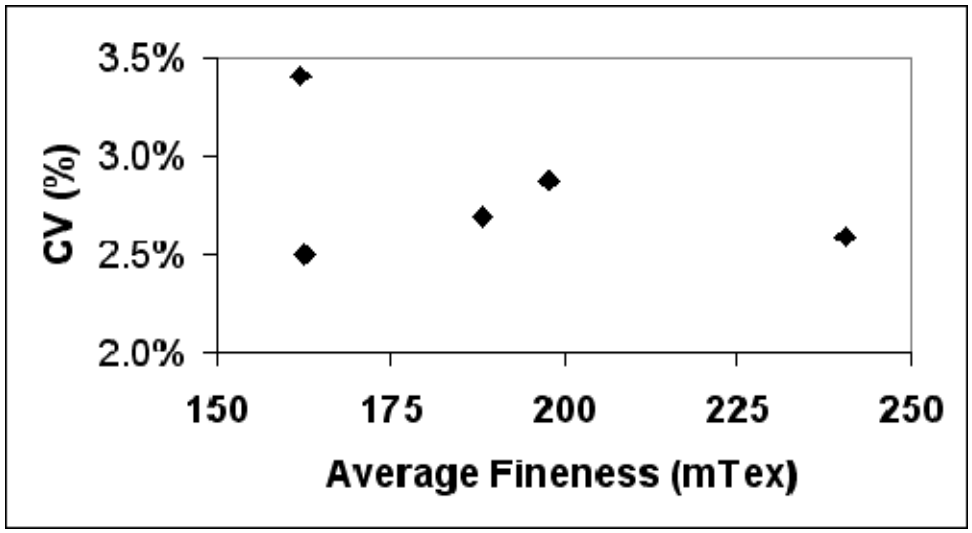

Figure 6. The Relationship Between Yarn Tenacity Values and (a) the micronaire value and (b) the average fibre linear density values, from Spinning Trials Comparing a Range of Australian Upland Cotton Varieties.