INTERNATIONAL WOOL TEXTILE ORGANISATION

TECHNOLOGY & STANDARDS COMMITTEE **HOBART MEETING**

Raw Wool Group **April 2005**

Chairman: A.C. BOTES (South Africa) **Report No: RWG 02**

A Between-Instrument Comparison of Staple Crimp Frequency Measured by Crimp Meters

By

David Crowe

Australian Wool Testing Authority Ltd PO Box 190, Guildford NSW 2161, Australia

SUMMARY

This paper provides estimates of the within and between instrument variances of Staple Crimp Frequency measured by a Crimp Meter. A set of 27 Sale Lots was selected to cover a broad range of staple crimp frequencies from the 3 wool-selling regions in Australia.

The average 95% Confidence limit was ± 0.31 crimps/cm. The average within-instrument variance was 0.0221 $(crimps/cm)^2$ and the average between-instrument variance was 0.0035 $(crimps/cm)^2$. The average Crimp frequency for the 27 Sale lots ranged from 1.7 to 5.9 crimps/cm.

The Analysis of Variance showed: no significant difference between replicates within crimp meter; no significant difference between crimp meters; and no interaction between wool and crimp meter for Staple Crimp Frequency. These results indicate the Staple Crimp Frequency measurement is highly repeatable.

A procedure has been developed to enable reporting of two mean Staple Crimp Frequencies for Sale Lots that exhibit a bimodal (two hump) distribution but requires validation on a larger number of Sale Lots.

INTRODUCTION

Staple Crimp Frequency, Fibre Curvature, Resistance to Compression and Bulk are all measures, which respond to essentially the same wool fibre attribute. Of the four, Staple Crimp Frequency has the simplest pre-measurement sample preparation procedure. The latter three techniques have all been shown to be sensitive to small changes in the sample preparation procedures and this has either delayed the development of a measurement standard or impacted on the commercial uptake of the measurements.

Traditional visual appraisal[2,3,4] of wool style has included the assessment of Staple Crimp Frequency. Systems such as the Bradford quality counts[1] were established as an indirect indicator of fibre diameter and as a means of assessing the uniformity of the Sale Lot for processing. For example, 4.5 to 5 crimps/cm relates to a 64's quality in the Bradford System.

Processing studies[5,6,7] have demonstrated that different values of Staple Crimp Frequency can affect processing performance in topmaking, spinning and fabric manufacture. Staple Crimp Frequency can also influence fabric properties such as thickness and handle[5].

Recent studies[8,9,10] have described a Crimp Meter for the automatic measurement of Staple Crimp Frequency. These studies also indicated good agreement between manual Staple Crimp Frequency measurement and the results obtained from a single Crimp Meter. This result gave impetuous for the development of a further two crimp meters to enable estimates to be made of the within-instrument and between-instrument variability.

This paper examines the within-instrument and between-instrument variances for a set of 27 Sale Lots selected to cover a broad range of staple crimp frequencies from the 3 wool selling regions in Australia.

MATERIALS AND METHODS

In Total, 27 Sale Lot display samples were purchased to cover a range of staple crimp frequencies from approximately 1.5 crimps/cm to 6.0 crimps/cm. The samples were sourced from sales in Melbourne, Sydney, Newcastle and Fremantle and included Crossbred and Merino fleece wool.

Each Sale Lot display sample was tufted using a single Mechanical Tuft Sampler (MTS) and approximately 60 staples were prepared in accordance with the requirements of IWTO-7[11]. The set of prepared staples for each Sale Lot was passed through the crimp meter, collected and then measured on another two crimp meters. Once all staples from the 27 Sale Lots were measured on each crimp meter the staples were measured a second time on each crimp meter.

Measuring the same set of prepared staples, rather than a second set of staples drawn from each Sale Lot display sample, on each instrument reduces the sampling variance and is described in IWTO-0[12] as an appropriate method for reducing sampling variance when comparing performance between instruments.

Analysis of Variance techniques were used to determine the significance between replicate within the trial (within instrument) and between instrument differences. The grand mean was calculated for each Sale Lot and the difference from the grand mean plotted for each replicate test within an instrument (6 sets of differences in total). Precision estimates were calculated based on the calculated Within-Instrument and Between-Instrument variances in accordance with the procedures defined in IWT0-0[12].

RESULTS AND DISCUSSION

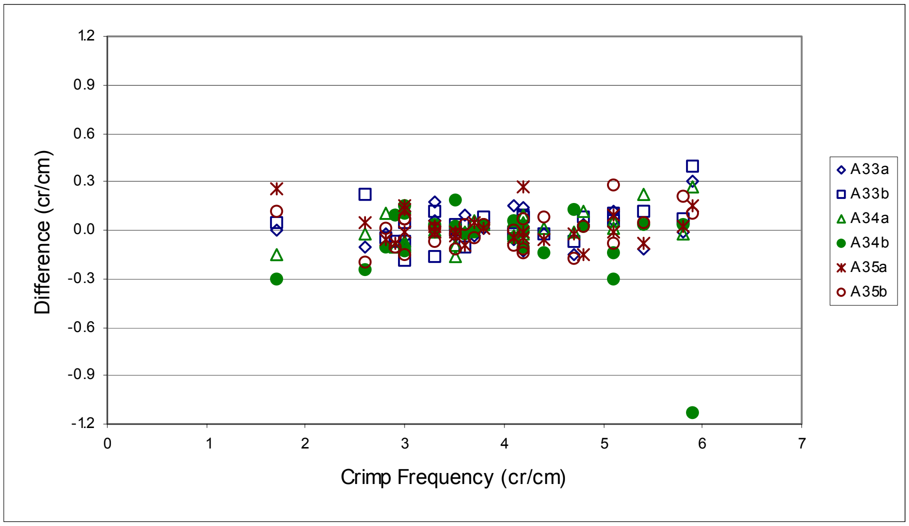
Table 1: Sale Lot Average Staple Crimp Frequencies (crimps/cm)

Sale Lot Code	Crimp Meter A33		Crimp Meter A34		Crimp Meter A35		Grand Mean
	Replicate A	Replicate B	Replicate A	Replicate B	Replicate A	Replicate B	
1	4.04	4.09	4.07	4.06	4.05	4.10	**4.1**
2	5.29	5.51	5.62	5.44	5.32	5.45	**5.4**
3	4.37	4.37	4.41	4.26	4.34	4.48	**4.4**
4	4.07	4.28	4.29	4.10	4.47	4.26	**4.2**
5	4.34	4.29	4.18	4.21	4.19	4.09	**4.2**
6	3.47	3.54	3.34	3.68	3.49	3.47	**3.5**
7	5.22	5.21	5.11	4.96	5.08	5.02	**5.1**
8	3.48	3.14	3.30	3.32	3.32	3.23	**3.3**
9	3.82	3.88	3.83	3.83	3.81	3.84	**3.8**
10	3.70	3.50	3.58	3.58	3.51	3.64	**3.6**
11	2.78	2.75	2.90	2.69	2.75	2.81	**2.8**
12	2.50	2.83	2.58	2.35	2.64	2.40	**2.6**
13	3.47	3.50	3.41	3.52	3.46	3.39	**3.5**
14*	6.20	6.29	6.17	4.77	6.05	6.01	**5.9**
15	4.21	4.28	4.25	4.18	4.15	4.06	**4.2**
16	2.95	3.05	2.89	2.87	3.13	2.85	**3.0**
17	1.70	1.75	1.55	1.39	1.96	1.82	**1.7**
18	4.55	4.63	4.69	4.83	4.68	4.53	**4.7**
19	3.67	3.72	3.76	3.69	3.74	3.66	**3.7**
20	2.89	2.81	2.94	3.15	3.15	3.07	**3.0**
21	4.25	4.07	4.16	4.15	4.05	4.01	**4.1**
22	3.36	3.42	3.29	3.34	3.29	3.31	**3.3**
23	3.12	2.92	2.90	3.10	2.99	3.06	**3.0**
24	5.15	5.16	5.15	4.80	5.19	5.38	**5.1**
25	4.83	4.88	4.92	4.82	4.65	4.82	**4.8**
26	5.79	5.87	5.77	5.84	5.82	6.01	**5.8**
27	2.99	2.83	2.79	2.99	2.81	2.79	**2.9**
Average	**3.93**	**3.95**	**3.92**	**3.85**	**3.93**	**3.91**	**3.91**
Omit 14	***3.85***	***3.86***	***3.83***	***3.81***	***3.85***	***3.83***	***3.84***

* The variation exhibited between results is due to the presence of two distinct crimp frequencies (Double crimp) in Lot 14.

The average staple crimp frequencies for the A and B replicate measurements on the 3 Crimp Meters were 3.93, 3.95, 3.92, 3.85, 3.93 and 3.91. The value of 3.85 for replicate B of Crimp Meter A34 was due to the lower average for lot 14, which was caused by the selection of the lower frequency secondary or double crimp (See page 6 for an in-depth discussion). There are only small differences between average replicate results and these are not statistically significant. Figure 1 presents graphically the differences from the Grand Mean for Staple Crimp Frequency for the 27 Sale Lots. The average results omitting lot 14 range between 3.81 crimps/cm and 3.86 crimps/cm.

Figure 1: Plot of Instrument Difference from Grand Mean for Staple Crimp Frequency (crimps/cm)



The plot shows a tight distribution about the zero line of about ± 0.3 crimps/cm for most test results. The Double Crimp result for Sale Lot 197067 measured, as the B replicate on Crimp Meter A34 is the only outlier.

The Analysis of Variance is presented in Table 2.

Table 2: Analysis of Variance Table.

Effect	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Probability
Instrument	2	4.55	2.2733	1.7374	0.1760
Sample	26	8678.74	333.7977	255.1185	0.0000
Instrument: Sample	52	64.42	1.2389	0.9469	0.5831
Replicate within Sample	27	22.57	0.8361	0.6390	0.9245
Residual	8913	11661.79	1.3084		

The analysis shows no statistically significant differences for:

- Repeat measures on the same instrument (P = 0.9245)
- Between different instruments (P = 0.1760)
- No interaction between Instruments and Samples (P = 0.5831).

The instrument averages were 3.94, 3.89 and 3.92 for A33, A34 and A35 respectively. These differences are found in the second decimal place and normal reporting of results would be to one decimal place.

Table 3: Summary of Instrument Variances and 95% Confidence Limits (corrected)

Sample Number	Mean Staple Crimp Frequency (crimps/cm)	Within-Instrument Mean Square (MSW) (crimps/cm)^2	Between-Instrument Mean Square (BSW) (crimps/cm)^2	Within-Instrument Variance (crimps/cm)^2	Between-Instrument Variance* (crimps/cm)^2	95% Confidence Limit (crimps/cm)
1	4.1	0.0008	0.0001	0.0008	0.0000	0.1
2	5.4	0.0170	0.0127	0.0170	0.0000	0.3
3	4.4	0.0074	0.0028	0.0074	0.0000	0.2
4	4.2	0.0210	0.0223	0.0210	0.0007	0.3
5	4.2	0.0025	0.0165	0.0025	0.0070	0.2
6	3.5	0.0205	0.0005	0.0205	0.0000	0.3
7	5.1	0.0040	0.0191	0.0040	0.0075	0.2
8	3.3	0.0205	0.0009	0.0205	0.0000	0.3
9	3.8	0.0008	0.0003	0.0008	0.0000	0.1
10	3.6	0.0095	0.0002	0.0095	0.0000	0.2
11	2.8	0.0083	0.0006	0.0083	0.0000	0.2
12	2.6	0.0363	0.0201	0.0363	0.0000	0.4
13	3.5	0.0034	0.0018	0.0034	0.0000	0.1
14#	5.9	0.3269	0.3228	0.3269	0.0000	1.1
15	4.2	0.0031	0.0104	0.0031	0.0037	0.2
16	3.0	0.0140	0.0089	0.0140	0.0000	0.2
17	1.7	0.0075	0.0880	0.0075	0.0402	0.4
18	4.7	0.0084	0.0178	0.0084	0.0047	0.2
19	3.7	0.0024	0.0006	0.0024	0.0000	0.1
20	3.0	0.0096	0.0362	0.0096	0.0133	0.3
21	4.1	0.0053	0.0113	0.0053	0.0030	0.2
22	3.3	0.0010	0.0044	0.0010	0.0017	0.1
23	3.0	0.0141	0.0003	0.0141	0.0000	0.2
24	5.1	0.0268	0.0471	0.0268	0.0102	0.4
25	4.8	0.0069	0.0111	0.0069	0.0021	0.2
26	5.8	0.0079	0.0069	0.0079	0.0000	0.2
27	2.9	0.0108	0.0070	0.0108	0.0000	0.2
AVG	**3.91**	**0.0221**	**0.0248**	**0.0221**	**0.0035**	**0.31**
Omit 14	***3.84***	***0.0104***	***0.0134***	***0.0104***	***0.0036***	***0.23***

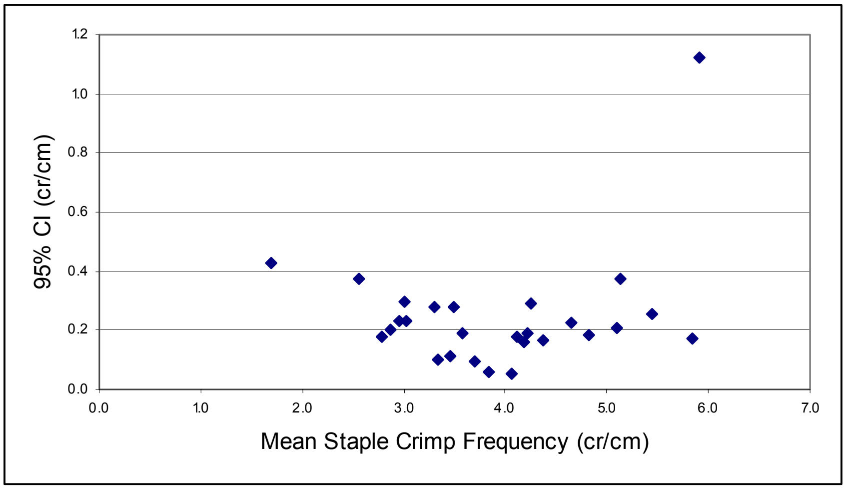
* Negative variances set to 0.0000.

The variation exhibited between results is due to the presence of two distinct crimp frequencies (Double crimp) in Sample 14.

The average 95% Confidence limit was ± 0.31 crimps/cm. The average within-instrument variance was 0.0221 (crimps/cm)^2 and the average between-instrument variance was 0.0035 (crimps/cm)^2. Omitting lot 14 the 95% Confidence limit reduces to ± 0.23 crimps/cm and the within-instrument variance reduces to 0.0104 (crimps/cm)^2 and the between-instrument variance becomes 0.0036 (crimps/cm)^2.

Variance estimates, uncorrected for negative variances, are reported in Table A1 of Appendix A.

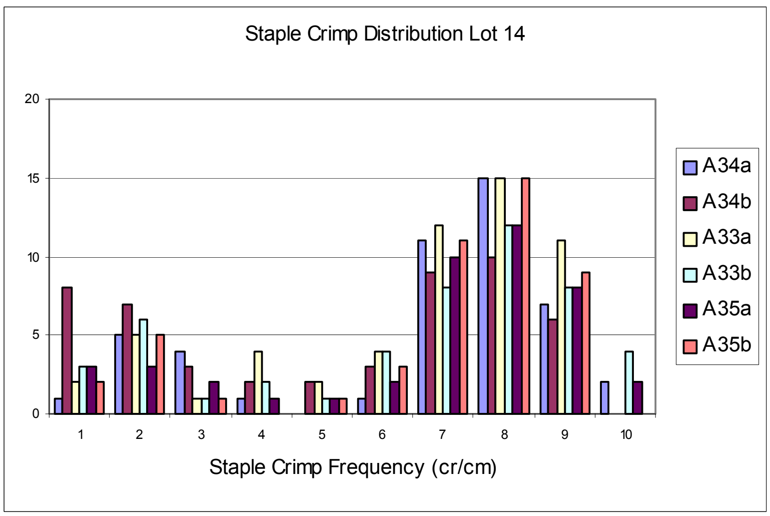
Figure 2: Plot of 95% Confidence Limits for Staple Crimp Frequency (cr/cm).



The data plotted in Figure 2 indicates relatively tight precision around the mean for all lots except for the lot 14, which exhibits 'double' crimp. The precision estimates seem to be independent of Mean Staple Crimp Frequency.

Staple Crimp Frequency Distributions

Figure 3: Histogram of Staple Crimp Frequency for Sale Lot 14 (Double Crimp) for the 6 replicate Tests

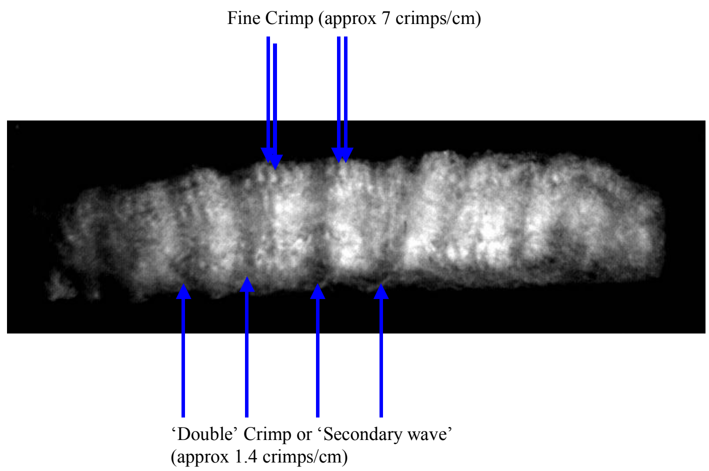


The data presented in Figure 3 exhibits a bimodal (2 humps) distribution. A single combined mean of 5.9 crimps/cm for such a distribution is clearly not appropriate because it has averaged the two populations of crimp frequencies. Double crimp is generally associated with higher crimp frequencies and an example of a staple exhibiting double crimp is shown in Figure 4a and 4b.

An alternate approach for describing these Sale Lots may be to calculate the mean Staple Crimp Frequency and if the mean is greater than 5.5 crimps/cm (based on the observation that double crimp is normally associated with wool of high crimp frequency) then the percentage of staples with a crimp frequency less than or equal to 3.5 crimps/cm should also be calculated. If the percentage of staples exceeds 10% of the measured staples then calculate a mean Staple Crimp Frequency for the population of staples less than or equal to 3.5 crimps/cm and another mean Staple Crimp Frequency for the population of staples greater than 3.5 crimps/cm.

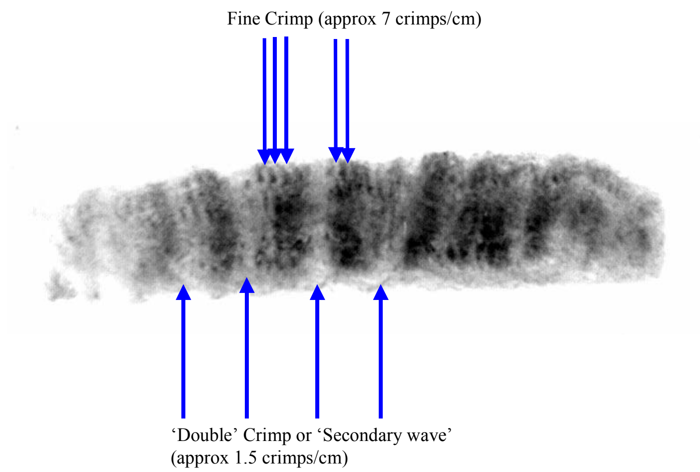
For lot 14 (Figure 3) the reported Staple Crimp Frequencies would be 7.2 crimps/cm and 1.6 crimps/cm, which would more adequately reflect the distribution of the lot. This procedure would need to be validated on a larger data set to evaluate its performance as a means of adequately describing Sale Lots exhibiting bimodal crimp frequency distributions.

Figure 4a: Image of Staple with a Double Crimp or Secondary Wave.



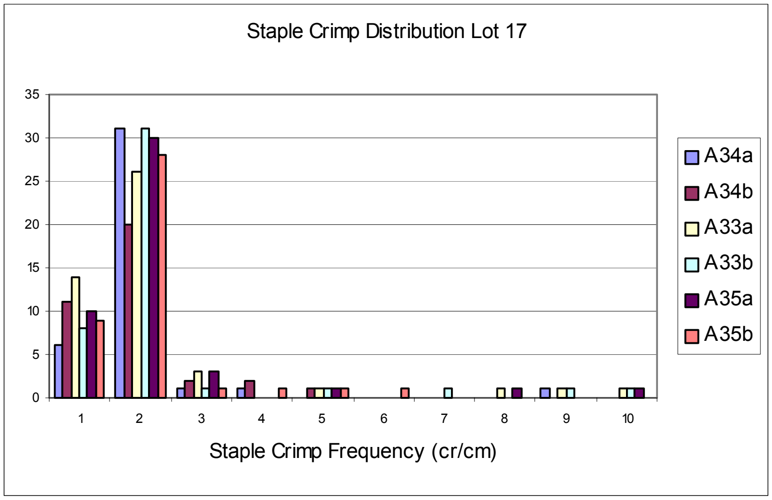
The Double crimp for the staple shown in Figure 4a was 1.4 crimps/cm while the underlying crimp was approximately 7 crimps/cm. The arrows on Figure 4a & 4b line up with the troughs of the two dominant crimp frequencies.

Figure 4b: Negative Image of the same Staple with a Double Crimp or Secondary Wave.



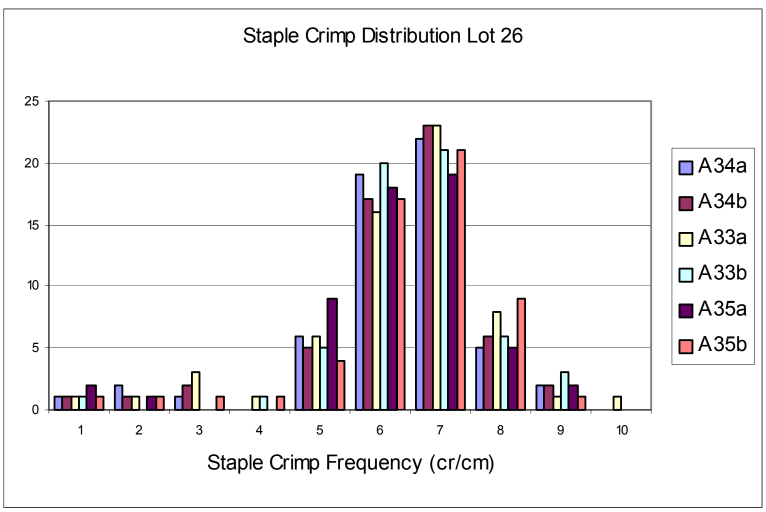
The Staple Crimp Frequency distributions are reported for some typical Sale Lots in Figures 5 to 8.

Figure 5: Histogram of Staple Crimp Frequency for Sale Lot 17 for the 6 replicate Tests



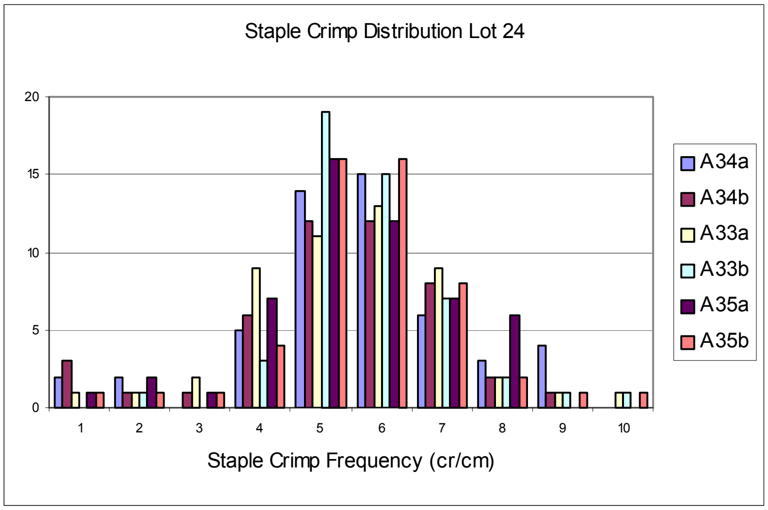
The Mean Staple Crimp Frequency for Lot 17 was 1.7 crimps/cm and adequately reflects the distribution. The majority of staples are in the 1 and 2 crimp/cm bins.

Figure 6: Histogram of Staple Crimp Frequency for Sale Lot 26 for the 6 replicate Tests



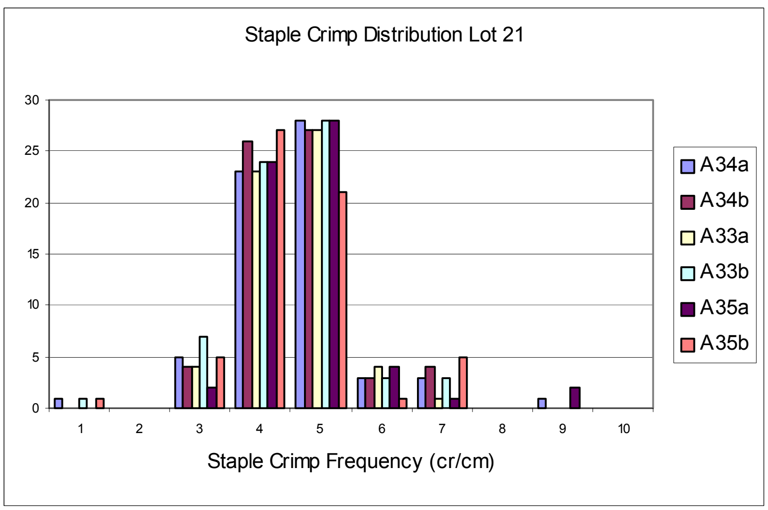
The Mean Staple Crimp Frequency for Lot 26 was 5.8 crimps/cm and adequately reflects the distribution. Most of the staples lie between 5 and 8 crimps/cm.

Figure 7: Histogram of Staple Crimp Frequency for Sale Lot 24 for the 6 replicate Tests



The Mean Staple Crimp Frequency for Lot 24 was 5.1 crimps/cm and adequately reflects the distribution. The majority of staples lie between 4 and 7 crimps/cm.

Figure 8: Histogram of Staple Crimp Frequency for Sale Lot 21 for the 6 replicate Tests



The Mean Staple Crimp Frequency for Lot 21 was 4.1 crimps/cm and adequately reflects the distribution. The majority of staples lie between 4 and 5 crimps/cm.

CONCLUSIONS

The Analysis of Variance showed: no significant difference between replicates within crimp meter; no significant difference between crimp meters; and no interaction between wool and crimp meter for Staple Crimp Frequency. These results indicate the Staple Crimp Frequency measurement is highly repeatable.

The 95% confidence limit was $\pm$ 0.31 crimps/cm and showed no dependency with Mean Staple Crimp Frequency. The average within-instrument variance was 0.0221 $(\text{crimps/cm})^2$ and the average between-instrument variance was 0.0035 $(\text{crimps/cm})^2$. The average Crimp frequency for the 27 Sale lots ranged from 1.7 to 5.9 crimps/cm.

Distributions containing a double crimp or secondary crimp may not be represented by a single Mean Staple Crimp Frequency. A procedure has been developed to enable reporting of two Mean Staple Crimp Frequencies for Sale Lots that exhibit a bimodal (two hump) distribution. This procedure needs to be validated with a larger data set.

Further trials are planned and will be reported at future meetings. These trials will include a between laboratory trial and a trial involving a much larger cross section of samples routinely measured for length and strength. This would assist the development of a standard.

In conclusion Staple Crimp Frequency is a highly repeatable measurement that has been demonstrated to effect topmaking, spinning and fabric properties. It would seem possible to incorporate the hardware and software into an updated ATLAS instrument at a relatively low cost and provide a routine measurement service on all lots currently measured for staple length and staple strength.

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10. Tang, L. and Crowe, D.W. (2003) *Measurement of Staple Crimp Frequency PART I. Manual Measurements using the Crimp Gauge.* IWTO T&S Committee, Istanbul, Report CTF1.
11. IWTO-7-00. *Sub-sampling Staples from Grab Samples.*
12. IWTO-0-04 *Appendix D – Statistical Methods.*

APPENDIX A

Table A1: Summary of Instrument Variances and 95% Confidence Limit (uncorrected)

Sample Number	Mean Staple Crimp Frequency (crimps/cm)	Within-Instrument Mean Square (MSW) $(crimps/cm)^2$	Between-Instrument Mean Square (BSW) $(crimps/cm)^2$	Within-Instrument Variance $(crimps/cm)^2$	Between-Instrument Variance* $(crimps/cm)^2$	95% Confidence Limit (crimps/cm)
1	4.1	0.0008	0.0001	0.0008	-0.0004	0.0
2	5.4	0.0170	0.0127	0.0170	-0.0022	0.2
3	4.4	0.0074	0.0028	0.0074	-0.0023	0.1
4	4.2	0.0210	0.0223	0.0210	0.0007	0.3
5	4.2	0.0025	0.0165	0.0025	0.0070	0.2
6	3.5	0.0205	0.0005	0.0205	-0.0100	0.2
7	5.1	0.0040	0.0191	0.0040	0.0075	0.2
8	3.3	0.0205	0.0009	0.0205	-0.0098	0.2
9	3.8	0.0008	0.0003	0.0008	-0.0003	0.0
10	3.6	0.0095	0.0002	0.0095	-0.0046	0.1
11	2.8	0.0083	0.0006	0.0083	-0.0039	0.1
12	2.6	0.0363	0.0201	0.0363	-0.0081	0.3
13	3.5	0.0034	0.0018	0.0034	-0.0008	0.1
14	5.9	0.3269	0.3228	0.3269	-0.0021	1.1
15	4.2	0.0031	0.0104	0.0031	0.0037	0.2
16	3.0	0.0140	0.0089	0.0140	-0.0025	0.2
17	1.7	0.0075	0.0880	0.0075	0.0402	0.4
18	4.7	0.0084	0.0178	0.0084	0.0047	0.2
19	3.7	0.0024	0.0006	0.0024	-0.0009	0.1
20	3.0	0.0096	0.0362	0.0096	0.0133	0.3
21	4.1	0.0053	0.0113	0.0053	0.0030	0.2
22	3.3	0.0010	0.0044	0.0010	0.0017	0.1
23	3.0	0.0141	0.0003	0.0141	-0.0069	0.2
24	5.1	0.0268	0.0471	0.0268	0.0102	0.4
25	4.8	0.0069	0.0111	0.0069	0.0021	0.2
26	5.8	0.0079	0.0069	0.0079	-0.0005	0.2
27	2.9	0.0108	0.0070	0.0108	-0.0019	0.2
AVG	**3.91**	**0.0221**	**0.0248**	**0.0221**	**0.0014**	**0.30**

The average 95% Confidence limit was ± 0.30 crimps/cm and the average within and between Instrument variance estimates were 0.0221 $(crimps/cm)^2$ and 0.0014 $(crimps/cm)^2$ respectively.