



INTERNATIONAL WOOL TEXTILE ORGANISATION

TECHNOLOGY & STANDARDS COMMITTEE

ISTANBUL MEETING

Commercial Technology Forum

November 2003

Chairman: A.G.DE BOOS (Australia)

Report No: CTF 03

Measurement of Staple Crimp Frequency.
Part 3: The Crimp Meter – Initial Evaluation.

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SUMMARY

In this Performance Trial, 27 wool samples were measured by a new instrument “ the AWTA Ltd Crimp Meter” and by the CSIRO Crimp Gauge.. The correlation between results produced by the two techniques was excellent (R value = 0.99, Slope of Geometric Regression = 0.94, and S.E. of Differences = 0.03 crimps/cm). The measurement success rate (76%) was consistent with previous Acceptance Test observations¹.

Measurement of low frequency wool was affected by erroneous detection of fifth harmonics. Unusual features of some staples (e.g. double crimp) also caused some anomalous results.

The precision of the Crimp Meter measurements is level dependent.

At this early stage in the development, Staple Crimp Frequency measurement at ATLAS appears to be feasible.

AIM

The purpose of this trial was to compare measurements made by the Crimp Meter with mean Staple Crimp Frequency values obtained using the manual Crimp Gauge, for a range of Sale Lots.

INTRODUCTION

This is Part 3 in a series of 3 papers examining the measurement of Staple Crimp Frequency. Part 1 reported measurements by the Crimp Gauge². Part 2 described the newly developed “Crimp Meter”¹. In this trial, the Crimp Meter is used to measure the staples already tested with the Crimp Gauge.

METHOD

Selection of Wool Samples

Twenty seven (27) Display Samples from Fleece Lots were obtained from around Australia. The target parameters were 9 lots from each of the 3 main selling Regions (i.e. Northern, Southern and Western), with 3 fine (<18µm), 3 medium (21µm - 25µm) and 3 coarse (>30µm). Within the fineness groupings, low, medium and high yielding lots were represented.

There was difficulty in sourcing fine wools from Fremantle; the shortfall was made up with extra samples from Sydney.

Tufts were drawn from each Display Sample³ and staples prepared using the procedures outlined in IWTO-7-00 (i.e. Mechanical Tuft Sampling followed by Staple Preparation using 4 operators). Each tray of staples was conditioned⁴ then covered to await measurement. The covering of the staples was designed to minimise the disturbance of the staples prior to measurement.

Crimp Gauge Measurements

CSIRO Crimp Gauge measurements determined as reported in Part 1² were used as the primary reference measurements for the purposes of this trial.

Crimp Meter Measurements

Three AWTA Ltd operators were trained to use the Crimp Meter. Pre-measurement checks including adjustment of illumination and recording the images of Calibration Patterns were performed by technologists prior to each work session. The voltage supplied to the light was adjusted so that a grey Working Tile would produce a mean result of 157.32 ± 0.25 greyscale units at the commencement of the work session.

Each staple was placed on the ATLAS feed belt by hand. The feed belt was run until the first staple dropped onto the stationary length belt. This staple could be observed on the PC monitor for the Crimp Meter. An image of the staple was recorded, and the length belt was run to remove the staple from the enclosure. The staple was returned to its tray rather than continuing on the ATLAS and being broken.

All the Lots were measured twice, with measurement of the second replicate commencing only after all the staples from the measurement of the first replicate were completed.

In normal ATLAS operation, a very small proportion of staples are caught on the feed belt photocell mounting plate and do not fall onto the length belt correctly. This generates a "Halt", requiring operator intervention. In anticipation of this possibility, or in the event that the staple landed on the length belt at an extreme angle, the operator was permitted to judge whether the staple required re-positioning prior to recording the staple image. A feature of the Crimp Meter software permitted those instances to be flagged.

Analysis

The analysis firstly compared the Crimp Gauge and Crimp Meter results, then examined data for outlier staples and/or Sale Lots, and the between-staple variation within a lot and the between-replicate variation.

RESULTS & DISCUSSION

Averaging Crimp Meter Results

With each successful measurement, the Crimp Meter recorded one or two dominant frequencies from that portion of the staple falling within the Field of View. When two were recorded, the arithmetic mean of these was used to represent the staple for that measurement.

The Crimp Meter made 3528 measurements. 70 % produced a single peak. For 12 %, two frequencies were recorded. For the remainder, no result could be recorded.

On 9 occasions (0.3% of all measurements), the staple did not fall onto the length belt properly, requiring the operator to re-position the staple as described above.

The Crimp Frequency by the Crimp Meter for each staple was evaluated by taking the average of the two replicates. The arithmetic mean of the individual staple results was calculated to represent the Crimp Frequency of the sale lot.

Comparison of the Crimp Meter and the CSIRO Crimp Gauge

The Crimp Meter and CSIRO Crimp Gauge results for each lot were compared using the techniques described in IWTO-0-00 Appendix B⁵. Results are shown in Tables 1 and 2, Figures 1 and 2.

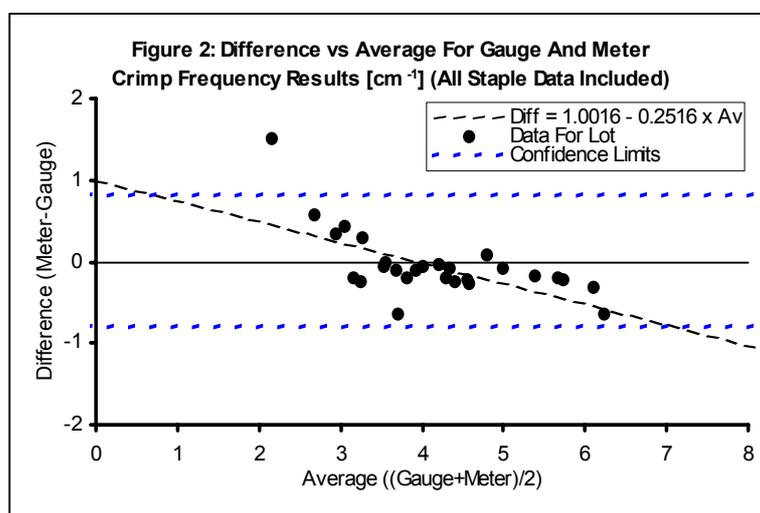
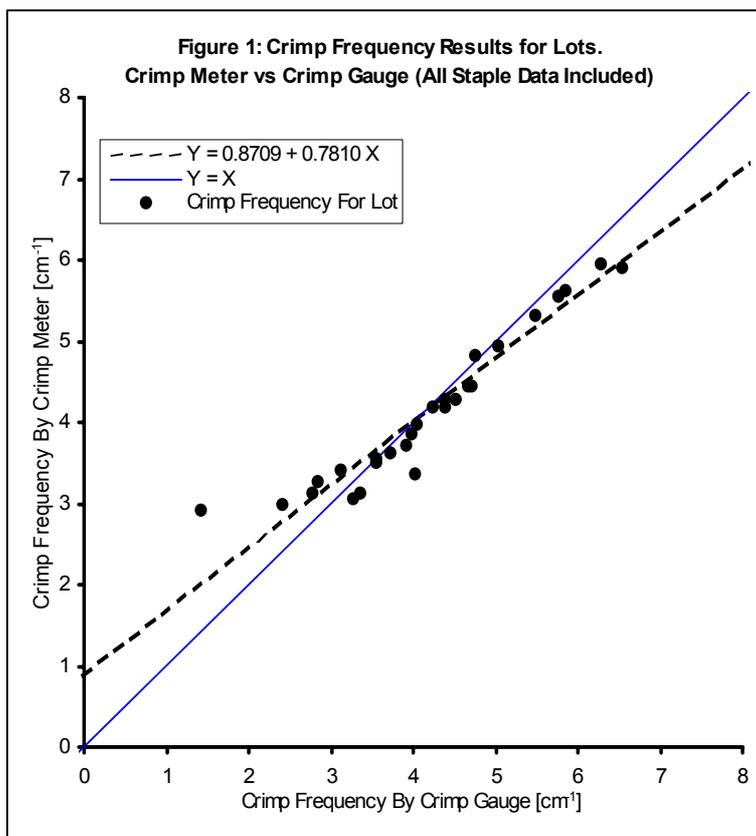
Table 1: Crimp Frequency Results for Lots

Lot	Crimp Gauge Reference Values (crimps/cm)	Crimp Meter Results for Lots			
		All Data (crimps/cm)	Difference from CSIRO Crimp Gauge (crimps/cm)	Outlier Staples Removed (crimps/cm)	Difference from CSIRO Crimp Gauge (crimps/cm)
1	4.4	4.2	-0.2	4.2	-0.2
2	5.9	5.6	-0.2	5.6	-0.2
3	4.7	4.4	-0.3	4.4	-0.3
4	4.7	4.5	-0.2	4.7	0.0
5	4.5	4.3	-0.3	4.4	-0.2
6	4.0	3.4	-0.6	3.6	-0.4
7	5.5	5.3	-0.2	5.2	-0.3
8	3.6	3.5	0.0	3.5	0.0
9	4.0	4.0	-0.1	3.9	-0.2
10	3.9	3.7	-0.2	3.7	-0.3
11	2.8	3.1	0.3	2.9	0.1
12	2.4	3.0	0.6	2.3	-0.1
13	3.7	3.6	-0.1	3.5	-0.2
14	6.5	5.9	-0.6	5.9	-0.6
15	4.4	4.3	-0.1	4.1	-0.3
16	3.3	3.1	-0.2	3.2	-0.1
17	1.4	2.9	1.5	1.4	0.0
18	4.7	4.8	0.1	4.9	0.1
19	4.0	3.9	-0.1	3.8	-0.2
20	3.1	3.4	0.3	3.2	0.0
21	4.2	4.2	0.0	4.2	0.0
22	3.6	3.5	-0.1	3.4	-0.1
23	3.4	3.1	-0.2	3.1	-0.3
24	5.8	5.6	-0.2	5.6	-0.2
25	5.0	4.9	-0.1	5.0	0.0
26	6.3	5.9	-0.3	6.1	-0.1
27	2.8	3.3	0.4	2.9	0.1
Mean	4.2	4.1	0.0^{NS}	4.0	-0.1^{***}
St Dev	1.2	0.9	0.4	1.1	0.2
St Error	0.2	0.2	0.1	0.2	0.0

**Table 2: Staple Crimp Frequency Results by Lot (all staple data included).
Summary of Statistical Data from Regression Analysis**

Statistic	Regression Type	
	Geometric Mean	Difference vs Average
Estimated Slope	0.7810	-0.2516
Standard Error of Slope	0.0468	0.0604
Significance of Slope: t-Value	4.6777	-4.1656
Significance	***	***
Significance of Correlation R-value	0.9540	0.6401
t-Value	15.9177	4.1656
Significance	***	***

The Mean Difference of -0.04 crimps/cm (Table 1) suggested an excellent match between the two methods. A t-value of -0.527 indicated that the difference is not significantly different from zero at the 5.0 % probability level. However, the plot of Differences vs Averages (Figure 2) revealed a strong level dependence and a regression heavily affected by one outlier.



Removal of Outlier Staples

The Crimp Gauge measurements were based upon a regime of retesting in cases where replicates differed by ≥ 1.5 crimps/cm. No retests were carried out for the Crimp Meter measurements. A comparison of the results for lots (Table 2, Figures 1 and 2) suggested that anomalous data for individual staples could be affecting the means. The low frequency crossbred Lot 17 was seriously affected. The notion was confirmed by examining histograms of staple data, and distribution statistics.

Early attempts to identify outlier Crimp Meter measurements within lots using the observed standard deviation were unsuccessful, with problem lots having an overly high standard deviation. Ultimately Tukey’s method ⁶ was applied to identify Crimp Meter measurement outliers on an individual measurement basis. The first and third quartiles (Q1 & Q3) for each lot’s distribution of results was determined, and the range Q1-1.5(Q3-Q1) to Q3+1.5(Q3-Q1) was deemed the “non-outlier zone”.

The values for the No-Outlier Ranges showed that this was ineffective at both ends for the double-crimped Lot 14, and at the low end for the crossbred Lot 17.

The effect on means of removing outlier results was minor for most lots, but Lot 12 and Lot 17 did move substantially (Table 1). Examination of the Frequency Domain FFT images of the outlier staples for Lot 17 (as per Figure 4 of Part 2 ¹) showed that rather obscure minor peaks, perhaps representing the fifth harmonic of the true result in both frequency and direction, produced the anomalous high results. The Crimp Meter software can discern second and third harmonics, but at this stage has not been designed to deal with fifth, seventh and higher primes.

Images of staples producing bad low frequency results in other lots were examined. They tended to be either staples of very poor Crimp Definition, or staples that fell onto the length belt at an extreme angle, outside the designed operating range.

The use of the Inter-Quartile Range technique may be used to prevent outliers corrupting Lot Means in the commercial implementation of the Crimp Meter.

A count of outliers permitted an Accepted:Rejected ratio to be evaluated for the trial measurements. The outcome, 76:24, is not far from the results of the Acceptance Test ¹ (77:23), although that used a different outlier check. Of the 24% rejected, approximately 1% were rejected in the Image Processing step prior to Image Analysis. The rejected images took around 25 seconds to process. Any delay generated by a small subset of staples will need to be accommodated in commercial testing.

Comparison of The Crimp Meter and the CSIRO Crimp Gauge – Outliers Removed

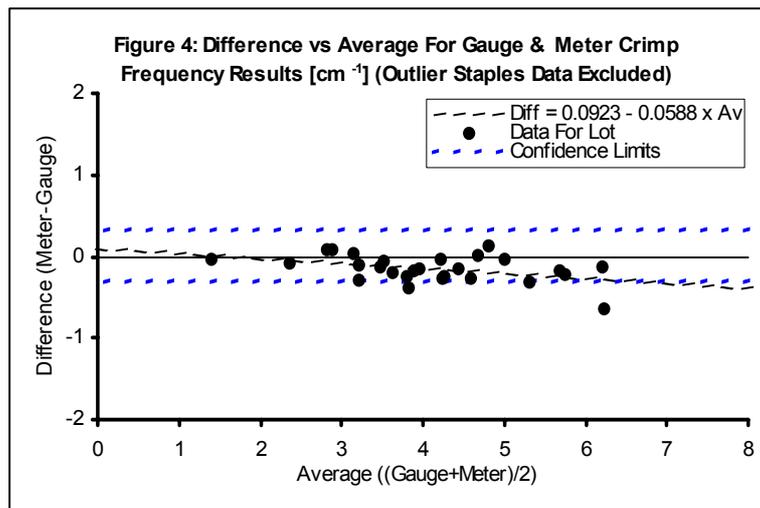
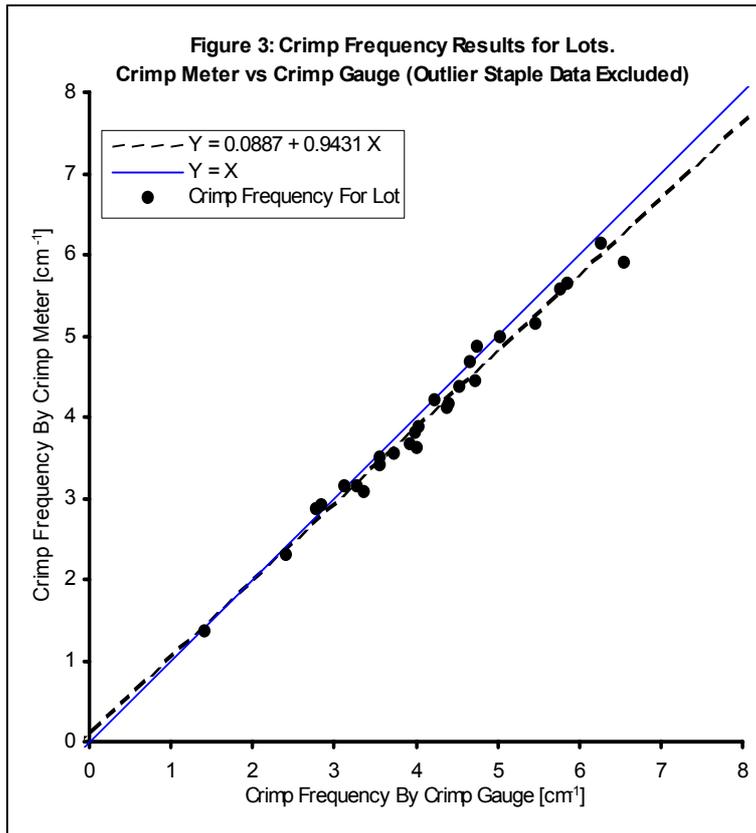
The comparison of results was repeated using the outlier-free data (Tables 1 and 3, Figures 3 and 4). The Mean Difference moved from -0.04 crimps/cm to -0.15 crimps/cm, the Standard Deviation of Differences changed from 0.41 crimps/cm to 0.16 crimps/cm, and the associated Standard Error of the mean from 0.08 crimps/cm to 0.03 crimps/cm. The Mean Difference had a t-value of -4.691, which indicated that the difference is significantly different from zero at the 0.1 % probability level. The result for the double-crimped Lot 14 has had a minor effect on the regression outcomes.

An excellent correlation between the Crimp Meter and the Crimp Gauge results was achieved (Table 3, Figure 3). Although the Mean Difference for the paired data, -0.15 crimps/cm, was statistically significant ($\alpha = 0.001$), the R value of 0.99, Slope of 0.94 and Standard Error of Slope (0.02) are strongly encouraging outcomes.

Neither the Crimp Gauge nor the Crimp Meter is a well established, frequently used technique. Whilst the CSIRO Crimp Gauge has existed for several years, its use within AWTA Ltd until now was rare and the operators involved were newly trained. The Crimp Meter was being used for the first time, making the close match between the results even more encouraging.

**Table 3: Staple Crimp Frequency Results by Lot (outlier crimp meter measurements excluded).
Summary of Statistical Data from Regression Analysis**

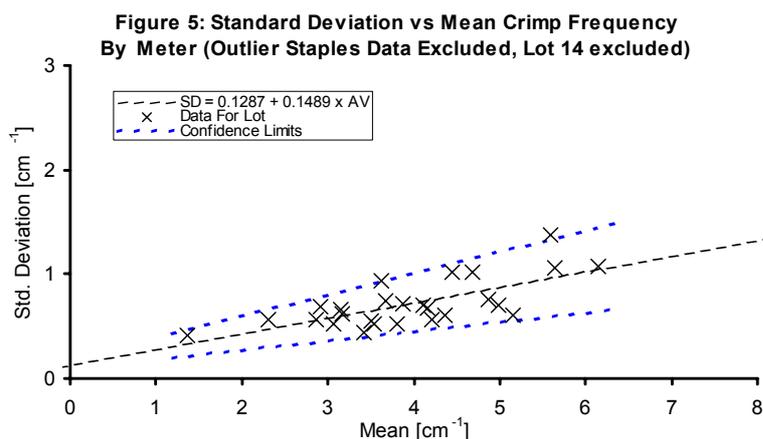
Statistic	Regression Type	
	Geometric Mean	Difference vs Average
Estimated Slope	0.9431	-0.0588
Standard Error of Slope	0.0243	0.0258
Significance of Slope:	t-Value	-2.3429
	Significance	*
Significance of Correlation	R-value	0.4143
	t-Value	38.5345
	Significance	***



Sale Lot with Overlaid Crimp

Lot 14 produced the largest difference between methods (-0.6 crimps/cm). If that data pair is excluded from the analysis, the Geometric Regression becomes “Crimp Meter = 0.0000 + 0.9682 x Crimp Gauge”, and the Geometric Mean slope, the Difference vs Average regression slope and correlation all become not significant ($\alpha = 0.05$). Staples in Lot 14 exhibited a double, overlaid crimp, with two ripples (7 crimps/cm and 2 crimps/cm) running along the length of the staples. The retest rules for the Crimp Gauge meant that several staples from this lot were retested because one operator had opted for the low frequency and the other the higher choice. When any staple with overlaid crimp was retested because the difference in Crimp Frequency measured by the two operators was >1.5 crimps/cm, the higher Crimp Frequency was chosen. There was no retest procedure for the Crimp Meter and the spread of data made the outlier detection procedure ineffective for this lot. For these reasons, the difference is not surprising.

Between Staple Variation of Crimp Frequency within a Sale Lot



The within lot Standard Deviation data was regressed against the Means (Figure 5). The Standard Deviation for the double-crimped Lot 14 was at odds with the data for the other lots and was excluded from the regression. The between-staple Standard Deviation increased with the Mean Crimp Frequency, with a slope of 0.15 and a correlation coefficient of 0.70.

The 95% Confidence Limit at 2 crimps/cm is $\approx \pm 0.16$ crimps/cm; whilst at 6 crimps/cm it is $\approx \pm 0.39$ crimps/cm.

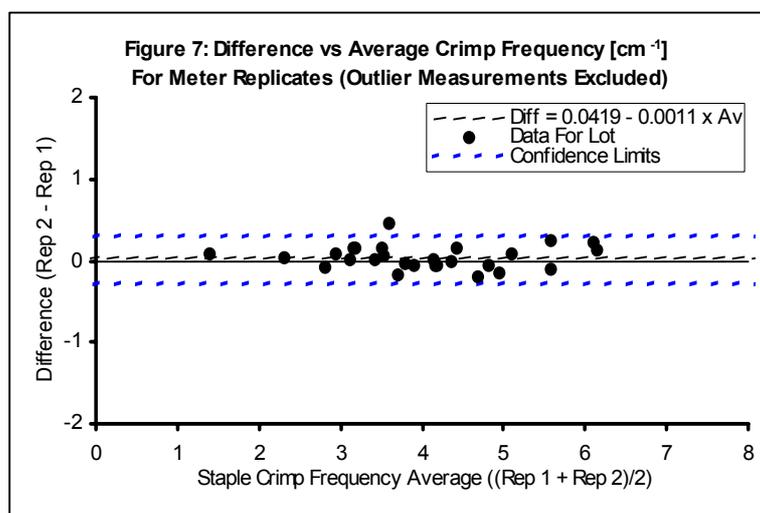
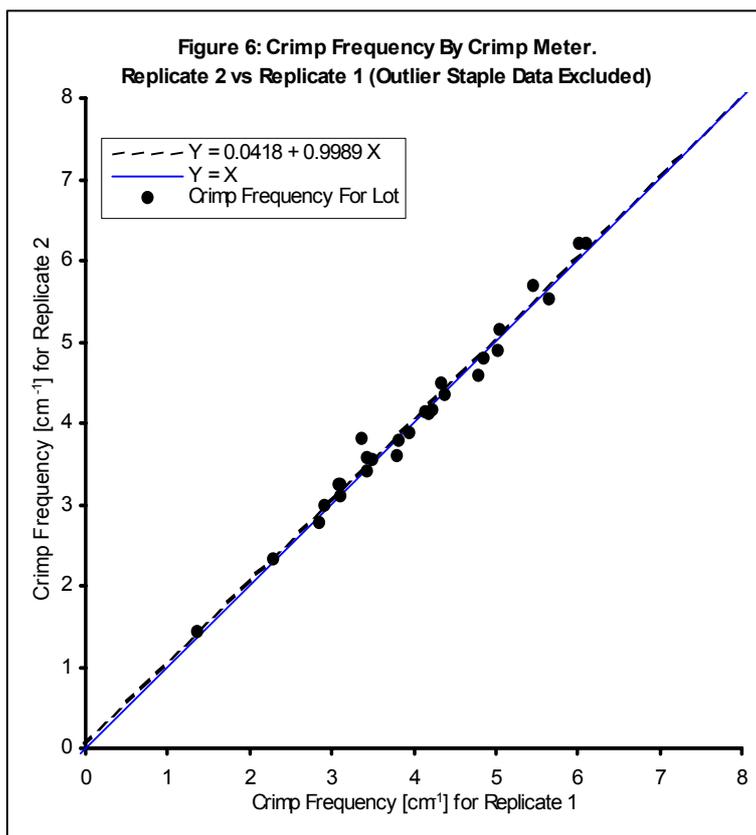
This is based on two (replicate) measurements per staple and has excluded a lot with double (overlaid) crimp. These Confidence Intervals are in good agreement with the theoretical calculation proposed by Tang and Crowe² who estimated the 95% Confidence Interval for a single crimp meter measuring 60 staples as ± 0.19 crimps/cm.

Table 5: Staple Crimp Frequency by Crimp Meter Results for Replicates (outlier crimp meter measurements excluded)

Sample Number	Replicate 2	Replicate 1	Difference (Rep2 – Rep1)	Average
	(crimps/cm)	(crimps/cm)	(crimps/cm)	(crimps/cm)
1	4.1	4.2	-0.1	4.2
2	5.5	5.6	-0.1	5.6
3	4.5	4.3	0.2	4.4
4	4.6	4.8	-0.2	4.7
5	4.4	4.4	0.0	4.4
6	3.8	3.4	0.5	3.6
7	5.1	5.1	0.1	5.1
8	3.6	3.4	0.1	3.5
9	3.9	3.9	-0.1	3.9
10	3.6	3.8	-0.2	3.7
11	2.8	2.8	-0.1	2.8
12	2.3	2.3	0.0	2.3
13	3.6	3.5	0.1	3.5
14	6.2	6.1	0.1	6.2
15	4.1	4.1	0.0	4.1
16	3.2	3.1	0.2	3.2
17	1.4	1.4	0.1	1.4
18	4.8	4.9	-0.1	4.8
19	3.8	3.8	0.0	3.8
20	3.2	3.1	0.1	3.2
21	4.2	4.2	-0.1	4.2
22	3.4	3.4	0.0	3.4
23	3.1	3.1	0.0	3.1
24	5.7	5.5	0.2	5.6
25	4.9	5.0	-0.1	5.0
26	6.2	6.0	0.2	6.1
27	3.0	2.9	0.1	2.9
Mean	4.0	4.0	0.0	4.0
Std Dev	1.1	1.1	0.1	1.1
Std Error	0.2	0.2	0.0	0.2

Table 6: Crimp Meter Results for Replicates – Regression Analysis (outlier crimp meter measurements excluded).

Statistic	Regression Type	
	Geometric Mean	Difference vs Average
Estimated Slope	0.9989	-0.0011
Standard Error of Slope	0.0252	0.0253
Significance of Slope:	t-Value	0.0429
	Significance	NS
Significance of Correlation	R-value	0.9920
	t-Value	39.2913
	Significance	***



Instrument Repeatability

The Crimp Meter results for each Replicate were compared (Tables 5 and 6, Figures 6 and 7).

The Mean Difference of 0.04 crimps/cm had a t-value of 1.360, which indicated that the Mean Difference is not significantly different from zero at the 5.0% probability level. The Standard Deviation of Differences was 0.14 crimps/cm. The regression analyses show that there was no level dependence.

The comparison of replicates with outliers removed demonstrated that the Crimp Meter measurements were consistent over the range of wools measured.

Estimation of the precision of the Crimp Meter requires an assessment of the variance between-laboratories, the variance between-instruments, and the sampling variance. This trial has not covered those areas.

CONCLUSIONS & RECOMMENDATIONS

Automated Staple Crimp Measurement at ATLAS appears feasible.

In the first Performance Trial of a Crimp Meter, the mean results for Lots closely matched those generated by the Reference Method.

Rules to handle unusual staples (e.g. double, overlaid crimps) need to be further developed.

Some changes should be made to improve the measurement of low Crimp Frequency staples by rejecting fifth and higher prime harmonics, and to speed up the Image Processing and Analysis steps.

A larger trial is planned to evaluate the between-laboratory and between-instrument variances and to further test the robustness of the technology.

ACKNOWLEDGEMENTS

The author thanks Dr Trevor Mahar (Research Manager, AWTA Ltd Research & Development) for his assistance in the design of this trial.

The selection of wool samples and the Crimp Gauge measurements were organised by David Crowe (Senior Research Officer, AWTA Ltd Research & Development) and Li Tang (Research Officer, AWTA Ltd Research & Development).

Staffing and equipment for the trial was arranged by Li Tang at AWTA Ltd's Sydney Laboratory. Crimp Meter operation was undertaken by Rosa Roa, Lynne Todorovic and Jason Ding.

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