Cotton Catchment Communities CRC

FINAL REPORT

(due within 3 months on completion of project)

Part 1 - Summary Details

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Cottonspec - Predicting Yarn Performance from Cotton Fibre Quality Parameters

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FINAL REPORT

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1. **Background**
In order to maintain its premium in the world cotton market it will be important for Australia to extend its position as a preferred supplier of high quality fibre. Australian cotton is currently used by spinners for the production of medium-fine yarns, i.e. in the Ne 30 to 40 count range, although efforts are afoot to extend the spinning range of Australian cotton to Ne 50 and 60. Currently it is not easy for spinners to accurately estimate key yarn quality parameters, e.g. yarn evenness and tenacity, in order to estimate the additional value to them of purchasing cottons with incrementally higher fibre quality.

This project has tackled the scientific challenge of predicting the key parameters of interest to the spinning mill manager from fibre quality measurements. The output of the project is a user friendly software package that can be used by spinners to predict the effects on their production of using higher (or lower) quality cotton. The software is potentially an important tool for marketing high quality Australian cotton fibre. For example, it could be used to illustrate quantitatively to a spinner the technical benefits of utilising a new variety of finer, longer cotton, e.g. Sicala 340BRF.

Cotton fibre maturity and fineness (linear density) are two important fibre characteristics affecting cotton yarn quality and spinning performance. CSIRO, in partnership with the CRDC and the Cotton CRC, has developed two new instruments, namely Cottonscan and SiroMat for quick and yet accurate measurements of the two fibre properties[1]. Another outcome of this project is the incorporation of linear density and maturity measurements into the Cottonspec prediction model. It is noted their inclusion the Cottonspec models, particularly of linear density, is solely on the basis of the additional predictive ability they give to any yarn quality prediction model.

Work on this project has occurred in four stages. They have been:
1. Liaison with and collection of industrial spinning data from three leading Chinese cotton spinning mills,
2. Development of a robust mechanistic and statistical model to predict ring spun yarn quality,
3. Validation of the model using Australian cotton and industrial spinning mill data and
4. Incorporation of the prediction models and data into software that can be used by mill and QC managers.

Further validation of the models and software is required before a commercial and release-to-market plan can be developed for the Cottonspec program. To this end a new project in which the current Cottonspec will be tested in five to six overseas (Chinese) mills has commenced.

There are currently no stand-alone, commercial yarn quality prediction programs available largely because modelling of yarn quality has largely centred on purely statistical models that fail in their ability to be applied widely because they overlook the mechanical associations between fibres in a yarn that affect final yarn quality. Cottonspec overcomes the limitations associated with statistical modelling by incorporating the rules of yarn mechanics in the model.

The closest commercial system to the Cottonspec is Cotton Inc.'s Engineered Fibre Selection (EFS) system. The EFS system is a software package used to manage USDA High Volume Instrument (HVI) data and allow optimisation of bale inventory in terms of yarn and process

[1] In June 2010 BSC Electronic P/L (Cottonscope P/L) the company licensed to manufacture the Cottonscan and SiroMat incorporated both measurements into the same instrument now called Cottonscope.

quality. The shortcomings of the EFS system are that it doesn't predict yarn quality and it does not allow for non-USA cotton to be used. Moreover, EFS considers only HVI-measured fibre properties. As many mills use a combination of growths and data to control their laydowns these limitations make the EFS system largely redundant in the day-to-day operation of large spinning mills.

However, aside from these limitations, the EFS system does provide a tool for spinners to manage the average quality (as described by HVI) of their lay-downs and in doing so allows some indirect prediction of yarn quality to be arrived at. The provision and control of the average fibre properties in bale lay-downs allows spinners to better appreciate the consequences of using particular quality cotton in their processing. From this perspective EFS adds value to the use of US cotton by creating the perception that the spinner buying US cotton is in partnership with the US cotton grower.

Project Objectives
The stated objectives of the project and whether they were achieved are listed in Table I below.

Table I – Project objectives, milestones, performance indicators and achievement

Objective	Milestone	Performance Indicator	Achieved
Apply theoretical mechanistic principles of ring spinning of wool to cotton ring spinning incorporating the role of fibre maturity, fineness and the different range of fibre lengths. Validate this model using spinning data collected from participating commercial Chinese mills and CSIRO mill data.	Develop a theoretical mechanistic model of cotton ring spinning (yarn quality and performance).	The role of fibre maturity, fibre fineness and the different range of fibre lengths incorporated into the new model. Prediction algorithms developed based on the new model and utilising the spinning data collected. The results well documented and reported to CRDC and Cotton CRC.	**Yes**
	Collect spinning data from participating commercial mills and CSIRO's mill.	Summary report to CRDC and Cotton CRC detailing the results.	**Yes**
	Validate the new spinning prediction model.	Summary report detailing the validation results. Industrial seminar held in China.	**Yes – numerous seminars held to date within individual spinning mills. Industry-wide seminars planned for 2011 after further validation.**

2. **Methods**

The activities and methods utilized to undertake this work are described in order of the four stages of work listed in the Introduction:

1. Liaison with and collection of industrial spinning data from three leading Chinese cotton spinning mills,
2. Development of a robust mechanistic and statistical model of cotton ring spinning,
3. Validation of the model using Australian cotton and industrial spinning mill data and
4. Incorporating the prediction models and data into a software that can be used by mill and QC managers.

Collection of industrial spin data from three Chinese cotton spinning mills

Cotton fibre samples from mill lay-downs and yarn test data have been supplied by three Chinese partner mills recruited by Dr Shouren Yang prior to June 2008 in lieu of the CRC Cottonspec project beginning. At the time Dr Yang was working on the project 'Enhancing China's capacity for Processing Superfine Australian Wool' as part of the Department of Agriculture, Forest and Fisheries (DAFF) Agricultural Technical Co-operation (ATC) Programme. The spinning mills that have contributed data and fibre and yarn samples since August 2008 are:

- Shandong Demian Incorporated Co., Dezhou Shandong
- Chongqing Sanxia Technology Textile Co. Ltd., Wanzhou District Chongqing
- Wenshang Ruyi Tianrong Textile Co. Ltd., Wenshang Shandong

Figure 1 shows a map of each mill's location in China.

Figure 1 – Stars show location of the current CRC Cottonspec partner mills in Shandong and Chongqing

Drs Yang and Gordon visited the three mills in June 2009, December 2009 and Feb/Mar 2010 in order to give direct updates on project progress, as well as to oversee spinning trials (in Feb/Mar 2010). The mills have been very appreciative of these visits and have continued to provide samples and data in anticipation of a working, validated Cottonspec program.

The visit to China in December 2009 also included first-time visits to a number of other leading cotton spinning mills identified by the China Cotton Textile Association (CCTA).

- *Changshan Hengxin Textiles Co., Shijiazhuang, Hebei*
- *Huamao Textile Co. Ltd., Anqing, Anhui*
- *Luthai Textile Co. Ltd., Zichuan Zibo, Shandong*
- *Huafang Textile Co. Ltd., Zhangjiagang, Jiangsu*

During visits to these mills presentations were made on the Cottonspec model with invitations extended to each mill to participate in validation trials of Cottonspec as part of the new Cottonspec project. Dr Yang also visited these mills again in late June 2010 as part of a trip to fulfil objectives for a number of other projects including the CCC CRC project 4.01.05 Technical support of SiroMat on the Australian Market.

Fibre samples were collected at least weekly by the mills from their lay-downs according to CSIRO's sampling procedure, whereby 10 to 20 grams of cotton are sampled from each bale in the lay-down, with the samples being accumulated separately into their origin. Fibre samples were tested for HVI by the Auscott Classing Office, Sydney NSW and for linear density (Cottonscan), maturity (SiroMat), neps and length (AFIS PRO) in CMSE's Cotton Test Laboratory. In addition, samples of semi-processed mill products, e.g. card, drawn sliver and roving, supplied by the mills were also tested for linear density (Cottonscan), maturity (SiroMat), neps and length (AFIS PRO). Table II list the fibre tests collected for the database.

Table II – Fibre data used in Cottonspec models

Instrument	**Fibre Properties**
High volume instrument (HVI)	Micronaire, length – upper half mean length, uniformity, short fibre content, strength – tenacity and elongation to break, colour – Rd and +b, trash - % trash, classing grade (machine) plus classing grade (classer)
Cottonscan	Linear density (fineness)
SiroMat (Cottonscope)	Maturity and distribution of maturity within sample
Advanced Fibre information System (AFIS)	Nep count, nep size, seed coat nep count and seed coat nep size, length – upper quartile length, mean length, short fibre content by weight and number, trash count, dust count, % trash

Yarn quality measurements included count (linear density), tenacity, elongation, evenness, imperfection counts and twist. These are standard yarn quality parameters that are tested as a matter of course in mills all over the world. Standards are available for each of these tests and as such test results between mills are reasonably comparable.

Later, as the databases for each mill grew large, the data sets were segregated on the basis of their different count and quality ranges, e.g. the quality of fibre and consequently yarn out of Chongqing Sanxia mill was consistently better than the Wenshang Ruyi Tianrong mill. Due to inconsistencies in receiving samples and data from the Shandong Demian mill their samples and data have not been included in the analysis. Table III lists the number of fibre samples collected from bale lay-downs per mill and the associated yarn data sets (weeks) attributable to the fibre samples. A dataset of CSIRO spun yarn from 12 different types of cotton (commercial and new CSIRO varieties) has also been used to assess the goodness of the Cottonspec yarn quality prediction algorithms.

Table III – Collected Fibre-Yarn Databases

Mill	Fibre data (bale lay-downs)	Yarn data (weekly av.)	Yarn count (range)
Chongqing Sanxia Technology Textile Co. Ltd.	442	57 combed	Ne 23 - 80
Wenshang Ruyi Tianrong Textile Co. Ltd	535	66 carded 72 combed	Ne 30 - 40
CSIRO MSE	12	72 carded 72 combed	Ne 30 - 60
Total sets	**989**	**339**	

2.1 Database Considerations

Of the three spinning databases, which could nominally be used for the development of Cottonspec yarn quality prediction algorithms, the first selected option is the Chongqing Sanxia database. This database contains 57 lots of combed weaving and knitting yarn data against 442 lots of raw cotton data. The second option is Wenshang Ruyi Tianrong database, which contains 66 lots of carded yarn data and 72 lots of combed weaving and knitting yarn data against 535 lots of raw cotton data. The third is the CMSE database, which contains 144 lots of carded and combed yarn data against 12 lots of raw cotton data.

A number of criteria are required for the database to represent the full gamut of fibre and yarn interactions. One criterion is that Cottonspec is based on the concept of 'best commercial practice'. That is the practice by which a good modern mill can achieve the best yarn properties and performance for particular cotton. Upon this criterion comparisons show that the spun yarn quality produced at the Chongqing Sanxia mill is better than that produced at both Wenshang Ruyi Tianrong and CMSE.

A second criterion is that the spun yarn is produced from bale lay-downs composed of cottons from various origins and of different properties. On this criterion, the databases of the two commercial mills are better than CMSE. The 144 lots of yarns produced at CMSE were from 12 single albeit diverse cotton lots, while for the two commercial mills the spun yarns were produced from bale lay-downs containing cottons of wide and various origin.

The third selection criterion is the accuracy of the database, i.e. how closely does the fibre data correlate to the yarn data. On this basis the CMSE dataset is more accurate than the two commercial mills, because a wider range of yarns (counts and twist) were produced from single, well described, cotton sources.

However, taking all factors into account the Chongqing Sanxia mill database was selected as the best for developing the Cottonspec prediction algorithms. Table IV lists the yarn counts and types included in the Chongqing Sanxia database. However, having selected the Chongqing Sanxia mill database, points also need to be made about the shortcomings associated with it, which has caused some issues in the development of the prediction algorithms.

Table IV – Chongqing Sanxia spinning database where JC = combed, CF = condensed spinning, K = knit yarn and B, C, D stands for different yarn types.

Yarn count	Yarn type	Lots	Subtotal
Ne 80	CF	2	2
Ne 50	CF	18	27
	JC	7	
	JCK	2	
Ne 40	JCB	2	24
	JCC	2	
	JCD	4	
	JCK	16	
Ne 32	CF	2	2
Ne 23	CF	2	2
Total			**57**

There are some drawbacks associated with the use of the Chongqing Sanxia mill database. The 57 lots of yarns in the database can be divided into 5 subgroups according to their yarn count. Fifty-one of the lots fall into Ne 50 or Ne 40 count yarns. The Ne 50 count group consists of 18 lots of condensed spun yarn lots and 9 lots of standard ring spun yarn lots. There are large differences in yarn quality between these yarns and their inclusion as a single lot means the influences of fibre properties on yarn quality may well be overshadowed somewhat by the effect of the spinning method.

Furthermore, the 24 lots of Ne 40 count yarns are all standard ring spun yarns with two thirds of knitting yarns and one third of weaving yarns. Knitting yarns have significantly lower yarn tenacity and elongation due to low twist factors.

There is also the issue that because the yarn count range is narrow, it is difficult to model the affect of the number of fibres in the yarn cross section on yarn quality. Thus, it is difficult to develop a good yarn evenness prediction model employing spinning draft theory using the Chongqing Sanxia mill database. A similar constraint is applied by the near constant twist factor used in continuous production.

However, to some extent these shortcomings can be overcome by further building the database and by testing and validating the algorithms using data from purposely designed spinning trials in the same mill (see below). To this end, the project leaders have built a very good relationship with the Chongqing Sanxia staff, who have made data and samples consistently available.

2.2 Properties of raw cotton used at Chongqing Sanxia mill

Descriptive statistics and identifications given to the fibre properties measured and used in the Chongqing Sanxia mill database for the Ne 50 and Ne 40 yarn counts are listed in Table V. High volume instrument (HVI) measurements were made both in Australia at the Auscott Classing Offices (with prefix H) and in the mill in China (with prefix M). Other Chinese-based measurements performed by the mill are also given the prefix M. Advanced Fiber Information System (with prefix A where same tests are also made by HVI) and Cottonscan tests (with prefix C) where made at CSIRO Cotton Test Laboratories.

Table V – Descriptive statistics of fibre properties in the Chongqing Sanxia database

	Ne 50				Ne 40			
	Mean	SD	Min	Max	Mean	SD	Min	Max
HVI & Chinese standard tests - mill								
MMFL (mm)	28.5	0.41	28	29.2	28.3	0.5	27.4	29.1
MFLD	5828	215	5509	6202	5784	249	5479	6138
MMic (ug/inch)	4.16	0.25	3.74	4.52	4.2	0.3	3.78	4.56
MFT (g/tex)	31.5	0.96	29.8	32.9	28.9	1.7	25.9	32.9
MUHML (mm)	29	0.58	27.7	29.6	28.7	0.5	27.9	29.7
MLU (%)	81.8	1.65	74.3	82.9	81.7	0.6	80.1	82.6
MSFC (%)	17.8	1.51	14.6	20.2	19.2	2.3	15.4	23.4
MNep count	845	166	559	1100	705	196	430	1118
HVI – Auscott Classing Offices								
HUHML (mm)	28.7	0.43	27.7	29.5	28.7	0.9	26.6	29.8
HLU (%)	82.6	0.46	81.2	83.3	81.9	1.9	75.7	84
HSFC (%)	9.2	0.79	8.05	11.1	9.26	0.8	7.88	11.4
HFT (g/tex)	31.9	1.43	28.7	34.1	30	1.8	26.7	33.4
HFE (%)	7.05	0.82	5.13	7.9	6.96	0.6	6.01	8.1
HFT*FE	225	30.8	157	268	208	26.1	178	262
HMic (ug/inch)	4.18	0.18	3.82	4.51	4.12	0.3	3.63	4.52
HMR	0.86	0.006	0.85	0.87	0.85	0.0	0.8	0.87
Cottonscan - CSIRO								
CFLD (mtex)	197	7.63	181	209	202	9.4	182.8	219.4
AFIS - CSIRO								
ANep (count/g)	303	31.8	268	377	289.5	26.4	235	342
L(w) (mm)	25.5	0.53	24.3	26.4	25.4	0.8	23.5	26.6
CVL(w) (%)	33	1.15	31.2	35.3	33.4	1.1	31.5	35.3
SFC(w) (%)	7.31	0.87	6.25	9.5	7.7	1.0	5.96	10.1
L(n) (mm)	21.4	0.58	20	22.1	21.1	0.9	19.1	22.5
CVL(n) (%)	44.1	1.69	41.3	46.9	45.3	2.1	42	48.8
SFC(n) (%)	20.4	1.92	17.7	24.6	21.6	2.4	17.2	26.6
AFLD (mtex)	166	6.61	157	177	165	7.1	150	179
IFC (%)	5.71	0.82	4.11	6.89	6.03	0.9	4.54	7.63
AMR	0.94	0.02	0.9	0.98	0.92	0.03	0.86	0.98
Twist Factor - mill								
TF	406	8.1	397	422	373	15.4	362	394

MMFL = mill mean fibre length, MFLD = mill fibre linear density, MMic = mill HVI Micronaire, MFT = mill HVI fibre tenacity, MUHML = mill HVI upper half mean length, MLU = mill HVI length uniformity, MSFC = mill HVI short fibre content[2], MNep = mill manual count of neps in an opened sliver sample

HUHML = HVI upper half mean length, HLU = HVI length uniformity, HSFC = HVI short fibre content, HFT = HVI fibre tenacity, HFE = HVI fibre elongation, HFT*FE = work or energy to break calculated from HVI tenacity and elongation measurements, HMic = HVI Micronaire, HMR = HVI maturity ratio[3]

CFLD = Cottonscan fibre linear density

[2] The short fibre measurement in HVI instruments in China is calibrated to give the percent fibres less than 16 mm rather than the percent fibres less than 12.5 mm in HVI machines elsewhere.

[3] HVI maturity ratio measurements are not considered sensitive to real changes in fibre maturity

ANep = AFIS nep count, L(w) = AFIS mean length by weight, CVL(w) = AFIS coefficient of variation in mean length by weight, SFC(w) = AFIS short fibre content by weight, L(n) = AFIS mean fibre length by number, CVL(n) = AFIS coefficient of variation in mean length by number, SFC(n) = AFIS short fibre content by number, AFLD = AFIS fibre linear density, IFC = AFIS immature fibre count, AMR = AFIS maturity ratio,

TF = twist factor

It is seen from Table V that the Ne 40 fibre results are more variable, i.e. have a wider range of values than the Ne 50 results, for a number of fibre properties, including mean length, SFC, length uniformity, tenacity and elongation, maturity, Micronaire, nep count and twist factor. This reflects the improvement in fibre quality demanded by the finer count yarns. It is expected that because of this wider range the correlations with yarn properties for the Ne 40 yarns are likely to be more significant than for the Ne 50 yarns.

It may also be seen that SFC, tenacity and elongation, nep count, immature fibre content (IFC) are more variable while mean length, linear density, length uniformity and the coefficient of variation in length are less variable. This suggests that the Ne 40 database may show stronger correlations with yarn quality than the Ne 50 database.

3. Results and Discussion

3.1 Single predictor model regression analysis

Yarn evenness

Correlations between yarn evenness and similar single fibre properties are shown in Tables VI to X for the two groups of Ne 50 and Ne 40 yarns. Due to the small size of the subsets (Ne 40 and Ne 50) the correlation coefficients of determination are typically not large, so the probability of linearity in the function is used to qualify the significance of the relationships.

Table VI – Correlations of mean fibre length with yarn evenness

		MFL	MUHML	MLU	HUHML	HLU	L(w)	L(n)
Ne 50	R^2(%)	42.2	26.5	2.0	0.0	7.8	0.1	25.0
	p	*0.00*	*0.00*	*0.23*	*0.44*	*0.09*	*0.32*	*0.01*
Ne 40	R^2(%)	14.3	16.5	23.3	10.8	3.0	15.4	7.3
	p	*0.04*	*0.03*	*0.01*	*0.07*	*0.21*	*0.03*	*0.11*

It is seen from Table VI that mill measured mean fibre length (MFL) and upper-half-mean length (MUHML) and AFIS length L(n) have significant correlations with yarn evenness for both Ne 50 and Ne 40 yarns. Length uniformity measured by the mill (MLU) and by HVI at Auscott (HLU) was also significantly correlated with yarn evenness.

Table VII – Correlations of SFC and length variations with yarn evenness

		MSFC	HSFC	SFC(w)	CV L(w)	SFC(n)	CV L(n)
Ne 50	R^2(%)	0.0	26.1	33.4	30.2	40.8	38.1
	p	*0.60*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Ne 40	R^2(%)	11.1	27.5	9.4	4.9	6.7	1.6
	p	*0.06*	*0.01*	*0.08*	*0.15*	*0.12*	*0.25*

The data in Table VII shows that SFC measured by HVI (HSFC) and AFIS (SFC(n) and SFC(w)) correlates strongly with yarn evenness although mill's SFC does not show this correlation for Ne 50 yarns. The correlation is generally better for the Ne 50 (finer count) yarn.

Table VIII – Correlations of fibre linear density with yarn evenness

		MFLD	CFLD	AFLD
Ne 50	R^2(%)	18.1	2.1	6.5
	p	*0.02*	*0.23*	*0.11*
Ne 40	R^2(%)	0.0	0.0	Wrong info
	p	*0.99*	*0.36*	

It is seen in Table VIII that fibre linear density measured by the mill (MFLD), Cottonscan (CFLD) and AFIS (AFLD) all correlate moderately with yarn evenness for Ne 50 yarns, although this correlation is not shown for Ne 40 yarns. From yarn evenness theory, fibre linear density is an important factor contributing to yarn evenness, which is largely determined by the number of fibres in the yarn cross-section. However, for the two databases yarn linear density is a constant and the variations in fibre linear density between lay-downs are small, with a coefficient of variation of around 4% (see Table V). This consistency is a reflection of the Chongqing Sanxia mill's diligence in quality control, i.e. consistent yarn quality relies on consistent fibre quality. Furthermore, the big differences in yarn properties caused by difference yarn types, i.e. standard ring spun vs. compact spun yarn, within each of the two yarn count groups also overshadow the effect of fibre linear density on yarn evenness.

Table IX – Correlations of fibre tenacity and elongation with yarn evenness

		M-FT	HVI-FT	HVI-FE	HVI-FT*FE
Ne 50	R^2(%)	30.6	5.6	15.5	17.9
	p	*0.00*	*0.08*	*0.21*	*0.02*
Ne 40	R^2(%)	1.5	41.6	44.1	58.6
	p	*0.27*	*0.00*	*0.00*	*0.00*

The data shown in Table IX demonstrate that fibre tenacity and elongation have very strong correlations with yarn evenness for both groups, though arguably the correlations are even stronger for Ne 40 yarns than for Ne 50 yarns. This can be explained by the fact that the influences of fibre properties in the Ne 50 database are overshadowed, to some extent, by the effect of spinning methods for this group, and by the weighting of knit yarns vs. woven yarns in the set. High quality cotton knit yarn relies to a greater extent on the tensile properties of the fibre. The data also suggests that fibre tenacity measured by the mill may subject to greater errors.

The strong influences of tenacity and elongation on yarn evenness are mainly due to the fibre breakage mechanisms in spinning, particularly during carding, where a large amount of weaker fibres are broken, resulting in a significant increase in SFC and a subsequent reduction in mean fibre length.

It is interesting to note in Table IX, that elongation has a stronger correlation with yarn evenness than tenacity, and the product of tenacity and elongation (breaking energy) has an even strong a correlation with yarn evenness for both Ne 40 and Ne 50 yarns. This indicates that for cotton spinning, fibre elongation is more important than tenacity as far as yarn quality and spinning performance is concerned. This is due to the fact that cotton fibre tenacity is quite strong (about 3 times of wool fibre tenacity) but its elongation is relatively much lower (only about 1/10 -1/7 of wool fibre elongation). A small decrease, say 1%, in fibre elongation leads to a significant decrease in both yarn tenacity and elongation according to yarn mechanics theory.

The results in Table IX provide good evidence that the breaking energy of the fibre is a better predictor of yarn evenness for cotton spinning than either fibre tenacity or elongation alone. This is simply because it is fibre breaking energy that determines the chance of fibre breakage in processing, e.g. carding, rather than fibre tenacity or elongation alone. However, the application of this property to yarn quality prediction has not been widely applied because of the lack of a HVI calibration for fibre elongation.

Table X – Correlations of Micronaire, maturity, and neps with yarn evenness

		M-Mic	H-Mic	H-MR	M-Nep	A-NEP
Ne 50	R^2(%)	14.0	0.0	0.0	0.0	7.0
	p	*0.03*	*0.98*	*0.64*	*0.54*	*0.10*
Ne 40	R^2(%)	0.0	0.0	0.0	Wrong info	4.0
	p	*0.95*	*0.52*	*0.91*		*0.18*

The data in Table X suggests that Micronaire and fibre maturity have essentially no influence on yarn evenness. Interestingly, AFIS nep count showed some influence on yarn evenness for both Ne 40 and Ne 50 yarns. But, mill measured nep count did not show any correlations with yarn evenness, most likely due to large measurement errors. The authors note the mill nep measurement test relied on an operator combing a sliver piece and counting neps manually without magnification.

In summary, the results of single predictor regression analysis show that fibre breaking energy is the most important cotton fibre property contributing to yarn evenness, followed by SFC and mean fibre length. According to yarn evenness theory linear density should also have important contributions to yarn evenness, but this is not clearly seen with the single variable analysis method because of the relatively small size and limitations of the spinning database. Micronaire and fibre maturity have essentially no influence on yarn evenness. The AFIS nep count had some influence on yarn evenness.

Yarn tenacity

Correlations between yarn tenacity and single fibre properties are shown in Tables XI – XV.

Table XI – Correlations of fibre length with yarn tenacity

		MFL	MUHML	MLU%	HUHML	HLU%	L(w)	L(n)
Ne 50	R^2(%)	29.9	3.8	0.0	16.3	2.7	34.5	6.8
	p	*0.00*	*0.17*	*0.87*	*0.02*	*0.20*	*0.00*	*0.10*
Ne 40	R^2(%)	0.0	0.0	44.9	5.8	11.6	18.3	32.9
	p	*0.34*	*0.46*	*0.00*	*0.13*	*0.06*	*0.02*	*0.00*

The data in Table XI shows that mean fibre length (and UHML) have strong influences on yarn tenacity. Length uniformity also shows some influence. For Ne 40 yarns mill measured mean fibre length (MHMFL) and upper-half-mean-length (MUHML) did not correlate, although this is likely to be due to the large errors associated with these measurements. The data suggests that AFIS fibre length is more closely correlated to yarn tenacity for both groups of yarns.

Table XII – Correlations of SFC and length variations with yarn tenacity

		M-SFC	HVI-SFC	SFC(w)	CV% L(w)	SFC(n)	CV% L(n)
Ne 50	R^2(%)	14.8	0.0	0.0	0.0	0.0	0.0
	p	*0.03*	*0.43*	*0.40*	*0.96*	*0.91*	*0.39*
Ne 40	R^2(%)	55.4	30.4	23.1	4.9	26.1	17.6
	p	*0.00*	*0.01*	*0.01*	*0.15*	*0.01*	*0.02*

It is seen from Table XII that for Ne 40 yarns, SFC and the coefficient of variation of length have very strong influences on yarn tenacity. But no such correlations are shown for Ne 50 yarns. As mentioned earlier that this could well be due to the following two reasons. Firstly, variations in SFC and coefficient of variation of fibre length are greater for Ne 40 yarns than for Ne 50 yarns (see Table V). Secondly, the strong effect of the spinning methods for Ne 50 group may overshadow the effect of fibre properties on yarn quality.

Table XIII – Correlations of fibre linear density with yarn tenacity

		MFLD	CFLD	AFLD
Ne 50	R^2(%)	0.0	14.1	0.0
	p	*0.62*	*0.03*	*0.01*
Ne 40	R^2(%)	0.0	4.9	Wrong info
	p	*0.82*	*0.15*	

According to yarn mechanics theory fibre linear density has significant influence on yarn tenacity through both its influence on yarn evenness and the yarn helical structure. However, the data in Table XIII only shows weak correlations between linear density measured by Cottonscan and yarn tenacity. Fibre linear density measured by mill (MFLD) and AFIS (AFLD) do not show any correlations. This could be due to a combined effect of small variations in fibre linear density (about 4%) and the strong effect of spinning methods for Ne 50 yarns, which may overshadow the effect of fibre properties on yarn quality.

Table XIV – Correlations of fibre tenacity and elongation with yarn tenacity

		M-FT	HVI-FT	HVI-FEL	HVI-FT*EL
Ne 50	R^2(%)	0.0	0.0	0.0	0.0
	p	*0.47*	*0.39*	*0.79*	*0.97*
Ne 40	R^2(%)	0.0	53.4	19.2	48.7
	p	*0.66*	*0.00*	*0.02*	*0.00*

The data shown in Table XIV is very interesting. Firstly, it shows that for Ne 40 yarns there are very strong correlations between yarn tenacity and fibre tenacity and elongation, measured by HVI. But no correlations are shown for Ne 50 yarns. This has confirmed the assumptions made earlier that the strong effect of spinning methods has overshadowed the effect of fibre properties on yarn properties for Ne 50 yarns.

Table XV – Correlations of Micronaire, maturity, and neps with yarn tenacity

		M-Mic	H-Mic	H-MR	AMR	IFC %	MNep	ANep
Ne 50	R^2(%)	0.0	12.1	23.5	0.6	0.0	10.2	Wrong info
	p	*0.42*	*0.04*	*0.01*	*0.29*	*0.44*	*0.06*	
Ne 40	R^2(%)	0.0	0.0	0.0	6.1	0.0	Wrong info	0.0
	p	*0.80*	*0.42*	*0.54*	*0.13*	*0.44*		*0.86*

Similar to the situation for yarn evenness discussed earlier, data in Table XV demonstrates that Micronaire has no significant bearing for yarn tenacity. Fibre maturity has some influences on yarn tenacity. Nep count, measured either by the mill or AFIS, does not show any clear link with yarn tenacity.

In summary, single predictor analysis shows that fibre tenacity, SFC and mean fibre length are the three most important factors contributing to yarn tenacity. Fibre linear density and maturity also have some influence on yarn tenacity. Micronaire has no significant bearing on yarn tenacity.

It has to be emphasized that these conclusions are drawn based on the two small spinning databases. The effects of some fibre properties on yarn evenness, in particular fibre linear density, are not clearly seen due to the limitations of the database mentioned earlier. Some of these shortcomings of the database can be overcome by using multiple regression techniques, which can adjust the relative importance of each factors contributing to yarn quality, including the effects of spinning methods and yarn twist.

3.2 Multiple predictor model analysis

Yarn evenness

Yarn evenness (CV) prediction models have been developed employing multiple linear regression techniques, for the Ne 40, Ne 50 and other yarn count subsets. The various equations for these databases are shown in Equations 3.1 – 3.6. Equations 3.2 and 3.3 are derived from the Ne 40 database, Equations 3.4 and 3.5 are derived from the Ne 50 database and Equations 3.1 and 3.6 are derived from the combined database of the 57 lots of yarns.

- **For yarn count Ne<40 and Ne≥23**

$$CV = 25.5 - 0.0630\ Tex - 0.00829\ FT * FE - 19.3\ SCFCV(Ne<50) + 0.0256\ LD + 0.132\ MFL \quad (3.1)$$

- **For yarn count Ne = 40**

For ring spinning:

$$CV = 19.2 - 0.00788\ FT * FE - 0.282\ MFL + 0.104\ IFC + 0.00859\ LD \quad (3.2)$$

For condensed spinning:

$$CV = (19.2 - 0.00788\ FT * FE - 0.282\ MFL + 0.104\ IFC + 0.00859\ LD) * SCFCV(Ne < 50) \quad (3.3)$$

- **For yarn count Ne<50 and Ne>40**

$$CV = 20.5 - 0.162\ MFL + 0.0444\ LD - 0.00797\ FT*FE - 9.79\ SCFCV(Ne<50) \quad (3.4)$$

- **For yarn count Ne=50**

$$CV = 20.5 - 0.162\ MFL + 0.0444\ LD - 0.00797\ FT*FE - 9.79\ SCFCV(Ne=50) \quad (3.5)$$

- **For yarn count Ne >50 and Ne≤80**

$$CV = 25.5 - 0.0630\ Tex - 0.00829\ FT * FE - 19.3\ SCFCV(Ne>50) + 0.0256\ LD + 0.132\ MFL \quad (3.6)$$

In these equations ‘tex’ refers to the yarn count, or yarn linear density, and SCF is a spinning correction factor applied to each yarn property in order to correct for the type of spinning system, i.e. ring or condensed spun yarn. The factors are defined as following with values listed in Table XVI.

- SCFYT = Spinning Correction Factor for yarn tenacity
- SCFYE = Spinning Correction Factor for yarn elongation
- SCFCV = Spinning Correction Factor for yarn evenness (CV)
- SCFThin = Spinning Correction Factor for thin places
- SCFThick = Spinning Correction Factor for thick places
- SCFNep = Spinning Correction Factor for nep count

Table XVI – Spinning correction factors for condensed spinning:

Yarn count	SCFYT	SCFYE	SCFCV	SCFThin	SCFThick	SCFNep
Ne>50	1.12	1.14	0.98	0.54	0.80	1.00
Ne=50	1.12	1.14	0.98	0.54	0.80	1.00
Ne<50	1.07	1.07	0.97	0.54	0.75	0.99

For ring spinning all correction factors = 1.

Variables used in the three prediction models are shown in Table XVII, where *p* stands for the significance level of the variable in predicting yarn evenness. It is seen that fibre breaking energy (H-FT*FE) measured by HVI, mean fibre length and linear density are three common factors used in these equations. It is seen that these variables are all highly significant, indicating that these three factors are the most important factors contributing to yarn evenness, largely in line with the results obtained from the single variable analysis.

Table XVII – Variables used in the prediction models

	H-FT*FE	HMFL	MFLD	SCFCV	IFC	Tex
Eq. 3.2 & 3.3	x	x	x		x	
p	*0.00*	*0.00*	*0.03*		*0.01*	
Eq. 3.4 & 3.5	x	x	x	x		
p	*0.00*	*0.09*	*0.00*	*0.00*		
Eq. 3.1 & 3.6	x	x	x	x		x
p	*0.00*	*0.00*	*0.03*		*0.01*	*0.01*

The stepwise regression technique allows the relative importance of these variables to yarn evenness to be illustrated. The results are shown in Figures 2, 3 and 4.

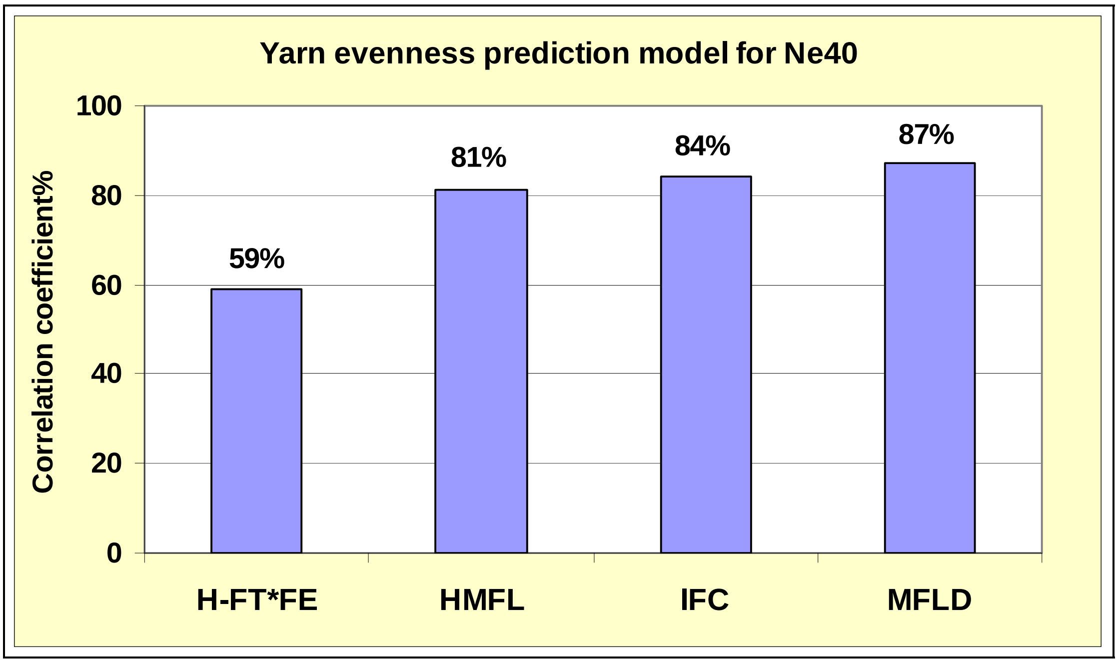

Figure 2 – Stepwise regression analysis of the yarn evenness prediction models 3.2 & 3.3

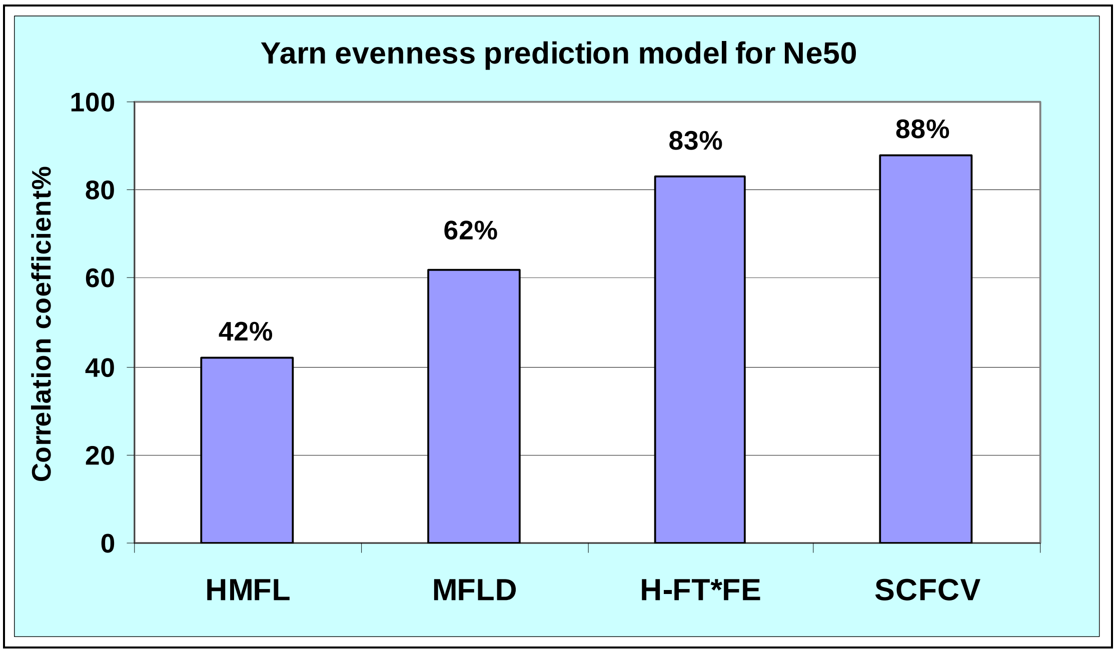

Figure 3 – Stepwise regression analysis of yarn evenness prediction models 3.4 & 3.5

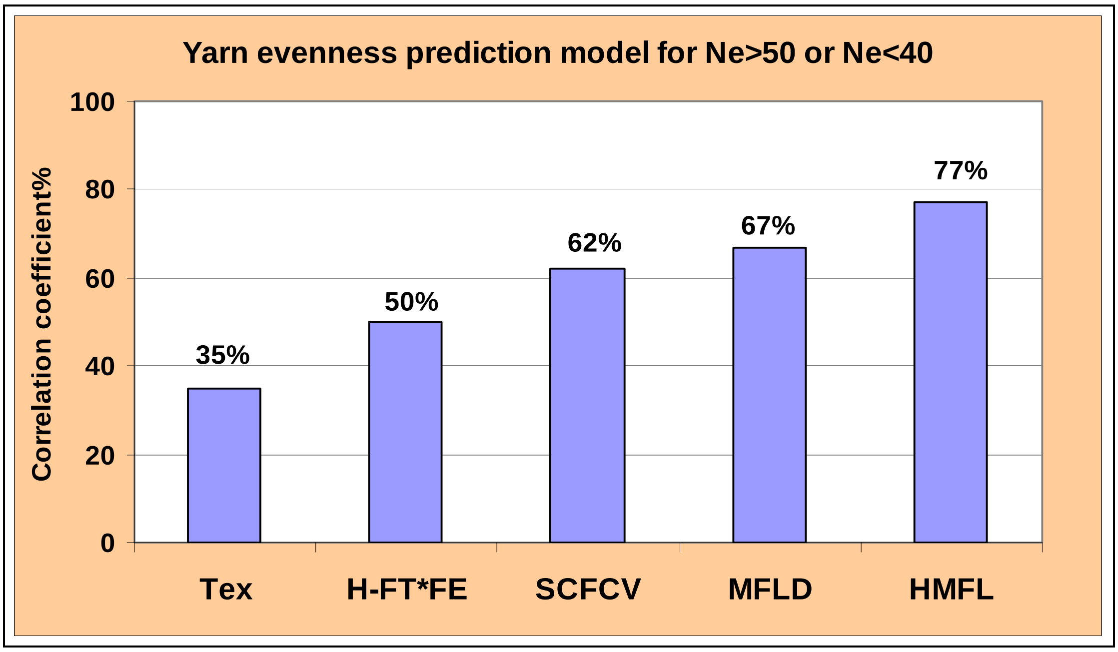

Figure 4 – Stepwise regression analysis of yarn evenness prediction models 3.1 & 3.6

Figure 2 shows that for Ne 40 yarns, fibre breaking energy plays a dominant role in determining yarn evenness, accounting for 59% of the observed variation in yarn evenness. This is followed by mean fibre length (measured by mill), accounting for an additional 22% of the observed variation. Immature fibre content measured by the AFIS and mill measured linear density accounts for an additional 6% of the observed variation. In total 87% of the observed variation in yarn evenness is accountable by these four variables.

Figure 3 shows that for Ne 50 group mean fibre length also plays a dominant role in determining yarn evenness, accounting for 42% of the observed variation in yarn evenness. This is followed by linear density and fibre breaking energy, accounting for an additional 20% and 21% of the observed variation, respectively. The spinning correction factor accounts for the remaining 5% of the observed variation. In total 88% of the observed variations in yarn evenness is accountable by these four variables.

Figure 4 shows that in the combined spinning database yarn linear density (tex) plays a dominant role in determining yarn evenness, accounting for 35% of the observed variation in yarn evenness. This is in line with yarn evenness theory, which states that yarn evenness is predominately determined by the number of fibres in the yarn cross section, which is determined by yarn count, and fibre linear density. Excluding the effect of yarn linear density it is fibre breaking energy that is the most important factor contributing to yarn evenness, accounting for additional 15% of the observed variation in yarn evenness on top of the effect of yarn linear density. This is followed by the spinning correction factor, an additional 12%, and fibre linear density, an additional 5% and mean fibre length, an additional 10% of observed variation respectively. A total of 77% of the observed variation in yarn evenness is accounted for by these five variables.

Excluding the effect of yarn linear density and spinning correction factor the three plots revealed a unique conclusion that is fibre breaking energy, mean fibre length and fibre linear density are the three most important ‘fibre’ factors contributing to yarn evenness.

Yarn tenacity

Yarn tenacity prediction models have been developed employing the same regression techniques, for Ne 40, Ne 50 and other yarn counts. The resulting equations are shown in Equations 3.7 to 3.12. Equations 3.8 and 3.9 are derived using the Ne 40 database.

Equations 3.10 and 3.11 are derived using combined database of Ne 40 and Ne 50 yarns with a total of 51 lots of yarn data. Twist factor is included in all equations because it plays an extremely important role in determining yarn tenacity; it determines the extent of inter-fibre cohesion in the yarn structure. However, for Ne 50 group there are only two knitting yarns and all other weaving yarns have essentially the same twist level so it is difficult to develop a yarn tenacity prediction model with yarn twist included based on Ne 50 database alone. Equations 3.7 and 3.12 are derived from the combined database with 57 lots of yarn data.

- **For yarn count Ne<40 and Ne≥23**

$$YT = - 15.4 - 0.413\ SFC16 + 0.0585\ TF - 0.544\ IFC + 7.65\ SCFYT(Ne<50) + 0.214\ Tex + 0.285\ UHML + 0.065\ FT \quad (3.7)$$

- **For yarn count Ne = 40**

For ring spinning:

$$YT = - 2.6 + 0.067\ TF + 0.369\ FT - 0.213\ CVL(n) - 0.273\ SFC16 - 0.353\ IFC \quad (3.8)$$

For condensed spinning:

$$YT = (- 2.6 + 0.067\ TF + 0.369\ FT - 0.213\ CVL(n) - 0.273\ SFC16 - 0.353\ IFC) * SCFYT\ (Ne < 50) \quad (3.9)$$

- **For yarn count Ne > 40 and Ne < 50**

$$YT = - 45.5 - 0.407\ SFC16 + 0.0841\ TF - 0.637\ IFC + 16.1\ SCFYT(Ne<50) + 0.886\ Tex + 0.377\ UHML + 0.327\ FE \quad (3.10)$$

- **For yarn count Ne = 40**

$$YT = - 45.5 - 0.407\ SFC16 + 0.0841\ TF - 0.637\ IFC + 16.1\ SCFYT(Ne=50) + 0.886\ Tex + 0.377\ UHML + 0.327\ FE \quad (3.11)$$

- **For yarn count Ne > 50 and Ne < 80**

$$YT = - 15.4 - 0.413\ SFC16 + 0.0585\ TF - 0.544\ IFC + 7.65\ SCFYT(Ne>50) + 0.214\ Tex + 0.285\ UHML + 0.065\ FT \quad (3.12)$$

Variables used in the three prediction models are shown in Table XVIII. It is seen that twist factor, mill measured SFC, IFC and fibre tenacity (or elongation) measured by HVI, are the four most significant factors selected in these equations. It is seen that majority of these variables are highly significant, indicating the factors are the most important in contributing to yarn tenacity, largely in line with the results obtained from the single variable analysis discussed earlier. The low significance level ($p=0.14$ and 0.36) of fibre elongation and tenacity in Equations 3.10 and 3.11 and 3.7 and 3.12 is most likely caused by relatively large measurement errors in fibre testing. Upper-half-mean-length also has important contributions to yarn tenacity although it is not used in Equations 3.8 or 3.9.

The stepwise regression technique allows the relative importance of these variables to yarn evenness to be illustrated. The results are shown in Figures 5, 6 and 7.

Table XVIII – Variables used in the prediction models

	TF	MSFC	HFT	HFE	IFC	UHML	Tex	CV L(n)	SCF YT
Eq. 3.8 & 3.9	x	x	x		x			x	
p	*0.00*	*0.09*	*0.00*		*0.07*			*0.01*	
Eq. 3.10 & 3.11	x	x		x	x	x	x		x
p	*0.00*	*0.09*		*0.14*	*0.00*	*0.07*	*0.00*		*0.00*
Eq. 3.7 & 3.12	x	x	x		x	x	x		x
p	*0.00*	*0.09*	*0.36*		*0.00*	*0.03*	*0.00*		*0.00*

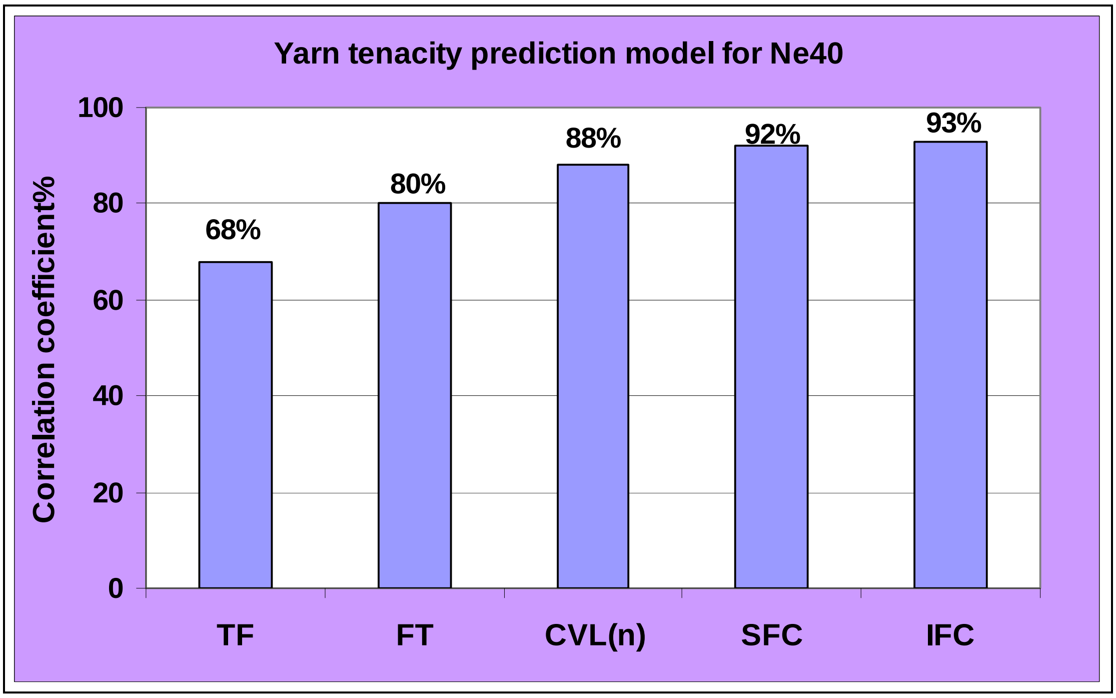

Figure 5 – Stepwise regression analysis of the yarn tenacity prediction models 3.8 & 3.9

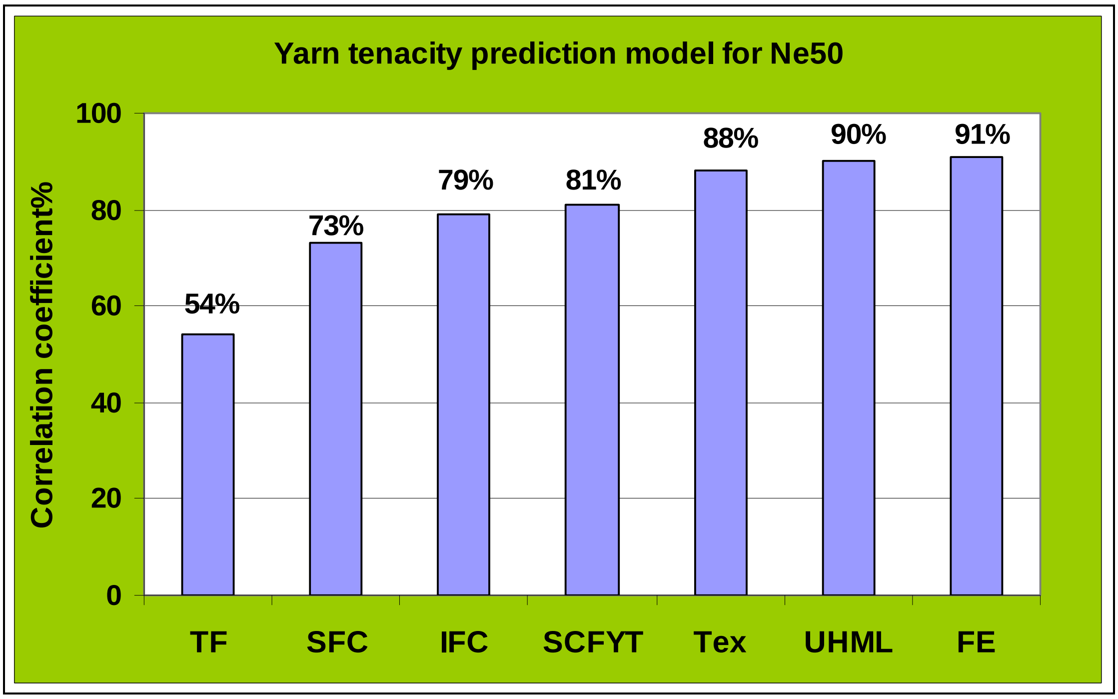

Figure 6 – Stepwise regression analysis of the yarn tenacity pred. models 3.10 & 3.11

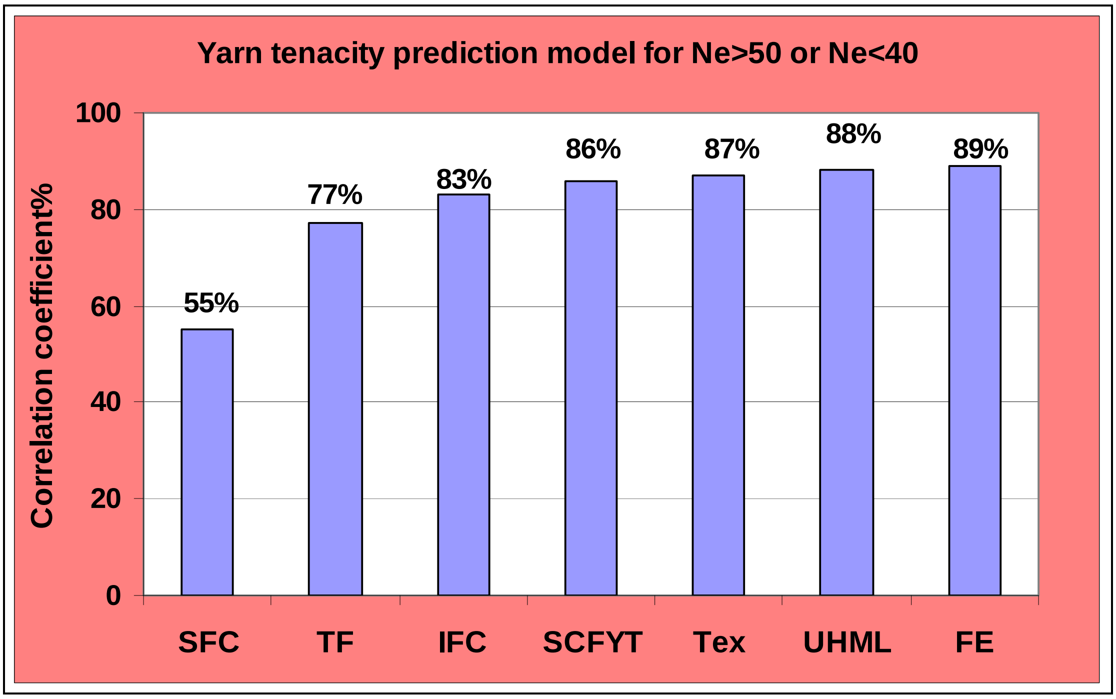

Figure 7 – Stepwise regression analysis of the yarn tenacity pred. models 3.7 & 3.12

Results shown in the three plots demonstrate that, excluding yarn parameters and spinning correction factors, mill measured SFC (%<16mm), tenacity (or elongation), upper-half-mean-length and IFC are the four most important cotton fibre properties contributing to yarn tenacity. The relative importance of these properties to yarn tenacity depends on yarn type, e.g. twist, linear density and spinning methods, as well as these other fibre properties.

The contribution to yarn tenacity of each individual variable can be estimated approximately from the three plots. For instance, Figure 5 shows that tenacity contributes 12% of the variation seen in the observed variation in yarn tenacity on top of the twist effect. Figure 6 shows that SFC contributes 19% contribution of the variation on top of the twist effect, while Figures 6 and 7 show that IFC contributes around 6% variation on top of the first two variables.

A conclusion may be drawn from above analysis that overall SFC is the most important fibre properties affecting yarn tenacity, followed by fibre tenacity (or elongation) and fibre maturity (as expressed by the IFC). Mean fibre length also plays a role in determining yarn tenacity.

The critical importance of SFC for cotton yarn tenacity is well supported by yarn mechanics theory through the ‘fibre ends’ effect, which is explained later in this discussion.

3.3 Testing of spinning prediction models

Calculated vs. measure yarn evenness and tenacity using the existing database

The relationships between measured vs. calculated yarn evenness and tenacity values for the 57 lots of yarn using the combined equations are shown in Figures 8 and 9, respectively. It is seen that the calculated yarn evenness and tenacity are highly correlated with that of the measured, demonstrating that the predicted data fits with the measured data very well.

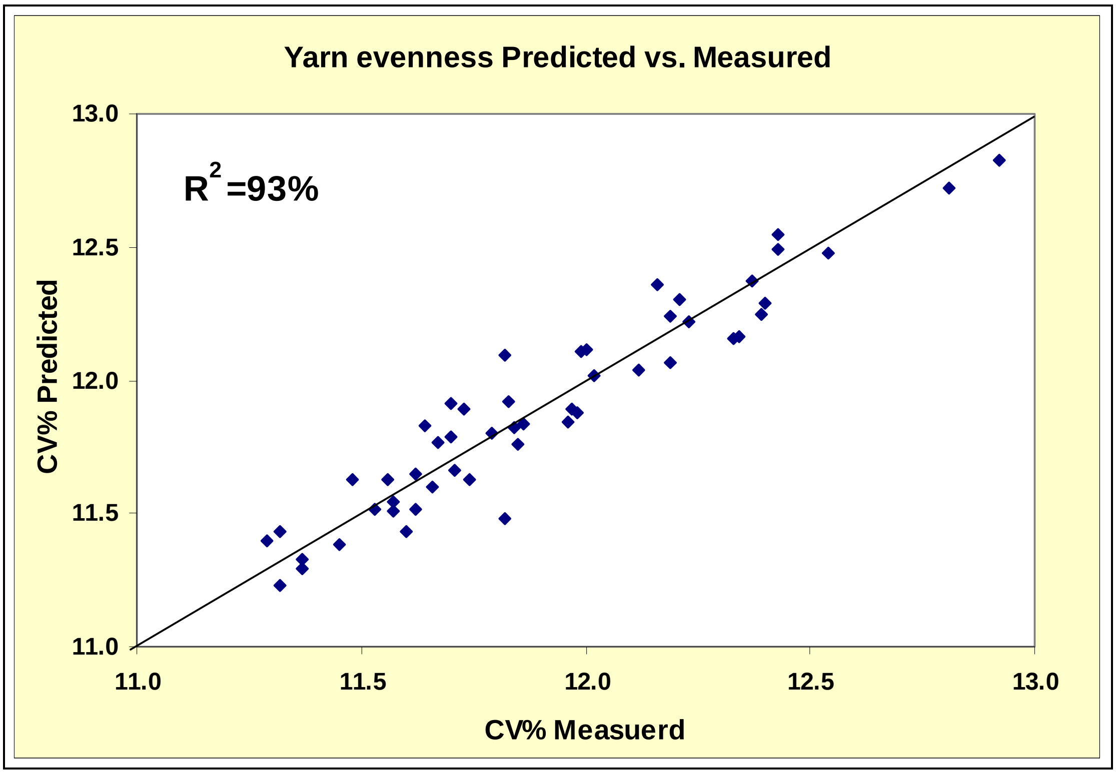

Figure 8 – Yarn evenness calculated vs. measured for 57 lots of yarn using Eq. 3.1

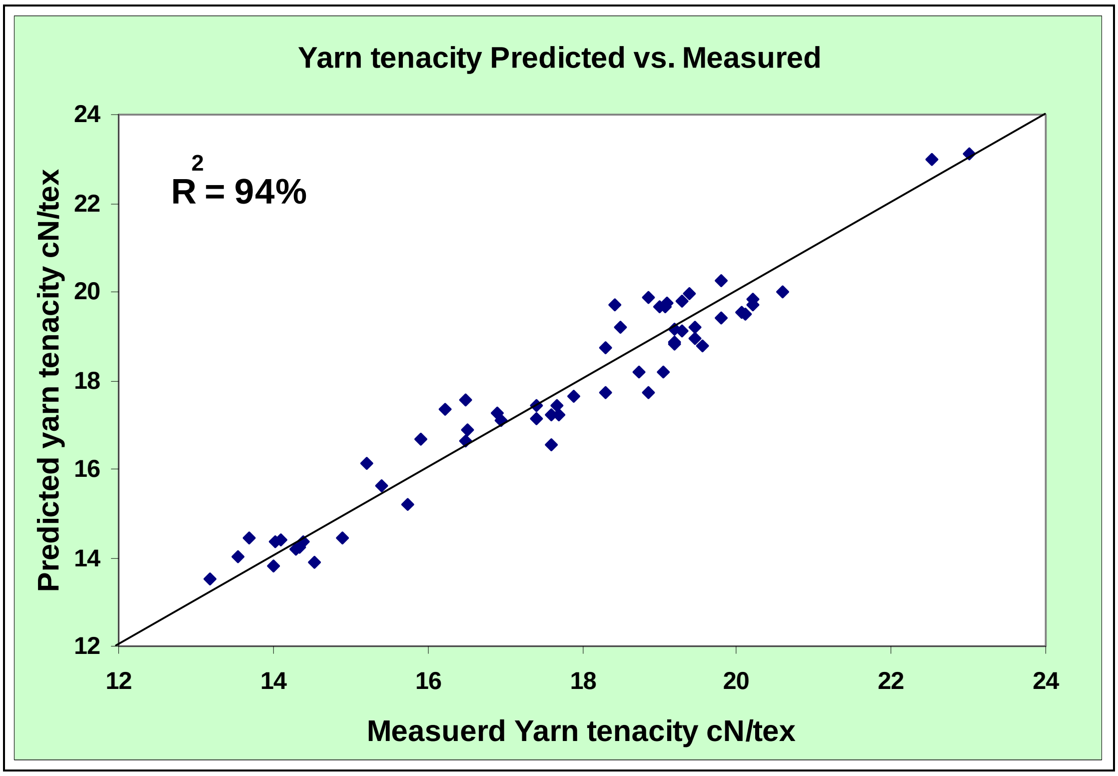

Figure 9 – Yarn tenacity calculated vs. measured for 57 lots of yarn using Eq. 3.7

Testing of the prediction algorithms – Cottonspec validation trials – Feb/Mar 2010

As part of the Cottonspec spinning trial conducted February through to May 2010, a cotton blending trial was completed at the Chongqing Sanxia mill. In this trial good quality Australian cotton was blended with US San Joaquin Valley (SJV) cotton in percentages ranging from 0%, 12.5%, 25%, 37.5% and 50%. For each blend ratio four types of yarn were spun; a total of 20 yarn types were produced.

Fibre properties for blended cottons are listed in Table XIX. For SJV cotton all data were provided by the mill. For Australian cotton, SFC and FLD were provided by the mill and other data were measured at CMSE using cotton samples provided by the mill. Because of the large between samples variations five raw cotton samples were taken for HVI testing.

Table XIX – Blended cotton fibre properties

No	%SJV	UHML mm	LU%	SFC %<16mm	MFLD Nm	HFT cN/tex	HFE %
AUS	0	29.8	81.70	19.23	5649	29.02	6.54
1	12.5	29.74	81.73	19.14	5665	29.42	6.63
2	25	29.68	81.76	19.04	5682	29.83	6.72
3	37.5	29.62	81.79	18.95	5698	30.23	6.81
4	50	29.56	81.81	18.86	5714	30.63	6.91
5	100	29.32	81.93	18.49	5780	32.25	7.27

The measured yarn evenness and tenacity vs. the predicted using the developed combined equations are shown in Table XX for the 20 lots of blend cotton yarns. Note that for the cotton blending trial, the mill did not provide mean fibre length using their hand method. As a result, UHML data were used to replace MFL in calculating the predicted yarn evenness.

Table XX – Measured and predicted yarn evenness and tenacity values for the Chongqing Sanxia mill blending trial

No	% SJV	Yarn type	Ne	TF	MCV %	PCV %	MYT cN/tex	PYT cN/tex
1	12.5	JC	40	400	11.30	11.50	16.90	17.07
2	25.0	JC	40	400	11.36	11.47	17.50	17.25
3	37.5	JC	40	400	11.31	11.44	17.70	17.42
4	50.0	JC	40	400	11.44	11.40	17.00	17.59
5	100.0	JC	40	400	11.13	11.27	18.20	18.29
6	12.5	CF	40	400	11.07	11.15	18.50	18.26
7	25.0	CF	40	400	11.03	11.12	18.20	18.45
8	37.5	CF	40	400	10.96	11.09	18.40	18.64
9	50.0	CF	40	400	10.88	11.06	18.70	18.82
10	100.0	CF	40	400	10.73	10.94	19.40	19.57
11	12.5	JC	50	405	12.45	12.17	16.80	16.40
12	25.0	JC	50	405	12.33	12.12	16.40	16.45
13	37.5	JC	50	405	12.27	12.06	16.60	16.49
14	50.0	JC	50	405	12.20	12.00	16.70	16.54
15	100.0	JC	50	405	12.04	11.77	17.40	16.72
16	12.5	CF	50	405	12.20	12.40	18.30	18.28
17	25.0	CF	50	405	12.15	12.35	18.60	18.32
18	37.5	CF	50	405	12.21	12.29	18.60	18.37
19	50.0	CF	50	405	11.90	12.23	18.90	18.41
20	100.0	CF	50	405	11.49	12.00	19.70	18.59

MCV = measured yarn evenness, PCV = predicted yarn evenness (CV), MYT = measured yarn tenacity, PYT = predicted yarn tenacity

The standard errors and relative standard errors for predicted yarn evenness and tenacity are shown in Table XXI.

Table XXI – Standard and relative standard errors for predicted yarn evenness and tenacity for the Chongqing Sanxia mill blending trial

	Standard error	Relative standard error %
Yarn evenness	0.21%	1.84
Yarn tenacity	0.39 cN/tex	2.19

The predicted yarn evenness and tenacity values vs. the measured values are plotted in Figures 10 and 11. The spinning data collected from this trial has been used as a test set for the prediction algorithms and the results confirm the prediction algorithms work very well. Predicted yarn evenness and tenacity were highly correlated to the measured data with the regression co-efficient of determination (r^2) being 0.87 for yarn evenness and 0.85 for yarn tenacity.

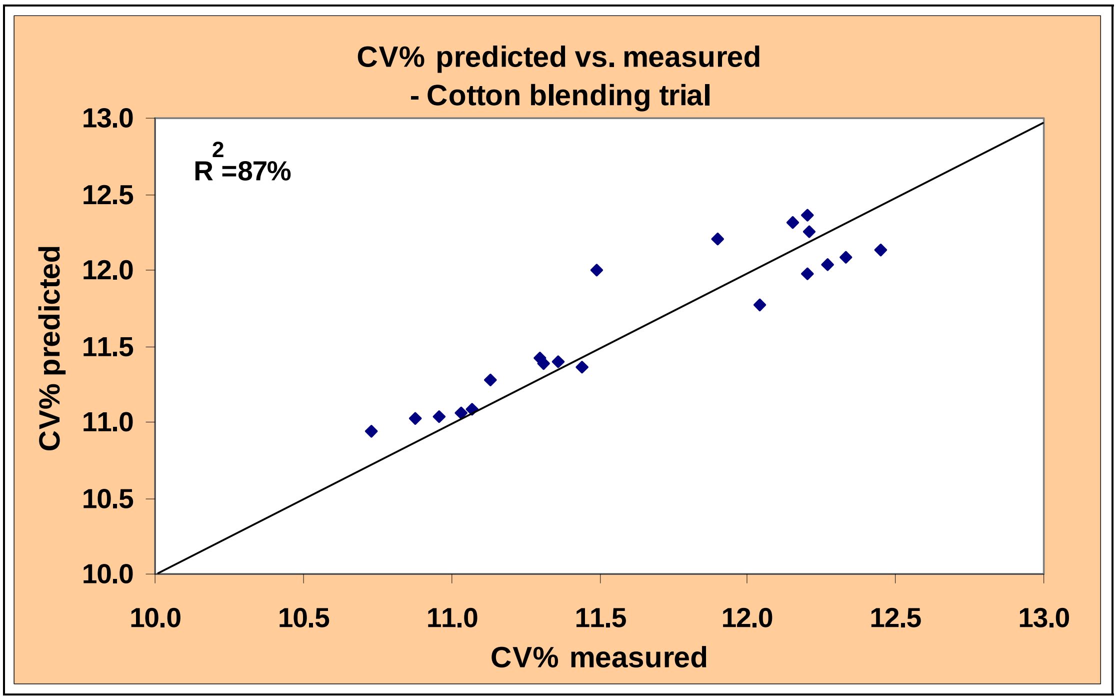

Figure 10 – Yarn evenness predicted vs. measured for 20 lots of blend cotton yarn

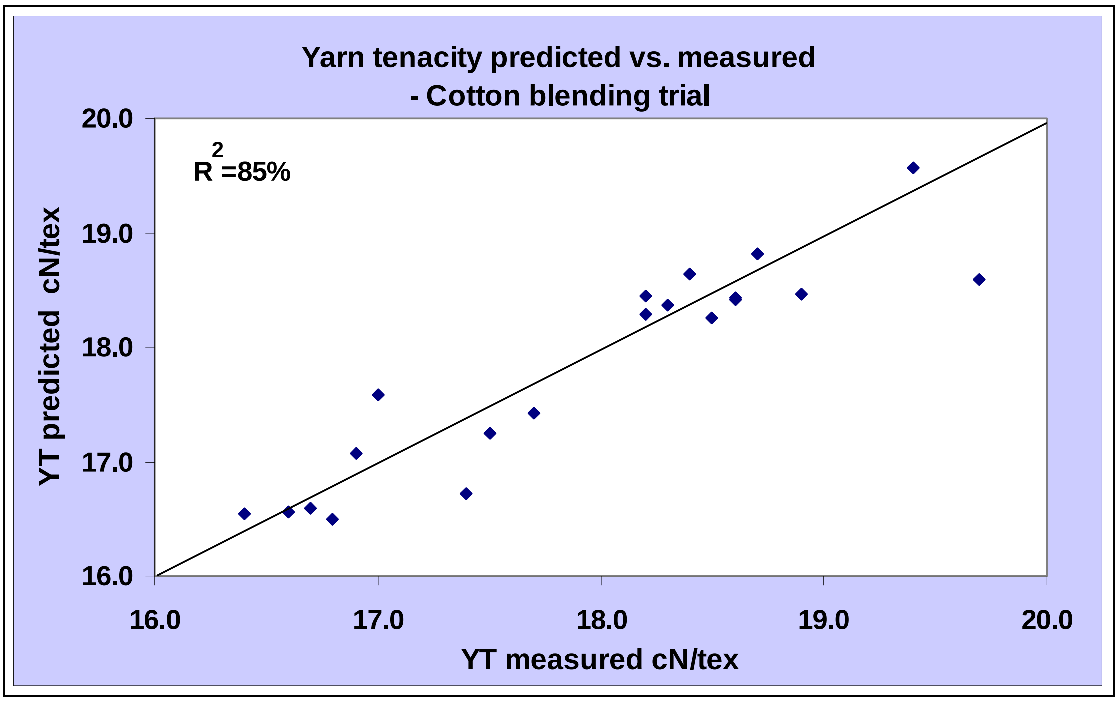

Figure 11 – Yarn tenacity predicted vs. measured for 20 lots of blend cotton yarn

3.4 Fibre-yarn interactions identified

The Chongqing Sanxia mill database was selected over the other sets largely because it covers a wide range of cotton origins, including US SJV, Pima, Chinese Xinjiang, Brazilian and Australian cotton, and a wider range of yarn types, including both ring spinning and condensed spinning yarns. The yarn count ranges in the Chongqing Sanxia database ranges from Ne 23 to Ne 80, although the number of data points for the coarser and finer yarns is currently limited.

The key to the success of development of Cottonspec prediction algorithms is to gain a clear understanding of the complex interactions of cotton fibre characteristic with cotton yarn properties. This has been achieved through development of the database and the application of theoretical modelling in the form of the multiple linear regressions of fibre data against yarn data, with considerations given to variables required as per the theoretical mechanical models of interactions between fibre and yarn.

This study revealed somewhat surprisingly that fibre breaking energy, i.e. the area under the stress-strain curve for a fibre (bundle) defined by the fibre's breaking strength and elongation, is the most important cotton fibre property contributing to yarn evenness, followed by mean fibre length and fibre linear density (fineness). This relationship emerges due to the fact that during the carding process fibre breakage occurs, which reduces mean fibre length and increases SFC. For cotton fibre to survive the carding process with minimal breakage, a high fibre breaking energy is required. An interaction between fibre linear density and fibre breakage in the card is also expected, i.e. finer or more immature fibres are more prone to break during carding. The larger the breaking energy required to break the fibre the less chance it will break in processing (carding). In turn, the greater the mean fibre length and reduced SFC in card sliver, and the better the yarn evenness and tenacity will be.

The critical importance of SFC to yarn tenacity is well supported by yarn mechanics theory through the 'fibre-ends' effect. For yarn made from staple fibres the coherence force between fibres is provided by inter-fibre friction where the frictional force provided by a fibre is proportional to its length. According to the 'fibre-ends' effect, a proportion of each of two fibre-ends does not make a positive contribution to this frictional force (actually making negative contributions by pulling the stretched yarn in the opposite direction to the tension applied to the yarn). The length of the fibre-ends, which make negative contributions to yarn strength, is nominally constant. With the magnitude of the fibre-ends effect dependent on fibre length, clearly, the shorter the fibre length, the greater the fibre-ends effect on yarn strength. Experimental results of the Cottonspec validation trial carried out recently at the Chongqing Sanxia mill gives strong support to this theory.

As well as the ‘fibre-ends’ effect the production cost or profitability-loss of fibre lost to high SFC must be taken into account. To illustrate this point we look at the data collected from the Cottonspec validation trials carried out at the Chongqing Sanxia mill, and compare these to a parallel trial (using the same Australian cotton) carried out at the Wenshang Ruyi Tianrong mill. Short fibre content results for raw cotton, card sliver and combed sliver, as well as the comb noil from both trials are shown in Table XXII.

Table XXII – SFC for raw cotton, card sliver and combed sliver, and comb noil

Mill	Product	SFC <16mm			Comb Noil%
Chongqing Sanxia	JC40S JC50S/60S	Raw cotton	Card sliver	Comb sliver	
		19.23	21.94	12.56	16.24
				11.82	20.51
Wenshang Ruyi Tian-Rong					22.5%

It is seen from Table XXII that after carding SFC increased by 2.5% indicating fibre breakage occurring in the carding procedure. In combing SFC was reduced by about 10%. Such an operation has a high cost with noil (SFC) ranging between 16.24 and 20.51%. Despite this the SFC of combed sliver was still quite high being about 12%, and would have led to negative impacts on yarn quality.

As shown in Table XXII Wenshang Ruyi Tianrong used a higher comb noil setting, which resulted in a higher noil of 22.5%. This was because Tianrong was in competition with the Chongqing Sanxia mill and did not take the production costs into account for this spinning trial. The trial results showed that yarn tenacity for Tianrong were better than for the Chongqing Sanxia mill despite the fact that Chongqing Sanxia spinning quality was normally considerably better than Tianrong. A comparison of yarn tenacity and evenness from the Tianrong and Chongqing Sanxia mills is plotted in Figure 12.

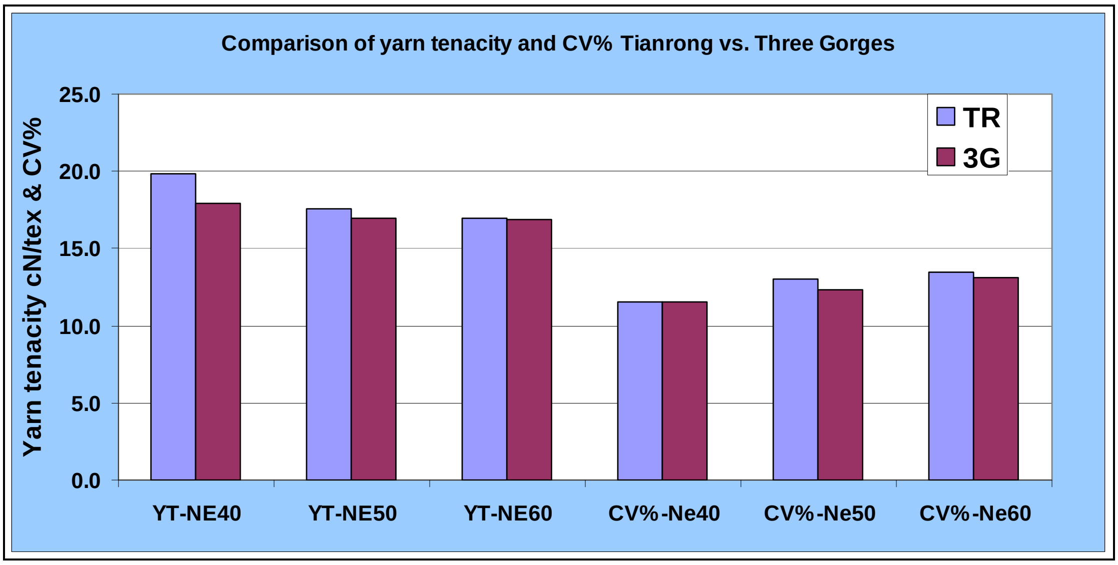

Figure 12 – Comparison of tenacity (YT) and evenness (CV%) values of yarn produced at the Tianrong (TR) and Chongqing Sanxia (3G) mills from the same cotton

3.5 Cottonspec interface and programming of the prediction algorithms

Based on experience gained in developing the wool spinning prediction package Yarnspec and by taking into account the reporting requirements from Chinese partner mills, a Cottonspec interface has been designed and programmed. The interface is specifically designed to meet Chinese mills' requirement with a multi-linguistic capacity.

The Cottonspec interface has two formats. One is a windows format to be used mainly as an education and cotton trading tool. Another format is an Excel format to be used by cotton spinning mills for quality control. The window format interface has been developed first and the Excel version will be developed in due course.

The programming of the prediction algorithms has been divided into two steps corresponding to the two formats of the interface. For the windows format the Cottonspec prediction algorithms have been programmed using C+.net as part of the Microsoft visual studio package using OO (object oriented) design techniques. The language of C+.net has been chosen because of its flexibility on the windows platform, and because it provides a neat method of allowing multiple language usage.

The interface itself uses the windows MDI (Multiple Document Interface) forms, where one form houses or allows docking of the other (child) forms. All forms are instantiated in a hidden state when the program begins. The forms are made available to the user on request from the dropdown menu at the top of the main (parent) form, following standard windows design structures. The child forms themselves, each provide class member variables to store the data input by the user, provide functionality to process this data according to the algorithms and output the result.

The Cottonspec software has been tested using the prediction algorithms and works well. Further testing in an industrial situation is required to ensure the software is easy to use and manage at the mill level.

3.6 Conclusions – modelling cotton spinning performance

In 1990's a worsted spinning prediction package Sirolan-Yarnspec was developed at CSIRO and successfully commercialized in late 1990's and early 2000's through Australia-China wool research collaboration programs [1-3]. In the Cottonspec project it was originally planned to extend the wool spinning prediction theory to cotton in developing Cottonspec. However, during the course of this project it was realized that worsted spinning prediction theory is not directly applicable to cotton spinning due mainly to the extensive preparation and combing of wool top (akin to cotton sliver), which removes short fibre before spinning.

For cotton spinning the role of card silver is similar to wool top. And it is the fibre properties of card sliver, not raw cotton, that ultimately determine cotton yarn performance. Therefore, cotton spinning prediction work should be divided into two steps. The first step is to develop a cotton formula that accurately predicts the fibre properties of card sliver. The second step is to then apply yarn mechanics and spinning drafting theory to predict cotton yarn performance from predicted card sliver properties.

As mentioned, modelling of yarn mechanics was also hindered by the limitations of the spinning database, which is developed from the Chongqing Sanxia mill's production rather than scientifically designed spinning trials. It has been found that, without purposely designed spinning trial data, it is difficult to derive yarn mechanics prediction models by fitting the spinning data into the models. For example, to derive the relationship between yarn twist and yarn tenacity and elongation, a purposely designed spinning trial is needed to get full picture of the dependence of yarn tenacity and elongation on yarn twist. Another example is the dependence of yarn evenness on yarn linear density. Although the mechanics theoretical model is available it is essential to have a purposely designed spinning trial, where a series of yarns of varying linear density is spun from the same lay-down, so that the theoretical model can be fitted with the experimental data.

Due to the limitations of the current spinning database this project is concentrated on establishing the complex relationships between raw cotton fibre properties and yarn properties using both single predictor and multiple predictor regression analysis methods. As mentioned, the shortcomings of the spinning database can be overcome by collecting more spinning data from partner mills and carrying out further purposely-designed spinning trials in collaboration with partner mills.

It is anticipated that with an expanded spinning database and more data from purposely designed spinning trials, to allow the incorporation of mechanical modelling, the preliminary spinning prediction models will be improved.

4. Future work

Further work as part of the new CRC project will be conducted to improve the quality of the spinning prediction algorithms. It is anticipated that the spinning prediction work will be divided into two steps. The first step is to collect data on the changes in fibre properties as a result of the process of turning raw cotton to carded sliver, and to develop relationships that allow the prediction of fibre properties in card sliver. The second step is to use the predicted card sliver properties to develop yarn evenness and tenacity prediction models by applying yarn mechanics and drafting theories.

To achieve the above objectives the existing spinning database will be greatly expanded by collecting more spinning data and carrying out further purposely designed spinning trials in close collaborations with the partner mills.

Due to the limitations of the spinning database, prediction models for yarn elongation, thin and thick places and neps are not satisfactory and further work will be carried out in due course to improve the accuracy of these prediction models.

All yarns produced at the Chongqing Sanxia mill are combed yarns and therefore the prediction algorithms are applicable to combed yarn only. This is largely satisfactory because the market for Ne 50 and 60s yarns applies predominantly to combed yarns. Nevertheless, prediction algorithms for carded yarn will be developed in due course using either CMSE's or Tianrong's spinning database.

5. Extension Opportunities

The Cottonspec program will be developed further over the next two years in the new CRC project to improve its prediction ability. At the same time as proposed yarn modelling and benchmarking trials are conducted in the new project in order to improve it, the concept of Cottonspec will be extended and promoted to mills and industry. These activities will be conducted initially via technical seminars to mills and industry conferences, but later this work could be conducted by a commercial entity operating in the cotton measurement and marketing world.

6. References

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7. Publications

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A large, although currently not altogether comprehensive database has been collected, built and tested, and a software programme written. The current limitations of the database, which is used in combination with fundamental models of yarn mechanic relationships, is that it includes too many variables. These over-ride the sensitivity of yarn mechanic relationships, e.g. there are differences between condensed and standard ring spun yarn that over-ride basic fibre-yarn relationships, and not enough range in factors such as fibre and yarn linear density and twist. Thus, it is difficult to develop a very good yarn evenness prediction model employing spinning draft theory, and as a consequence yarn tenacity, using the database as it currently stands. These shortcomings can be overcome by further building the database and by testing and validating the algorithms using data from purposely designed spinning trials in the same mill.

Nevertheless, validation spinning trials confirm the current prediction models work very well. In separate spinning trials predicted yarn evenness and tenacity were highly correlated to the measured data with the regression co-efficient of determination (r^2) being 0.87 for yarn evenness and 0.85 for yarn tenacity, with standards errors of ±0.21% for yarn evenness and ±0.39 cN/tex for yarn tenacity.

New and additional work as part of a continuing effort in developing and validating Cottonspec will enhance this yarn quality prediction.