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Yarn Strength Prediction in Relation to Fibre Length

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Summary

A first study carried out with 34 very different cottons, the various span lengths of which had been measured with a Fibrograph 230 A, has clearly shown that after the 1/8" gauge tenacity the 50% span length had the most significant effect on single end yarn strength.

A second investigation was performed on 1009 cottons which presented a wide spread of all fibre properties. Multiple regression analysis was performed on the whole set and also on three sub-sets comprising the individual length groups (short, medium, long). The results indicated that the most significant regression equations derived were those obtained with the 1009 samples. They yielded also a better explanation of the yarn strength than the equations obtained with the different length groups.

The simplest and best regression equations found in the course of these investigations are shown and explained.

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Estimation of yarn breaking strength through a knowledge of fibre properties is of considerable value to both the cotton breeder or geneticist and the cotton spinner. Many scientists have worked on this subject and there are numerous publications dealing with yarn strength prediction.

The Institut de Recherches du Coton et des Textiles (IRCT) carries out research programs in the field of tropical agriculture and plant breeding overseas and in particular in the developing countries.

The fibre testing laboratory of the Institute, located in Montpellier (France) receives over 6,000 samples of cotton coming from all over the world for evaluation of fibre properties each year. With these samples the laboratory performs several hundreds of spinning tests on a miniature Shirley (Platt) spinning plant. The study presented in this paper was based on the results obtained in 1975 and from 1979 to 1981.

The question may arise: how can the numerous measurements produced with the laboratory instruments be made available and be profitable to the breeder and to the spinner? Which are the most useful and essential fibre properties?

The breeder deals mainly with agronomic and production parameters and with individual fibre characteristics to select better plants, whereas the spinner will want to know what yarn strength he will obtain from the raw cottons which he has bought.

A single yarn strength prediction formula using well defined fibre properties could be very valuable for the spinner. Today the new high volume instruments (H.V.I.) already give the most important fibre measurements in a very short time. The print-out of the recorded data also displays an estimate of the yarn strength. This is a very important evolution in cotton technology and may change completely the nature of cotton marketing in the near future.

Joe HEMBREE, in Texas, has already shown the benefits that spinners could get from buying their bales whilst considering the estimate of the yarn strength and ensuring that the mixes will preserve the same average fibre properties, especially of the micronaire, from blend to blend.

The most usual fibre property measurements are length and uniformity, bundle strength at the "0" gauge or the 1/8" gauge, elongation, and micronaire. They all contribute with some others such as fineness, colour, foreign matter content, to the estimation of yarn strength through a prediction formula.

The fibre property which is most associated with yarn strength whatever the yarn count or the type of spinning (conventional or open end) is fibre strength. For years investigations have shown that the fibre strength measured with a 1/8" gauge strength tester correlates much better with yarn strength than the fibre strength measured with a "0" gauge strength tester. One may wonder why the latter procedure is still favoured by the cotton marketing trade when the research community has abandoned it. To date no international calibration standard cotton for 1/8" gauge strength testing has been available. This situation is coming to an end and new standards including 1/8" Pressley and Stelometer Tenacity are being prepared and will be realised very soon.

Next to fibre strength, length and micronaire reading (which is a measurement combining fineness and maturity) also contribute to some extent to yarn strength. Fineness and maturity may now be measured with the IIC-Shirley Fineness/Maturity Tester.

In the last ten years the measurement of fibre length has undergone an important change due to new available equipment, especially the high volume fibre testing instruments (H.V.I.). In the first prediction formulas, the classer's staple length was used. Later the different Fibrograph measurement values such as the upper half mean length (UH.ML), the mean length (M.L.), then the 2.5% and 50% span lengths were used.

The I.R.C.T. Laboratory was especially interested in the span lengths obtained with the Model 230 A Digital Fibrograph. This instrument enables us to obtain the various span lengths that are necessary to draw fibrograms. Figure 1 shows such a fibrogram. The span length is not an end-to-end fibre measurement nor an actual length but is an estimate of that fibre length which is equalled or exceeded by the given percentage number of fibres in a randomly selected bundle.

Generally two particular span lengths are measured, the 50% SL and the 2.5% SL, which give in turn the uniformity ratio of the two lengths. Constructing the tangents at the point 100% and 50% of the amount, two new values, the mean length (ML) and the Upper half mean length can be obtained, values given by the older Fibrograph (Model 183 Servo Fibrograph). On the drawing it can be observed that the mean length (M.L.) is a measurement corresponding to a span length value situated between the 20 and 10% SL (for most raw cottons). Furthermore the mean length (M.L.) is almost equal to twice the 50% SL.

The mean length (M.L.), as well as the 50% SL, is an important length because it is the length that most influences the spinning process and the yarn properties. The 50% SL is influenced more by the short fibre content than is the 2.5% SL.

In 1975 the I.R.C.T. Laboratory determined the fibrograms and the fibre properties of 34 very different cottons which were later sent to a spinning laboratory in Knoxville, Ten (USA) to be spun into 27 tex yarn. All the simple and multiple regressions between the individual or associated fibre characteristics and the yarn skein strength were analysed. The main results are shown in Table 1. These results indicate that 55% of the variation in yarn strength may be explained by the 1/8" gauge fibre strength alone. The 50% span length alone explained 34%, the 25% span length 37.9%, the 2.5% span length 34.7% of the variation. Combining the 1/8" gauge fibre strength with the different span lengths by multiplication of the two properties provided evidence that the new parameter explained the yarn strength variation at a higher level: (TEN 1/8 x 50% SL) accounted for 67.9% and (TEN 1/8 x 2.5% SL) for 73.5%. Adding the micronaire value into the multiple regressions resulted in a still better explanation of the yarn strength variation: the coefficient of determination (square of the multiple correlation coefficient R) reached 88% for the association (TEN 1/8 x 50% SL) + MIC whereas this coefficient dropped to 83.5% with the association (TEN 1/8 x 2.5% SL) + MIC. This may be explained by the fact that the negative correlation existing between the micronaire value and the measurement of the different span lengths increases from the 50% span length to the 2.5% span length.

On the basis of the results of this first study, performed with a small number of samples presenting a wide range of fibre properties, it could be concluded that it was desirable to include the 50% span length rather than the other span lengths in the prediction formula.

During the 1979, 1980 and 1981 seasons, 1,009 samples were processed on a Shirley (Platt) miniature plant at the Laboratory in Montpellier. All the fibre properties of the raw cotton were determined (50 and 2.5% span lengths) on a Fibrograph 430, Pressley "0" gauge strength, Stelometer 1/8" gauge tenacity and elongation, the three airflow parameters, micronaire, fineness and maturity ratio on the IIC-Shirley fineness/maturity tester. The samples came from different crops in a great number of cotton producing countries (commercially grown varieties, or varieties from experimental fields of the Institute, saw-ginned or roller-ginned). The purpose was to obtain the largest range possible for each fibre characteristic (Table 2). Thus the range covered by the 2.5% span length was 25.4 to 35.5 mm, by the uniformity 39 to 52%, by the micronaire reading 2.7 to 5.7, by the 1/8 gauge Stelometer tenacity 14.1 to 26.3 g/tex, by the fineness 117 to 259 mtex, and so on. The colour grades of these fibres ranged from Good Middling to Strict Low Middling. Each fibre property presented a fairly good distribution.

All the samples were spun in 27 tex yarn with a twist factor calculated in function of the 50% span length and the micronaire readings to obtain optimum strength. The single end yarn strength (on an Uster Automatic Tester) and the skein strength were measured in cN/tex.

The simple correlations between fibre strength and fibre properties as well as multiple stepwise regressions were calculated for the whole set of 1,009 samples but also for 3 groups of data representing a classification by the 2.5% span length:

- Group SHORT : 95 cottons measuring 25.4 - 26.9 mm (1" - $1^{1}/32"$)
- Group MEDIUM: 769 cottons measuring 27.0 - 30.1 mm ($1^{1}/16"$ - $1^{5}/32"$)
- Group LONG : 145 cottons measuring 30.2 - 35.5 mm ($1^{3}/16"$ - $1^{3}/8"$)

The fibre property values and their range for each group are shown in Table 3.

Considering first the simple correlations between yarn strength and some fibre properties for each group of samples it may be seen from Table 4 and Figure 2 that the correlation coefficients calculated with the single end yarn strengths are almost identical with those calculated with the skein strength.

Taking into account the 1,009 samples, there was a good correlation (r = 0.70) between the 1/8" gauge fibre tenacity and the yarn strength (50% of the variation explained).

The correlation reached the same level for the MEDIUM and the LONG length groups but was higher (r = 0.78) for the SHORT cottons. Analysing the relationship between yarn strength and "0" gauge fibre strength, one can see that the correlation was very poor (r = 0.30) explaining only 9% of the yarn strength variation in 1,009 cottons. It was slightly better (r = 0.40) for the MEDIUM and LONG groups and reached 0.60 for the SHORT groups.

Both the 50% and 2.5% span lengths accounted only for 25% in the explanation of the variation for the whole set of cottons but their influence dropped when each length group was separately considered (13% in the best case).

The uniformity ratio presented only low correlations. The same was observed with the micronaire value, but its negative correlation was slightly higher in the LONG cotton group. On the other hand the fineness (linear density) had a stronger influence on the yarn strength than the micronaire and its correlation was highest with r = -0.51 in the LONG length group.

The parameter (1/8" gauge fibre tenacity x 50% span length) showed the highest correlation with a coefficient of $r \simeq 0.81$, explaining alone 65% of the variation when taking into account the 1,009 cottons. Its correlation coefficient was only 0.74 to 0.79 for the separate length groups.

The results show that the relationships may differ according to the length groups considered. Wrong conclusions might be drawn from these relationships if a wide range of fibre properties do not exist in the cottons, especially a wide range of lengths.

For the prediction of yarn strength, one fibre property or one parameter combining different characteristics will anyway be insufficient. This is the reason why 3 or more fibre properties are generally included in the prediction formulae and is why they are not simple to use.

Furthermore it may be emphasized that no one formula can be universal.

Nevertheless, in order to give the breeder and possibly the spinner a useful tool, some of the simplest multiple regression equations obtained in the present study and having a reasonable precision (7 - 8%) have been listed in Table 5. The only equations reported are those calculated with the 1,009 cottons because none of the regressions found with the 3 length groups gave a better explanation of the yarn strength variation.

Two of those regression equations are presented graphically. Figure 3 shows the prediction of the yarn strength with the formula:

cN/tex = 8.28 + 0.029 (1/8 Tenacity x 50% SL) - 0.49 micronaire

(error of estimate = 0.57 cN/tex)

when the micronaire reading is equal to 4. One can see the contribution of the 50% SL and the 1/8" gauge fibre tenacity to the single-end yarn strength. Thus, for a cotton having a 1/8" fibre strength of 19 g/tex and a micronaire reading of 4, in order to get a yarn:

of 13 cN/tex the 50% SL must be 12 mm
of 14 cN/tex " " " " " 14 mm
of 15 cN/tex " " " " " 16 mm.

Two millimeters in 50% SL contribute to 1cN/tex in yarn strength.

With a 3.5 micronaire cotton, having the same fibre strength, (19g/tex) a 50% span length of 13.5 mm is required in order to obtain a 14 cN/tex yarn strength.

This example has clearly emphasized the importance of the 50% SL as an independent variable.

Another regression equation in which the fineness (linear density) takes the place of the micronaire reading is illustrated by Figure 4.

$$cN/tex = 9.38 + 0.027\ (TEN\ 1/8 \times 50\%\ SL) - 0.015\ fineness$$

(error of estimate 0.55 cN/tex)

This equation gives a better explanation of the variation of the yarn strength than the former one (72.5% against 71.1%).

Having a cotton of 28 mm ($1^{3}/32"$) in 2.5% span length, with a uniformity ratio of 47.5%, the 50% span length will be 13.3 mm. According to its fineness, it may be seen from the graph, which fibre tenacity is necessary to spin a yarn of 14 cN/Tex in strength.

With a 155 mtex fineness, the 1/8" fibre tenacity must be 19.2 g/tex.
With a 185 mtex fineness, " " " " " " 20.5 g/tex.
With a 215 mtex fineness, " " " " " " 21.7 g/tex.

Also it appears that in the case of a 155 mtex fineness the fibre must present a combination of a 12.1 mm 50% SL and 21 g/tex tenacity or of a 15 mm 50% SL and a 17g/tex tenacity in order to obtain an estimated yarn strength of 14 cN/tex.

In conclusion a prediction formula giving satisfaction for a 27 tex yarn strength will depend on 3 parameters:

The fibre strength measured with a Stelometer 1/8" gauge strength tester.
The 50% span length.
The fineness expressed as micronaire reading or as fineness
(in which case the explanation will be improved).

These simple regresssion equations used in the laboratory of the I.R.C.T. might certainly be adapted by other laboratories by only changing the constants or certain regression coefficients.

Today the evaluation of cottons (length, strength, micronaire) can be done by high volume fibre testing instruments (H.V.I.) which also calculate with the tested fibre properties an estimate of the yarn strength. The research work presented in this paper has shown that it is possible to reasonably predict the yarn strength with well chosen fibre variables, especially the one concerning the length. Equations are already useful and will certainly be more and more so in the future to both breeders and spinners.

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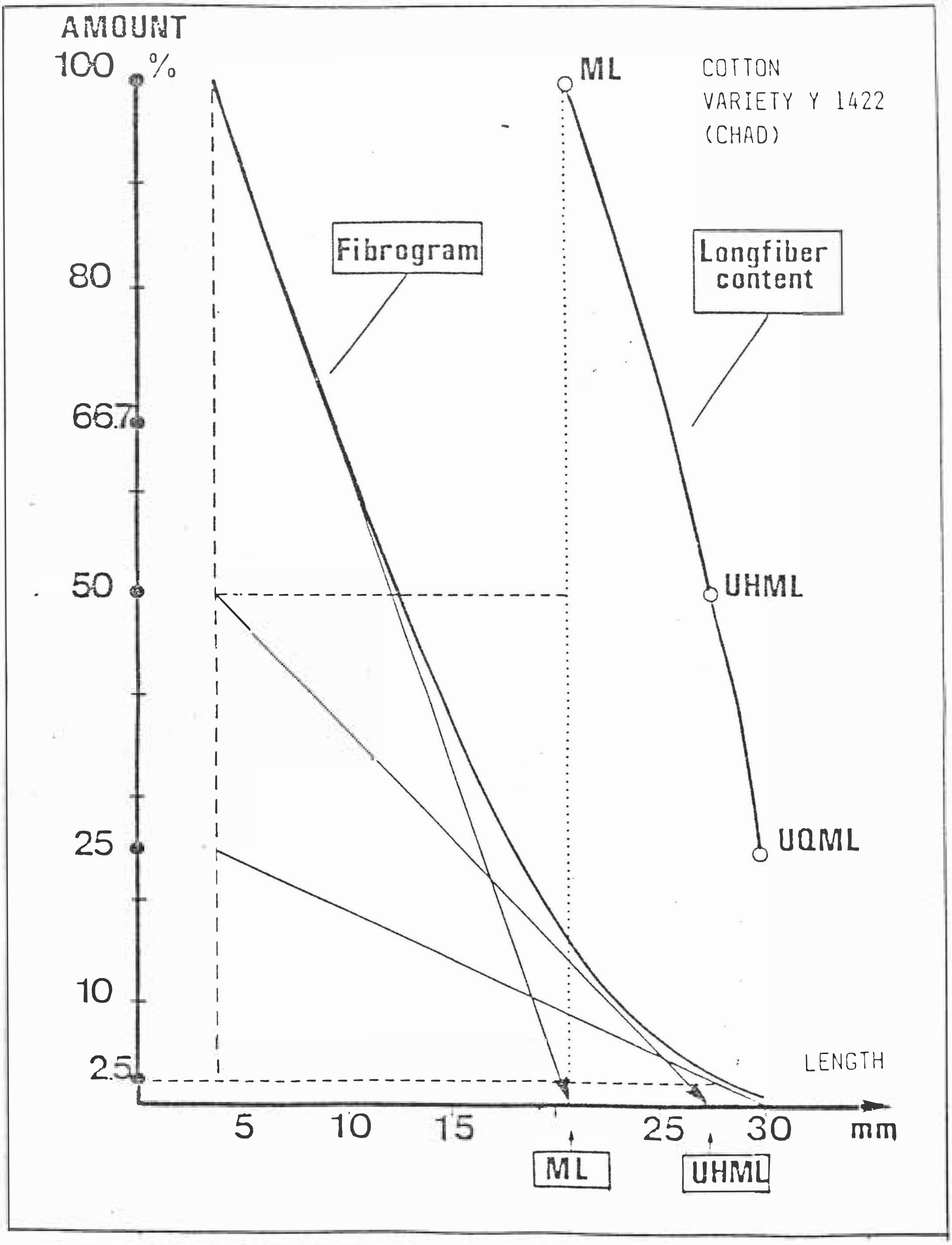

FIG. 1 FIBROGRAM FIBROGRAPH 230 A

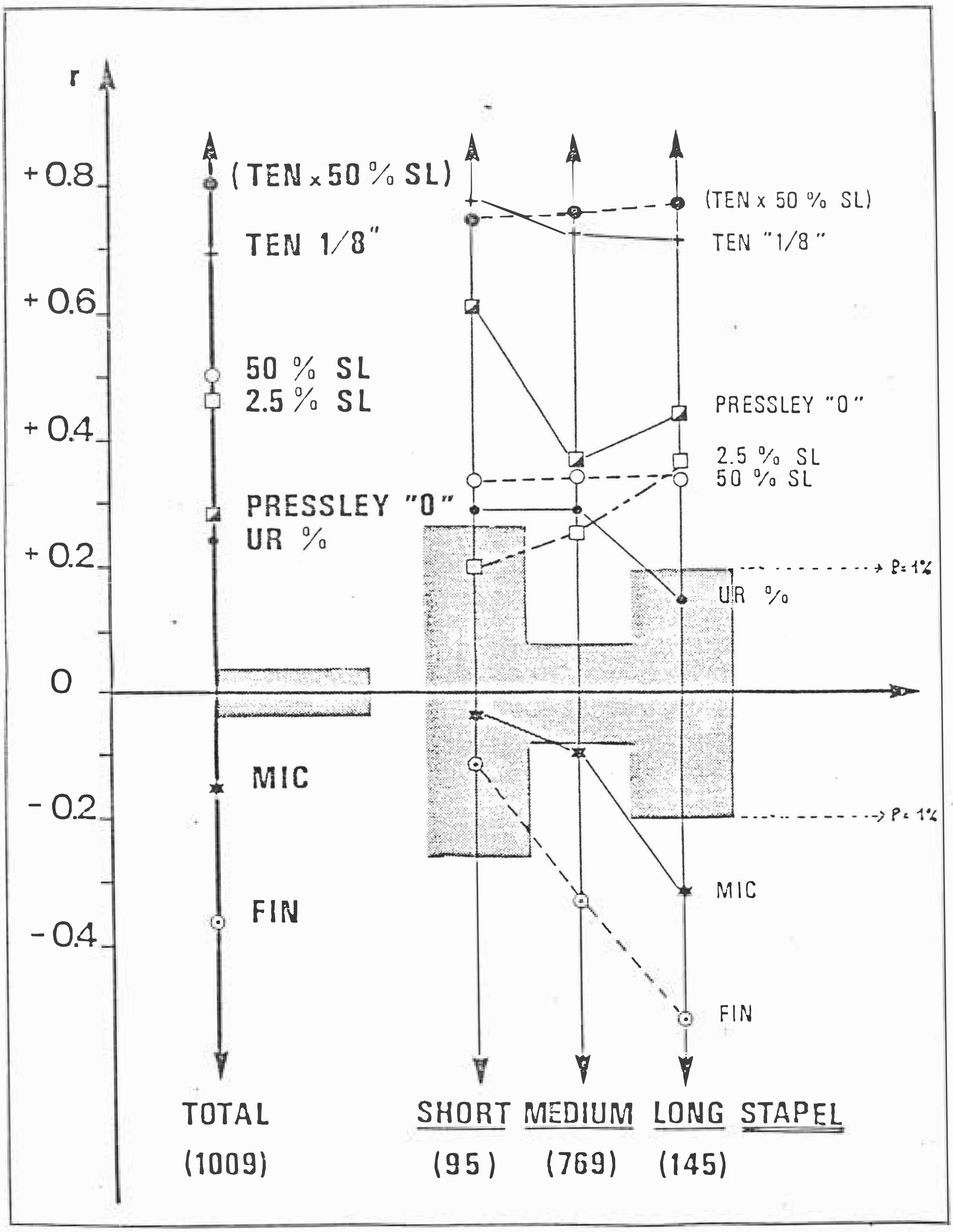

FIG. 2 SIMPLE CORRELATION COEFFICIENTS r

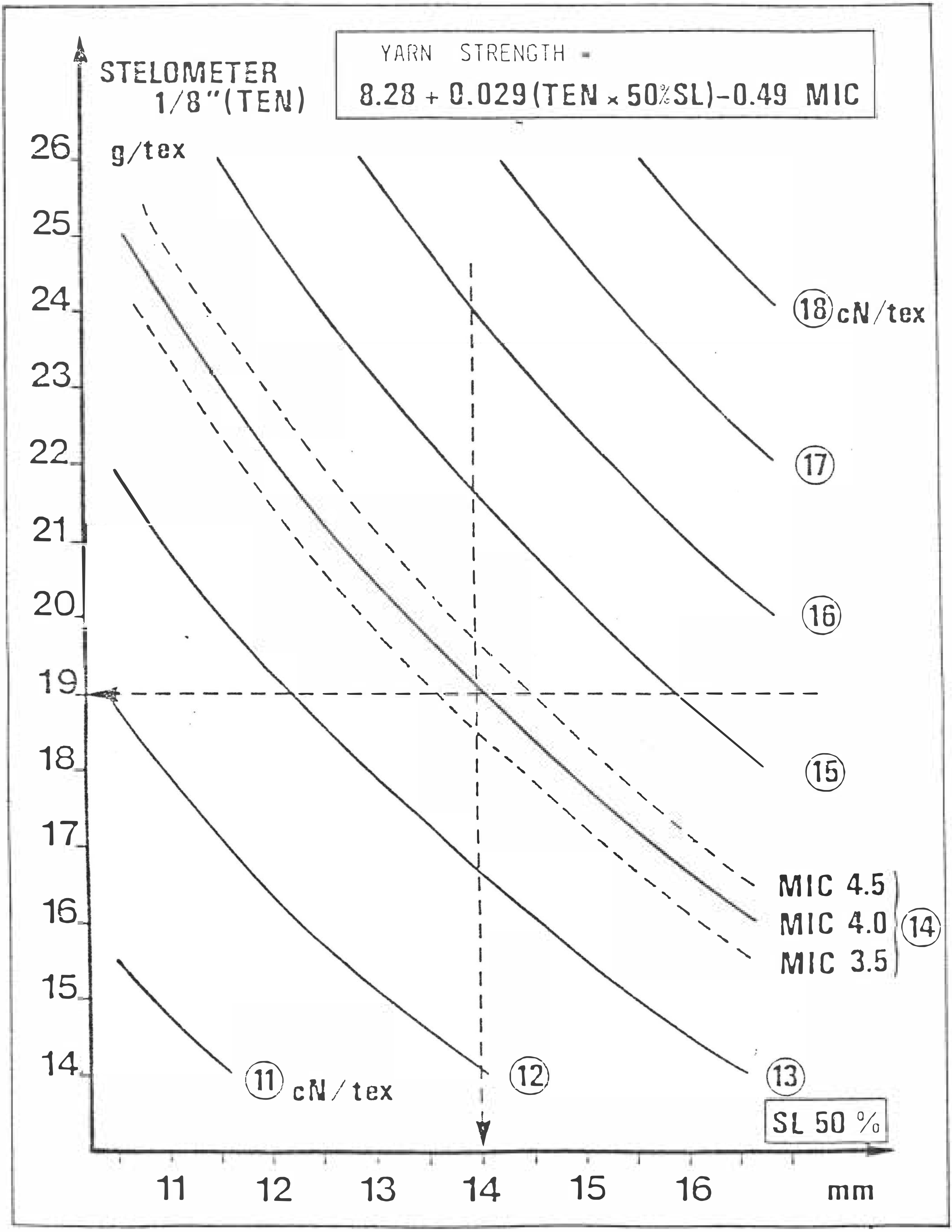

FIG. 3 YARN STRENGTH PREDICTION FOR A 4.0 MICRONAIRE COTTON

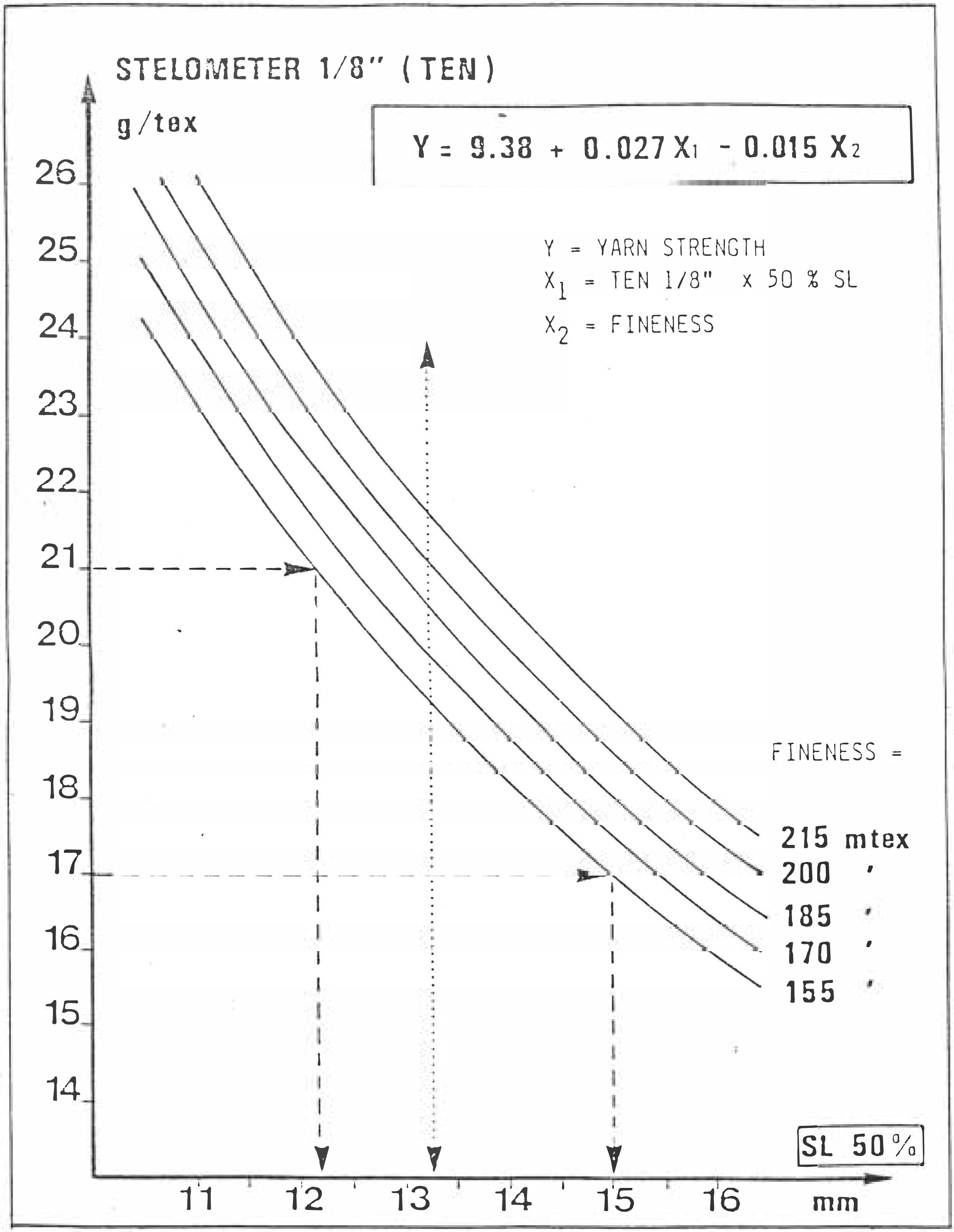

FIG. 4 FIBER PROPERTIES FOR A 14 cN/TEX YARN STRENGTH

Table 1

Study Of 34 Cottons Spun in KNOXVILLE (USA) 1975

Explanation Of The Yarn Skein Strength (27 tex Yarn)

By Some Fiber Properties

		Determination Coefficient (r^2 ou R^2 x 100)
Yarn Skein Strength -	1/8" - gauge Tenacity (TEN)	55.9 %
"	50 % Span Length	34.0 %
"	25 % S.L.	37.9 %
"	10 % S.L.	35.5 %
"	2.5 % S.L.	34.7 %
"	Micronaire	41.3 %
Yarn Skein Strength -	(TEN x 50 % SL)	67.9 %
"	(TEN x 25 % SL)	70.3 %
"	(TEN x 10 % SL)	72.5 %
"	(TEN x 2.5 % SL)	73.5 %
Yarn Skein Strength -	(TEN x 50 % SL) + (Mic)	88.0 %
"	(TEN x 25 % SL) + (Mic)	87.3 %
"	(TEN x 10 % SL) + (Mic)	85.3 %
"	(TEN x 2.5 %) + (Mic)	83.8 %
"	(TEN) + (Mic)	78.0 %

Simple correlation coefficients r

Micronaire -	1/8" - gauge Tenacity	- 0.251
"	50 % SL	- 0.106
"	25 % SL	- 0.213
"	10 % SL	- 0.305
"	2.5 % SL	- 0.422
"	Uniformity Ratio	- 0.417

Table 2

Distribution Of The Main Fiber Properties

(1009 COTTONS)

Fiber Property	Value Mini - Maxi	Range	Average
Length 2.5 % SL mm	25.4 - 35.5	12.4	28.7
" 50 % SL mm	11.0 - 16.8	5.8	13.3
" Uniformity %	39.2 - 52.7	13.5	46.3
Micronaire Index	2.7 - 5.7	3.0	4.2
Fineness mtex	117.0 - 259.0	142.0	184.9
Standard Fineness mtex	143.0 - 326.0	183.0	211.0
Maturity Ratio	0.59 - 1.06	0.47	0.88
1/8" Fiber Strength g/tex	14.1 - 26.3	12.2	19.3
Elongation %	4.6 - 11.3	6.7	7.1
Pressley "0" 1000 PSI	55.6 - 112.0	55.4	87.8
Reflectance Rd %	67.5 - 83.5	16.0	77.3
Yellowness + b	6.5 - 11.9	5.4	9.0
Yarn Strength			
Single End (USTER) cN/tex	10.3 - 18.0	7.7	13.6
Skein cN/tex	7.7 - 13.1	5.4	10.3

Table 3

Fiber Characteristics

by Length Group

	95 SHORT		769 MEDIUM		145 LONG	
	mini - maxi	average	mini - maxi	average	mini - maxi	average
Length 2.5 % SL mm	25.4 - 26.9	26.4	27.0 - 30.1	28.6	30.2 - 35.5	31.1
" 50 % SL mm	11.1 - 13.8	12.1	11.0 - 15.5	13.2	12.6 - 16.8	14.6
" Uniformity %	42.2 - 51.9	46.0	39.2 - 52.5	46.1	41.6 - 51.9	47.1
Micronaire Index	3.1 - 5.7	4.3	2.7 - 5.6	4.2	2.7 - 5.4	4.1
Fineness mtex	143 - 253	194	129 - 240	185	117 -226	180
Standard Fineness mtex	159 - 301	225	161 - 326	211	143 -292	202
Maturity Ratio						
1/8" Fiber Strength g/tex	14.1 - 25.6	19.0	15.1 - 25.9	19.4	15.7 - 26.3	19.4
Elongation %	4.6 - 11.0	6.9	48. - 11.3	7.1	5.3 - 9.7	7.3
Pressley "0" 1000 PSI	61.3 - 105.4	90.1	56.4 - 110	88.1	68.6 -112	85.1
Reflectance Rd %	67.5 - 82.9	75.5	69.5 - 82.2	77.4	71.5 - 83.5	78.3
Yellowness + b	6.5 - 11.0	9.2	6.6 - 11.9	9.0	7.4 - 10.6	9.1
Yarn Strength						
Single End (USTER) cN/tex	10.3 - 14.9	12.7	10.9 - 16.7	13.6	11.7 - 18.0	14.4
Skein cN/tex	7.7 - 11.2	9.6	8.2 - 12.8	10.3	9.1 - 13.1	10.9

Table 4

Simple Correlations Coefficients Between

Yarn Strength and Some Fiber Properties

In Relation with The Length Group

a) Dependant Variable : Single End Yarn Strength

Independant Variable	Total 1009 Cottons	SHORT 95	MEDIUM 769	LONG 145
Length 2.5 % SL	0.484	0.189	0.264	0.373
" 50 % SL	0.502	0.332	0.350	0.327
" Uniformity	0.276	0.281	0.279	0.163
Micronaire	- 0.139	- 0.031	- 0.103	- 0.323
Fineness	- 0.352	- 0.107	- 0.320	- 0.512
Fiber Strength 1/8"	0.699	0.777	0.721	0.709
Pressley "0"	0.286	0.622	0.365	0.440
Reflectance Rd	0.185	- 0.021	0.108	0.180
Yellowness + b	0.055	0.374	0.084	- 0.212
(TEN 1/8 x 50 % SL)	0.806	0.742	0.763	0.773

b) Dependant Variable : Yarn Skein Strength

Length 2.5 % SL	0.494	0.216	0.280	0.351
" 50 % SL	0.524	0.382	0.369	0.365
" Uniformity	0.302	0.323	0.293	0.223
Micronaire	- 0.118	0.021	- 0.084	- 0.325
Fineness	- 0.315	- 0.056	- 0.281	- 0.496
Fiber Strength 1/8"	0.700	0.807	0.722	0.695
Pressley "0"	0.256	0.584	0.338	0.403
Reflectance Rd	0.126	- 0.101	0.039	0.113
Yellowness + b	0.107	0.419	0.143	0.178
(TEN 1/8 x 50 % SL)	0.818	0.786	0.773	0.779
Significant at P0.01	0.081	0.260	0.100	0.200

Table 5.

Main Regression Equations

To Predict The Yarn Strength (27 tex Yarn)

(1009 cottons)

a) Single End Yarn Strength - (USTER) cN/tex

Constant	(TEN x 50 % SL)	Mic.	Fineness	UR %	Variance Explained %	Error Estimat
6.45	+ 0.028				64.9	0.62
8.28	+ 0.029	- 0.49			70.2	0.52
10.25	+ 0.032	- 0.42		- 0.06	71.1	0.57
9.38	+ 0.027		- 0.015		72.5	0.55
10.35	+ 0.028		- 0.013	- 0.03	72.7	0.55

b) Yarn Skein Strength - cN/tex

4.76	+ 0.022				66.9	0.46
6.03	+ 0.022	- 0.34			71.3	0.43
7.26	+ 0.023	- 0.30		- 0.04	71.9	0.42
6.68	+ 0.021		- 0.01		72.5	0.42
7.32	+ 0.022		- 0.01	- 0.02	72.7	0.42

with TEN = Stelometer 1/8" Fiber Strength
50 % SL = 50 % Span Length mm
Mic = Micronaire Index
Fineness = Average Fineness mtex.