STATISTICAL ANALYSIS OF RELATION BETWEEN COTTON FIBRE PROPERTIES AND OPEN-END YARN TENACITY

BY

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ABSTRACT

This paperdeals with the prediction of open-end cotton yarn tenacity from fibre strength, mean fibre length and fibre fineness. Statistical analysis is provided to find the influence of fibre characteristics on yam tenacity. Five different types of cotton, either individually or blended together, were spon into 19 O.E. yarn of 14.5 - 16.5 Tex at twist factor α2/3 80 to 90 turns/m.$Nm^{-2/3}$. Fibre strength, mean fibre length are significant factors for prediction O.E. yarn tenacity. Poor correlation between yarn tenacity and micronaire reading was found, when both mean fibre strength were kept constant.

The results gained are useful to predict OE yarn properties according to raw material available, solving the question of manipulation to keep stability in yarn quality of the predetermined characteristics.

1. INTRODUCTION

The behaviour of O.E. yarn could not be explained without intensive knowledge about the internal structure of the yarn. Practically there is no universal definition to explain the internal struzture of the O.E. yarn. But, it is accepted that the fibres are assembled into O.E. yarn as hooked or folded fibres which seriously impire their ability to carry much load, because each limb of the folded fibres tends to act as a separate short fibre. For this reason the twist factor needed to give maximum strength is higher than for ring spun yarns.

The main factor affecting the structure of the yarn could be sumaerized as follows:

i) the properties of fibres as elements of structure.
ii) the distribution of fibre in the yarn.
iii) the mutual relation between fibres.

It is not practicable to analise thoroughly all these factors together. The present paper deals with the relationship between fibre properties and yarn tenacity.

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Many studies have been carried out to clarify the effect of fibre properties on yarn characteristics. RUSACA and SANDS /1/ analised the ring spun yarn. LOUIS and FIORI /2/ studied the relationship between fibre characteristic and ring spun yarn strength and breakage. BOGDAN /3/ predicted the ring spun yarn strength from fibre properties and twist inserted.

Recently, some work has been carried out to predict O.E. yarn strength from the so-called coefficient of spin-in fibres. HAFEZ /5/ established an equation to predict O.E. yarn strength from fibre length, bundle strength and twist inserted. RAMEY, LAWSON and WORLEY /6/ have studied intensively the relationship between most fibre properties and O.E. and ring spun yarn tenacity and they formulated different equations for yarn strength.

2. YARN PRODUCTION AND TECHNIQUE OF EVALUATION

2.1. MATERIAL

The raw cotton used was selected to achieve as homogenous blend as possible, also to keep the number of minimum fibres in cross-section of the open-end yarn. Table /1/ shows the characteristics of the types of cottons used in the experiments of the present work.

Table (1): The mean Fibre Properties of raw material.

Fibre properties	TYPE OF COTTON				
	RUSSIAN Sort I	RUSSIAN Sort II	EGYPTIAN Menofi	AFGANISTAN	IRAN
Mean Fibre length in (mm)	24.1	21.3	28.64	27.3	22.1
Micronaire reading (μg/inch)	4.9	4.7	3.93	4.06	4.23
Pressely index	7.11	7.69	8.4	7.51	7.19

2.2. METHOD

Table (2) shows 19 types of open-end spun yarn produced under industrial conditions from the five different types of cotton given either individual components or blended together with different blend ratios. All yarns have counts ranging between 14.5 and 16.5 tex and twist α 2/3 ranging from 80 to 90 turns/m. $Nm^{-2/3}$, rotor speed 31000 r.p.m.

Table (2): Main fibre properties for different blends.

Sample	Blending Ratio					Fibre property		
	RUSS. Sort I,	II	EGYP.	AFGAN.	IRAN	Micro-naire reading	Pressely index	Mean Fibre length (mm)
1			100			3.93	8.40	28.26
2	36	17	35	12		4.22	7.59	26.26
3				100		4.23	7.51	27.50
4	45		55			4.33	7.84	25.78
5	65		35			4.39	7.66	25.34
6	50		33	17		4.16	7.74	25.04
7	44	44		12		4.43	7.36	25.82
8	25	25	33	17		4.24	7.10	26.27
9	55		45			4.07	7.53	26.00
10	54	29		17		4.44	7.20	26.87
11	25			75		3.88	7.01	25.78
12	50			50		4.02	7.16	24.55
13	75			25		4.31	7.41	26.00
14	48		25		27	4.42	7.41	24.95
15	56	18		26		4.36	7.02	26.09
16	74				26	4.65	7.11	23.35
17	56	18			26	4.55	7.09	24.39
18	100					4.70	7.11	23.80
19	82	18				4.73	7.22	23.34

The yarns were produceu at MELETA TEXTILE Factory in CSSR. All materials were produced through the following machines:

Rieter Karosel aggregate	B2/10
Condenser	A2
Blending Bale belt (65 mm)	B2
Mono--cylinder cleaner	B4
Auto-mixer	B7/1
Cleaner type (I) ERM	B5/5
Cleaner type (II) ERM	B5/5
Aerofed	A7/2
Carding machine "cristalina"	C1/2
Automatic sliver line	C7/2
Auto leveler Drawing	D7/2
Drawing frame CSSR	RP 300
Spinning frame	BD 200 R

All macbines are Rieter except the drawing frame, second passage are type RP 300 anu the spinning frame BD 200 R are CSSR maue.

2.2.2. Optimal Sliver

The conditions for the preparation of a good sliver is given in Ref. /7/. The following factors were taken into consideration for producing open-end yarns of good quality:

i) Maximum Linear variation in count of the sliver not to exceed 1.3%.
ii) Maximum mass irregularity on uster, c.v.% equal to 2.8%.
iii) Maximum mass of hard impurities in one gram sliver not to exceed 4 mg.
iv) In case of using shirley analyser the maximum value of non-lint is 0.11 %.

Thus, the slivers produced were of 3.5 K. Tex to 3 K. Tex and the uster C.v. % values were 3.38 to 3.95 which were considered acceptable.

2.2.3. Measurments of Fibre and Yarn Properties

The main fibre properties were measured according to the procedure stated in standard CSN, and given in Table (1). A summary of the results, Micronaire reading, mean fibre length and pressely index of the blend are illustrated in Table (2).

Measurments of yarn strength: The zellweger Uster Tensomatt tester was useu, and 200 tests per yarn were performed.

All tests were provided at the standard atmosphere after storing tbe yarns for at least 24 hours in the standard atmosphere.

2.3. TECHNIQUE OF EVALUATION OF RESULTS

Because of the nature of the problem, where the independent variables, "mean fibre length, micronaire reading and pressely index", are varying together and it is experimentally imposeible to vary only one of them and to have the others constant, so the multiple correlation and regression become a useful statistical tool for evaluating the results of the experiments.

The multiple regression and correlation is found in any standard experimental statistical book. The theory and application is found in Reference /8/ where this problem is studied in details and an example for textile engineering is applied. The multiple regression formula is given as:

$$Y_1 = a + b_{12.34} X_2 + b_{13.24} X_3 + b_{14.32} X_4 \quad \ldots\ldots(1)$$

The figures in the above equation indicates to which variable the (b) coefficient is related, while the figures after the dot indicates which variables have been included in the estimated equation, and which given specific consideration within each coefficient.

A program in FORTRAN for evaluation of the very complicated numerical calculation was used. The results were gained from a computer Russian type MINSK 22 of the High School of Textile Engineering in Lilerec CSSR.

3. RESULTS AND DISCUSSION

The following results were obtained from a Russian Computer type MINSK 22 at the high school of Textile in LIBEREC, Chechoslovakia.

Table (3): Simple Correlation Coefficients[a].

Fibre property		Correlation value between fibre property and Open-end yarn tenacity
Micronaire reading	M	r_{12} = - 0.6877 (s)
Pressely index	PI	r_{13} = 0.8348 (s)
Mean fibre length	L	r_{14} = 0.8381 (s)

(a): Zero order coefficient of correlation

(s): Significant at level 0.01 %

Table (4): Partial Correlation Coefficients between O.E. yarn tenacity and Fibre property.

Fibre property	Correlation Coefficients	
	1st order coef.	2nd order coef.
Micronaire reading at pressely index=constant.	$r_{12.3}$ = -0.7128 (s)	-
Pressely index at mean length = const.	$r_{13.4}$ = 0.84049 (s)	-
Pressely index; micronaire kept const.	$r_{13.2}$ = 0.8468 (s)	-
Mean fibrs length, pressely index-const.	$r_{14.3}$ = 0.816 (s)	-
Mean fibre length, micronaire kept const.	$r_{14.2}$ = 0.7252 (s)	-
Micronaire reading, mean fibre length- const.	$r_{12.4}$ = 0.4006 (N)	-
Micronaire reading, pressely index and fibre length kept constant.	-	$r_{12.34}$ -0.5828 (N)
Pressely index, micronaire and mean fibre length kept constant.	-	$r_{13.24}$ -0.8503 (s)
Mean fibre length, micronaire and pressely index kept constant.	-	$r_{14.23}$ -0.7324 (s)

(N): Not-significant at 0.01 % level.

Table (5): Multiple Correlation Coefficient Relating Fibre Prop erties to O.E. Yarn Tenacity.

Fibre Property	Open-end yarn tenacity	
	Multiple Coefficient of correlation	Coefficient of determination
Pressely index, Mean fibre length	$R_{1.34}$ = 0.9461	0.8952
Micronaire reading, mean fibre length	$R_{1.24}$ = 0.9224	0.7500
Micronaire reading, pressely index	$R_{1.23}$ = 0.8660	0.8660
Micronaire pressely ind., mean fibre length	$R_{1.234}$ = 0.9648	0.9308

Table (6): Coefficient of Correlation between fibre Properties

i) Simple coefficient of correlation

- Micronaire reading and pressely index r_{23} = -0.3912$^{(N)}$
- Micronaire reading and mean length r_{24} = -0.6149$^{(N)}$
- Pressely index and fibre length r_{34} = 0.563^{s}

ii) Partial coefficient of correlation

- Micronaire reading and mean fibre length, pressely index kept constant. $r_{24.3}$ = -0.5188$^{(N)}$
- Micronaire reading and pressely index, mean fibre length kept constant. $r_{23.4}$ = 0.06906$^{(N)}$
- Pressely index and mean fibre length, micronaire reading kept constant. $r_{34.2}$ = 0.4442$^{(N)}$

Table (7): Standard Deviation and Regression Coefficient

i) Standard Deviation

Zero order	First order	Second order
$s_1 = 0.5682$	$s_{1.2} = 0.4125$	$s_{1.23} = 0.2194$
$s_2 = 0.2368$	$s_{1.3} = 0.3128$	$s_{1.24} = 0.2840$
$s_3 = 0.3400$	$s_{2.3} = 0.2180$	$s_{1.34} = 0.1863$
$s_4 = 1.1282$	$s_{4.2} = 0.8897$	$s_{3.24} = 0.2803$
		$s_{4.23} = 0.7971$

ii) Regression Coefficients

$a_{1.23} = 5.188$	$b_{12.3} = -1.023$	$b_{13.2} = 1.116$
$a_{1.34} = -5.6629$	$b_{13.4} = 1.0439$	$b_{14.3} = 0.2737$
$a_{1.234} = 0.02558$	$b_{12.34} = -5.6659$	$b_{13.24} = 0.86152$
		$b_{14.23} = 0.2159$

3.1. PREDICTION OF O.E. YARN STRENGTH FROM COTTON FIBRE PROPERTIES

i) The proposed formula is based on using the multiple linear regression. The regression equation for estimating the tenacity of O.E. yarn from micronaire reading, mean fibre length and pkessely index is given as:

$$T = 0.025558 - 0.56659\ M + 0.8652\ PI + 0.20159\ L \quad ......(2)$$

where:

T : Predicted yarn strength in g/tex.
M : Micronaire value (4.0 - 4.9 ug/inch)
PI: Pressely index (3.9 - 4.9)
L : Mean fibre length (24 mm to 29 mm).

In equation (2) M, P.I., and L are equivalent to X_2, X_3, and X_4 respectively in equation (1). Equation (2), as any regression equation, is limited to O.E. yarn of counts ranging between Nm 60-68 (16.5 - 14.5 tex) and twist multiplier ranging between α 2/3 (80 and 90).

(ii) Correlation between fibre properties and yarn tenacity

The multiple coefficient of correlation $R_{1.234}$ equal to 0.9648, is considered very high because the explained variation $R^2_{1.234}$ = 0.9308 (= 93%) and only the unexplained variation by this model is only 0.07 (= 7%). Also, the multiple coefficient of correlation is bighely significant from zero value, where:

$$F_{cal.} = \frac{R^2_{1.234}\ (17 - 4)}{(1 - R^2_{1.234})} = 201.76 \gg F_{0.01}$$

$$F_{0.01}\ (\text{for } f_1 = 3,\ {}_2 = 15) = 5.42$$

that means the correlation is statistically highly significant between tenacity of O.E. yarn and fibre properties. Moreover, the standard error of the observed values is 0.1303 and the standard error of estimated valuas is given as:

$$s_{1.234} = s_1 \sqrt{1 - R^2_{1.234}} = 0.1535$$

which is slightly higher than the observed. So, the estimated agree with the observed.

(iii) Testing the significance of regression coefficients:

Using Analysis of variance one can find whether the relation ship between the tenacity of yarn and each of the mentioned fibre-properties differs from zero, i.e. to test whether the regression equation must include the tested variable or not. This was carried out for three values of (b), namely $b_{13.24}$, $b_{14.23}$, and $b_{12.34}$. For $b_{13.24}$

Source of variation	Degree of freedom	Sum of squares	Mean square	Variance ratio
y_1 on X_2, X_4	2	4.6005		
addition of X_3	1	1.1091	1.1091	
Y_1 on X_2, X_3, and X_4	3	5.7096		39.2
unexplained variation by Y_1 on X_2, X_3, and X_4	15	0.4224	0.02829	
Total	18	6.134		

It is found that, Fcal 39.2 $> F_{0.01}$ = 8.68 (for f_1 = 1, f_2 = 15) which means that X_3 is significant and must be included in the regression equation.
and For $b_{14.23}$

Source of variation	Degree of freedom	Square variation	Mean variation	Variation ratio
Y_1 on X_2, X_3	2	5.2189		
addition of X_4	1	0.4907	0.4907	
Y_1 on X_2, X_3, X_4	3	5.70962		17.344
unexplain by Y_1 on X_2, X_3 and X_4	15	0.4224	0.02829	
Total	18	6.1341		

Here also $b_{14.23}$ is significant and regression equation must include X_4.

and For $b_{12.34}$

Source of variation	Degree of freedom	Square variation	Mean variation	Variation ratio
Y on X_3, X_4	2	5.4912		
addition of X_2	1	0.21835	0.21838	
Y_1 on X_2, X_3, X_4	3	5.7096		7.717
unexplained by Y_1 on X_2, X_3, and X_4.	15	0.4224	0.02829	
Total	18	6.1341		

F_{cal} = 7.717 $< F_{0.01}$ (f_1 = 1 and f_2 = 15) = 8.68

that means $b_{12.34}$ is not significant at the 0.01 level and the regression equation would not include X_2. That is agreement with the results obtained by RAMEY and others 161 for O.E. yarn count 27 tex (37 Nm). But on the other hand $F_{calculated}$ 7.717 is greater than $F_{0.05}$ = 4.54 and $F_{0.025}$ equal 6.2 which is significant at these levels where usually in textile engineering 0.05 level is used. In this case, according to the statistical rule of significance test, one can say that the effect of micronaire reading is poor.

H_o: $b_{12.34}$ = 0 at level 0.05 and can not refuse

H_A: $b_{12.34} \neq 0$ at level 0.01

(iv) In case of eliminating X_2 from regression equation(2) one should use the following formulea under the same limitation in equation (2):

$$T_{(g/tx)} = -5.6629 + 1.0439\ PI + 0.2737\ L \qquad \ldots\ldots(3)$$

The standard error of predicted values 0.2137 is higher than the observed value 0.1303. Table (8) shows the measured values of yarn tenacity and prediction according to equations (2) and (3). These values are plotted in Figs. (1) and (2).

3.2 RELATIONSHIP BETWEEN FIBRE PROPERTIES:

From Table (6) the partial coefficients are not significant at the 1% level. This is in agreement with the results obtained by RAMEY and others /6/. I their case for awide variety of cotton. The measurment of Fibre tenacity, was carried out by a stelometer tester, with zero and 1/8 inch ga ge. The differences obtained in the present work and that of other works anay be due to the use of blends. The correlation coefficients obtained are higher than that obtained by RAMEY/6/.

3.3. EFFECT OF FIBRE PROPERTIES ON O.E. YARN TENACITY:

3.3.1 Effect of fibre finneness

From Table (4) the partial coefficient of correlation between the tenacity of O.E. yarn and micronaire reading, when both presesly index and mean fibre length are constant is $r_{12.34}$ = - 0.5828 which is generally considered low. Finneness increased the explained variation from 0.8952 to 0.9308 (as shown in Table (5)), i.e. 0.036, which is a small value. According to RAMY /6/. Finnenese have no effect on O.E. yarn tenacity for coarser count 27 tex,. This results could be extend for higher counte, i.e. finenese has insignificant effect on O.E. yarn tenacity.

3.3.2 Effect of fibre strength

From Table (4) the partial coefficient of correlation between the tenacity of O.E. yarn and presesly index, where the mean fibre length and micronaire reading are constant, is $r_{13.24}$ = 0.8508.

The value of the correlation coefficient is high, which agrees with the results obtained for ring spun yarns.

3.3.3 Effect of fibre length

From Table (4) the partial correlation $r_{14.23}$ between the tenacity of O.E. yarn and the mean fibre length where the

Table (8): Observed and Predicted yarn Tenacity According to Equations (2) and (3).

No.	Observed value	According to Eq. (2)		According to (3)	
		Predicted value	% from observation	Predicted value	% from observation
1	10.56	10.73	1.6	10.84	1.78
2	9.55	9.47	-0.86	9.44	-1.07
3	9.52	9.64	1.28	9.70	1.90
4	9.50	9.52	0.24	9.58	0.55
5	9.40	9.25	-1.60	9.27	-1.40
6	9.31	9.38	-0.80	9.27	-0.42
7	9.24	9.04	-2.11	9.08	-1.65
8	9.16	9.03	-1.40	8.94	-2.40
9	9.11	9.44	3.70	9.31	2.23
10	9.06	9.00	-0.60	9.02	-0.35
11	8.93	9.17	2.40	8.71	-2.40
12	8.92	8.87	-0.61	8.53	-4.36
13	8.86	9.20	3.90	9.18	3.70
14	8.80	8.93	1.50	8.90	1.15
15	8.70	8.86	1.80	8.80	1.20
16	8.37	8.22	-1.75	8.15	-2.60
17	8.28	8.57	3.50	8.55	-3.00
18	8.17	8.28	1.40	8.27	1.20
19	8.12	8.27	1.85	8.26	1.75

△ : Ratio between difference in measured and predicted to the measured value (%).

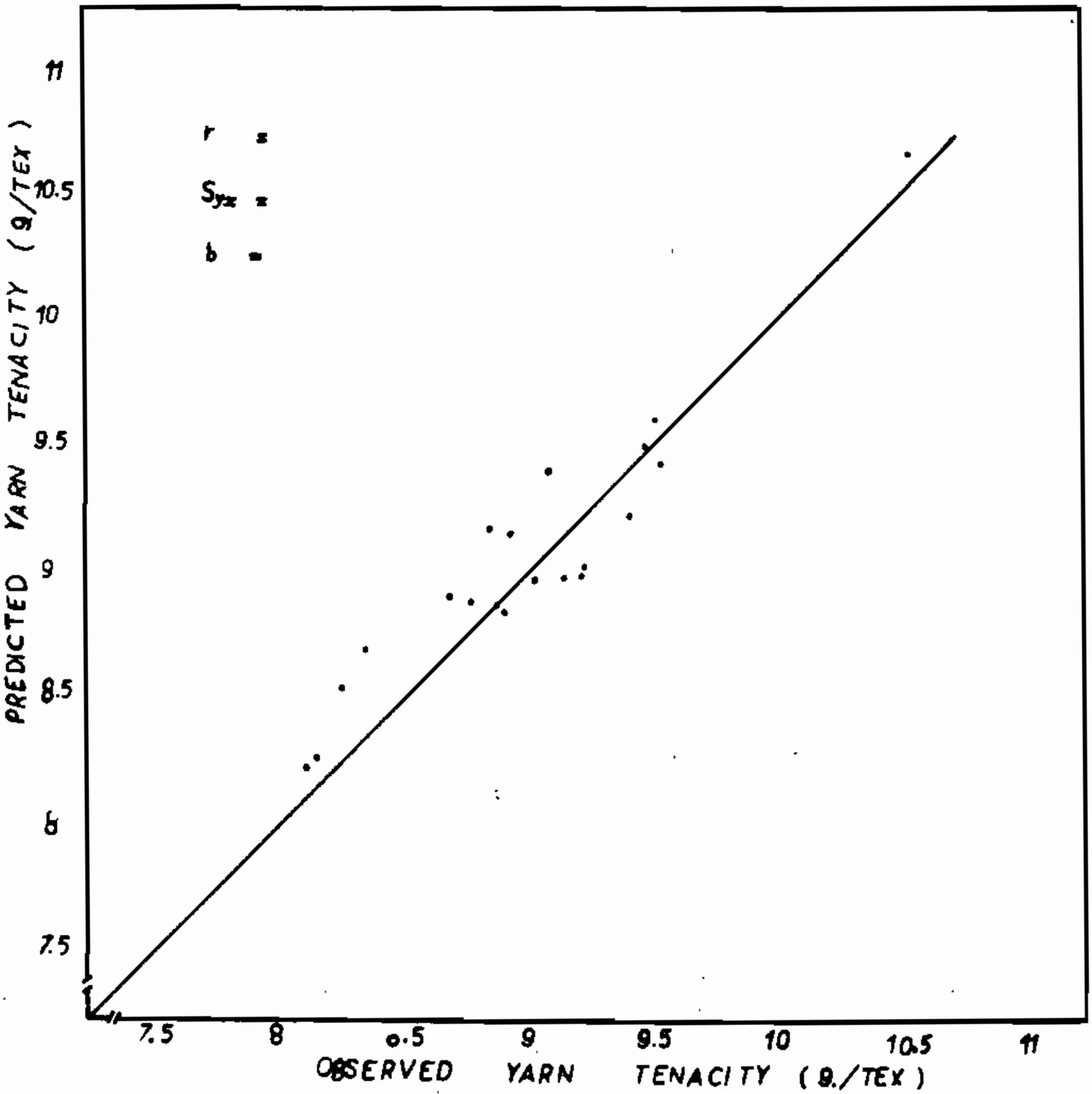

FIG.1. RELATIONSHIP OF PREDICTED TO OBSERVED YARN TENACITY FOR OPEN-END YARN

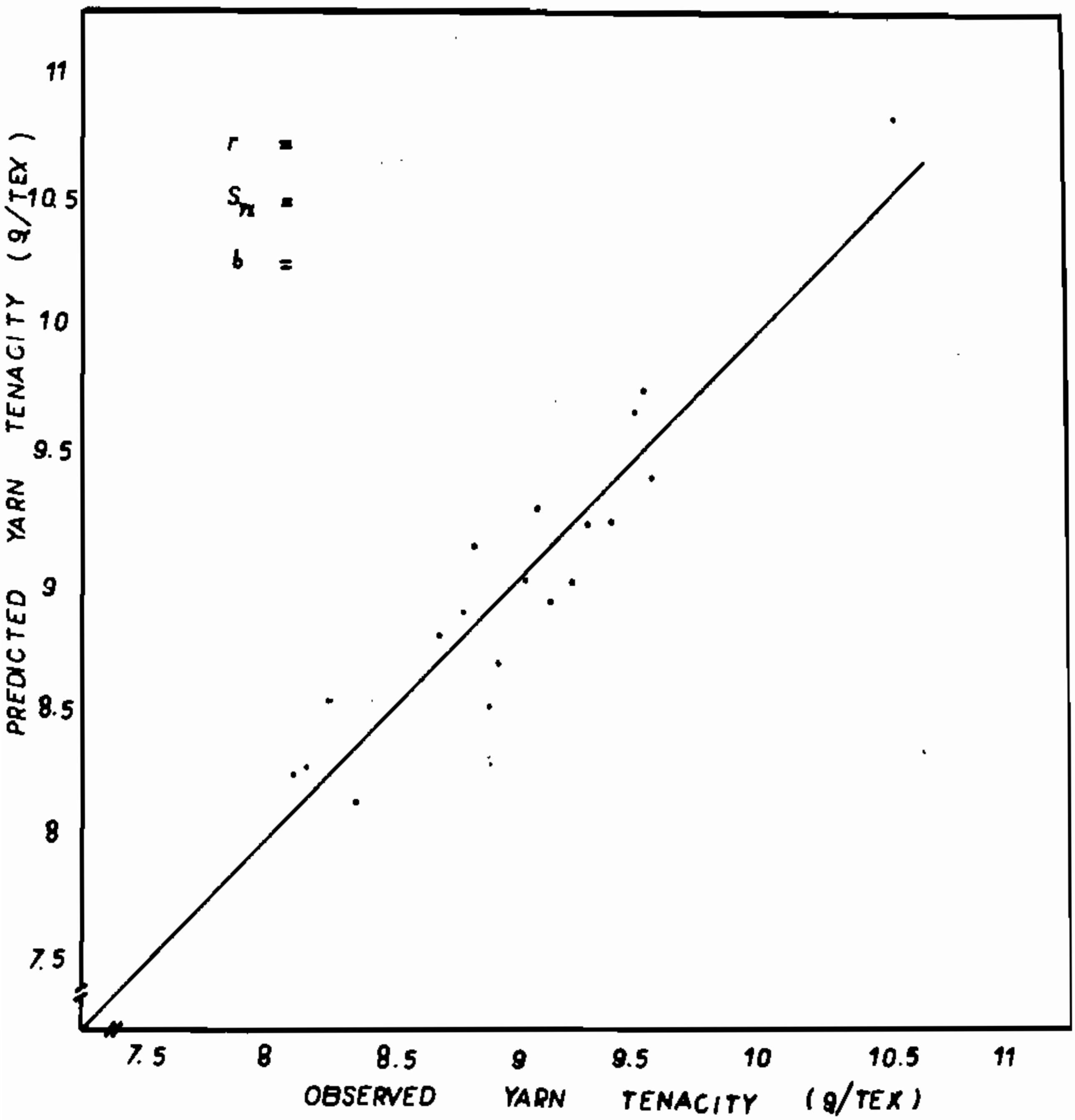

FIG. 2. RELATIONSHIP OF PREDICTED TO OBSERVED YARN TENACITY (g./TEX.) FOR OPEN-END YARN.

micronaire reading and presseley index are kept constant is 0.7324, which is considered high, and $F_{cal} = 19.64 \gg F_{0.1} = 8.4$. This result agree with the work of KRAUSE, SOLIMAN/9/ and VOUGHN /10/.

3.3.4 Direct and indirect effect of fibre properties on yarn tenacity

The B coefficient of analysis which is a relative measure of the importance of X_2, X_3 and X_4 on Y and indicates how many standard deviation of movements in Y will be associated with one standard deviation increase or decrease in X_2, X_3 and X_4.

In the present case one standard deviation increase in the pressely index produces 0.5155 standard deviation in the tenacity of the yarn, and also one standard deviation increase in the mean fibre length, produces 0.4102 standard deviation in yarn tenacity. That reflects the variability of fibre properties on the yarn variability and the importance of homogenity of the blend. The direct and indirect effect of each variable on yarn tenacity are given in Table (9).

It is clear that, the effect of pressely index on yarn tenacity has the greatest in fiusnce compared to the isngth of fibre. But the micro naire reading has vary slight effect.

The indirect effect indicates the interaction of each factor on the tenacity. It was recognized that the indirect interaction of pressely index and mean fibre length is the greatest.

Table (9): Direct and Indirect Effect of Fibre Variables on Yarn tenacity

	X_2 = M	X_3 = PI	X_4 = L	Total
Direct effect	0.05556	0.26575	0.16820	0.4956
Indirect effect				
X_2, X_3	0.04753	0.04753		0.0938
X_2, X_4	0.05800		0.05800	0.11524
X_3, X_4		0.1161	0.11610	0.2322
$\sum$	0.1609	0.4294	0.3423	0.9327
%	17.26	46.03	36.69	100

The sum of direct and indirect, for pressely index is about 46% and for mean fibre length is 34% and for micronaire reading is only 17%. Furthermore, the direct effect of micronaire reading alone without interaction of length and strength is very low /about 6% only/, where the indirect effect is 11%. Also one can say that the total direct effect of these properties together is 53%, this means that the interaction of these factors give the rest of yarn tenacity.

4. CONCLUSION

Two regression equation have been developed for predicting open-end yarn tenacity. The formulas are based on fibre strength, mean fibre length with or without adding fibre fineness. The formulas can be used because of the high coefficient of determination and the low standard error estimation.

O.E. yarn tenacity is greatly ffected by fibre strength, and mean fibre length over the range of counts produced, i.e. between 14.5 to 16.5 tex, the effect of fibre fineness was found to be of a little effect.

The direct effect of the mentioned properties explain only, about 50% of total Nariation in yarn tenacity. This tenacites the small coefficient of spin-in of fibre in the yarn and lower O.E. yarn strength.

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