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ISOLATED WEAK PLACES AND OTHER PHYSICAL PROPERTIES OF COMMERCIAL COTTON AND COTTON BLEND RING AND ROTOR YARNS

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ABSTRACT

The isolated weak places and other physical properties of some 120 commercial cotton, cotton/polyester and polyester yarns, mostly ring, but including some rotor (OE) samples, have been measured. Different measures of isolated weak places were obtained and the correlations between these as well as between them and other yarn tensile properties, determined. The results have been summarised in graphical and tabular form to illustrate the main trends and to facilitate their use for reference and quality control purposes.

INTRODUCTION

It is becoming increasingly clear[1-11] that the frequency and strength of the isolated weak places in a yarn have an important bearing on the behaviour and performance of the yarn during its subsequent conversion into fabric. Such weak places play a role in the frequency of yarn breaks during fabric manufacturing and yarn preparation, and hence have a significant effect on the efficiency of these processes. It is therefore important that an accurate measure of weak places in a yarn be obtained for quality control purposes and that this be monitored and controlled on a routine basis as is done for other important yarn properties.

Because of the importance of yarn weak places and the general lack of information and "reference" or "average" value data in this field, a project was initiated at SAWTRI which was aimed at measuring yarn weak places and finding the correlation between different measures of weak places as well as their correlation with other yarn tensile properties. A second objective of the project was to establish "average" or "typical" values for the weak places and other important physical properties of commercial cotton and cotton blend yarns produced locally, which can be used as a basis of reference in quality control and research laboratories. A third objective was to establish the effects of various fibre and processing parameters on yarn weak places and other yarn properties so as to assist the industry in their continued quest for the accurate prediction and improvement of yarn quality. This report deals with the results of a study on commercial cotton and cotton/polyester blend yarns with specific emphasis on the correlations between different measures of weak places and the establishment of "average" or "typical" values for these and other physical properties of such yarns.

EXPERIMENTAL

A total of 127 commercial weaving and hosiery yarns (Table 1) was obtained from various textile mills in South Africa. The yarns comprised ring cotton, cotton/polyester and polyester as well as rotor (open-end) cotton and ranged in linear density from 10 to 60 tex, there being some combed yarns at the fine end of the range.

The physical properties of the yarns were tested using standard test procedures. The yarn tensile tests were carried out both on an Uster Dynamat (C.R.L.) and an Uster Tensorapid tester, the latter at a rate of extension of 5 000 m/min and with 1 000 tests per sample. The Shirley Constant Tension winding test was carried out at two different tensions (10 000 metres of yarn being tested in each case), from which the tension required to produce 9 breaks per 1 000 metres was estimated[12], therefore, the higher the tension result, the better the yarn in terms of weak places.

TABLE I

LIST OF YARNS

CODE*	TYPE OF YARN		NUMBER OF YARNS
A	Carded Cotton	(Ring)	29
B	Combed Cotton	(Ring)	44
C	Carded Cotton	(Rotor)	13
D	Polyester	(Ring)	7
E	Polyester/cotton	(Ring)	34

* Used in Figs 1 to 27

From the Tensorapid results, the strengths of the weakest, 2nd weakest and 5th weakest places in 1 000 tests were read off and, in addition, the strength (Y) of the weakest place in 1 000 tests as well as that of the weakest place in 10 000 tests were estimated by assuming a normal (Gaussian) distribution and applying the following two formulae:-

Weakest place in 1 000

$$Y \text{ (in cN)} = X\,(1 - 0{,}03\ CV)$$

Weakest place in 10 000

$$Y \text{ (in cN)} = X\,(1 - 0{,}04\ CV)$$

where X = mean breaking strength (cN) and CV = CV of breaking strength (%).

Yarn irregularity and imperfections were determined on both the new automatic Uster Tester II as well as on the older B-series Uster range of testers. Hairiness was measured (at the standard 3 mm distance) on a Shirley Yarn Hairiness Meter while the yarn faults were measured by means of an Uster Classimat. Yarn-to-metal friction was measured on a SAWTRI Yarn Friction Meter.

RESULTS AND DISCUSSION

YARN WEAK PLACES

Correlations Between Different Measures of Weak Places

The correlations between the different measures of weak places are given in Table II from which it can be seen that the various measures of weak places

TABLE II

CORRELATIONS BETWEEN DIFFERENT MEASURES OF YARN WEAK PLACES

	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6
Y_1	1	0,968	0,960	0,928	0,955	0,968
Y_2		1	0,998	0,963	0,988	0,997
Y_3			1	0,959	0,984	0,993
Y_4				1	0,981	0,968
Y_5					1	0,992
Y_6						1

Y_1 : Shirley Tension (cN) required to produce 9 breaks per 1 000 m
Y_2 : Calculated strength of weakest place in 1 000 breaks
Y_3 : Calculated strength of weakest place in 10 000 breaks
Y_4 : Measured strength of weakest place in 1 000 breaks
Y_5 : Measured strength of second weakest place in 1 000 breaks
Y_6 : Measured strength of fifth weakest place in 1 000 breaks

were highly correlated. Nevertheless, for accurate prediction (better than 1,5%), the correlation should generally exceed 0,990. If this is used as a criterion, then only parameters Y_2, Y_3, Y_5 and Y_6 are sufficiently highly related (correlated) to allow the one to be predicted from the other with an accuracy better than 1,5%. From this it follows that, when 1 000 tensile tests are carried out per sample, the strength of the weakest place (Y_2), calculated from the mean breaking strength and its standard deviation and assuming a normal distribution, cannot be used to accurately predict the measured strength of the weakest place (Y_4). Neither can it accurately predict the Shirley tension (Y_1) required to produce 9 breaks in 1 000 metres, although it is a fairly accurate measure of the strengths of the 2nd (1,7% accuracy) and 5th (0,9% accuracy) weakest places (in 1 000 tests) and of the predicted strength of the weakest place in 10 000 tests (0,7% accuracy).

The reliability of the test results for isolated weak places is important because of the infrequent nature (rarity) of such weak places, particularly in respect of the measured strength of the weakest place and the Shirley test results. Another important consideration is the relative usefulness of these different measures of yarn weak places in predicting the performance of the yarn during winding and fabric manufacturing. This aspect still needs investigation for cotton type yarns. In the mean time, however, until a more rapid tensile test becomes available which will allow a measure of weak places to be obtained quickly and accurately it may be advisable to monitor the calculated weakest place in 1 000 tests (Y_2) for routine quality control purposes. This should be more useful than using the mean breaking strength or its CV or both independently.

From Fig. 1 it can be seen that the results for the different types of yarn generally fall on the same line, i.e. follow the same relationship between Shirley test result and the predicted strength of the weakest place in 1 000 tensile tests, except for the polyester yarns (D) which tended to have lower Shirley value than expected from the predicted (estimated) strengths of their weakest place in 1 000 tests. With the exclusion of the Shirley values, the various types of yarns exhibited similar relationships between the measured and predicted values for weak places (e.g. Figs. 2 to 4). What emerges very clearly is that the measured strength of the weakest place is sometimes much lower than that predicted from the mean strength and CV (assuming normal distribution).

It is interesting to note (Table II) that the calculated values (Y_2 and Y_3) provide, if anything, a better measure of the Shirley Constant Tension Winding test result (Y_1) than do the measured values for the stength of the weakest and second weakest place, respectively.

If the Shirley test result is taken to represent a measure of the performance of the yarn during winding and fabric manufacturing, in terms of weak places, then it does not appear possible to adequately predict it from the normal tensile test results (mean and standard deviation), even when doing 1 000 tests per sample. From this it follows that there is a need for a rapid and automatic test for isolated weak places which correlates well with the Shirley test and, by assumption, with the performance of a yarn during winding and fabric manufacturing. An instrument has been designed[13] to do this and it is presently under evaluation.

Correlation Between Isolated Weak Places and other Tensile Values

A question which needs answering is how highly correlated the various measures of isolated weak places are with other more commonly used tensile test values. It was found that even though the correlations were all high, mostly over 0,9 (Table III), they are generally not high enough to allow the results of the isolated weak places to be predicted with sufficient accuracy from the mean tensile strength results (i.e. Tensorapid, Dynamat and Skein tests). The only exception was the correlation ($r = 0{,}991$) between the calculated strength of the weakest place in 1 000 tests (Y_2) and the Tensorapid mean strength. Nevertheless, even in this case, the calculated strength of the weakest place can vary by as much as 100 cN at a constant mean breaking strength (Fig. 5), obviously depending upon the CV of strength. Interestingly enough, the Shirley values were slightly better correlated with the skein strength results than with the other average tensile strength values, confirming that the skein strengh results are more sensitive to weak places than are the single thread results.

Once again it emerged that the different yarns generally followed a similar relationship between their mean strengths and the strength of their weak places although there was a tendency for the combed ring cotton yarns and the rotor cotton yarns to perform better in terms of weak places than one would expect from their mean braking strengths (Figs 5 and 6). The reverse tended to apply for the polyester yarns.

According to the results, the Shirley Tension values were more closely related to the yarn breaking strength than to either extension at break or work-to-break.

At the *same average yarn breaking strength*, rotor yarns were, if anything, superior to the carded ring yarns in terms of weak places, although it should be remembered that rotor yarns are generally weaker than ring yarns and that a coarser rotor yarn would be necessary to achieve the same average strength as a ring yarn. These findings are in line with the generally accepted view that the strength of rotor yarns is lower but less variable than that of ring yarns.

From Fig. 7 it is apparent that, at a certain specific mean breaking strength, the polyester and polyester/cotton yarns had higher work-to-break values than the all-cotton yarns, due to the higher extension values of the yarns containing polyester.

As can be seen from Fig. 8, the relationship between the Shirley Tension values and the average skein strength per thread in cN (i.e. CSP x tex x 0,00471) appears to be largely unaffected by the yarn type (i.e. carded, combed or rotor) although there appeared to be an effect of blend, in that the polyester/cotton yarns had weaker places (i.e. lower Shirley values) than expected from their skein strength values. This is associated with a greater non-uniformity in the strength of these yarns as mentioned previously.

In terms of the relationship between skein strength and work-to-break, the cotton yarns formed one group while the polyester/cotton and polyester yarns formed another group, largely due to the differences in yarn extension which were reflected in the work-to-break results, but not in the skein strength results.

There is generally a fairly good correlation (r = 0,985, Table III) between the calculated strength of the weakest place in 1 000 tests (single end) and the mean skein strength results (calculated per thread), but it is not as good as its correlation (0,991) with the mean Tensorapid strength results (Fig. 5).

TABLE III

CORRELATION BETWEEN MEASURES OF WEAK PLACES AND AVERAGE TENSILE STRENGTH

PROPERTIES	CORRELATION COEFFICIENT (r)
Shirley vs Dynamat Mean Strength	0,967
Shirley vs Tensorapid Mean Strength	0,964
Shirley vs Tensorapid Work-to-Break	0,695
Shirley vs Skein Strength (per thread)	0,967
Calculated weakest place in 1 000 tests vs Dynamat Mean	0,983
Calculated weakest place in 1 000 tests vs Tensorapid Mean	0,991
Calculated weakest place in 1 000 tests vs Tensorapid Work-to-Break	0,860
Calculated weakest place in 1 000 tests vs Skein Strength	0,985
Calculates weakest place in 10 000 tests vs Dynamat Mean	0,976
Calculated weakest place in 10 000 tests vs Tensorapid Mean	0,981
Calculated weakest place in 10 000 tests vs Tensorapid Work-to-Break	0,849
Calculated weakest place in 10 000 tests vs Skein Strength	0,978

Correlation Between Tensorapid and Dynamat Results

There was an excellent correlation (r = 0,997) between the Tensorapid and Dynamat mean breaking strength values (Fig. 9). The higher Tensorapid values can be largely ascribed to the much higher test speed ($<$ 1s) used on the Tensorapid compared to that (20s) used on the Dynamat. The correlation (r = 0,989) between the extension values of the two instruments was also high (Fig. 10). The CV of breaking strength values of the two instruments were not all that highly correlated (r = 0,60), probably as a result of the greater variability of CV values in general.

Both the Tensorapid and Dynamat mean breaking strength values were highly correlated (r = 0,988) with the skein strength, although the correlation was not so high that it allowed the one to be accurately predicted from the other. The following two relationships applied:

CSP = 139 (Dynamat Tenacity in cN/tex) + 249

CSP = 129 (Tensorapid Tenacity in cN/tex) + 228

r = 0,94

GENERAL YARN PROPERTIES

In view of the fact that a fairly large number of yarns, all commercially spun, have been tested, it was considered useful to collate the data in such a way that they could be used as a basis of comparison and reference and for quality control purposes. To this end, the various yarn properties have been plotted against yarn linear density in Figs. 11 to 27 and the main trends are discussed briefly below:

Hairiness

With the exception of the combed cotton yarns, where hairiness increased with increasing yarn linear density, hairiness was largely independent of yarn linear density. The results were therefore averaged and the averages for the different types of yarns are given in Table IV, from which it can be seen that the rotor yarns were the least hairy, followed by the polyester and polyester/cotton yarns, with the combed and carded ring cotton yarns the most hairy. All the yarns were tested on cones, i.e. after winding.

Friction

In terms of friction, the yarns could be divided into two groups, namely waxed and unwaxed. The friction on the unwaxed yarns ranged from about 27 cN to about 50 cN (as measured on the SAWTRI Yarn Friction meter), friction tending to increase with increasing yarn linear density (from about 35 cN for a 15 tex yarn on average to almost 50 cN for a 60 tex yarn). The friction of the waxed yarns ranged from about 10 cN to about 25 cN. There was no obvious difference in the friction of the different types or blends of yarns. The friction of a waxed yarn (cotton, polyester/cotton or polyester) destined for knitting should ideally be about 15 cN and should not exceed 20 cN. The friction of yarns destined for weaving will be much higher because they are generally not waxed during winding.

Irregularity and Imperfections

Fig. 11 shows irregularity (Uster Tester II) plotted against yarn linear density, the results falling into two broad categories, with the carded ring cotton

TABLE IV

AVERAGE VALUES FOR CERTAIN YARN PROPERTIES

Code*	No. of Yarns	Linear Density (tex)	Hairiness (Hairs/m)	Tenacity (cN/tex)	Extension (%)	CSP	Twist Factor (turns/cm $\sqrt{tex}$)
A	29	35,4	54	16,5	6,1	2344	39,0
B	44	17,8	57	15,9	5,3	2357	35,5
C	13	47,6	19	13,0	6,8	1876	40,0
D	7	16,6	31	27,1	11,1	3613	33,9
E	34	20,6	38	20,4	8,8	2833	35,4

*A — carded cotton (ring)
B — combed cotton (ring)
C — carded cotton (rotor)
D — polyester (ring)
E — polyester/cotton (ring)

and the rotor cotton yarns lying at approximately the same level, and the other ring yarns lying at a lower level. Regression curves, representing the average values for the plotted results, have been superimposed onto the data points. If these are compared with the Uster average values published elsewhere[14] then it appears that, on average, the locally produced rotor cotton yarns and finer carded cotton yarns were more irregular than the Uster averages while, on average, the combed cotton yarns were similar to the Uster averages and the polyester/cotton yarns were better.

The irregularity values obtained on the older Uster evenness testing equipment (B Series) were found to be similar to those obtained on the new Tester II.

The frequencies of imperfections (Tester II) have been plotted against yarn linear density in Figs. 12 tot 14 with the regression (average) curves once again superimposed. It can be seen that, in general, the carded cotton yarns contained the most imperfections and the polyester/cotton and combed cotton yarns the fewest. The rotor yarns tended to contain a relatively large number of neps (Fig. 14) possibly due to the presence of wrapper fibres. On the whole, the locally produced rotor and combed ring cotton yarns were found to compare unfavourably with the Uster "average" in terms of thick places.

The Uster Tester II values were generally higher than those of the old tester (almost double) in the case of thick places, but were generally lower (by about 30%) in the case of the frequency of neps.

The correlation between the irregularity (CV%) values obtained on the two ranges of Uster instruments was 0,887, while for thin places it was 0,646, for thick places 0,620 and for neps 0,800.

Shirley Tension

From Fig. 15 it can be seen that, as expected, the tension required to produce 9 breaks in 1 000 metres, in the Shirley Constant Tension winding test, increased with increasing yarn linear density, the polyester/cotton and polyester yarns being generally slightly superior to the all-cotton yarns and the carded cotton yarns generally superior to the rotor yarns. The latter may be due to the fact that an inferior raw material is often used for rotor spinning.

Weakest Place in 1 000 tests

Fig. 16 shows the strength of the weakest place in 1 000 tests, calculated ($x - 3\sigma$) from the mean breaking strength (x) and standard deviation (σ), from which it can be seen that, at a constant yarn linear density, the polyester and polyester/cotton yarns were generally best in this respect and the rotor yarns the worst. This was also observed for the Shirley Tension results.

Weakest Place in 10 000 tests

Fig. 17 shows the calculated ($x - 4\sigma$) strength of the weakest place in about 10 000 tests, which followed the same general trends as the weakest place in 1 000 tests (Fig. 16), as discussed above.

Breaking Strength

Fig. 18 shows mean breaking strength, as obtained on the Dynamat, plotted against yarn linear density, while Fig. 19 shows the results obtained on the Tensorapid. The trends are the same in both cases although the Tensorapid values lie at a higher level, with the polyester and polyester/cotton yarns the strongest and the rotor cotton yarns the weakest. The regression lines are again superimposed for purposes of comparison. The locally produced yarns were generally stronger than the Uster "average" yarns, except in the case of the fine combed cotton yarns.

The Tensorapid CV of breaking strength results have been plotted in Fig. 20 with the average curves once again superimposed. The locally produced yarns appeared to compare favourably with the Uster averages.

The tenacity values (Fig. 21) were largely independent of yarn linear density, except in the case of carded cotton and polyester/cotton yarns where it increased with increasing yarn linear density. The average tenacity values are given in Table IV. Fig. 21 and Table IV clearly illustrate the superior strength of the polyester and polyester/cotton yarns as well as the fact that the rotor yarns were some 20% weaker on average than their ring-spun counterparts. Except for the fine combed yarns, the tenacity of the locally produced yarns was generally better than the Uster averages, particularly in the case of the polyester and polyester/cotton yarns. The average tenacity (16,5 cN/tex) for present day carded ring cotton yarns is higher than that (14,2 cN/tex) obtained by Aldrich[15] in 1975 for locally produced cotton ring yarns.

Extension

As can be seen from Fig. 22, the extension of the polyester yarns was highest followed by that of the polyester/cotton yarns, there being little difference between the extensions of the different types of the all-cotton yarns. The extension of these latter yarns generally increased slightly with increasing yarn linear density. In general the extensions of the local yarns were similar to Uster averages.

The CV of extension (Fig. 23) of the polyester/cotton yarns tended to be higher than that for the other yarns, the CV of yarn extension generally decreasing with an increase in yarn linear density.

Work-to-Break

Work-to-break has been plotted against yarn linear density in Fig. 24 from which it can be clearly seen that the yarns fall into two groups, the one group, comprising the polyester and polyester/cotton yarns, having higher work-to-break values than the other group comprising the all-cotton yarns. The results of the local yarns generally fell close to the Uster averages.

Fig. 25 shows that the CV of work-to-break tended to decrease with increasing yarn linear density, with the polyester/cotton yarns generally showing the highest values and the combed cotton yarns the lowest values.

CSP

Fig. 26 shows the polyester and polyester/cotton yarns to have the highest CSP values and the rotor yarns the lowest, these values having been averaged in Table IV. If these results are compared with those obtained by Aldrich[15] in 1975, then it appears that locally produced cotton ring yarns are stronger today than what they were some ten years ago, the average CSP being 2 200 then and 2 344 now.

Twist

Fig. 27 shows that, as expected, the yarn twist (in turns/m) was largely determined by the yarn linear density and that the rotor yarns were generally more highly twisted than the ring yarns while the polyester and polyester/cotton yarns contained less twist than the all-cotton ring yarns. The CV of yarn twist (determined on a Zweigle automatic twist tester by the double-untwist test in the case of the ring yarns and the treble untwist-twist test in the case of the rotor yarns) varied between 2% and about 6%, the average being about 4%. There appeared to be little difference between the various types of yarns in this respect. The yarn text twist factors varied from about 30 to about 50.

TABLE V

AVERAGE VALUES FOR CLASSIMAT FAULTS (CARDED RING COTTON YARNS)

1,3	1,1	0,9	0,6			
27	8,5	3,1	1,1			
138	30	8,6	4,3			
1205	90	21	10		5,6	
				39		7,4
				812		16
				5		3,8

TABLE VI

AVERAGE VALUES FOR CLASSIMAT FAULTS (COMBED RING COTTON YARNS)

1,1	0,9	0,7	0,2			
13	5,7	1,9	0,5			
71	21,4	5,4	2,2			
355	39	11	4,7		2,6	
				7,6		17
				105		9
				2,6		5,1

TABLE VII

THE AVERAGE VALUES FOR CLASSIMAT FAULTS (ROTOR COTTON YARNS)

0,3	0,5	0,6	0,1			
8,1	3,2	1,4	0,3			
32	7,2	2,5	1,4			
24,6	14	6,7	3,5		2,7	
				31		6,6
				234		2,2
				8,5		13

TABLE VIII

AVERAGE VALUES FOR CLASSIMAT FAULTS (RING COTTON/POLYESTER YARNS)

1,8	1,9	0,6	0,3			
23	10	3,5	0,6			
174	42	10	2,3			
798	73	17	5,3		3,7	
				12,3		30
				422		18,9
				6,1		7,4

A4	B4	C4	D4			
A3	B3	C3	D3			
A2	B2	C2	D2			
A1	B1	C1	D1			
					E	
				F		G
				H1		I1
				H2		I2

Classimat Faults

Tables V to VIII give the number of Classimat faults per 100 km for the different yarn types excepting the all-polyester yarns for which no results were available. It should be noted that the results were obtained on the yarns after clearing.

With respect to the frequencies of thick places, the average values given in Tables V tot VIII compare favourably with the corresponding Uster average (50%) values, with the exception of A_1 faults which are short (less than 1 cm in length) and have a relatively small cross-section. This type of fault is generally regarded to be mainly a function of the raw material rather than of the processing conditions. With respect to thin places, the ring yarns (cotton and cotton/polyester) generally compared favourably with the Uster average values except for the A_1 type thin places (less pronounced) where the results for the local yarns were inferior. The rotor yarn thin place results generally compared unfavourably with the Uster averages.

SUMMARY AND CONCLUSIONS

The isolated weak places and other physical properties of 127 commercial cotton, cotton/polyester and polyester ring and rotor (open-end) yarns have been measured. Different measures of weak places were obtained, namely the tension required to produce 9 breaks per 1 000 m in the Shirley Contact Tension Winding test, the strength of the weakest places in 1 000 tests, measured as well as calculated, based upon the assumption that the strength results follow a normal (Gaussian) distribution. The correlations between these measures of weak places as well as between them and other yarn tensile properties were determined.

It was found that the average yarn breaking strength did not provide a reliable guide of the strength of the isolated weak places in the yarn and in view of the fact that it is the latter which could largely determine the breakage behaviour of the yarns during subsequent winding and fabric manufacturing, it is important that a measure be obtained of yarn weak places for routine quality control purposes. Because of its time consuming and manual nature, the Shirley Constant Tension Winding test is not feasible for this purpose. Until such time that a very rapid tensile test appears on the market* it would be advisable for a firm to calculate the strength of the weakest place in 1 000 tests (or 10 000 tests), as indicated in this report and to monitor this for routine quality control purposes. For this purpose it would be advisable to carry out about 1 000 tests per yarn batch if this is at all feasible.

The Uster Tensorapid (high speed, constant rate of extension) and Dynamat (relatively slow constant rate of load) results were found to be highly correlated, although, as expected, the Tensorapid strength values were generally slightly higher than the Dynamat values.

*An instrument developed at SAWTRI for this purpose is presently under evaluation.

Various yarn physical properties, such as irregularity, frequencies of imperfections, hairiness, single thread strength and extension, CSP, isolated weak places and work-to-break, were plotted against yarn linear density (tex), distinguishing between the various yarn types (carded ring, combed ring and rotor) and blends (cotton, cotton/polyester and polyester). Average (regression) curves have been superimposed onto the points and these can be taken to represent the average or typical values for the relevant types of locally produced yarns.

The locally produced yarns generally compared favourably with overseas standard values (Uster 50% values) in terms of mean breaking strength and extension at break. In terms of irregularity and imperfections, the locally produced relatively fine carded ring and rotor cotton yarns on average compared unfavourably with the Uster averages. This also applied to the smaller (A_1) type of Classimat faults but not to the larger and longer categories. If the results obtained here for single thread strength (Dynamat) and CSP are compared with results obtained on locally produced carded cotton yarns more than a decade ago, then it appears that there has been some improvement in the tensile properties of such commercially produced yarns since then.

THE USE OF PROPRIETARY NAMES

The names of proprietary products where they appear in this report/publication are mentioned for information only. This does not imply that SAWTRI recommends them to the exclusion of other similar products.

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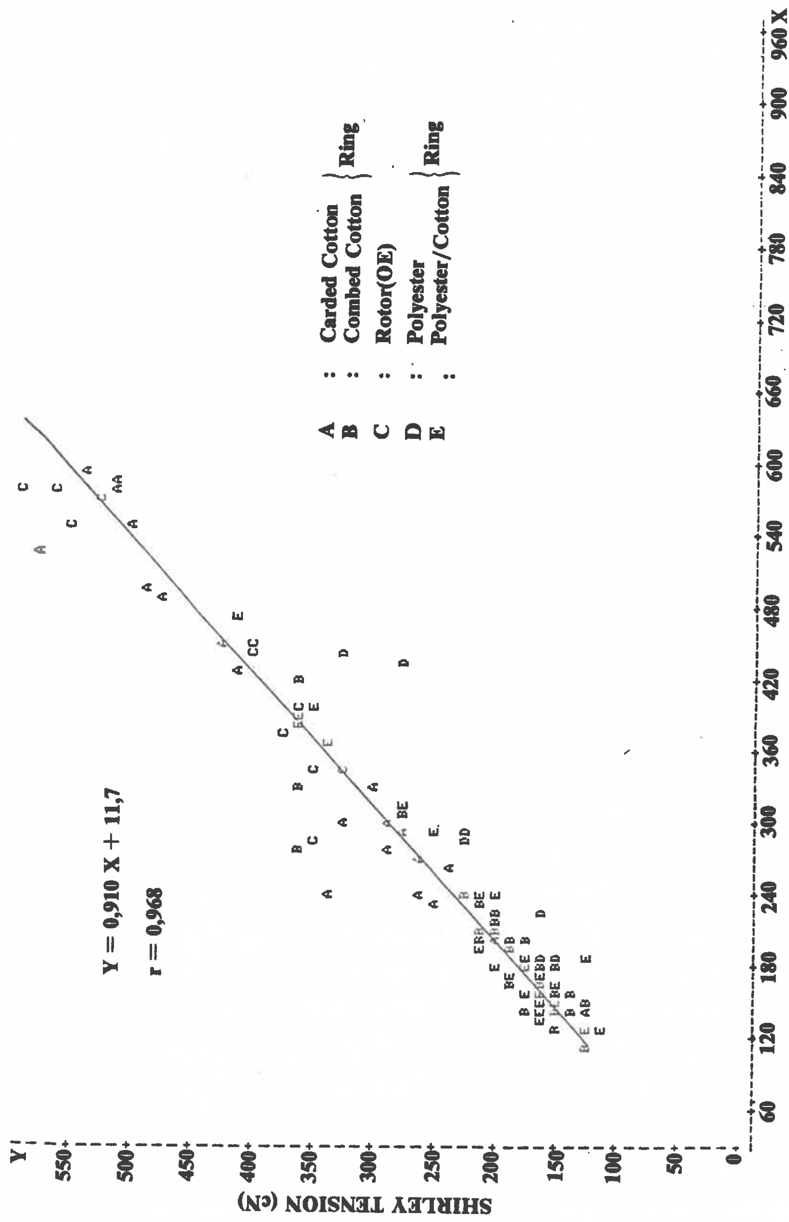


Fig. 1 – Shirley Test Result vs Calculated Strength of Weakest Place in 1 000 Tests.

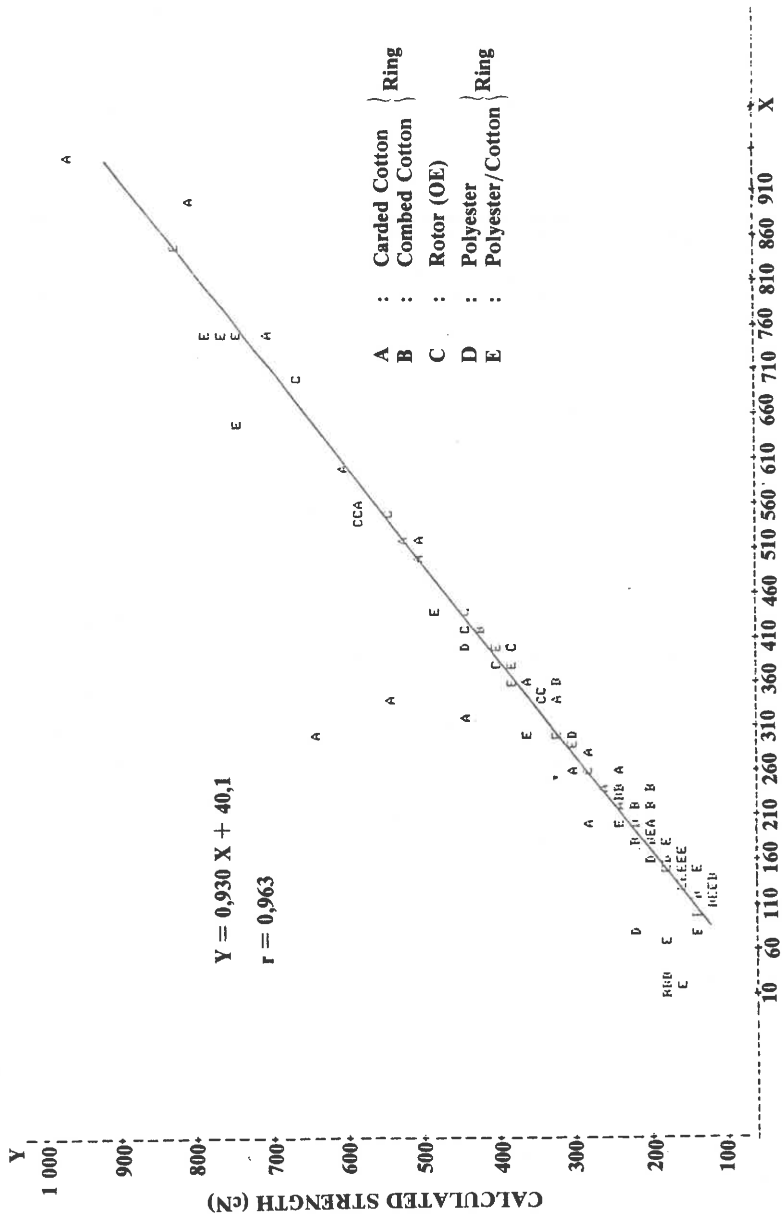


Fig. 2 – Calculated vs Measured Strength of Weakest Place in 1 000 Tests.

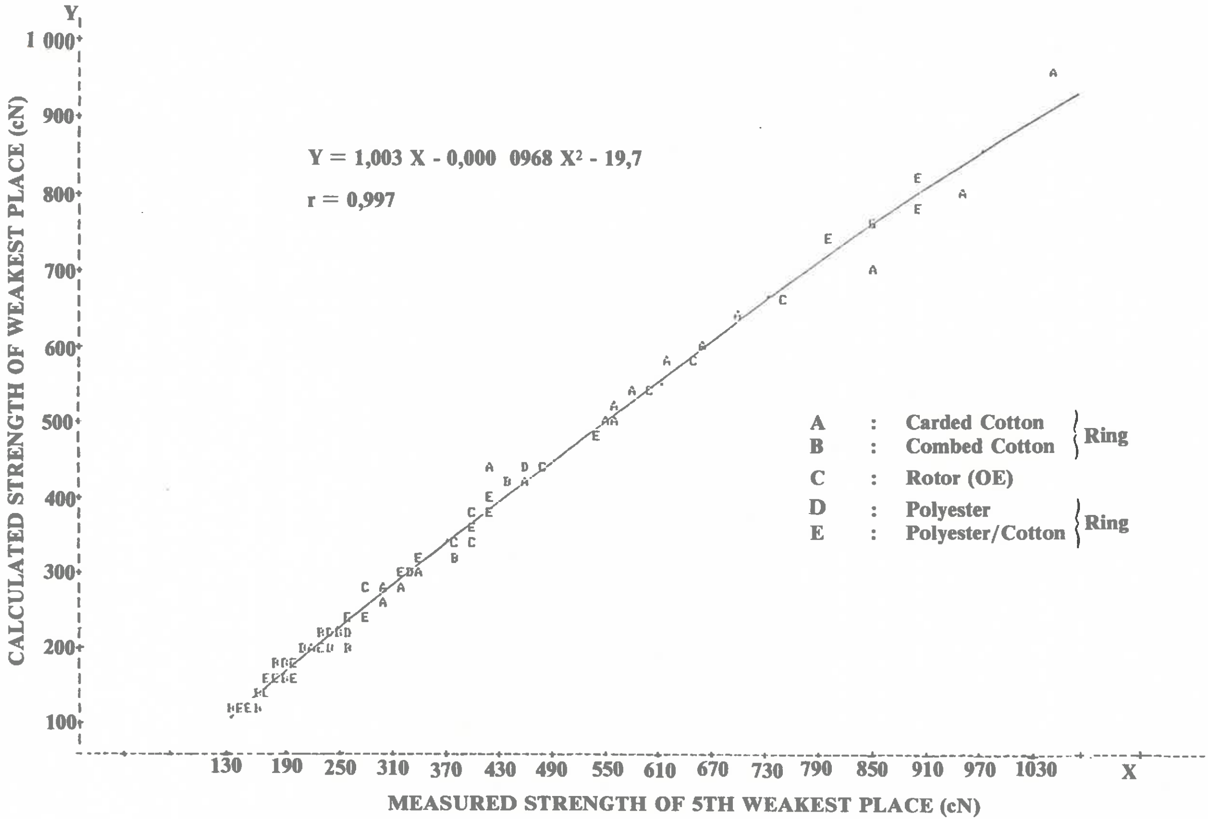


Fig. 3 – Calculated Strength of Weakest Place vs Measured Strength of 5th Weakest Place in 1 000 Tests.

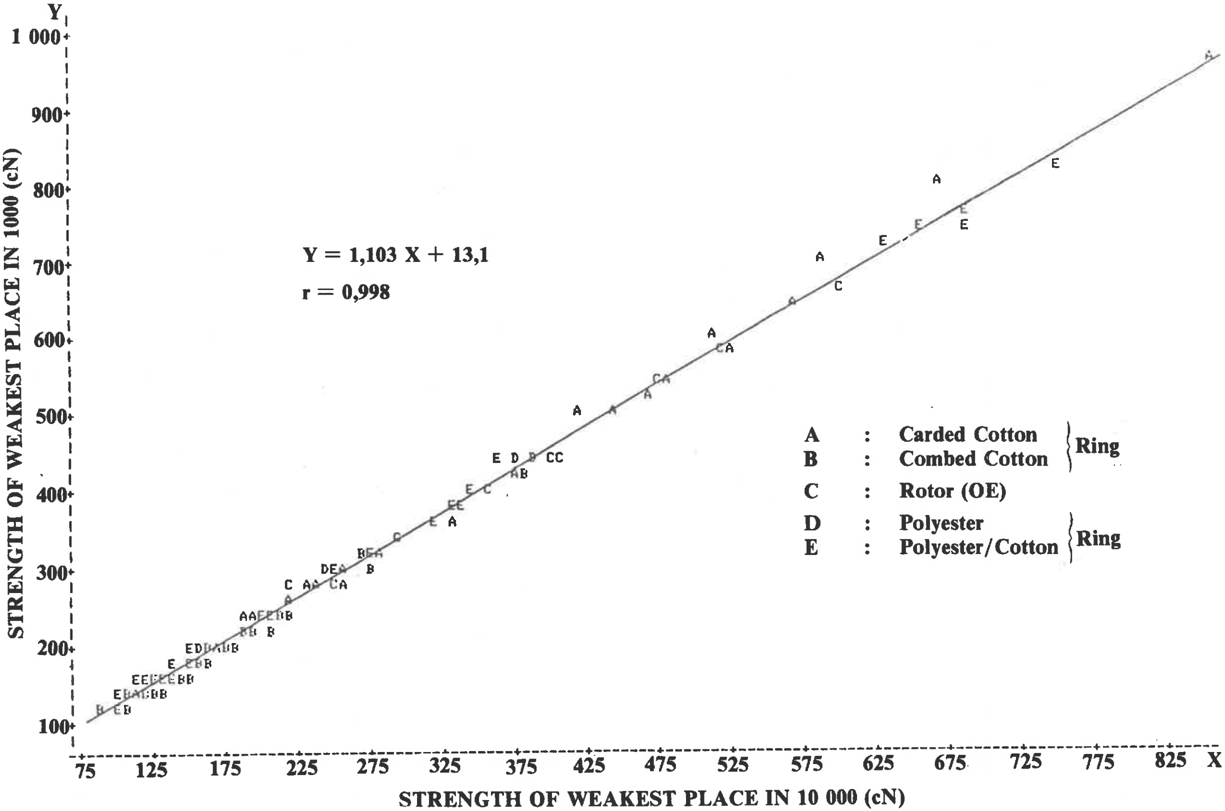


Fig. 4 – Calculated Strength of Weakest Place in 1 000 Tests vs Calculated Strength of Weakest Place in 10 000 Tests.

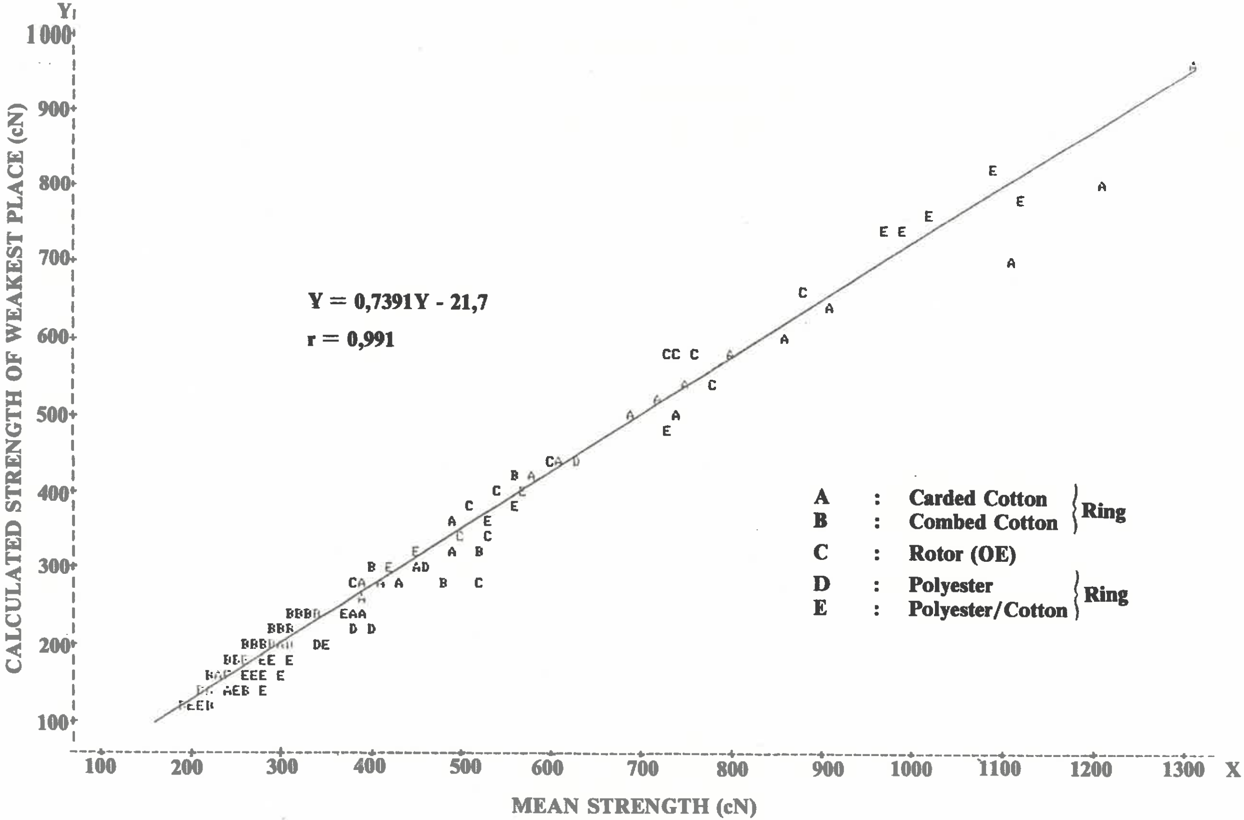


Fig. 5 – Calculated Strength of Weakest Place in 1 000 Tests vs Mean Breaking Strength (Tensorapid Test).

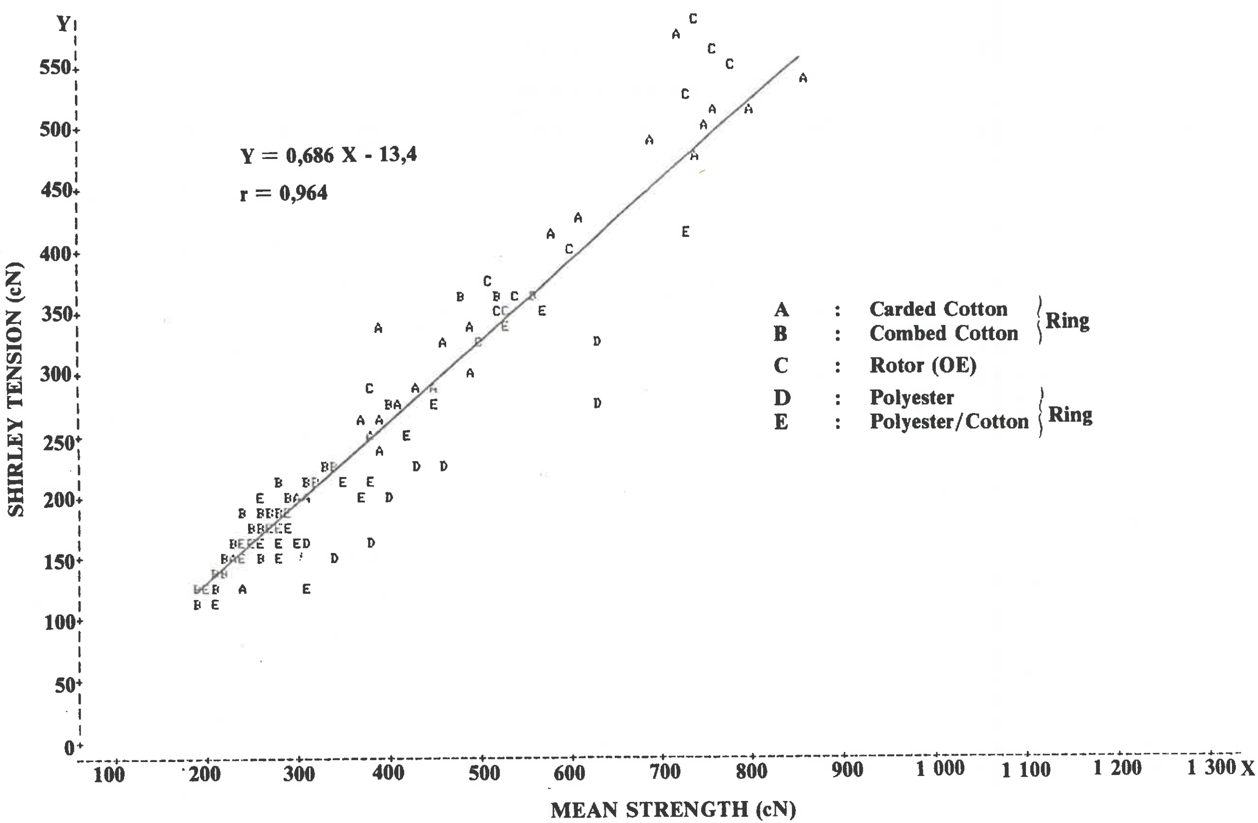


Fig. 6 – Shirley Tension vs Mean Breaking Strength (Tensorapid Test).

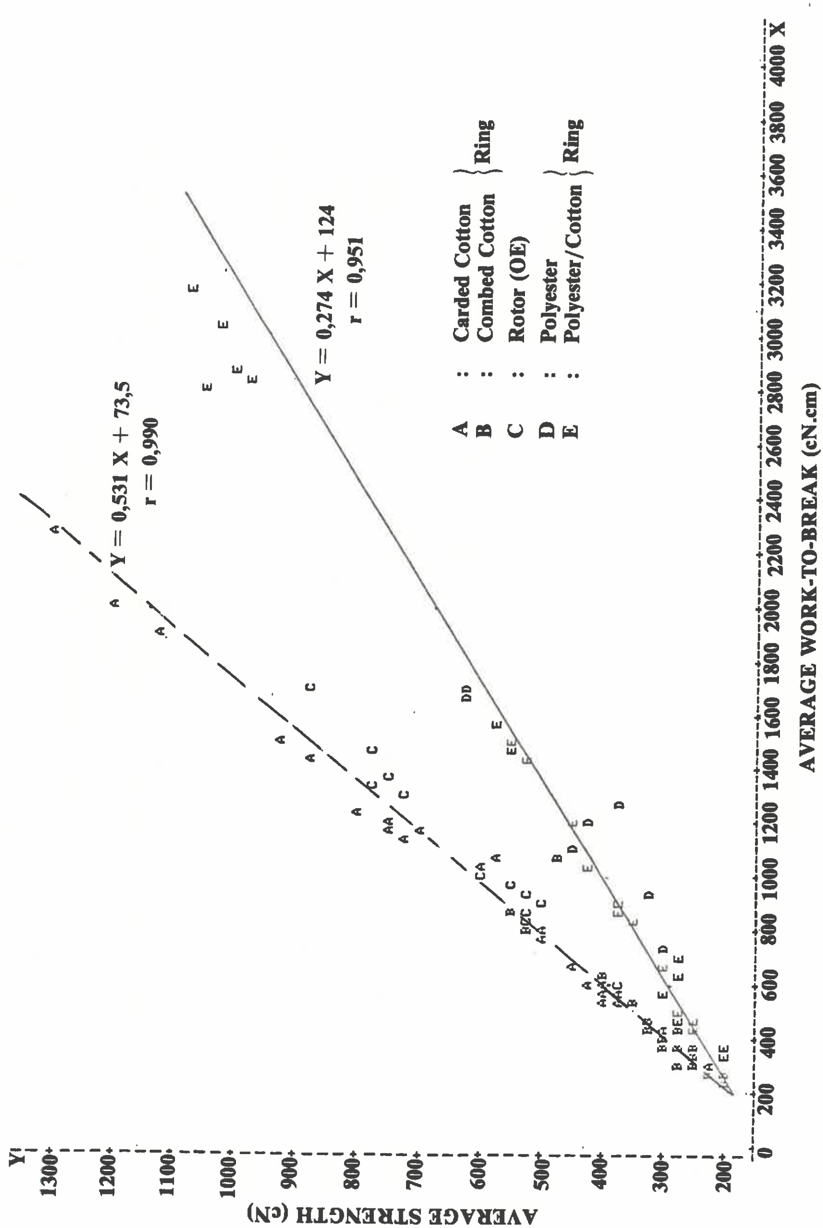


Fig. 7 – Average Strength vs Average Work-to-Break (Tensorapid)

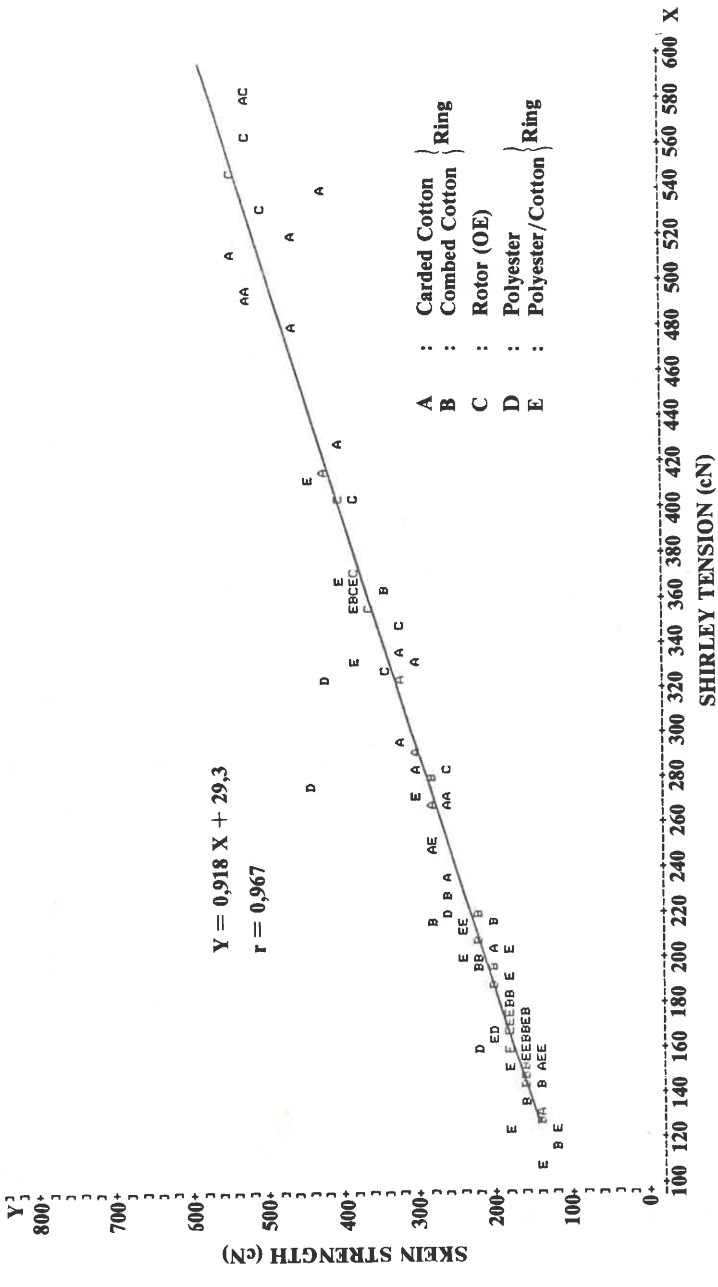


Fig. 8 – Skein Strength (cN) per Thread vs Shirley Tension.

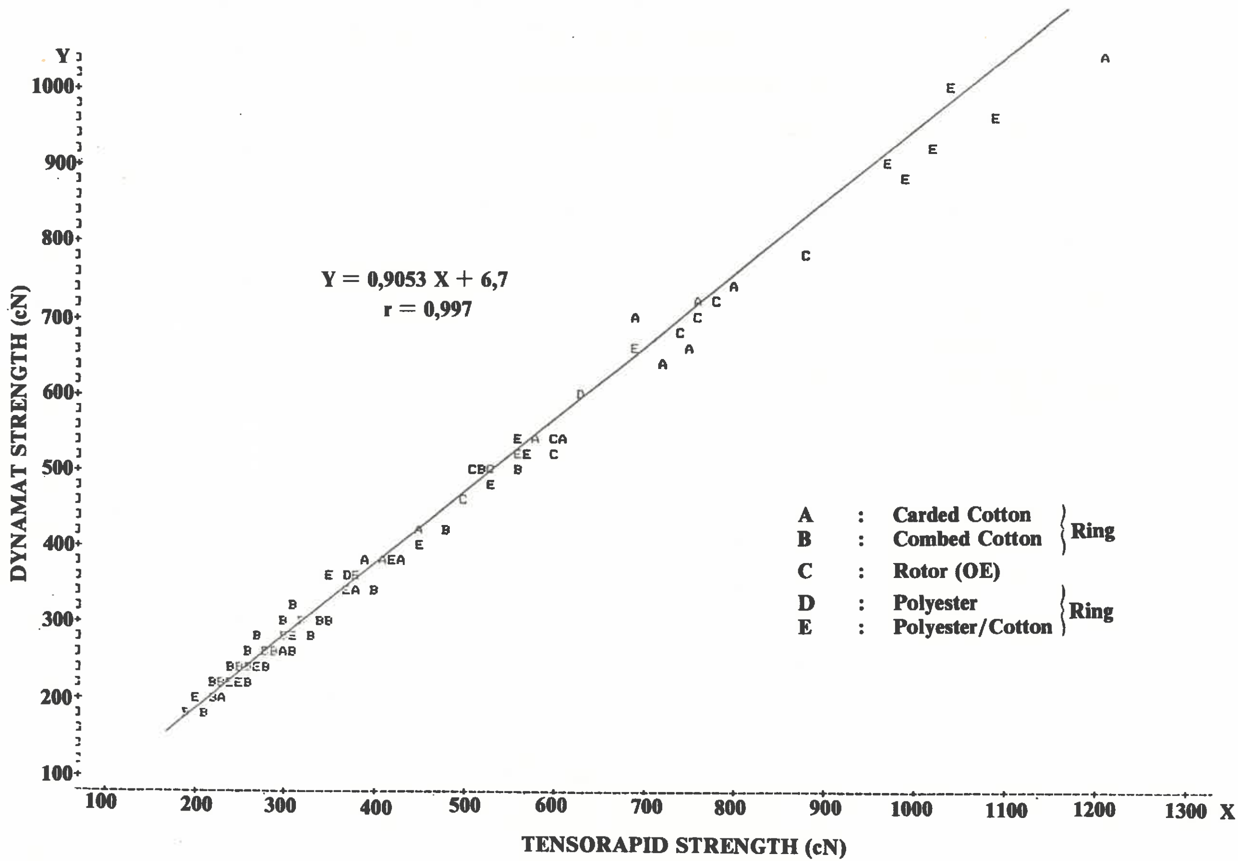


Fig. 9 – Dynamat Mean Strength vs Tensorapid Mean Strength

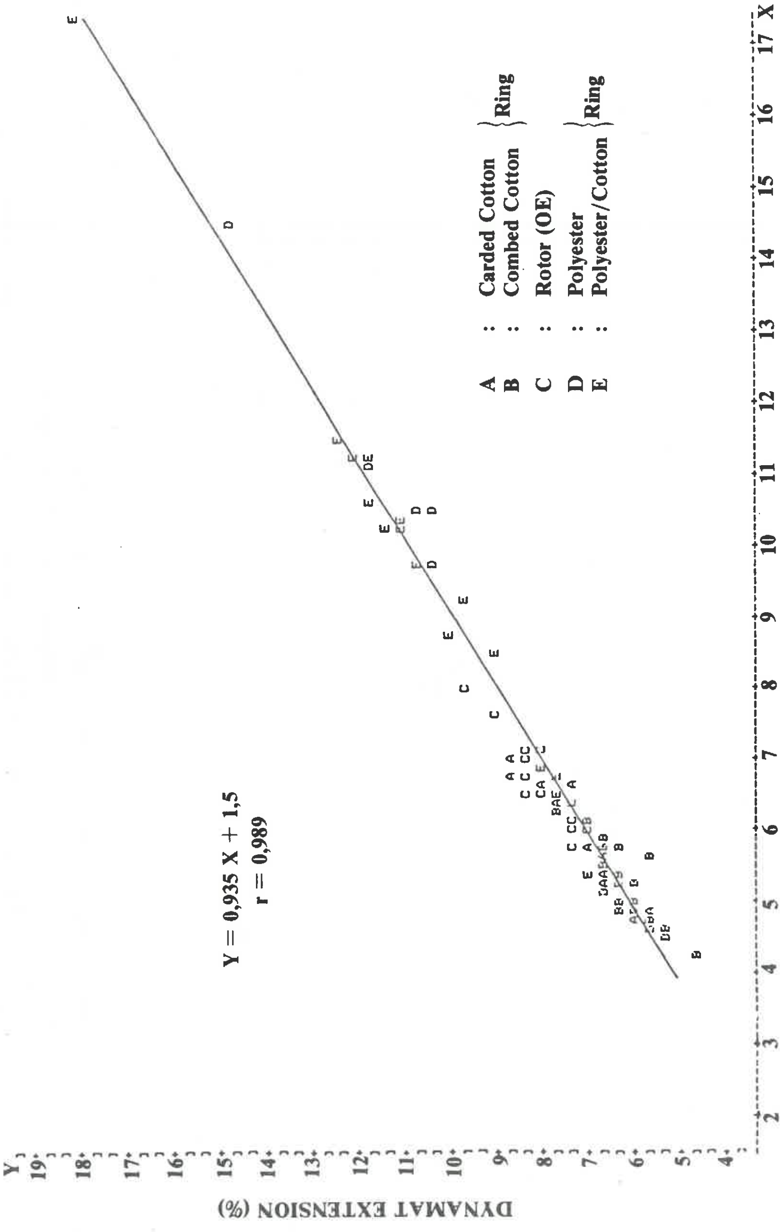


Fig. 10 – Dynamat Extension at Break vs Tensorapid Extension at Break

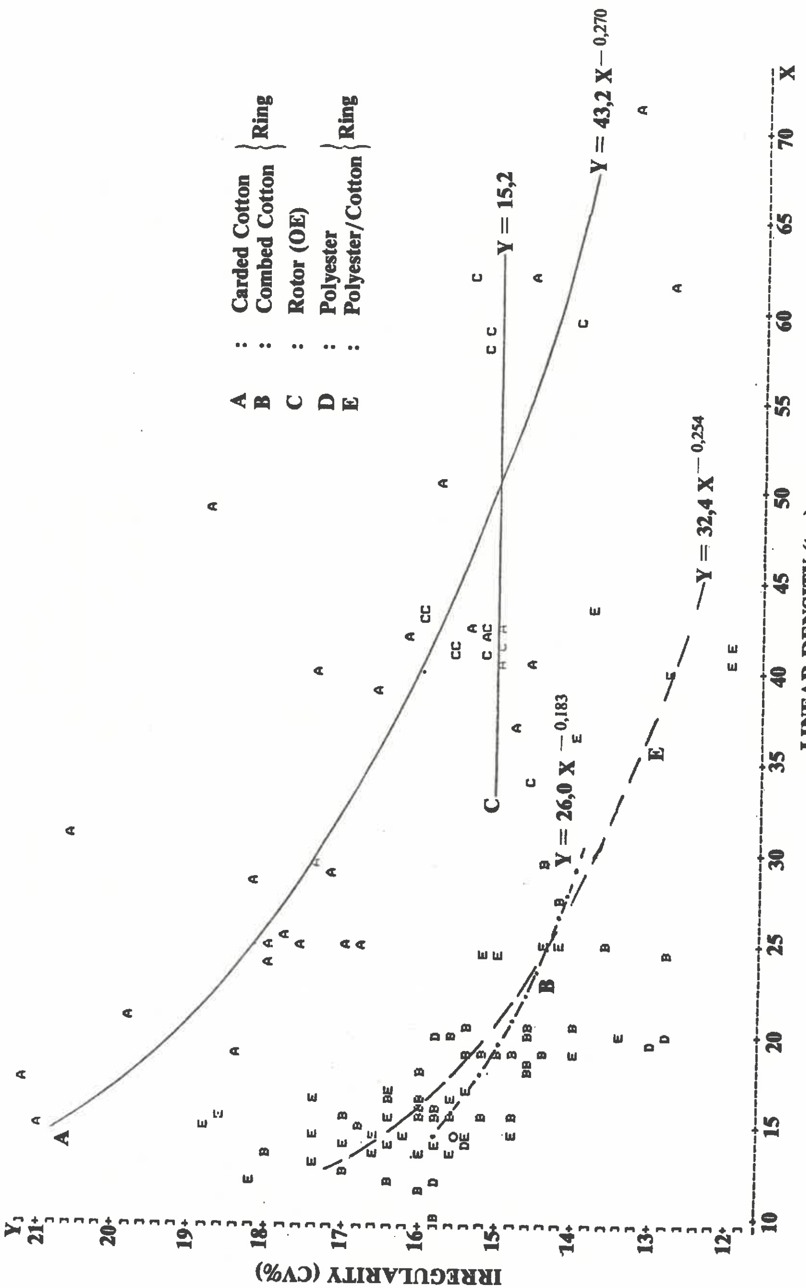


Fig. 11 – Irregularity vs Yarn Linear Density (Uster Tester II)

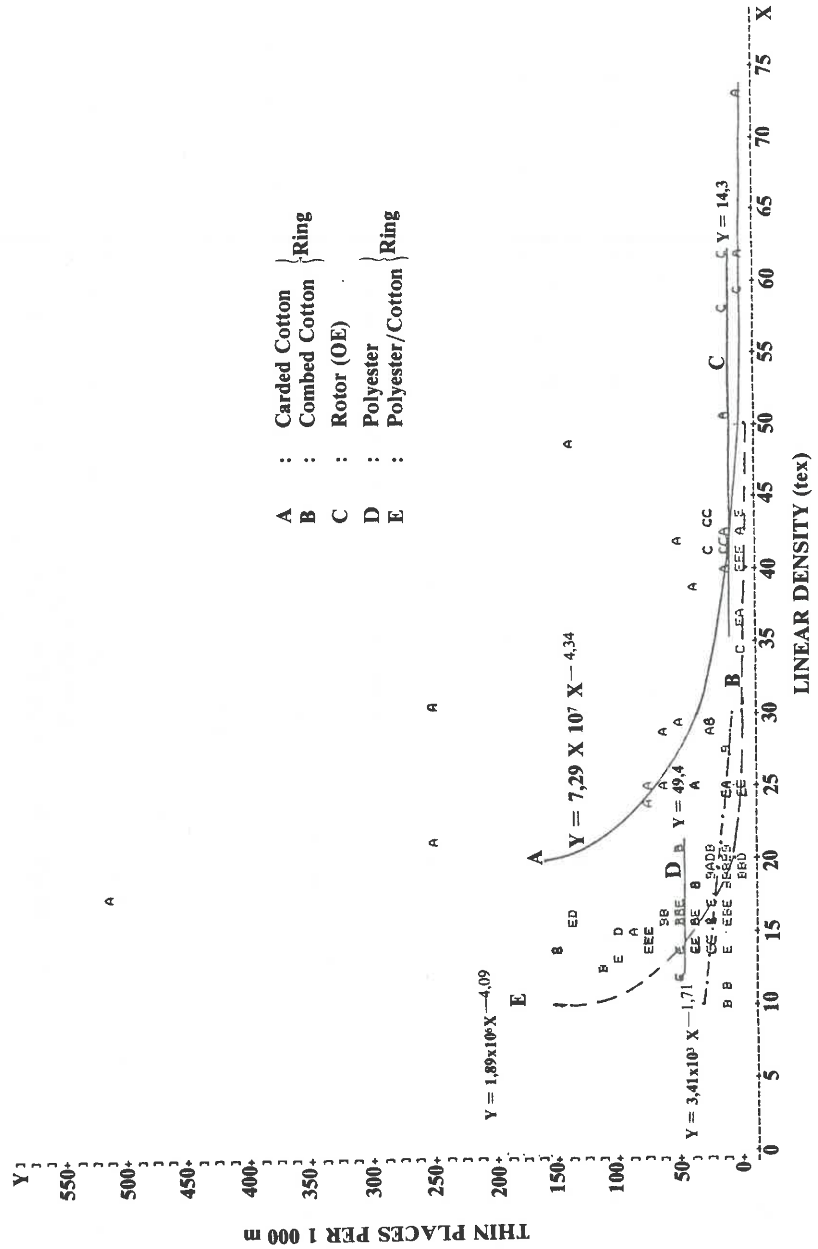


Fig. 12 – Frequency of Thin Places (Uster Tester II) vs Yarn Linear Density.

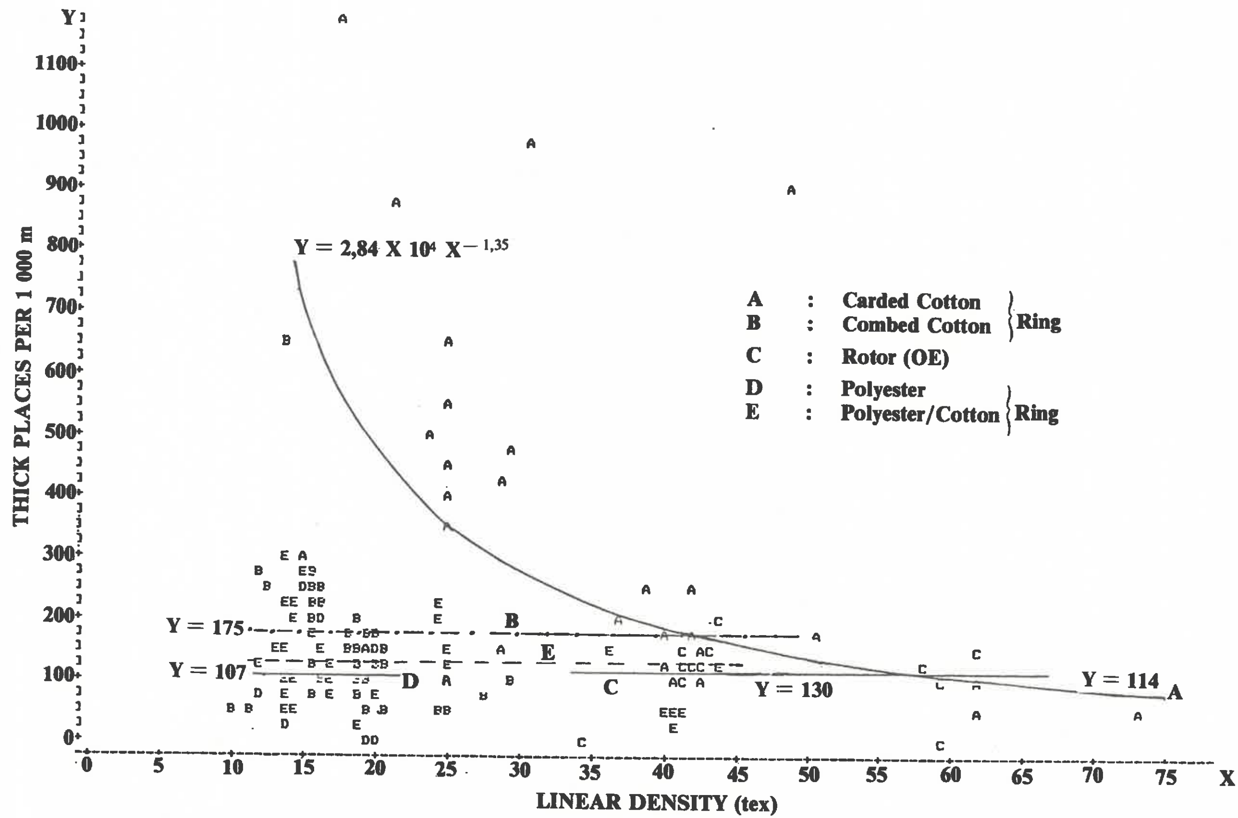


Fig. 13 – Frequency of Thick Places vs Yarn Linear Density (Uster Tester II).

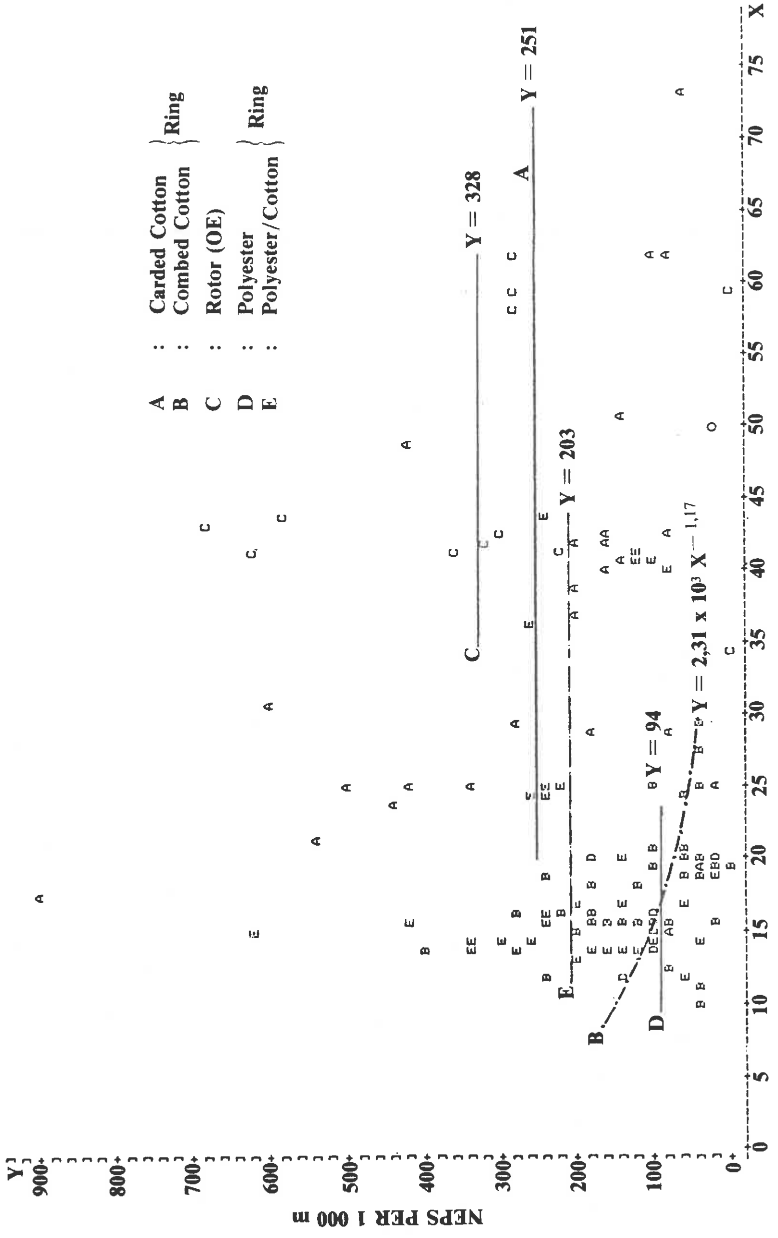


Fig. 14 – Frequency of Neps vs Yarn Linear Density (Uster Tester II)

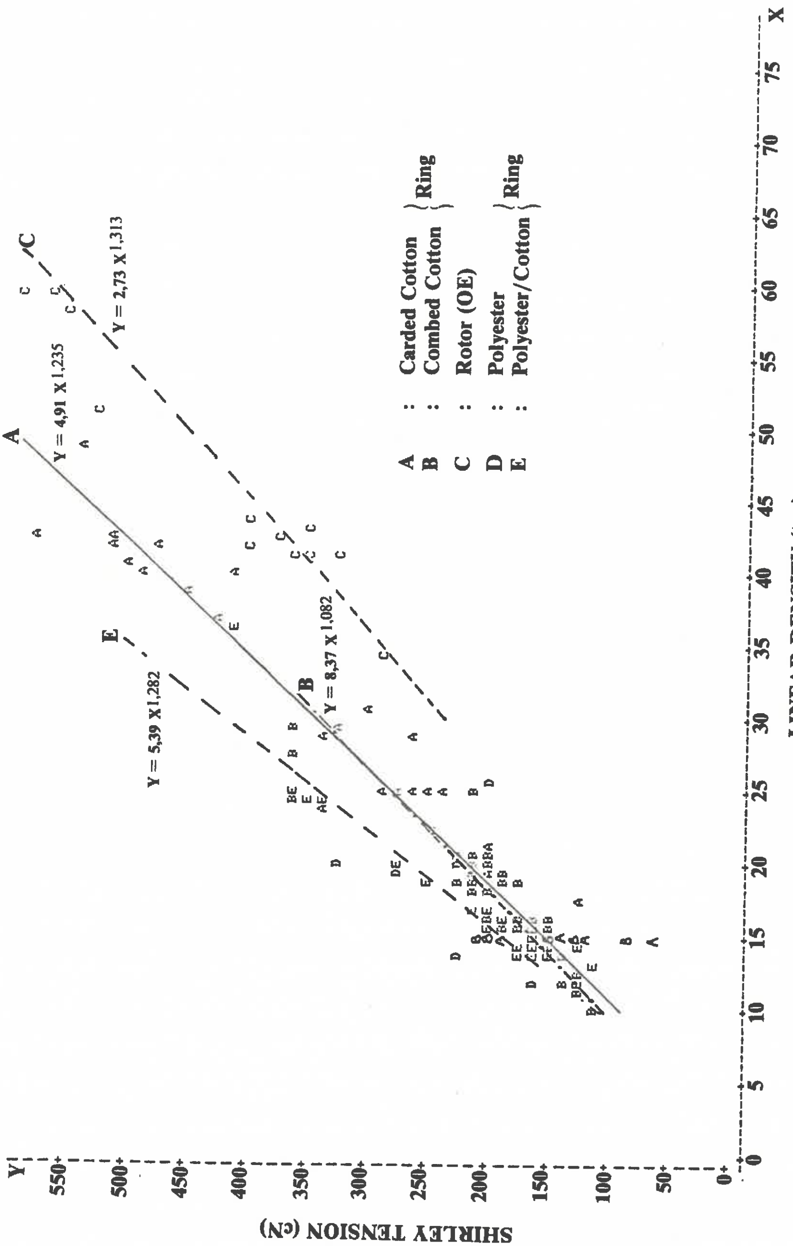
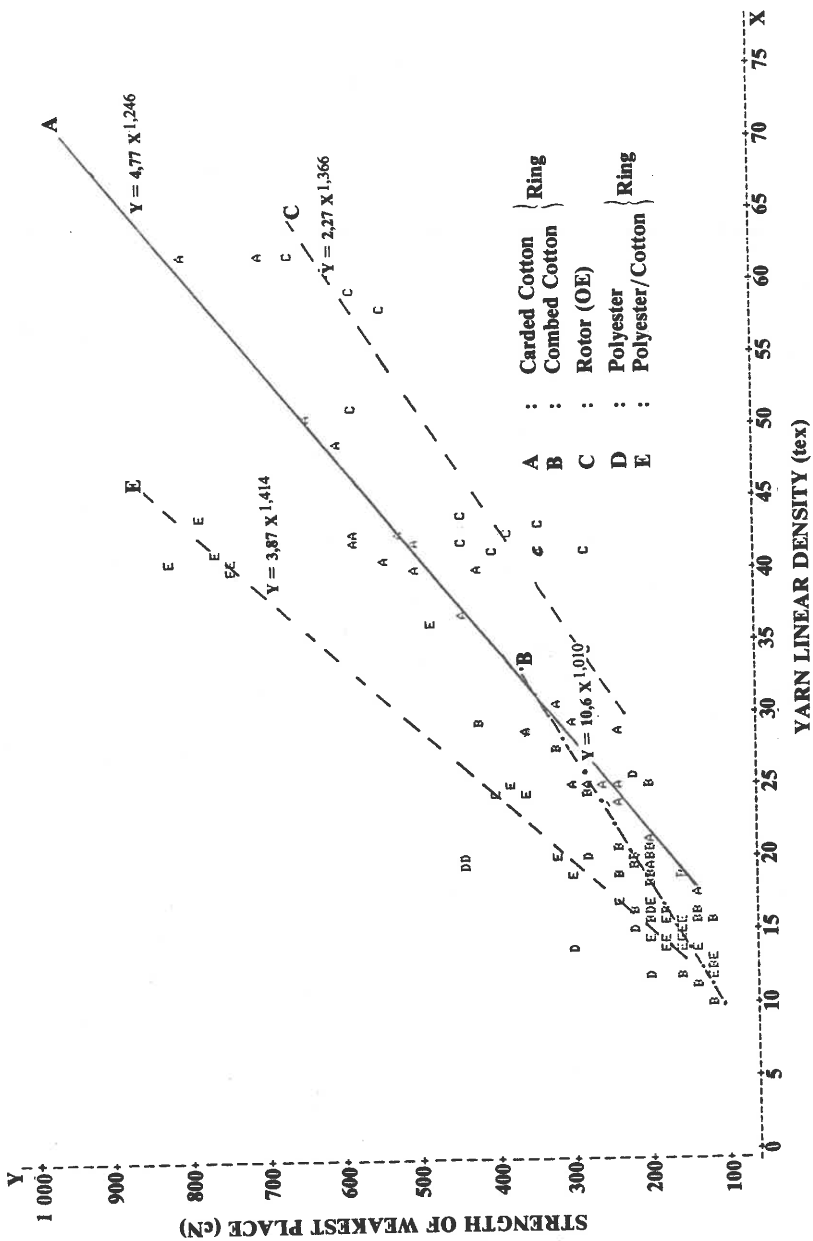


Fig. 15 – Shirley Tension Required to Produce 9 Breaks per 1 000 m vs Yarn Linear Density.



Fog. 16 – Calculated Strength of Weakest Place in 1 000 Tests vs Yarn Linear Density (Tensorapid Test).

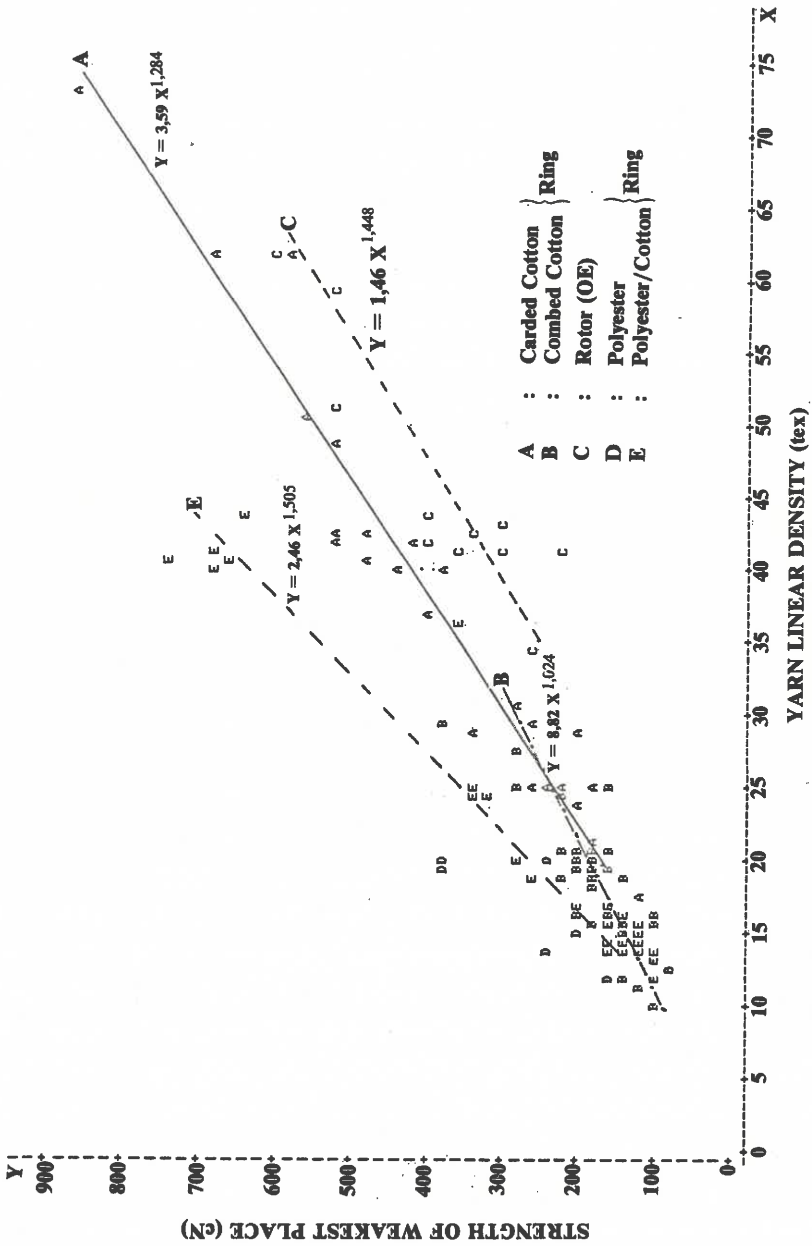


Fig. 17 – Calculated Strength of Weakest Place in 10 000 Tests vs Yarn Linear Density (Tensorapid Test).

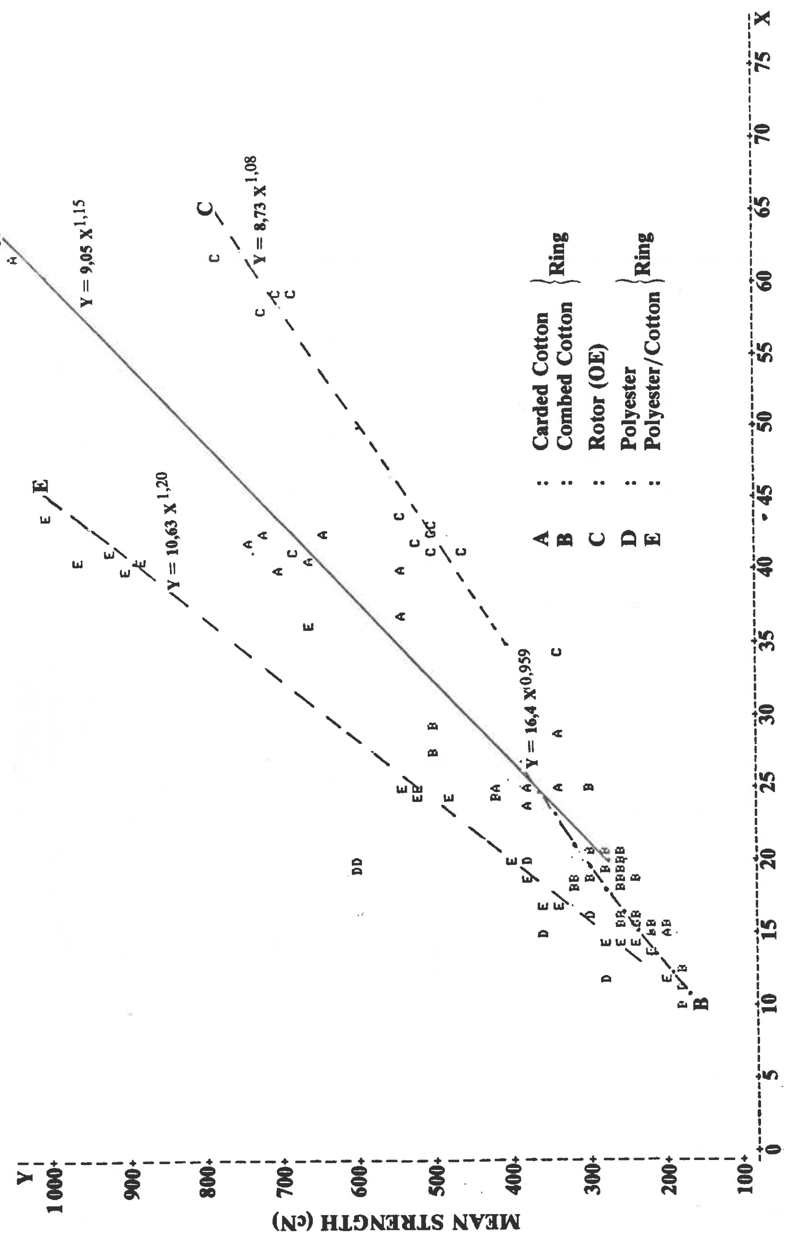


Fig. 18 – Dynamat Mean Breaking Strength vs Yarn Linear Density.

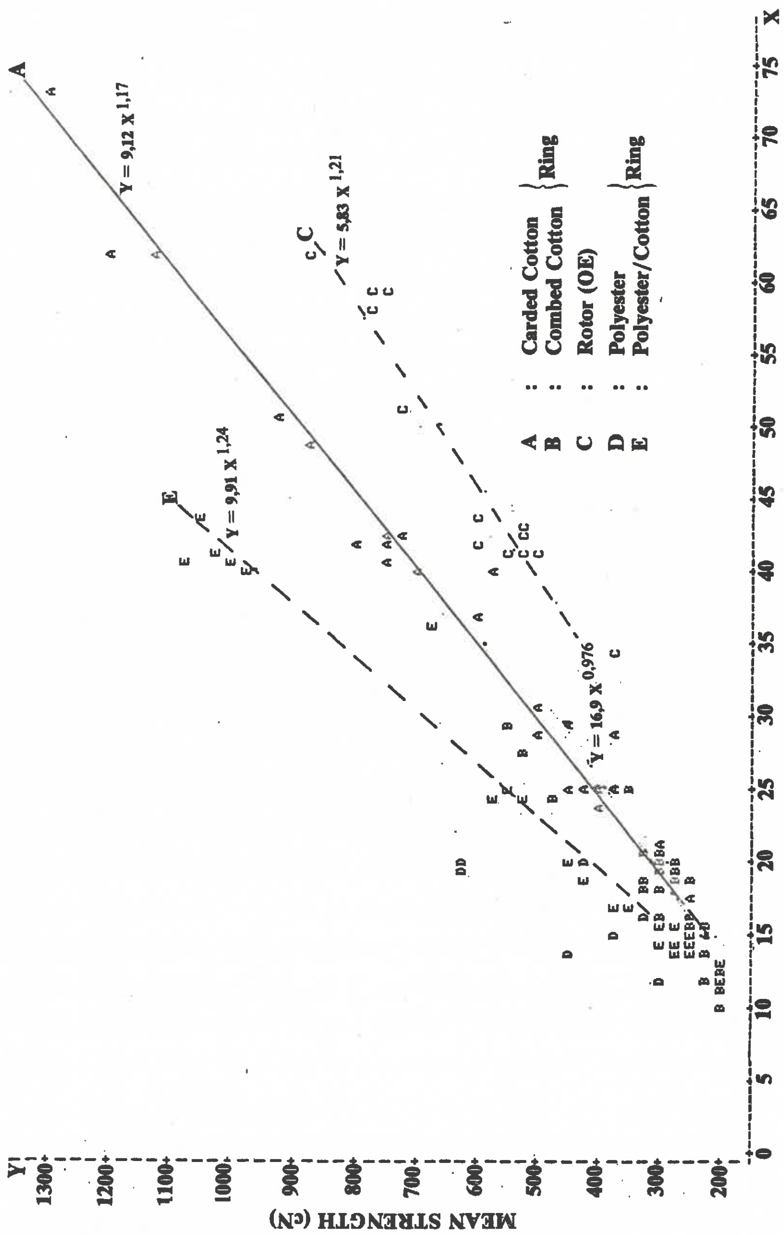


Fig. 19 – Tensorapid Mean Breaking Strength vs Yarn Linear Density.

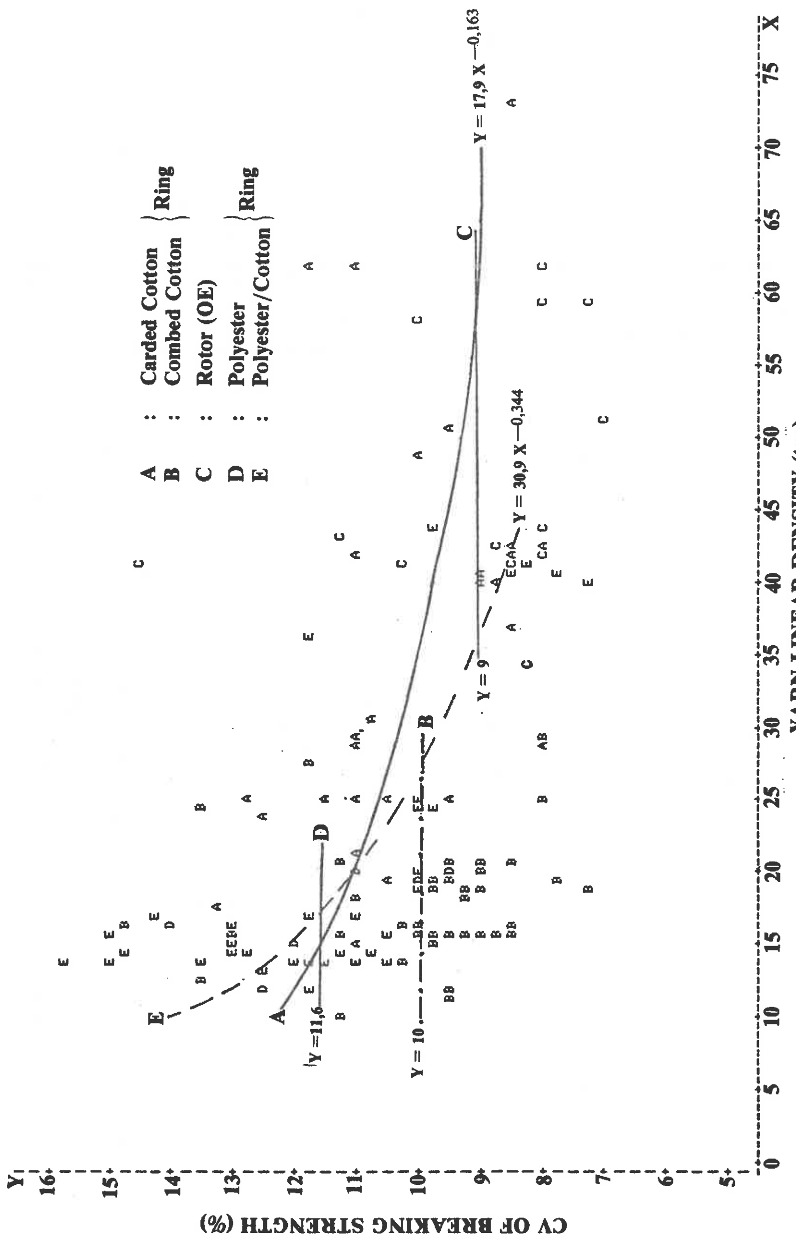


Fig. 20 – CV of Breaking Strength vs Yarn Linear Density (Tensorapid)

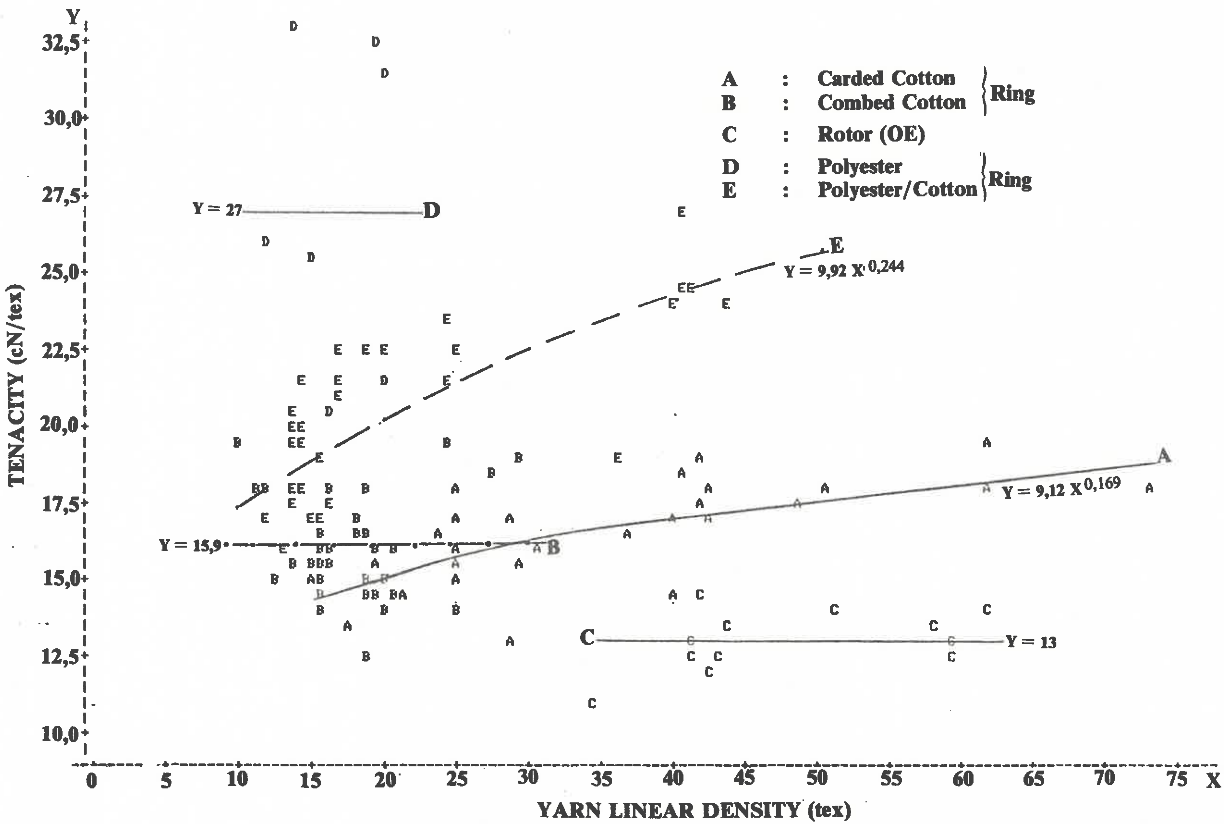


Fig. 21 – Yarn Tenacity vs Yarn Linear Density (Tensorapid)

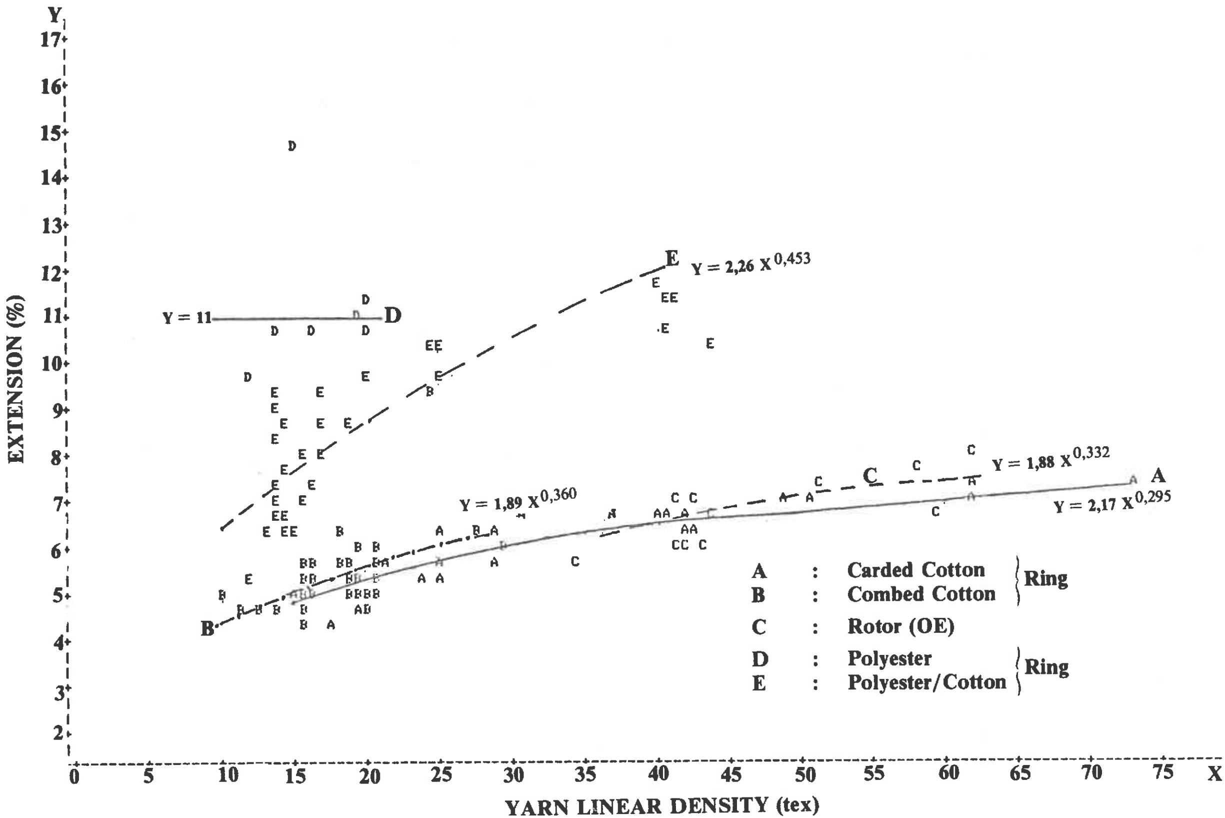


Fig. 22 – Yarn Extension at Break vs Linear Density (Tensorapid Test).

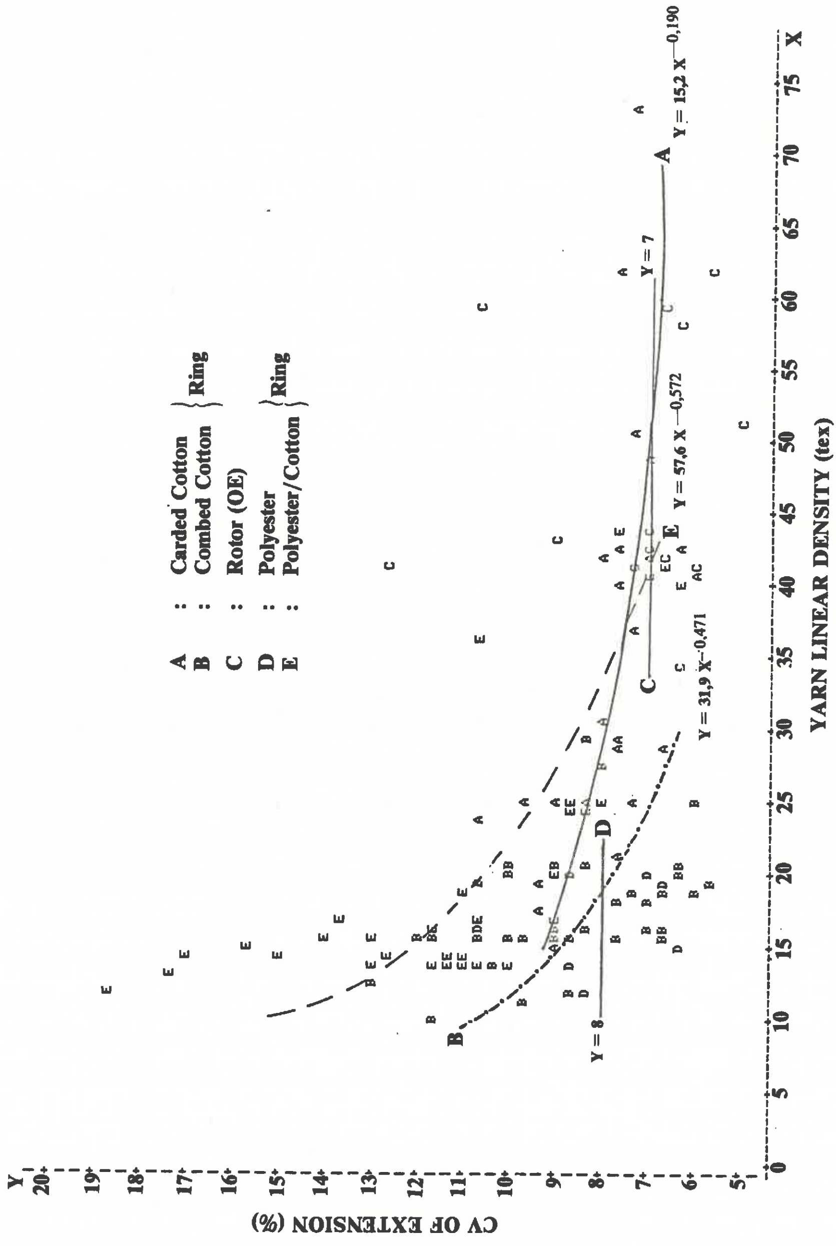


Fig. 23 – CV of Yarn Extension vs Yarn Linear Density (Tensorapid Test).

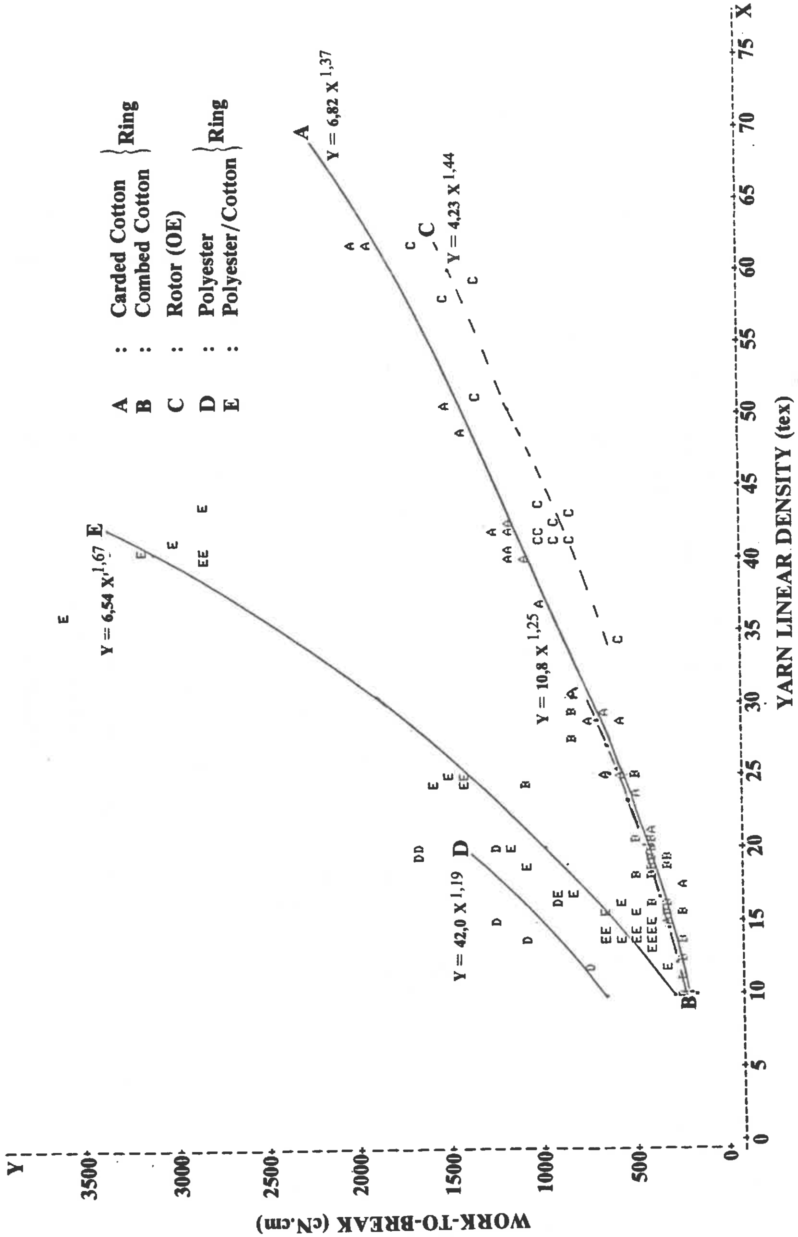


Fig. 24 – Work-to-Break vs Linear Density (Tensorapid Test).

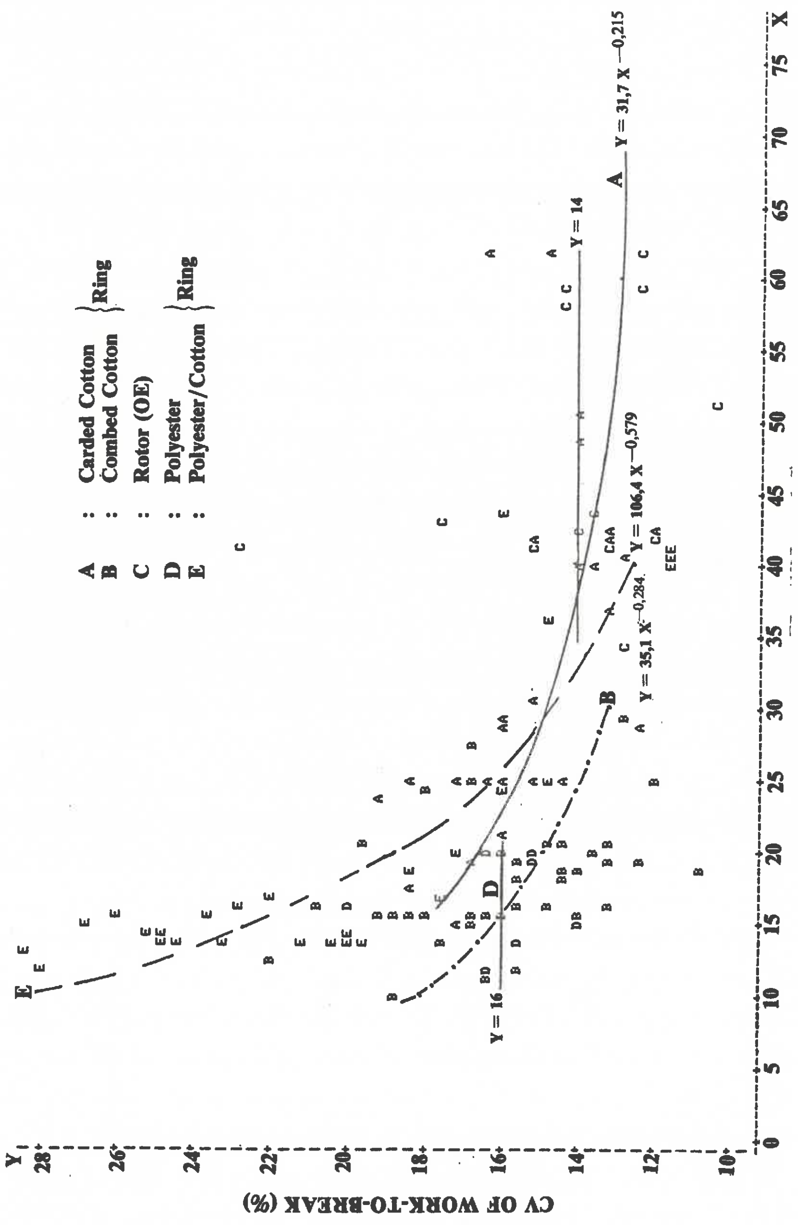


Fig. 25 – CV of Work-to-Break vs Yarn Linear Density (Tensorapid Test).

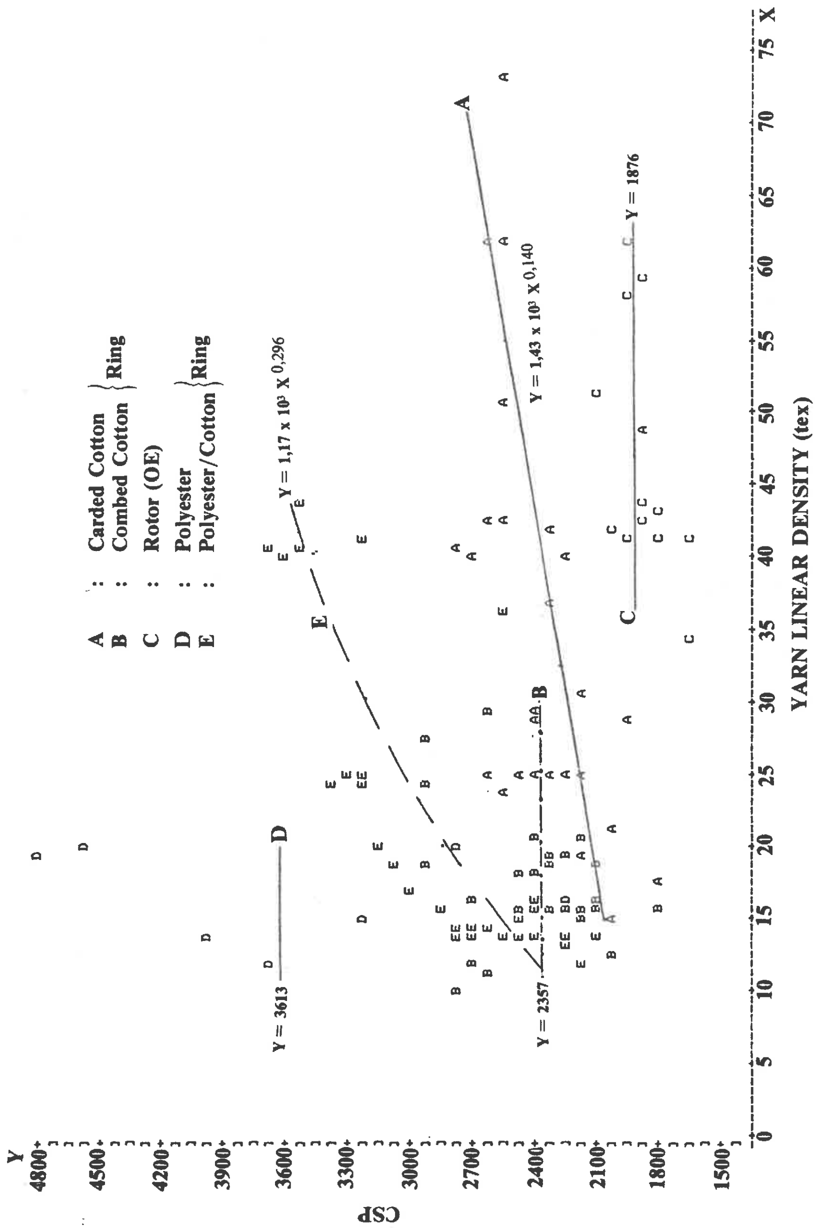


Fig. 26 – CSP vs Yarn Linear Density

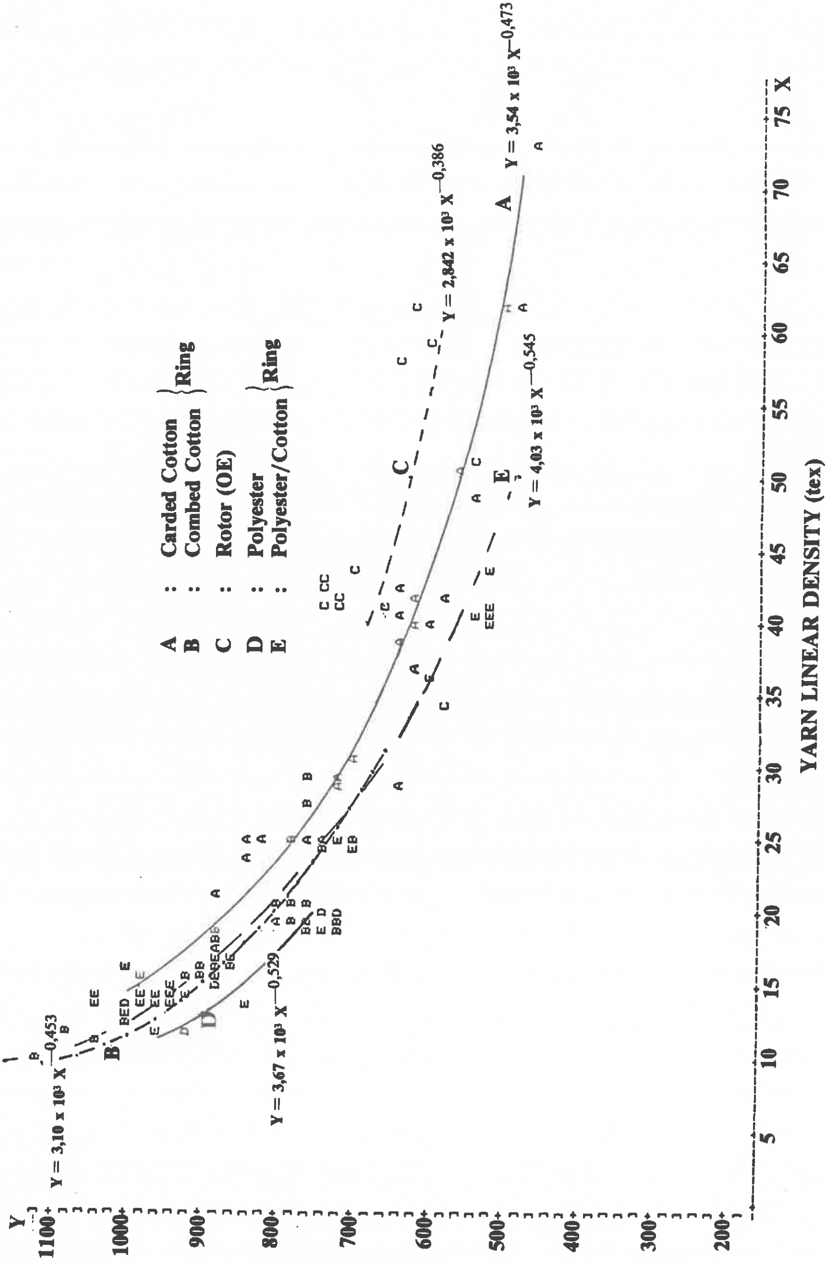


Fig. 27 – Yarn Twist vs Yarn Linear Density.

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