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An Analytical Study of the Point of Rupture of Two-Fold Wool Worsted Yarns

by

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AN ANALYTICAL STUDY OF THE POINT OF RUPTURE OF TWO-FOLD WOOL WORSTED YARNS

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ABSTRACT

The breaking strength and extension of a range of wool worsted hosiery and weaving yarns were related to the average linear density of the yarn segment and that of the yarn at the point of rupture. It was found that, on the average, only about 60 per cent of the breaks occurred at the thinnest place within the test segment while approximately 20 per cent of the breaks occurred at the second thinnest place. Multiple regression analyses carried out on the results showed that the breaking strength of a segment was correlated with both the average linear density of the test segment and the linear density of the yarn at the point of rupture. This indicated that movement of twist to places of lower than average linear densities plays an important role in increasing the breaking strength of thin places in the yarn.

KEY WORDS

Breaking strength — two-fold worsted yarns — point of rupture — extension — linear density — thin places.

INTRODUCTION

In a previous study on single yarns[1] it was found that in only about 50 *per cent* of the tests carried out on a single thread strength tester did the yarn actually break at the thinnest place in the test segment. This indicated that the well known phenomenon of twist running into thin places plays an important role in increasing the strength of thin places within the yarn. As a result of this nearly one out of two yarn breaks occurred at a point other than the thinnest place i.e. at a point where fibre cohesion was probably relatively low. This means that if it is intended to eliminate weak places in a yarn during normal yarn clearing, solely by using yarn linear density as a criterion, many weak places which are not necessarily very thin will remain in the yarn while, on the other hand, many thin places of acceptable strength will be removed unnecessarily. This is based on the assumption that the same trends observed during that study will also hold for those very thin places present in the yarn which would exceed the normal practical clearing limits. Because of the practical implications of these findings it was decided to extend the investigation to cover two-fold wool worsted yarns to establish whether the same conclusions apply to these yarns. Both hosiery and weaving yarns were covered in this study.

TABLE I

DETAILS OF YARNS USED

Yarn No.	Resultant Linear Density (R tex/2)	Folding Twist (S t.p.m.)	Shade
Hosiery			
1	72,9	190	Navy
2	76,0	251	Undyed
3	43,8	352	Undyed
4	71,7	222	Charcoal
5	66,1	214	Red
6	58,2	265	Undyed
7	80,6	174	Rust
8	62,6	216	Dark Brown
9	60,7	211	Black
10	36,1	390	Undyed
11	55,0	268	Green
Weaving			
12	49,4	528	Blue Mix
13	49,6	533	Charcoal
14	40,4	649	Undyed
15	35,2	696	Brown
16	49,6	526	Grey
17	36,2	452	Undyed
18	60,8	492	Olive Green
19	50,0	520	Undyed
20	49,8	512	Charcoal
21	52,6	592	Yellow

EXPERIMENTAL

Twenty-one two-fold yarns, comprising 11 hosiery and 10 weaving yarns and covering a range of linear densities, twists and shades, were used during this investigation (See Table I for details of the various yarns).

A short length of yarn was run through the Uster evenness tester at a speed of 4 metres/min and a trace of the yarn linear density was obtained by means of a recorder coupled to the evenness tester. Slot 6 and an Average Value setting of 16,5 were used throughout this investigation. The speed of the chart was 50 cm/min.

A knot tied in the yarn acted as an accurate reference point. After approximately one metre of yarn had passed through the measuring head (slot) of the evenness tester the instrument was stopped, the yarn cut and removed from the tester. After this the yarn was transferred to an Uster Automatic Breaking Strength Tester which had been adjusted beforehand to give a time of break of 20 ± 3 seconds (ISO Specification) for the yarn under test. The yarn was clamped under tension (imparted by a hysteresis tensioner) in the jaws of the tester so that the knot was level with the lower edge of the bottom jaw. The tester was put into operation and the yarn allowed to break in the normal manner. Immediately the yarn had ruptured the tester was switched off and the yarn cut level with the lower edge of the top clamp after which the tester was again set into operation to activate the automatic recording of the breaking strength and extension values. When the jaws of the tester opened the yarn was removed and the respective lengths of the two yarn segments as well as the total mass of two segments were determined.

From the ratio of the length of the yarn held in the lower clamp to that of the yarn held in the upper clamp a point was located on the recorder chart which corresponded approximately to the point of break of the yarn. In most cases this point could only be located approximately since the point at which the yarn had broken was not always clearly defined due to many of the fibres having slipped apart and not broken during the rupture of the yarn. This was especially the case for the hosiery yarns. A similar problem was encountered in the previous investigation[1]. Two values (Uster readings X_1^1 and X_2^1, respectively) were read off from the chart paper, the one (X_1^1) at the point the break was calculated to have occurred and the other (X_2^1) at the thinnest place lying within a distance of ± 2 mm (corresponding to approximately ± 1,6 cm of yarn) from this point (See Fig. 1). In many cases X_1^1 coincided with X_2^1, however. The latter reading was taken since it was estimated that an experimental error of approximately this magnitude could have been present in the determination of the lengths of the two yarn segments. The reason for this error has been discussed above. This procedure was carried out 20 times on each of the 21 yarns.

The breaking strength and elongation at break (termed extension) of each yarn segment tested were obtained from the charts of the breaking strength tester while the average linear density (resultant tex) of each of the yarn segments was calculated from the test length and mass of the yarn.

A graph relating the Uster readings (X_1^1 and X_2^1) to the linear density of the yarn (termed X_1 and X_2, respectively) at these points was obtained from the area under the linear density curve and the average linear density of the yarn segment on which the curve was obtained (See Fig. 2).

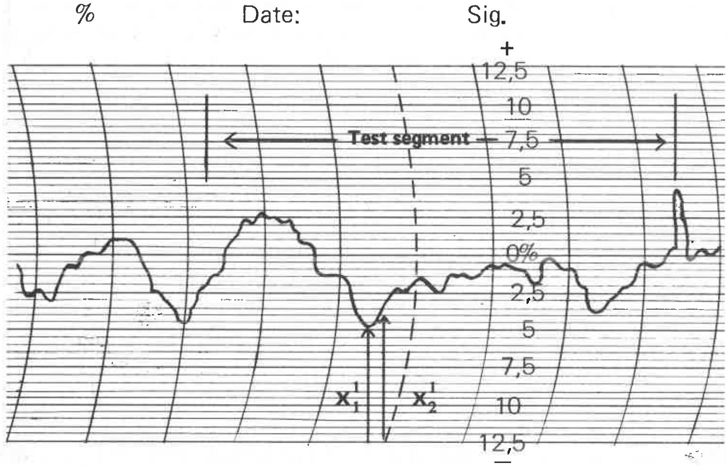


FIGURE 1

Typical trace of yarn linear density obtained by means of the Uster

RESULTS AND DISCUSSION

In Fig. 2 yarn linear density has been plotted against the Uster chart reading and the following two curves, derived by the least squares method, have been superimposed:

Hosiery yarns:

Linear density (in tex units) $= 4{,}32\ (\text{Uster value})^{0{,}84}$ .... (1)
Correlation coefficient (r) = 0,997
Number of readings (n) = 36

Weaving yarns:

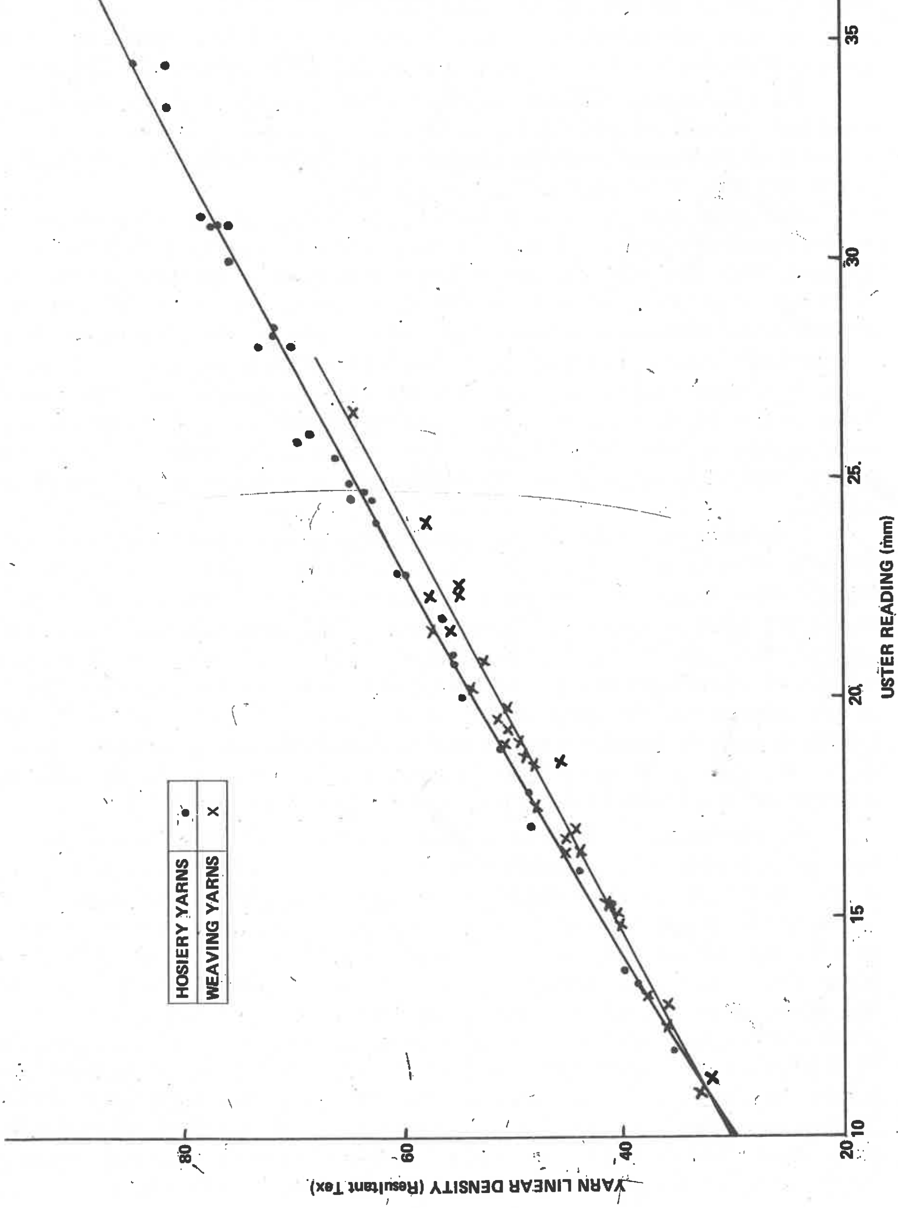
Linear density (in tex units) $= 2{,}11\ (\text{Uster value}) + 9{,}3$ .... (2)
r = 0,988 n = 30

The above two equations could therefore be used to convert the Uster chart reading corresponding to a particular point on the yarn to the linear density of the yarn at that point.

It is interesting to note that the weaving yarns tend to lie slightly lower than the hosiery yarns indicating that the greater compactness of the former, due to the much higher twist factors employed, may have influenced the Uster readings slightly. It is also apparent that the relationship between the Uster values and the yarn linear densities deviates slightly from linearity in the case of the hosiery yarns. This is reflected in the exponent (0,84) of the Uster value in equation (1).

FIGURE 2

Resultant yarn linear density versus Uster reading



A multiple regression analysis was carried out on the results of each yarn with either breaking strength or extension as the dependent variable (Y) and the average linear density of the piece of yarn tested (X_3), the linear density of the yarn at the point the yarn was calculated to have broken (X_1) and the linear density of the thinnest place within ± 1,6 cm from this point (X_2) as the independent variables.

The distribution of breaks is given in Table II while results of the multiple regression analyses are given in Tables III to V. The results obtained on the hosiery and weaving yarns were generally similar and have therefore been grouped together in the discussion of the results. (See Tables II to V).

The results given in Table II show that on the average only about 60 *per cent* of the breaks occurred at the thinnest place in the yarn segment subjected to the breaking load. This is of the same order of magnitude as the value obtained previously on single yarns. In all about 80% of the breaks occurred at either the thinnest or second thinnest place in the yarn. This equals the value obtained previously for the single yarns indicating that the breakage pattern is very similar in the two cases. It is interesting to note too, that although the distribution of breaks (see Table II) is remarkably similar for the weaving and the hosiery yarns there appears to be a greater tendency for the hosiery yarns to break at a relatively thick place than for the weaving yarns to do so. The differences were statistically not significant, however.

Considering the results of the multiple regression analyses carried out on the breaking strength values (Table III) a very interesting fact emerges namely that the average linear density (X_3) of the yarn segment plays an important role in determining the breaking strength of the segment since the t-values associated with it are generally the highest. This is rather surprising since it indicates that the breaking strength of a yarn segment is generally dependent on both the average linear density of the segment and the linear density of the yarn at the point rupture. Multiple regression analyses with breaking strength as dependent variable and either X_3 and X_1 or X_3 and X_2 as independent variables also gave t-values for X_1 and X_2, respectively, which were on the average slightly lower than those for X_3.

The dependence of breaking strength on the average linear density (X_3) can perhaps be explained by considering the movement of twist within a length of yarn as it would have occurred during the spinning and folding operations and by assuming that this movement of twist, to a point of lower linear density, is limited to a distance of the order of the test length employed here, namely 50 cm. The higher the average linear density of the yarn segment relative to that of the very thin places present within its length the greater will be the increase in twist at these places and therefore the higher the cohesion and consequently the breaking strength of these places. If, for argument's sake, therefore, two thin places of the same linear density, one in each of two yarn segments which differ in average linear density, are considered then the twist in the thin place in the yarn segment having the higher linear density will be higher than that in the thin place in the yarn segment having the lower linear density. The breaking strength of the former thin place should

TABLE II

DISTRIBUTION OF BREAKS

Yarn No.	PERCENTAGE OF BREAKS OCCURRING AT			
	Thinnest Place	Second Thinnest Place	Third Thinnest Place	Other Places
Hosiery				
1	65	5	15	15
2	55	30	10	5
3	45	30	15	10
4	65	15	15	5
5	45	5	10	40
6	70	5	15	10
7	50	20	20	10
8	50	25	15	10
9	70	10	0	20
10	65	25	0	10
11	40	30	25	5
Average	56	18	13	13
Weaving				
12	70	15	10	5
13	50	25	25	0
14	75	15	10	0
15	60	20	15	5
16	60	30	5	5
17	55	30	10	5
18	45	25	20	10
19	60	25	15	0
20	65	20	10	5
21	40	45	10	5
Average	58	25	13	4
Overall Mean	57	21	13	9

TABLE III

RESULTS OF MULTIPLE REGRESSION ANALYSES CARRIED OUT ON THE BREAKING STRENGTH RESULTS

Yarn No.	Total Correlation Coefficient	t-values		
		Average Linear Density of Segment (X_3)	X_1	X_2
Hosiery				
1	0,88***	3,5**	0,8	-0,7
2	0,88***	2,9*	1,6	0,3
3	0,81***	3,2**	1,0	0,2
4	0,92***	2,8*	0	2,0
5	0,87***	4,9***	-1,3	1,3
6	0,90***	3,6**	-0,4	1,3
7	0,87***	2,7*	-0,3	2,0
8	0,63**	2,0	1,7	-0,6
9	0,92***	3,5**	-1,3	3,5**
10	0,90***	1,4	-0,1	3,0**
11	0,89***	2,6*	0,1	1,2
Weaving				
12	0,82***	1,6	0,1	1,0
13	0,91***	2,9*	-0,2	1,4
14	0,91***	3,0**	0,1	1,8
15	0,84***	1,6	-0,2	1,3
16	0,92***	4,0***	-1,0	2,3*
17	0,70***	1,3	0,1	1,5
18	0,89***	3,3**	0,3	1,4
19	0,83***	1,2	0,4	0,7
20	0,88***	2,0	0,2	1,7
21	0,78***	3,3**	0,7	-0,2

*** Significant at the 0,1% level
** Significant at the 1% level
* Significant at the 5% level

X_1 is the linear density of the yarn at the point the break was calculated to have occurred.

X_2 is the linear density of the thinnest place in the yarn lying within a distance of ± 1,6 cm of the point corresponding to X_1

TABLE IV

RESULTS OF MULTIPLE REGRESSION ANALYSES CARRIED OUT ON THE EXTENSION RESULTS

Yarn No.	Total Correlation Coefficient	t-values		
		Average Linear Density of Segment (X_3)	X_1	X_2
Hosiery				
1	0,51*	-0,3	1,8	-1,4
2	0,61**	-1,2	1,3	0,3
3	0,55*	-0,9	1,5	-0,3
4	0,74***	-0,6	-0,6	2,3*
5	0,54*	1,8	-1,0	0,9
6	0,38	0,5	0,1	0,2
7	0,69**	0,1	-0,4	1,7
8	0,54*	-1,4	1,8	-1,0
9	0,77***	-0,5	3,3**	-1,5
10	0,78***	-2,8*	-0,6	3,2**
11	0,68**	-0,5	-0,1	1,5
Weaving				
12	0,36	-0,7	-0,6	1,1
13	0,38	1,5	-0,3	-0,6
14	0,76***	-2,9*	-0,1	2,0
15	0,55*	0	0,2	0,5
16	0,58*	-1,1	-0,4	1,3
17	0,31	-0,7	0,4	0,7
18	0,71***	-0,3	0,6	1,1
19	0,67**	-1,3	0	1,0
20	0,84***	-1,8	-0,3	2,7*
21	0,17	-0,1	0,5	-0,1

*** Significant at the 0,1% level
** Significant at the 1% level
* Significant at the 5% level

X_1 is the linear density of the yarn at the point the break was calculated to have occurred.
X_2 is the linear density of the thinnest point in the yarn lying within ± 1,6 cm of the above point (X_1).

TABLE V

CORRELATION BETWEEN BREAKING STRENGTH AND EXTENSION

YARN NO.	CORRELATION COEFFICIENT
Hosiery	
1	0,61**
2	0,68***
3	0,62**
4	0,79***
5	0,83***
6	0,70***
7	0,80***
8	0,56*
9	0,72***
10	0,62**
11	0,80***
Weaving	
12	0,60**
13	0,25
14	0,53*
15	0,85***
16	0,63**
17	0,74***
18	0,84***
19	0,86***
20	0,83***
21	0,63**

*** Significant at the 0,1% level
** Significant at the 1% level
* Significant at the 5% level

therefore be higher than that of the latter due to increased fibre cohesion provided the twist does not exceed the level required for maximum strength, in spite of the fact that the linear density of the two thin places is the same.

It therefore appears that the breaking strength of the weakest place in a yarn is not only determined by its linear density but is also determined by the average linear density of the whole segment subjected to the load. It is felt that the contribution of the latter is due to its effect on the twist level of the thinner places within that segment although the relative errors in the respective readings may be a contributory factor. The movement of twist (the well known one of twist running into thin places) which takes place at the time of spinning and folding (i.e. before the heat setting of the yarn) therefore plays a significant role in increasing the strength of thin places within the yarn. Breaking strength has been plotted against X_3 (average segment linear density) and X_2 in Figs. 3 and 4, respectively, the results being grouped according to whether they represent dyed or undyed, weaving or hosiery yarns.

The t-values are on the average slightly higher for X_2 than for X_1 which appears to justify the assumption that there is an experimental error in the location of the point of break on the recorder chart. The correlation between breaking strength and the linear density of the yarn at the calculated point of break was generally lower than that between breaking strength and the linear density of the thinnest place occurring within a distance of ± 1,6 cm of the former.

Additional regression analyses with breaking strength as the dependent variable and X_1, X_2 and X_3, singly or in various combinations, as independent variables confirmed the above results.

From the above it follows that if weak places in a yarn are to be removed not only must their linear density be considered but also the twist present, with the latter apparently greatly dependent upon the average linear density of the yarn in the vicinity of the weak place.

Another, although not unexpected, result which emerges from the multiple regression analyses is that the variation in yarn breaking strength encountered in practice can to a large extent be ascribed to the variation in the linear density of the segments tested. Therefore, by weighing the yarn tested and calculating its average linear density (from the test length and the number of tests carried out) a correction can be applied to the mean breaking strength to allow for the difference between the linear density of the yarn tested and that of the parent yarn (i.e. yarn population). This would reduce the error in the mean breaking strength to a value lower than the error of the mean calculated in the normal manner from the standard deviation of the breaking strength results and the number of tests carried out.

As far as the extension results are concerned (See Table IV) the picture is not very clear. In general the total correlation coefficients are much lower than those obtained for breaking strength indicating that the *extension* is much less dependent upon the three variables selected than the *breaking strength.* In fact in a number of

FIGURE 3

Individual breaking strength values versus average linear density of each segment (X_1)

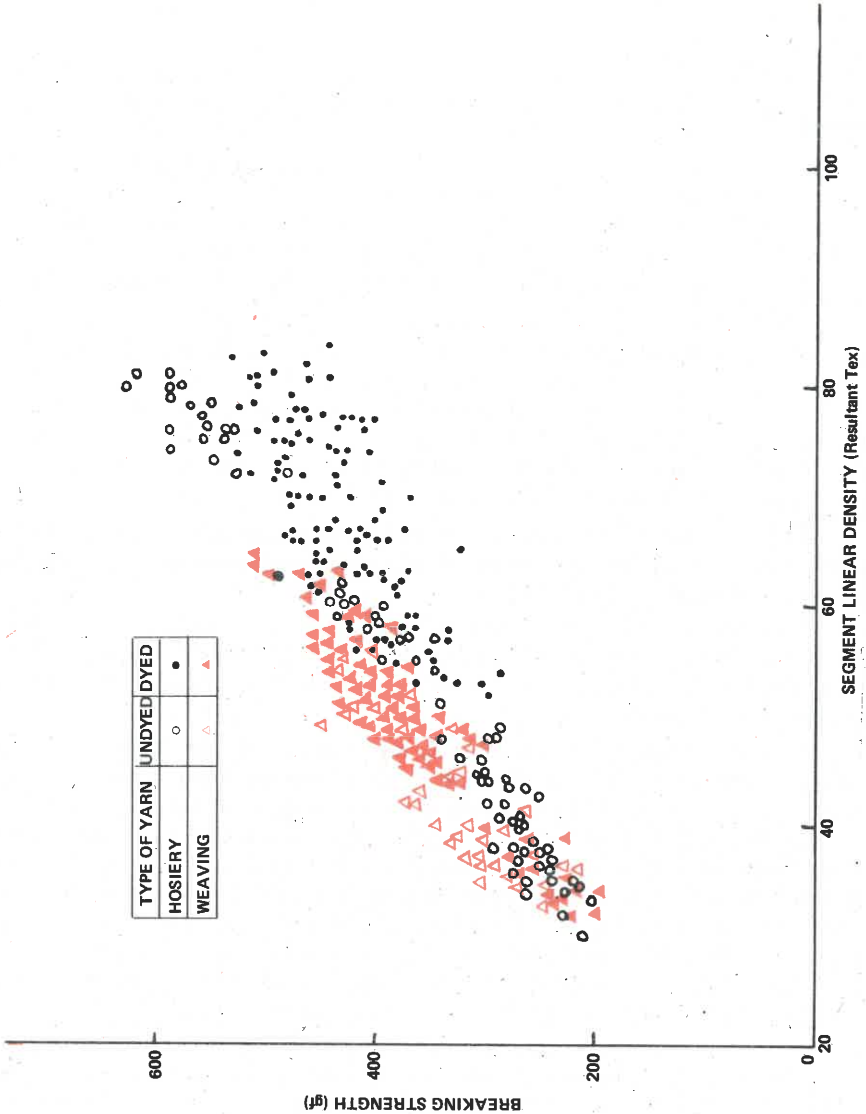


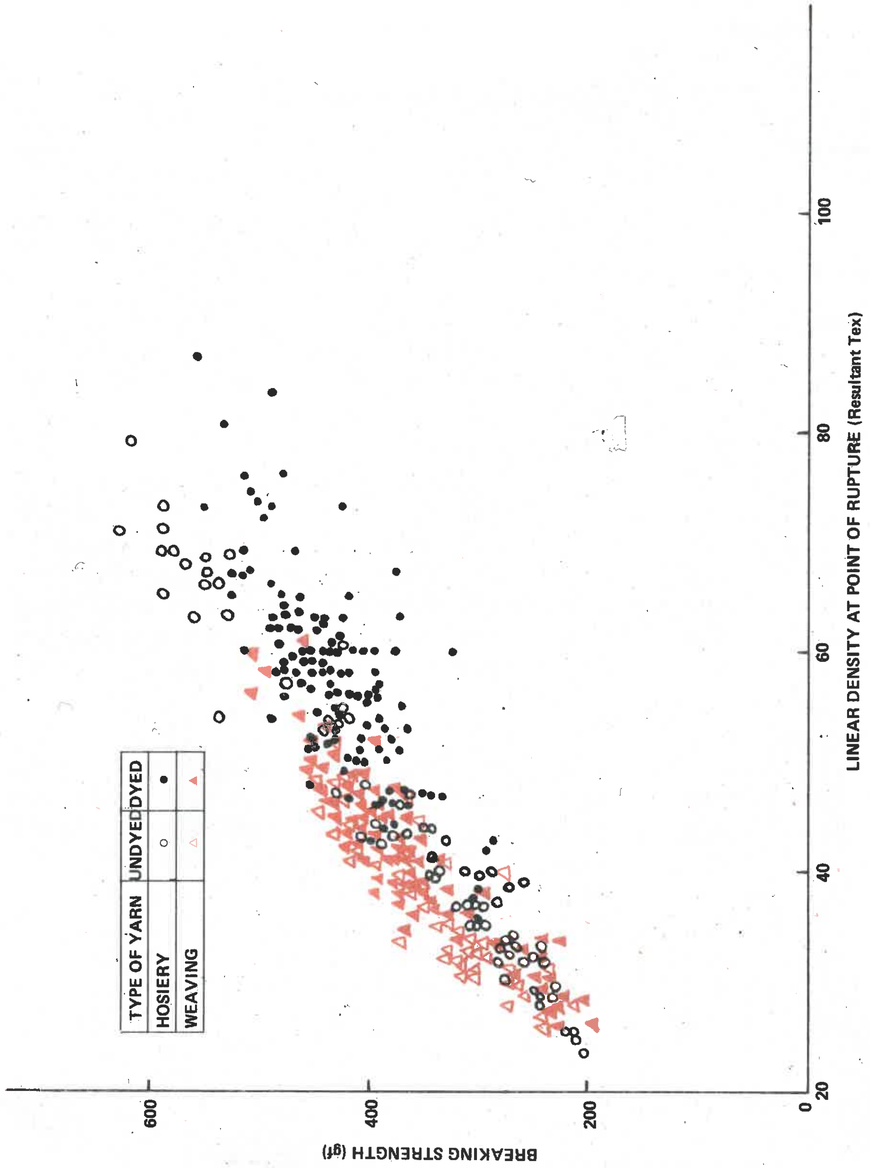
TABLE VI

COMPARISON OF THE RESULTS OBTAINED UNDER THE SPECIAL CONDITIONS EMPLOYED DURING THIS INVESTIGATION AND THOSE OBTAINED UNDER NORMAL TESTING CONDITIONS

YARN NO.	RESULTANT LINEAR DENSITY (TEX)		BREAKING STRENGTH				EXTENSION			
	Normal Conditions	Present Conditions	Mean (gf)		C.V. (%)		Mean (%)		C.V. (%)	
			Normal	Present	Normal	Present	Normal	Present	Normal	Present
Hosiery										
1	73,1	75,9	429	439	7,3	11,3	6,2	6,6	15,0	14,0
2	76,0	76,8	555	565	6,4	6,1	16,5	15,1	19,4	19,2
3	43,8	43,6	262	291	9,5	8,3	12,1	10,6	27,0	15,8
4	71,7	71,7	476	476	6,3	8,9	11,5	11,3	21,0	24,3
5	66,1	67,0	436	424	10,1	8,6	14,5	13,8	22,0	17,9
6	58,2	57,8	419	397	8,1	8,7	13,4	12,7	29,4	23,0
7	80,6	78,1	497	466	8,7	9,6	9,7	9,8	20,3	17,0
8	62,6	62,6	428	438	7,0	6,4	14,0	14,8	21,5	22,2
9	60,7	61,3	427	425	8,7	9,5	13,7	14,5	23,5	19,3
10	36,1	35,8	257	248	10,1	10,5	14,8	14,7	29,1	31,7
11	55,0	55,0	343	344	9,5	10,6	10,5	10,4	21,0	22,8
Weaving										
12	49,4	49,4	367	367	8,8	7,9	16,3	15,8	27,0	19,1
13	49,6	50,4	386	401	9,3	7,7	21,1	21,1	24,5	14,9
14	40,4	39,3	320	322	9,7	9,2	24,7	23,8	23,0	20,7
15	35,2	35,7	237	245	10,3	11,5	15,3	15,6	26,1	28,5
16	49,6	50,2	368	377	8,8	7,0	18,9	16,7	22,3	25,5
17	36,2	36,7	271	264	12,8	8,6	15,8	14,7	33,0	26,3
18	60,8	59,2	426	436	7,3	9,0	18,7	18,8	23,5	23,1
19	50,0	50,0	412	384	9,3	10,8	24,7	20,7	21,1	31,4
20	49,8	50,3	389	390	9,3	8,2	21,0	19,7	23,8	23,8
21	52,6	52,7	400	406	7,5	5,7	20,7	20,2	20,3	16,5

FIGURE 4

Individual breaking strength values versus yarn linear density at point of rupture (X_2)



cases neither the total correlation coefficient nor the t-values were significant showing that in these cases the variation in the extension is not accounted for by variation in any of the three variables included in the analyses. Thus it appears as though other factors such as interfibre cohesion (which in turn depends upon twist), fibre length, fibre friction etc., may play a much greater role in determining the extension of a yarn than in determining the breaking strength of the yarn.

In Table V results are presented of a regression analysis carried out on the breaking strength and extension results. It is apparent that, although there is a highly significant correlation between breaking strength and extension within a yarn, there is a great deal of variation in the one which is not related to variation in the other. This is illustrated by Fig. 5 in which extension has been plotted against breaking strength for a few hosiery and weaving yarns.

In Table VI the average linear density and tensile values obtained under the special test conditions necessitated during this study are compared with those obtained when employing routine test methods. It is apparent that the results obtained under the two different test conditions generally agree well. There also appears to be no consistent trend in the differences between the two sets of results and it is therefore concluded that the conditions employed during this study give results which closely resemble those obtained under normal test conditions.

Finally, it is interesting to compare the yarn breaking tenacities as based upon the three different linear density values used during the multiple regression analyses (see Table VII). As would be expected the yarn breaking tenacity based upon the linear density of the yarn at the point of rupture is significantly higher (on the average about 17 *per cent*) than that based upon the average linear density of the segment, due to the higher tex value of the latter. This difference in tenacity is therefore an approximate measure of the yarn strength which is forfeited due to thin places in the yarn, ignoring the effect of twist movement. It is also interesting to note that the average breaking tenacity of the weaving yarns is about 14 *per cent* higher than that of the hosiery yarns.

SUMMARY AND CONCLUSIONS

The breaking strength and extension of a range of two-fold wool worsted yarns have been related to the average linear density of the yarn segment tested and the linear density of the yarn at the point of rupture. Multiple regression analyses showed that the breaking strength of a yarn segment was related to both the average linear density of the segment and the linear density of the yarn at the point of rupture. This indicates that the linear density of a yarn in the vicinity of the point of rupture plays an important role in determining its strength probably due to its effect on the movement of twist to the thin places in the yarn segment. The extension results were not very highly correlated with either of the above two parameters which suggests that other yarn and fibre parameters such as fibre cohesion, twist etc. play an important role in determining the extension

FIGURE 5

Extension versus breaking strength for a few of the yarns tested

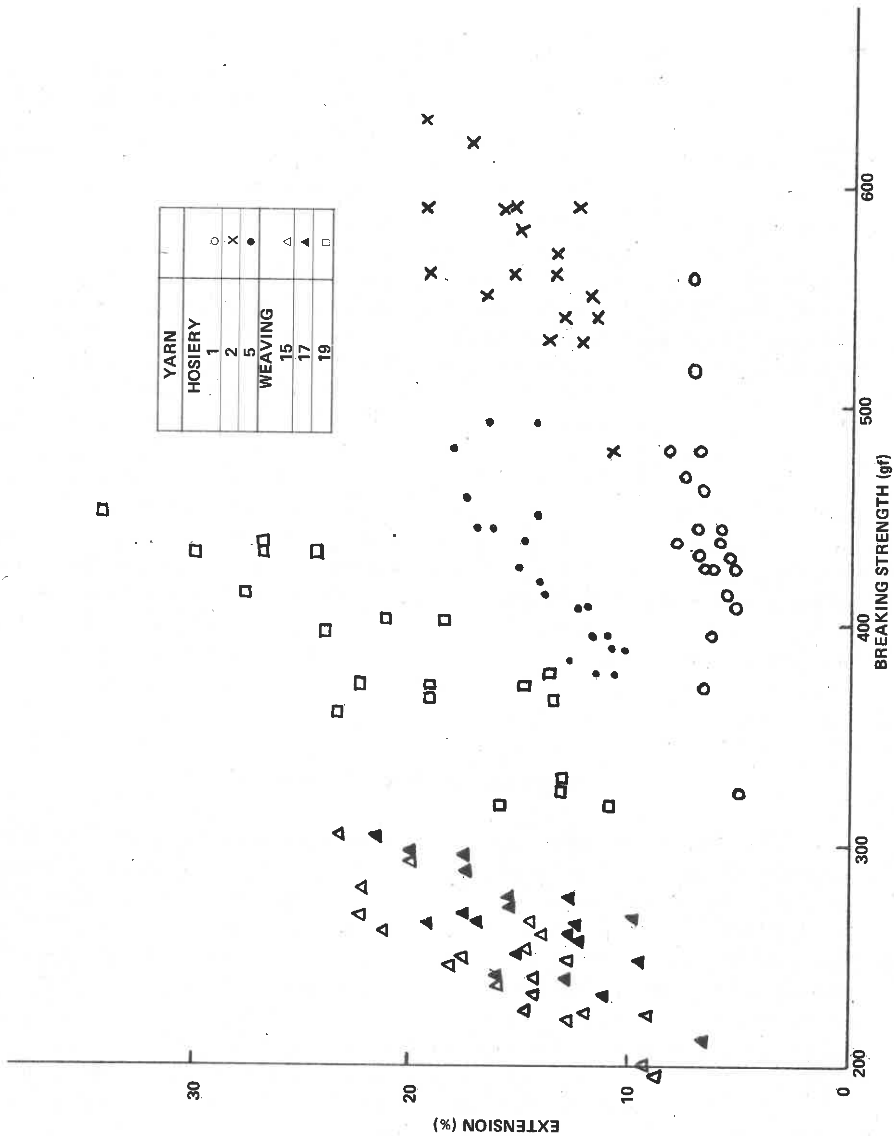


TABLE VII

AVERAGE YARN BREAKING TENACITY (BREAKING STRENGTH/TEX)

Yarn No.	BREAKING TENACITY (gf/tex)		
	Based upon average Linear Density of Segment	Based upon Linear Density X_1	Based upon Linear Density X_2
Hosiery Yarns			
1	5,79	6,64	6,93
2	7,36	8,19	8,44
3	6,66	7,79	8,18
4	6,64	7,67	7,89
5	6,33	6,71	7,00
6	6,86	7,63	8,23
7	5,97	6,70	7,10
8	7,00	7,65	7,97
9	6,94	8,06	8,37
10	6,97	7,91	8,22
11	6,25	7,23	7,58
Average	6,6	7,5	7,8
Weaving Yarns			
12	7,45	8,56	8,90
13	7,95	8,99	9,29
14	8,18	9,34	9,66
15	6,87	7,60	7,90
16	7,53	8,42	8,74
17	7,18	7,82	8,34
18	7,35	8,38	8,73
19	7,67	8,79	9,04
20	7,77	9,08	9,38
21	7,71	8,46	9,05
Average	7,6	8,5	8,9

of a yarn segment under load. Although a highly significant correlation was found between the breaking strength and extension results within a yarn a great deal of variation could occur in the one property without a corresponding variation in the other (i.e. the scatter of the points was rather large).

It was also found that only about 60 *per cent* of the breaks observed occurred at the thinnest place within the test segment while about 20 *per cent* of the breaks occurred at the second thinnest place. This lends support to the argument that the distribution of twist ("twist running to thin places") within the test segment plays an important role in increasing the strength of thin places and in determining the point at which the yarn breaks. This may have to be taken into consideration if an electronic clearer is to be designed which is to remove weak places as opposed to thin places in a yarn.

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