Journal of the Textile Institute Transactions
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/jtit20

28—VI.—Tensile Tests for Cotton Yarns i.—A Survey of Current Tests

Version of record first published: 22 Jan 2013.

To cite this article: (1926): 28—VI.—Tensile Tests for Cotton Yarns i.—A Survey of Current Tests, Journal of the Textile Institute Transactions, 17:7, T305-T316

To link to this article: http://dx.doi.org/10.1080/19447027.1926.10599949

28—VI.—TENSILE TESTS FOR COTTON YARNS
i.—A SURVEY OF CURRENT TESTS

By Edward Midgley, B.Sc., and
Frederick Thomas Peirce, B.Sc., F.Inst.P.
(British Cotton Industry Research Association)

INTRODUCTION AND SUMMARY

The numerical result of a test depends on many things quite distinct from the practical quality of the yarn, that is its ability to withstand the strains imposed in industrial processes and wear. These foreign effects must be understood and controlled if a sound practical judgment is to be based on the test. In this series of papers the tests available are analysed from this standpoint, the first giving a general survey and an analysis of the lea test, the method most generally used. As the record of experience in this laboratory, this may be of practical utility to other testing departments, though no claim is made that the statements are all original.

The necessity for testing, and more accurate testing, is emphasised under modern conditions by the greater intensity of competition, new developments such as unions with artificial silks and the increasing supply of unfamiliar varieties of cotton. Testing hastens the gathering of experience on the problems thus raised, and puts it on a basis independent of the personal equation. Yarn testing provides the most direct control, for yarn quality limits that attainable in the fabric and is the criterion of the value of the raw cotton.

Tensile strength, for which alone yarn is commonly tested, does not entirely define the textile value, which is also affected by extensibility, elasticity under moderate tension, flexibility, diameter, regularity, external appearance, snarling twist, and resistance to wear. In the ideal test, the routine will be based on scientific method, while the character measured is chosen with a single eye to practical needs.

The objects of testing are to gain information on (A) the textile quality of the yarn, (B) the technique of spinning, or (C) the quality of the raw cotton. Success in the first object is necessary to that in the others, and the test must be made as close an indication as possible of the way in which the yarn will make up into a fabric. Whatever the object, the first condition for a sound judgment is that one variable factor only must enter; for example, to compare two yarns, the conditions of testing must be identical; to compare the efficiency of two cards, draw frames or humidities in spinning, the mixings, other spinning processes and the testing must be kept identical; to compare two cottons, they must be put through the same machines and tested under the same conditions.

The numerical test result, however, on which opinion must be based, depends not only on the textile quality of the yarn, the object of the test, but also on the following factors, taking them as they arise in the test routine—

(1) Sampling.
(2) Nature of test.
(3) Efficiency of instrument.
(4) Atmospheric conditions.
(5) Length of specimen.
(6) Rate of break.
(7) Expression of results.

Faulty control on any of these points may make the test deceptive.

An analysis of each of these factors is given in this and the following papers, though for convenience they are not discussed exactly in the above order.

Sampling and Expression of Results

That the strength of the broken test pieces should yield information on the strength of the batch as a whole, the sampling must be true and the results suitably expressed. Methods of sampling necessarily vary with the object of the test. In general, known sources of variation should be avoided in any single batch, and sufficient specimens from numerous positions tested in order that the result may represent the whole, not merely a chance portion. The arithmetical mean is then taken as the measure of the strength of the batch. To what extent this is true can only be judged from the differences between individual results; the mean alone is not sufficient.

A simple calculation doubles the value of a result, namely, to find the *mean deviation* (M.D.) which is the average difference between the mean and the individual values. Expressed as a percentage this is a sound measure of the irregularity, a low value of which is itself desirable as a regular yarn is more economical of material, easier to handle, and better in the fabric.

Yarn is never designed to bear a strain liable to injure the places of average strength. There is a large factor of safety, and the strength, as a practical quality, depends rather on the number of places where the breaking load falls below a dangerous minimum. This can be found directly from the mean deviation, so also can the probable amount by which the mean obtained may differ from the mean value for the whole batch.

In trying to isolate some effect, such as that of humidity or mercerising or a spinning process, the great irregularity of cotton yarns makes it difficult to measure the real difference caused by the change, for quite large differences may be due to sampling alone. The latter may be diminished by increasing the number of tests, but this adds to the work, and its value is limited by the nature of spinning.

Local irregularities are produced by the variability of cotton hairs and by the way they draft in the final spinning processes, and these are troublesome enough. But, like a ground swell under waves and ripples, longer variations are introduced by changes in the mixing, variations in the lap or in humidity, and by differences between spindles. So irregularity is not diminished by taking larger specimens and samples to the extent expected from calculations on the inch-to-inch irregularity, and the larger a batch of yarn the more irregular it is.

For many purposes this irregularity may be overcome by a simple device, namely, to wind a number of turns on a wrap-reel, fix sticking plaster at two opposite points, and cut into two lots. Each of these *cut-skein samples* contains the alternate threads of the same length of yarn, and the means given by the two are very closely identical when similarly treated and tested. Control tests which are described below show a difference on 40 threads of less than ½ per cent., less than 1/10th the difference on the same number of tests even on consecutive lengths from the same cop. This device has been used when measuring the effects of humidity, rate of loading, tendering by light, acid treatment, rubbing, &c., many of which could never otherwise have been detected, being lost in spinning irregularities when comparison is made between two independent samples. The amount of testing may be diminished with little loss in precision by winding on a large reel and making a number, say eight, similar samples at a time.

Atmospheric Conditions

To anticipate a more complete account, the breaking load and extension of a 36's Sakel yarn were found to increase by about 5 per cent. of the value at 70% R.H. (relative humidity) for an increase of 10% R.H. Such an example shows that it would be unfair to compare two yarns on results obtained at different humidities, and that all tests should be carried out on yarns conditioned and tested under standard conditions. Taking into consideration normal conditions to which cotton materials are exposed in mills, weaving sheds and warehouses, in use on and off the human body, and the general practice of testing houses, the standard 70% R.H. at 70° F. has been adopted for this work and future testing by the methods described.

The results given in the present papers were obtained in a testing room controlled by a plant which circulates air saturated at a known temperature (the dew point) and maintains the room at a higher temperature. A room may also be controlled by a plant which drives a current of air through either a drying or moistening chamber, according to the properties of a hygroscopic control, the weight of a fabric[5] or the length of animal hairs.[4]

In the absence of full control, the specimens may be conditioned beforehand in a *humidified box*[1], the room humidity being kept as near 70% as possible by heating and ventilation. In the present experiments the specimens were conditioned overnight in such a box, built with double walls of asbestos sheeting and containing control solution, thermo-regulator, and ventilated hygrometer. As a minimum, temperature and humidity records may be kept, but the corrections are uncertain and variable.

Efficiency of Instrument

The breaking load is not directly observed in testing, but only a reading on an instrument scale. The exactitude with which the actual force on the yarn is given depends on the design and calibration of the instrument. The scales are calibrated by the steady reading due to a hanging weight, and even when in perfect order an instrument may give readings different from the actual force because calibration is done with the parts still, whereas in testing they are moving. Under the latter conditions any frictional resistance on parts moved by the recording grip is subtracted from the true tension. A less obvious error is introduced by the momentum of moving parts, if the velocity alters during the tests, for it takes force to change rate of motion. The errors and limitations of machines commonly used, when properly calibrated and in perfect order, are discussed analytically in Paper IV. of this series.

The scale of a *deadweight machine* is very sensitive, the limit of reading being only a fraction of 1% of the breaking load, and small compared with the variations along a yarn, tested on an instrument of suitable range. The friction is negligible if the lever be mounted on ball bearings and the pawls press lightly on the ratchet of the scale. Momentum errors are negligible at ordinary speeds. An eccentric roller (*vide* Paper IV.), which gives a very even scale and rate of loading, greatly improves the single-thread tester used in the present work.

A possible error in the single-thread test may be caused by loss of twist in handling, but can be avoided with due care. Readings of breaking load can then be accepted as the maximum tension in the yarn, when the machine is properly used. The lea tester is also sufficiently accurate from this point of view.

Extension readings in the lea test, as generally carried out, have little significance and are usually ignored. On the single-thread tester they have great value, and a device is usually incorporated for measuring extension, the simplest being a rod which moves with the lower grip till rupture. Its efficiency depends on a nice adjustment of the weighting of the lever on the lower grip, and the friction which holds the rod after rupture of the specimen. The initial tension affects the extension reading. It may be adjusted by hanging a weight on the specimen before fastening in the lower grip or by a slight displacement of the recording lever, but the advantage is doubtful, as this increases the danger of loss of twist and slip in the grips and the tension may be altered in fastening. The apparent extensibility may also be altered by previous tension, as in winding, which takes out a useless, inelastic extension without causing any real change in extensibility as a practical quality. The reading scale is not sensitive, about 1 in. movement in all, even on long spans. In fine, single-thread extension measurements need close watching, and some degree of uncertainty attaches to such results.

The *Moscrop machine* performs the single-thread test automatically at a much greater rate than the standard deadweight tester, giving a permanent record, and there is little danger from loss of twist. It is shown in Paper IV., however, that these advantages are accompanied by serious momentum errors unless the speed is reduced below the usual rate of 8 cycles per minute, especially with weak yarns. The operation is seriously affected by careless treatment of springs and by dirt on bearings, there being much more to go wrong than in deadweight machines, but the springs are accurate at all speeds and the friction is negligible when the machine is in good working order.

The scale is as sensitive as the regularity of yarns demands, for it was found by trial that neither the mean nor the mean deviation was appreciably changed by reading to one-tenth of an interval. The pendulum type of scale is, indeed, unnecessarily sensitive, and the large intervals of the Moscrop record are a distinct convenience in calculation.

Nature of Test

Let it be granted that a good representative sample has been taken, tested under controlled conditions on a reliable instrument, and that a mean figure of known statistical significance has been obtained which truly describes the batch under test. What information does this figure give as to the real strength of the yarn, that is, whether it will stand processing or will break in winding, doubling, dressing, weaving, or knitting? This depends on the nature of the test itself, and its relation to the strains which the yarn has to stand in practice.

Actually, yarns are not often employed for lifting weights, like a metal chain, and the effective strength of a yarn depends more on the amount of quick extension it can undergo without injury than on breaking load. The usual test for metals is, quite soundly, to measure the force which injures or breaks the specimen under a slowly increasing tension, and this has been adopted as the standard test for textiles. Many other tests—wear, oscillating, stress-strain, ballistic—are conceivable and practicable, which may give better measures of strength. But though the information it gives is not so directly practical as in the case of metals, the breaking load under steadily increasing tension is a simple criterion, and necessary to the full interpretation of more thorough tests, description of which will be deferred to subsequent papers.

Determined as it is by the slipping and rupture of fibres at the weakest part of the length, the breaking load is not a single-valued quantity characteristic of the yarn alone, but depends on the rate of break and the length of specimen, which may vary in different tests and processes of manufacture.

The effect of the rate of break is described in Paper III. of this series, where it is shown that the yarn offers more resistance to a rapid strain but breaks at the same extension.

Length of Specimen

The longer the specimen of a given yarn the weaker will its weakest spot be on the average, hence the lower the mean breaking load, irregular yarns showing the greatest change. The effect is analysed mathematically in Paper V., where necessary relations are found between the mean strength and irregularity of specimens of different length. Experimentally it was found that the breaking load dropped by about 6% on increasing the length of specimen from 10 in. to 30 in., whilst the extensibility decreased in direct proportion and the mean deviation of breaking load by about 10%. Within the limits of statistical uncertainty, and allowing for known deviations from the normal random distribution of strength, the observed effect of the length of specimen agreed with that deduced theoretically.

From the standpoint of making test results agree with practical behaviour, it is advisable to test lengths of the same order as the free length under tension in processes such as winding, doubling, dressing, weaving, &c. A long specimen, the usual 24 or 27 inches, is desirable on this account as well as because of the greater regularity and more accurate measure of extension.

The Lea Test

In this, the most universal yarn test, a lea of 120 yards is tested in the form of a skein by a gradually increasing tension, which distributes itself more or less evenly among the 160 threads. The thread in which the tension first exceeds the breaking load snaps, others follow, the remainder begin to slip, and the machine records the maximum force transmitted during this process.

Yarn is not used in the form of such skeins, the strength of which is only of interest as a guide to the average strength of individual threads. The criterion by which to judge the results of the test is then the ratio between the lea strength and that of 160 single threads, which will be called the "lea ratio" and expressed as a percentage. As it is not nearly 100%, the lea test is certainly not a direct measure of thread strength. It is usually about 75%, but may vary even from 50% to 90%. The test is therefore not a reliable index to thread strength, for obviously it may make a yarn appear weaker than another when it is really half as strong again.

To inquire what the result depends on and what it really measures, it will be found convenient to divide the total result into two parts, (A) the load registered when the first thread breaks, and (B) the increase that occurs during the process of breaking and slipping. They depend chiefly on the yarn properties, (1) thread strength and its variability, (2) extensibility and its variability, (3) roughness; and on the testing conditions, (4) placing on the hooks, (5) rate of break.

Even single-thread strength shows a variation with the *rate of break*, but this is a real property of the yarn and inappreciable over the range of speeds of lea testing. The effect on apparent lea strength is more serious as high speed gives the threads near a broken one less chance of slipping, thus increasing the indeterminate part (B) of the result. Standardising the rate of fall of the lower jaw does not ensure the same rate of break on different machines, and even on the one instrument weak specimens are broken more quickly than strong ones. Gégauff[2] has noted that strong leas give a lower lea-ratio than weak ones. It is not practicable to arrange for a constant time of break, and it is best to minimise the indefinite portion (B) of the load by reducing speed. The practice of exaggerating the result by speeding up the machine exaggerates its errors only.

A great difference in the evenness of tension and gripping of the threads may be made by the manner of *placing the lea on the hooks*. Comparison tests showed that a difference of about 15% was made by releasing one end of the lea after winding, this causing the threads to overlap one another in the test. Even putting the lea on with a twist or half-hitch made less difference. A considerable part of the result is still of the type (B) when the lea is in the form of a ribbon, without overlapping of threads. This is shown by the fact that the strength per thread is about 15% less for quarter leas than for full leas, though the first break must occur at a lower tension in the latter.

No definite relation can be found between yarn properties and lea ratios in the ordinary test in which the result varies indeterminately between that which would be given if the threads could not slip at all and if the maximum reading occurred when the first thread breaks. The latter figure can be simply calculated from the analysis given in Paper V., from the mean single-thread strength and the mean deviation of the extensibility. It can be realised by testing quarter leas in a regular band at a reduced speed, the resulting figure being a useful measure of single thread quality, especially as the regularity of extension is a useful property itself. In the ordinary test, results on five types of yarn give an average lea ratio of 81%, calculated ratio to the first break of 71%, the difference being due to a very irregular addition of load after the first break. The iregularity of lea strength was found to be of the same order as that calculated, which is much greater than that of the mean of 160 threads. In fact, 8 single-thread tests give a mean as precise as the result of a lea test. These conclusions are supported by an analysis of extensive data on single-thread and lea strength given in a recent paper by Hall.[3]

DESCRIPTION OF EXPERIMENTS

Control Test on Single-Thread Strength of a Pair of Cut-Skein Samples

The mean breaking load in grams on 40 threads of 36's Sakel unsized yarn was—

(*a*) $359{\cdot}7 \pm 3{\cdot}3$ Difference $1{\cdot}6 = 0{\cdot}45\%$ of the mean.
(*b*) $358{\cdot}1 \pm 4{\cdot}7$ P.V. of difference$=\sqrt{3{\cdot}3^2+4{\cdot}7^2}=5{\cdot}74$.

If one set had been treated, e.g., mercerised, the difference shown would have been almost entirely due to that treatment, even though, from the variability of each lot taken by itself, only a difference of $3 \times 5{\cdot}74 = 16{\cdot}2$ would be regarded as significant. Disregarding the division into two complementary sets, the mean breaking loads were—

First 40 lengths 370·5.

Second 40 lengths 347·3. Difference 23·2=6·47%.

Had one set of tests been made on 30 yards of yarn and another on the next 30 yards, the difference due to sampling alone would have been 23·2, fourteen times that between the sets of alternate threads, and any small effect due to treatment would have been entirely swamped.

Control Test on Sized Yarn (otherwise as above).

(*a*) $399{\cdot}0 \pm 4{\cdot}7$ Difference 1·2=0·30% of the mean.

(*b*) $397{\cdot}8 \pm 5{\cdot}7$ P.V. of difference 7·4.

Length of Specimen

If the breaking loads of short specimens be distributed about a mean value according to the normal law of deviation, then the decrease in the mean for a greater length is proportional to the mean deviation for the short length and to a factor depending only on the ratio of the lengths. If r be the ratio, v the factor,

$$v = 5{\cdot}3\ (1 - r^{-\frac{1}{5}})$$

very approximately. The variability also decreases, so that the ratio of the mean deviation of the long to that of the short specimens (u) is $r^{-\frac{1}{4}}$.

The variation with length was measured on several yarns by testing alternate specimens of 10 and 30 inches, also by measurements on consecutive lengths of 10 and 30 inches, with the results shown in Table I. (Variability is measured with a little more accuracy by the Standard Deviation, the square root of the mean square deviation. This was used in analysing these results, the M.D. given being 0·798 times the S.D., as for a normal distribution).

Table I.

Observed Effects of Length on Single-Thread Test.

Sample	No.	Length	Breaking Load in gms.	M.D.	Extension %	Difference of Breaking Loads, grams
36's Sakel	277	10″	$367{\cdot}8 \pm 1{\cdot}5$	28·8	6·84	
(*alternate*) ...	277	30″	$359{\cdot}6 \pm 1{\cdot}3$	26·5	6·96	$8{\cdot}2 \pm 2{\cdot}0$
36's Sakel	100	10″	$392{\cdot}9 \pm 2{\cdot}6$	31·2	7·82	
(*consecutive*) ...	100	30″	$370{\cdot}3 \pm 2{\cdot}0$	23·7	6·91	$22{\cdot}6 \pm 3{\cdot}3$
32's American ...	200	10″	$207{\cdot}4 \pm 1{\cdot}2$	17·6	6·01	
Ring Yarn ...	200	30″	$196{\cdot}4 \pm 1{\cdot}1$	16·0	5·93	$11{\cdot}0 \pm 1{\cdot}6$
20's Waste	200	10″	$264{\cdot}0 \pm 2{\cdot}9$	49·1	8·50	
(*alternate*) ...	200	30″	$235{\cdot}4 \pm 2{\cdot}8$	46·6	5·97	$28{\cdot}6 \pm 4{\cdot}2$
20's Waste	100	10″	$291{\cdot}0 \pm 3{\cdot}1$	36·5	7·83	
(*consecutive*) ...	100	30″	$236{\cdot}9 \pm 3{\cdot}6$	42·6	6·68	$54{\cdot}1 \pm 4{\cdot}8$
32's American ...	600	9″	$234{\cdot}1 \pm 0{\cdot}7$	19 4	7·24	
Ring Yarn ...	600	27″	$220{\cdot}0 \pm 0{\cdot}6$	17·5	6·81	$14{\cdot}1 \pm 1{\cdot}0$

When the length is trebled, the theoretical difference is 1·05 times the mean deviation of the short length; the M.D. of the longer specimens is 0·74 times that of the shorter. As these values are based on probability considerations, the actual ratios over 100 or so specimens must vary widely. The observations show an invariable decrease with length, the changes being greater in the more irregular yarns and of the order to be expected. The M.D. also decreases, but less than the theoretical amount.

The most crucial test is that shown at the bottom of Table I. The samples were two complementary sets of 30 lots of 20 threads. The M.D. of breaking load was found on each lot separately, the mean value for 9″ specimens being $19·42 \pm 0·58$, for 27″ specimens $17·53 \pm 0·52$. The ratio of these is $0·903 \pm 0·038$, which is greater than the theoretical 0·74 by 4·3 times its probable error. Of the 30 differences between the means of complementary twenties, 28 showed the 9″ threads stronger, the mean being $14·1 \pm 1·0$. The theoretical difference is $1·05 \times 19·42 = 20·4 \pm 0·6$. The difference between these two values is 5·4 times its probable error. The ratio of the percentage extensions is 0·94, the same as the ratio of breaking loads.

The changes are significantly less than those deduced from a normal random distribution, as that does not apply strictly to a yarn. The average difference between consecutive pieces is less than between pieces taken at random and it is the former that determines the effect of length. When multiplied by 0·707 ($1/\sqrt{2}$) it should give a figure the same as the mean deviation, if the distribution be normal. Calculated from the consecutive threads, this figure was for 36's Sakel 28·1 against a M.D. of 31·2, for 20's waste 30·6 against 36·5.

For any given thread, the curve of load against extension is very nearly a straight line. The total extension is merely the sum of the extensions of all the portions, consequently the extension as a percentage of the length should be proportional to the breaking load, when the length of specimen only is altered. Measurements of extension are less accurate than those of breaking load, and therefore show more irregular variations, but on the whole a decrease is shown of the same order in percentage as that of breaking load. (The extension of the waste yarn was particularly irregular, as specimens often extended considerably between maximum tension and complete rupture.)

Lea Test

Mounting of Specimen—A great difference in the evenness of tension and gripping of the threads may be made by the manner of placing the lea on the hooks. To estimate the possible variations, comparison tests were carried out on leas wrapped from the same cop and placed in six different ways. (1) *Ribbon*—The lea, spread evenly on a wrap reel, was transferred carefully without allowing the threads to touch or overlap. (2) *Normal*—The wrapped lea was held at both ends to prevent twisting. (3) *Band*—The lea was held at one end only, and straightened by running a finger along it before placing. (4) *Half-twist*—The two ends of the lea were placed on the hooks from opposite sides, i.e., to give one longitudinal half-twist. (5) *Half-hitch*—An extra turn was given over one hook, two parts of the band overlapping. (6) *Unequal Tension*—The last ten of the eighty turns were 1½″ less in circumference. The mean strength by method (1) on 14 cops of 20's Indian yarn was 61·2 lbs., and the mean ratios between the results by each method, and that of method (1) were—

Ribbon	Normal	Band	Twist	Half-hitch	Unequal Tension
100	$101 \pm 1·7$	$115 \pm 2·6$	$108 \pm 3·1$	$108 \pm 2·3$	$86 \pm 1·7$

In the last, the 20 tight threads (12·5% of the lea) break or slip without contributing to the final load (14% less than that of the lea), but give enough friction to allow the remainder to show its full strength.

The first five results illustrate well the effect of increasing friction. The second type of lea is drawn by the tension into a ribbon similar to the first and shows no significant difference. In the third, many threads overlap and grip each other rigidly towards the end of the test, greatly increasing the portion (B) of the load. In the fourth and fifth the friction is further increased, but now to such an extent that the tension cannot distribute itself in the earlier part of the test, thus decreasing the portion (A).

The comparison between ribbon and band was repeated on a gassed 60's West Indian yarn. The mean of 20 values of the ratio was $112 \pm 0{\cdot}9$. Method (3) is probably closest to ordinary practice, but it gives the worst conditions, for the added load is a chance thing, incapable of control or interpretation as a yarn quality.

Whilst careless mounting increases the friction between the threads, this may be further diminished by testing smaller skeins. Leas, half-leas, and quarter-leas were wrapped in rotation from a cheese of 60's West Indian yarn to a total number of 72 of each size and tested, by method (2), with the following result—

No. of threads ...	160	80	40
Mean breaking load ...	42·3	19·1	8·86 lbs.
Ratio per lea	100	$90{\cdot}4 \pm 0{\cdot}7$	$84{\cdot}4 \pm 0{\cdot}9$

As the strength should *decrease* with length, and the break is slower for the full leas, the friction on the hooks of 80 turns is responsible for a considerable addition of load, even when the mounting is careful. By observation, no addition of load occurs after the first break in a quarter-lea, but a decided increase with full leas, although direct quantitative measurement of the portion (B) could not be made with precision.

Yarn Properties—Many attempts have been made to find some relation between observed "lea ratios" and various properties of the yarn. Smith[6] states that the ratio is greater for low twists, which may be due to the effect on extensibility or surface friction, and to the fact that the highly-twisted yarns are generally the stronger. The factors that may affect the chance process of breaking and slipping are so complex, and the empirical relations so irregular, that there is no hope of improving the significance of the test as it stands by such observations. It can only be given definite meaning by a logical analysis and by bringing it into relation with calculable and reproducible conditions.

Three cases of such conditions may be distinguished—(*a*) a long continuous thread in which the tension remains uniform, (*b*) a set of threads gripped at the ends so that the extension is uniform, (*c*) the same but slipping after the first break. The degree to which an actual test approximates to one or other of these cases depends on the friction at the hooks.

Using a full lea with threads overlapping, the test makes a rough approximation to (*b*). The portion (B) of the load after the first break is not, however, that given by the theoretical condition, but varies with the speed, the number, roughness, and extensibility of the threads and the manner of mounting. Even if the threads are held in a positive grip, the maximum load is not related to thread strength as simply as in the other two cases (see further, Paper V.), and there are more practical difficulties. Trial tests gave erratic results owing to a kind of tearing, the distribution of tension among the threads depending on the position of the threads first ruptured.

Cases (*a*) and (*c*) give a simple relation. The "lea ratio" is less than 100 by v times the irregularity; where v is the same factor as before and the irregularity, the mean deviation as a percentage of the mean, is for (*a*) that of the breaking load, for (*c*) that of the extension. As the manner of break depends on the friction between the yarn and the hook, measurements were made of this which are described in Appendix I. The coefficient of friction is 0·15 and the ratio between the tensions on two sides of a half turn over the hook which the friction can maintain is about 1·6. This is not sufficient to maintain any appreciable differences of tension at the beginning of a test, i.e., when all the tensions are small, provided the lea is wrapped evenly without overlapping, nor to allow an increase of load after the first threads break. On the other hand, the differences in tension developed by differences in the load-extension ratio are insufficient to cause slippage, so that the actual conditions of the test can be made to approximate very closely to case (*c*).

In such a case the portion (B) of the load is reduced to insignificance, and the portion (A), the whole result, gives a "lea ratio" depending only on the irregularity of extension and the factor v, which is 3·38 for 160 threads. The mean deviation of the extension will be $160^{-\frac{1}{5}}=0{\cdot}36$ of that of the breaking extension of single threads and the irregularity of lea strength the same as that of lea extension as the variation of the mean ratio of load to extension over batches of 160 is negligibly small.

Results obtained on several yarns are given in Table II. with the calculated and observed ratios between single-thread and lea tests. A very large number of observations would be necessary to fix the lea ratio and the mean deviation of extension accurately enough to test a statistical theory. but these results are sufficient to show that the calculated load at first break is of the same order but rather less than the observed lea strength. The irregularity is not significantly different from that calculated. The lea test has not the statistical significance of 160 single-thread tests, but of 8 only.

Table II.

Comparison of Single-Thread and Lea Strengths.

Sample	Lea Test			Single Thread Test					Lea Ratio		Lea Irregularity Calculated
	No. of Tests	Lea Lbs.	Irregularity	No.	Thread Oz.	Irregularity	Extension %	Irregularity	Observed	Calculated	
60's West Indian ...	10	37·5	6·4	200	4·81	10·4	3·8	8·0	78	73	4·0
36's Sakel ...	20	106·8	3·9	277	12·69	7·3	7·0	6·5	84	78	3·0
32's American	20	62·8	3·5	200	6·94	8·1	5·9	7·2	90	76	3·4
20's Indian	32	64·5	4·6	160	8·48	10·3	5·6	9·0	76	70	4·1
20's Waste ...	8	63·2	3·2	200	8·30	19·9	6·0	12·9	76	56	8·2

The conditions of case (*a*), which give the simplest relation to single-thread strength, could be realised by winding thread over a number of small independent pulleys, a method only practicable for a dozen or so strands. The lea test as it stands can best be improved by testing quarter-leas as untwisted ribbons at half the usual speed, when the portion (B) is eliminated and the conditions of case (*c*) realised.

APPENDIX I.

Yarn and Hook Friction

When a thread passes over a cylindrical bar, in contact over a semicircle, the friction just equals the difference of tension when the ratio of the tensions on either side is a constant which depends on the frictional coefficient of the thread and metal. If the thread just moves under a tension T_1, and the opposing tension be T_0, then

$$T_1/T_0=e^{\mu\pi}=a$$

where μ is the coefficient of friction.

T_1 and T_0 were measured directly by hanging two pans on a thread passing over the upper brass hook of the lea tester, and adding lead shot one by one till movement just persisted. By loading each pan alternately a series of values was obtained with increasing tension.

A quicker method, involving both hooks of the tester, is to tie one end of a thread to one of the hooks and pass it several times round the hooks, suspending a known weight from the other end. If the load be T_0, and the lower hook be traversed at a constant speed, the force on the upper hook when the load is being raised is

$$T=T_0(1+a+a^2+ \cdots\cdots),$$

the number of terms being equal to the number of threads, and

$$T=T_0(1+\frac{1}{a}+\frac{1}{a^2}+ \cdots\cdots)$$

when the load is being lowered. A large number of values of a can be quickly obtained with different loads and numbers of turns. The force on the upper hook is measured on the dial of the tester, the bob and pawls being removed from the pendulum.

Using these methods on six threads of 36's Sakel, a mean value of 0·153 was obtained for μ. A value of 0·151 was obtained on 20's waste yarn and of 0·153 on 60's West Indian. The value is that between brass and the surface of the cotton hair, and is independent of the structure of the yarn. The value of a corresponding to $\mu=0{\cdot}152$ is 1·61.

APPENDIX II.

In a paper published recently[3] some data on hank tests of wool are given, with the number of strands varying from 1 to 128. They show excellently the drop of breaking load due to variability of extension, from 1 to 32 threads, after which the mutual support of the more numerous threads introduces the additional load (B) and a slight rise. Table III. shows the data (Table A, *loc. cit.*) fitted to the formulæ of the theory used above. When the breaking loads are fitted for 1 and 32 threads, a very probable value is given for the irregularity of extension and the formula fits the earlier observations, falling below them for the 128 strands. The standard deviations follow the $r^{-\frac{1}{2}}$ series, with which they are compared, as closely as the number of tests would allow.

The conclusion drawn by the observer[2] that the rise for larger hanks is desirable, and gives a closer approximation to the "true" value as shown by single thread tests is the very reverse of the real meaning of the curve, for the fall is significant and calculable, the rise adventitious and of no useful meaning. It appears to vary widely even among the three yarns of this table, being less for the smoother worsted yarns.

The decrease of strength when the hanks are clamped could not possibly occur if the initial tension were uniform and the specimen loaded evenly, but agrees with the experience in this laboratory. A sound test cannot be hoped for along that line.

Table III.

Variation of Strength per Thread with Number of Threads.

Yarn	Threads	Tests	Breaking Load ÷ No. of Threads		Standard Deviation	
			Observed	Calculated	Observed	Calculated
			gms.	gms.		
2/32's Worsted $a_r = a_1 - 16v$ Irregularity of Extension = 5·0%	1	200	316	320	35	34
	4	60	311	304	27	26
	8	40	301	296	22	22
	32	19	277	286	14	17
	64	20	279	282	9	15
	128	20	284	278	11	13
2/36's Worsted $a_r = a_1 - 15v$ Irregularity of Extension = 5·6%	1	120	270	270	25	25
	2	60	262	262	18	22
	4	60	255	255	20	19
	8	60	254	248	22	17
	32	12	229	238	9	12
	64	12	230	234	10	11
	128	12	241	230	6	9
16's Woollen $a_r = a_1 - 40v$ Irregularity of Extension = 11·5%	1	200	347	347	50	60
	2	100	333	325	49	52
	4	50	306	305	51	45
	8	36	289	288	50	40
	16	24	249	275	37	34
	32	24	267	262	30	30
	64	24	288	251	50	26
	128	24	300	243	23	23

REFERENCES

[1] Fabrics Co-ordinating Research Committee. First Report, p. 46. London, H.M. Stationery Office, 1925.
[2] Gégauff. Bull. Soc. Ind. Mulhouse, 1907, **77**, 153.
[3] Hall. J. Text. Inst., 1925, **15**, T223.
[4] Parker and Jackson. J. Soc. Chem. Ind., 1925, **44**, 223-233T.
[5] Shorter and Hall. J. Text. Inst., 1923, **14**, T305.
[6] Smith. Text. World, 1925, **67**, 1425.

Shirley Institute
Didsbury

Received for publication, 9th October 1925