Tensile Strength, Elasticity and Elongation in Yarns

Factors Affecting Tensile Strength and Elongation in Tests

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The tensile strength and elasticity of yarns is largely dependent on the elongation, crimpiness, adhesion and smoothness of the individual fibers, as well as the number of fibers in any cross-section of a yarn and the twist in the yarn.

Whenever one characteristic outweighs the others, the true tensile strength does not become discernible. For instance, when good and sound fibers are used in a yarn with little twist, the co-efficient of resistance between the individual fibers is small, and the yarn slips apart at the weakest spot, hence no actual breakage of fibers takes place. In such a case, the individual fiber strength has no influence. Yet, when fibers of little strength are used in the manufacture of warp yarns, for instance, the added twist is of no avail beyond a certain amount and a stronger fiber of better quality is required. In order to get the full benefit of this fiber strength, a certain amount of twist must be given.

Effect of Twist

Whenever sufficient twist is inserted, taking advantage of the full fiber strength, no slipping is caused at the breaking point and the full benefit is obtained. As soon as excessive twist is used, the fiber strength passes the critical point and the tensile strength begins to reduce.

Hard twisted yarns are less voluminous, are smaller in diameter than soft twisted yarns because of a pressure exerted by the twist against the central core, which increases with the number of turns. The greater the turns of twist in a yarn, the more the central fibers are compressed by the surrounding fibers, so that the diameter actually decreases as the turns increase, yet the yarn number remains practically the same.

In the twisting of yarn, the outside layers of fibers receive a greater amount of relative twist than the inner or centrally located fibers. The core fibers actually receive little twist and the elastic limit of the outside fibers is reached long before the inside fibers. In such a condition, the outside fibers will break apart and the inside fibers will slide apart in a tensile strength test, which does not permit the full tensile strength to be attained. The ideal point is reached when through the agency of twist, the pressure of the outside fibers against

Editor's Note:—The following article is an excellent, most comprehensive discussion of a little understood subject.

the inner fibers is of such magnitude that a slipping of the inner fibers becomes impossible. Beyond that point, the outside fibers will break, snap, or tear, having reached their elastic limit. This constitutes the turning point in the tensile strength.

Elastic Limit of Fibers

If the individual fibers are compressed a great deal by a high twist, the co-efficient of friction between them is much greater than the cohesion of the fiber molecules. The separation of the whole yarn in a tensile strength test occurs only by the rupture of practically every individual fiber. Since the structure of yarn causes the outer fibers to be stressed more than the central fibers, and they reach their elastic limit more rapidly than the inner ones, the danger exists that these fibers will exceed their elastic limit and break long before the central fibers will do so. This danger is relatively greater in low count yarns than in fine count yarns, because the pressure of the outer against the inner layers is comparatively smaller in the latter.

Ordinarily hard twisted yarns possess a higher tensile strength than soft twisted yarns, all other things being equal. The twist should not be any higher than the requirements and use of the yarn demand as far as strength is concerned. The twist limit is dependent on the elastic limit of the raw material used. If this limit is exceeded by the amount of twist, the yarn becomes brittle with a consequent loss in tensile strength.

Ideal Condition

Therefore, the greatest possible tensile strength of a yarn is reached only when enough twist is used to reach the elastic limit of the individual outside and inside fibers, and in breaking the yarn that all fibers in the cross-section actually break and *not slip by each other*.

But such a twist is generally high and exceeds the elastic limit of the outer fibers in most cases. This must be avoided under all circumstances. Yet, the spinner generally does not reach the elastic limit because the more twist he inserts, the more his production decreases, which increases the cost of the yarn very rapidly.

Fibers in Cross-Section of Yarn

In regard to the number of fibers in a yarn cross-section, it is well-known that the distribution of the same in a yarn varies within certain limits, and the number is never the same in any two places in the yarn. Thin and thick places occur continually in any yarn. Such variations are at present unavoidable and are brought about in the preparatory processes and spinning itself. The automatic distribution of the fibers starts in the woolen system of yarn spinning at the card or web divider. In other systems, it is accomplished by doubling, drawing, combing, rubbing, etc.

Effect of Twist Variation

The twist during spinning runs to the thin places much more readily because of the smaller resistance in those places (having less fibers in the cross-section). Yet, this excess of twist in the thin places does not compensate for the lack of twist in the thick places. Yet, it is a well-known fact that the breaking of a yarn during processing or in a strength test, will invariably occur at a "thin" or "tight" place in the yarn. The yarn consumer, therefore, abhors nothing more than the use of an uneven or "twitty" yarn, especially for warp, aside of the fact that such a yarn does not make a uniform or even cloth. The thick places in the yarn are, therefore, much stronger because they have more fibers in their cross-section than those having the exact theoretical number for the respective yarn size. Only those places in a yarn, where the accumulation of the fibers has been so great that the yarn has absorbed hardly any twist in spinning, are an exception here. The less the number of thick and thin places in a yarn, the higher the average tensile strength will be.

The equalization of distribution of the fibers in the lengthwise direction of sliver, roving or roping, and finally in yarn, by means of many doublings, only can be accomplished to a limited degree. There are influencing forces in such processes which offset any such attempts. The number of individual fibers in a cross-section of a yarn control the diameter of the yarn, the weight per unit length, and eventually the yarn number. Everything else being equal, the more fibers in the diameter of a yarn, the greater the tensile strength, the greater the weight of the yarn, and the smaller the yarn count.

Theoretical Fibers in a Cross-Section

If ordinary cotton fibers are laid end to end, without overlapping one another, the English cotton count would be a theoretical size equivalent to the average diameter of the cotton fiber which varies between 2700 and 3700, or an average cotton yarn of about 3200/1. The theoretical number of fibers in the diameter of any cotton yarn can, therefore, be calculated and found by dividing 3200 by the yarn number. Hence, a number 50 cotton yarn has 3200÷50=64 fibers in a cross-section.

As the present methods of carding, drawing, combing and spinning do not permit an absolute uniform distribution of fibers in cross-section, it is impossible to make a 100% even yarn. Lately, Frederic Jannink has invented modifications in these processes, which have reduced the unevenness to a considerable extent and improved the quality of yarns in this respect.

Other Factors

The above mentioned variations in the number of fibers in the cross-section of a yarn have no direct bearing on the average size of the yarn, since the same will average out quite well. Yet, these variations have a considerable bearing in tensile strength tests.

The more uneven the yarn is, and the less fibers there are in a cross-section, the lower the tensile strength of the yarn will be. The reason is that the yarn invariably severs at the particular place where the least number of fibers is in the cross-section. The quality of the individual fibers (in mixtures for instance), also has an influence on the tensile strength. If any particular fiber in a cross section has considerably more strength than the others, it imparts this strength to the yarn during a strength test.

When one considers the many varieties of cotton fibers originating in as many different countries, it can be realized that considerable differences in tensile strength are brought about by influences due to soil, climate, as well as culture and fertilization. Even the same cotton from the same source varies from year to year in quality and average tensile strength. There is no doubt that excessive dry heat, prolonged damp weather, or early frosts, all have their due influence on the growth and maturity, not only in respect to length of fiber, but also the actual structure of the individual fiber. In some seasons, the presence of dead cotton fibers in raw cotton is especially pronounced and noticeable. These fibers react quite differently to the usual bleaching and dyeing operations than the ordinary cotton fiber.

Arbitrary Strength Standards

In order to properly judge the tensile strength of a yarn, certain arbitrary quality numbers, which are obtained from a No. 1 yarn of a definite quality and with a definite amount of twist, are ascertained. Naturally, these arbitrary numbers are variable. They are based on a No. 1 cotton yarn made with an American fully middling cotton and are as follows:—

For soft twist...............4000
For medium twist...........5200
For hard twist...............6500
For very hard twist.........8000

The normal tensile strength of a single cotton yarn is found by dividing these arbitrary standards by the particular yarn number, for instance:—

20/1 soft twist cotton yarn has a tensile strength of $\frac{4000}{20} = 200$ grams

40/1 medium twist cotton yarn has a tensile strength of $\frac{5200}{40} = 130$ grams

40/1 hard twist cotton yarn has a tensile strength of $\frac{6500}{40} = 162$ grams

30/1 very hard twist cotton yarn has a tensile strength of $\frac{8000}{30} = 266$ grams

According to Johannsen, the normal tensile strength of cotton yarns is found mathematically by the following formula:—

$$\frac{\text{Arbitrary strength standard}}{\text{yarn number}} = \text{normal tensile strength}$$

In this way, anyone can check any results obtained on a tensile strength testing machine.

Calculating Standards

Below is given a table of a number of English cotton yarns made of fully middling American cotton and calculated by means of the above formula:

Tensile Strength of Single Cotton Yarns in Grams with Varying Amounts of Twist

Yarn No.	Soft Twist	Hard Twist	Very Hard Twist
10	400	650	800
16	250	400	500
20	200	320	400
24	170	270	330
30	130	215	280
36	110	180	210
40	100	160	190

The mean elongation of cotton yarns according to Herzfeld have the following approximate percentages:—

Numbers	*Elongation*
20 to 30	4.5 to 5.0%
30 to 40	4.0 to 4.5%
40 to 60	3.8 to 4.0%
60 to 80	3.5 to 3.8%
80 to 120	3.0 to 3.5%
120 to 140	2.5 to 3.0%
140 to 170	2.0 to 2.5%

For checking the tensile strength of linen yarns, Karmarsch has set up the following formula:—

$$P = \frac{19{,}000}{Ne} \text{ to } P = \frac{21{,}000}{Ne}$$

where P is the tensile strength in grams, and Ne the yarn number. For example, a 20^s English linen yarn would, therefore, have a theoretical tensile strength of:

$$\frac{19{,}000}{20} = 9{,}500 \text{ to } \frac{21{,}000}{20} = 1{,}050 \text{ Grams}$$

For a four-ply sewing thread $P = \frac{21{,}385}{Ne}$:

For two-ply linen twine made of finely heckled flax, $P = \frac{21{,}316}{Ne}$

Three-ply $= \frac{35{,}000}{Ne}$

Fiber Strength Standards

According to Heerman, the tensile strength in kilograms figured on the basis of one square millimeter cross-section, is as follows:—

Wool	10.9 kg.
Jute	28.7 kg.
Cocoanut fiber	29.2 kg.
Flax	35.2 kg.
Cotton	37.6 kg.
Sisal	45.0 kg.
Raw silk	44.8 kg.

The tensile strength in grams of various types of "wool" fibers, according to Bowmann in "The structure of wool fiber" is as follows.—

Saxony	2.54 gr.
Australian Merino	3.25 gr.
Southdown	5.59 gr.
Alpaca	9.68 gr.
Leicester	32.63 gr.
Mohair	38.09 gr.

According to Cropelli, raw silk of 9/11—11/13 deniers of various tensile strength is judged in Italy as follows:—

Breaking load of 1— 5 g.	= entirely useless
" " " 5 — 10 g.	= very poor
" " " 10 — 20 g.	= poor
" " " 20 — 30 g.	= medium
" " " 30 — 40 g.	= fair
" " " 40 — 45 g.	= good
" " " over 45 g.	= very good

They classify silk as to the elongation percentages, as follows:—

Elongation at breaking point of	
1 — 5%	entirely useless
5 — 10%	very poor
10 — 15%	poor
15 — 20%	medium
20 — 25%	good
over 25%	very good

European silk dyeing plants agreed in 1912 in regard to the classification of the tensile strength and elongation of raw silk, as follows:—

1.—Tensile strength:—
  is fair, if it is 3 times the denier.
  is good, if it is 3½ times the denier.
  is very good, if it is 4 times the denier.

2.—Elongation:—
  is considered fair, if it is 18 — 20%.
  is considered good, if it is 20 — 22%.
  is considered very good, if it is over 22%.

Degummed silk is at present considered to have a somewhat smaller tensile strength than the corresponding size in raw silk, i.e., about 2.5 — 3.5 grams for each denier, as against 3 — 4 grams per denier in raw silk.

For wools, no standards have been set, because the diameter, length and quality show too large variations. The various kinds of rayon yarns have not been standardized as yet in any way.

Effect of Moisture Content

In addition to the foregoing, the tensile strength of yarns is quite dependent on the moisture content. Here, the temperature and relative humidity of the test room during a test must be considered, which should be a relative humidity of 65% at 66-70° F. temperature. For the practical comparison of yarn strengths, the temperature and moisture conditions always should be the same in the testing room. This can be obtained if the samples are exposed for a period of 24 hours in such a room. *(To be continued)*