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Tensile Behavior of Ring, Rotor, Air-Jet and DREF-3 Friction Yarns at Different Gauge Lengths

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ABSTRACT

The tensile behavior of Ring spun, Rotor spun, Air-jet spun and DREF-3 Friction spun yarns has been investigated at high strain rates and different gauge lengths. It is observed that the increase in gauge length from 150 mm to 500 mm decreases continually the yarn tenacity, breaking extension, but increases the breaking work and the modulus. The rotor spun yarns exhibit a minimum reduction in tenacity while the air-jet spun yarns show a greater drop in tenacity and breaking extension when tested at longer gauge lengths. Amongst all yarns, the ring spun yarns exhibit highest tenacity and modulus followed by rotor spun yarns and air-jet spun yarns. The yarn tenacity, breaking extension, breaking work and breaking time are found to be power law functions of gauge length while the modulus is preferably a logarithmic function of gauge length. The percentage increase in tenacity is higher in case of 20 Ne cotton ring spun yarn followed by the corresponding rotor spun and air-jet spun yarns. All these observations ascribe to the nature of the responses of the constituent fibers at differences amongst the structures of these yarns.

Keywords: Tensile Behavior, Specimen Length, Tenacity, Breaking Extension, Failure, Structure

1. Introduction

It is well known that the tensile behavior of a spun yarn depends largely on the characteristics and structural arrangements of its constituent fibers. Every spinning technology produces a yarn of unique structure owing to its unique method of fiber integration and nature of twisting. Hence, the geometric configurations of fibers are different in the yarns spun on different spinning systems. For instance, a ring spun yarn exhibits a near cylindrical helix structure, which is almost not valid in case of rotor spun, friction spun, and air-jet spun yarns. The core-sheath structure and differential twisting of fibers is a common feature of rotor spun and friction spun yarns. Similarly, an air-jet spun yarn consisting of a core of parallel fibers wrapped by sheath fibers, exhibits a fasciated yarn structure. Therefore, due to the marked structural differences, the responses to the tensile forces of these yarns are expected to be different. In addition, the failure mechanics of yarns as a combined phenomenon of fiber slippage and breakage is also likely to be different in the above yarns of differing structural features. Further, the theoretical analysis of the tensile behavior of a staple-fiber spun yarn is highly complex, mainly because of discontinuities at fiber ends. Also, yarns in many textile operations are subjected to sudden stresses at high stress-induced speeds. For instance, during the insertion of weft, whether by projectile or air jet, the yarn has to withstand accelerations of many thousands of times greater than that due to gravity. Hence it becomes important to understand the stress-strain responses of yarns under non-standard loading conditions vary over a range of strain rates and specimen lengths.

The effect of rate of loading on the tensile properties of spun yarns was first investigated by Midgeley and Pierce [1] (1926). Working on a 16-Tex cotton yarn, the authors observed that the yarn breaking strength bears an inverse logarithmic relationship with the time-to-break, expressed in seconds. Working on the same subject at a later date, Meredith [2] (1950) observed that the breaking strength of ring spun cotton yarn drops by 9% for every tenfold increase in the breaking time ranging from 10 seconds to 10 hours. The author had also shown that a low twist yarn gives a larger percentage drop in strength as compared to a normal twist yarn and that the maximum breaking extension for normal twist yarn occurs within the breaking time range of 1-10 seconds. The compliance ratio, which Meredith defined as extension per unit load, was shown to decrease linearly with the logarithm of extension rate. A drop in compliance ratio of 7.8% was observed with a ten-fold increase in the rate of extension.

Kaushik et al. [3] Studied the influence of extension rate and specimen length on the tensile behavior of rotor spun acrylic/viscose yarn. They found that the maximum yarn tenacity occurs at a strain rate of 20 cm/min for a gauge length of 10 cm and at a strain rate of 100 cm/min for a gauge length of 50 cm. The breaking extension on the other hand, was shown to increase with increase in extension rate.

Hearle and Thakur [4] studied the effects of rate of extension and gauge length on the load-extension behavior of twisted multifilament yarns. They observed sharp (catastrophic) yarn breaks at a specimen length of 10 cm but the breaks were partial and non-simultaneous at shorter gauge lengths (2.5 cm and 1.0 cm). The rate of extension, in addition to gauge length, was found to influence the breakage mode. Thus partial breaks were observed even at a 10 cm gauge length when the rate of extension was sufficiently low. The authors explained that the elastic energy stored in a yarn that is under increasing axial tension will be a function of the gauge length and that the energy stored in the short test specimen may not be adequate to cause sharp and instantaneous breaks.

Realff *et al.* [5] dealt with the influence of gauge length on yarn properties. The yarns produced on ring, air-jet, and rotor spinning systems were tensile tested at a range of gauge lengths above and below the mean staple length. At longer gauge lengths, yarn failure was found to be the result of combined slippage and breakage of fibers. At shorter gauge length, yarn failure was shown to result from a greater extent of fiber breakage and less slippage. The balance between slippage and breakage was shown to vary with yarn structure. Thus slippage was found to be more predominant in the failure of air-jet yarn, especially at longer gauge lengths. The strength obtained at very short gauge length was shown to differ considerably from that predicted based on the weakest link theory and the authors argued that this deviation from a predicted value serves as proof of a change in failure mechanism at very short gauge lengths.

Hearle, Grosberg and Backer. [6] proposed that the mechanism of failure might also change due to a decrease in the test length. They observed different range of failure zone sizes of ring spun and rotor spun yarns, for different gauge lengths. This is given in Table 1. According to their observation, for ring-spun yarn there are many broken fibers and a small failure zone size in the 76.2 mm gauge length. At 12.7 mm gauge length, there is a concentration of fiber breaks and a few pulled-out fibers in the failure zone; here the extensive fiber breakage would result in a substantial decrease in lateral pressure on the few remaining fibers present in the failure zone. The specimen of < 2 mm has a small failure zone size with highly concentrated fiber breaks.

Table 1. Range of Failure Zone Sizes for Different Gauge Lengths

Yarn Type	Gauge length (mm)	Failure zone size (mm)
Ring spun	76.2	< 3
Ring spun	12.7	2-4
Ring spun	< 2	0.5-2
Air-jet spun	76.2	3.5-10.5
Air-jet spun	12.7	3-8
Air-jet spun	< 2	0.5-2

For air-jet spun yarns, the failure zone at 76.2 mm gauge length is characterized by a greatly reduced cross-section over a length of 8mm. These tapered ends suggest that fiber slippage has dominated the failure process, since few wrapper fibers appear to be broken as identified in the SEM photomicrograph. Upon failure of these wrapper fibers, there is a decrease in inter-fiber pressure, thus leading to increased fiber slippage and ultimately, yarn failure is dominated by slippage. The change in mechanism from fiber slippage to fiber breakage appears clearly in photomicrograph, where the 12.7 mm gauge length sample exhibits a concentrated region of thinning and the < 2 mm gauge length sample shows numerous broken fibers with a comparatively small number of fibers pulling out in the yarn center. When both ring spun and air-jet spun yarns are tested at well above and well below the staple length of 31.8 mm, the air-jet spun yarn shows lower strength in the first case and higher strength in the second case as against the ring-spun yarn. In the first case, the failure mechanism for air-jet spun yarn is slippage dominated but for ring-spun yarn it is breakage dominated. But in the second case, the air-jet spun yarn shows more strength than ring spun yarn because the difference in surface helix angle (θ), since $\theta > 0$ for ring spun yarn and $\theta \cong 0$ for core fibers in air-jet yarn. While comparing the influence of gauge length on failure for ring spun yarn and rotor spun yarn, they found from SEM photomicrographs that the ring spun yarn fails by fiber breakage at both long and short gauge lengths. But the rotor yarn shows a change in failure mechanism from a fiber slippage dominant failure at longer gauge length (127 mm) to a fiber breakage dominant failure at shorter gauge length (12.7 mm and < 2 mm).

Oxenham *et al.* [7] compared the effect of gauge length on ring spun and open-end friction spun yarns and found that the strength of ring spun yarn shows a sharp drop as the gauge length increases from 1 mm to 40 mm (which is approximately the fiber length). The strength of friction-spun yarn also drops sharply as gauge length increases, but for this yarn it decreases in gauge length from 1 mm to 20 mm (which is almost equal to the fiber extent in this yarn). For gauge lengths greater than 40 mm, the strength of ring spun yarn appears to be fairly constant whereas the strength of the friction spun yarn continues to decrease as the gauge length increases, reflecting the discontinuities observed in the yarn formation zone in friction spinning.

Peirce [8], after studying the strength and variability theoretically, proposed the "chain weak link" theory and has shown that the predicted probability distribution Fl (x), for the strength at any gauge length l from a knowledge of strength distribution Fl0 (x) at a given length l0 is given by:

$$F_l(x) = 1 - [1 - Fl_0(x)]^m \text{, where } m = l / l_0$$

He established the following relationship between the strength, test length and irregularity:

$Z_L = Z\left[1 - s/Z4.2\left(1 - r^{(-1/5)}\right)\right]$ and,

$${sL}/{s} = r(-1/5)$$

Where Z_L =Strength of staple yarn at gauge length L

r = (Tested gauge length, L / elementary length, le)

Z = Average strength of elementary lengths,

s = Standard deviation of element strength

sL= Standard deviation of the yarn strength at tested gauge length L.

Some researchers (Grant et al. [9], Pillay [10], Kapadia [11]) have attempted empirical approaches to understand the nature of strength variation with the test length. They found the following logarithmic, exponential, and power law relationships between tenacity (T) and gauge length (L):

$$T = a + b\log L$$

$$T = ae^{bl}$$

$$T = aL^b$$

where a, b are constants.

A power law equation gives rise to singularities at extreme values of L, i.e., when L= 0, tenacity becomes infinity and when L=∞, tenacity become zero, neither of which is actually true.

Hattenschwiler *et al*. [12] in order to identify the breaking point in the tested sample, applied the following method. Within the yarn sample, exactly 50-cm length was marked and the yarn was tested on an Evenness Tester recording a diagram. Following the tensile strength, the exact point of rupture with the 50-cm length was measured. The identified breaking point was then marked in the diagram previously recorded on the Evenness Tester. This method offers the possibility of verifying whether rupture took place in a thin place or thick place. For cotton ring spun yarn (30 Ne), they found that approximately half of all ruptures happened in parts of the yarn which were above the mean value, whereas the other half occurred in parts which were below the mean value. In the region of thick places, ruptures were recorded up to +60% cross-sectional increases, whereas in the area of thin places they had occurred up to a minimum of –40%. They argued that the rupture takes place at a thin place due to more stress concentration in that zone. But thick place becomes weakest point, if the difference in mass between thin place and thick place is considerable; there will be a significantly higher amount of twist in the thin place, as compared to the thick place, thus leaving the thick place with a very low tensile strength.

Hussain *et al*. [13] have used six yarn samples spun from different varieties of cotton on ring spinning and rotor spinning to study the effect of gauge length on the three principal tensile properties, namely tenacity, breaking strain, and specific work of rupture. The yarns were tested at gauge lengths ranging from 1 cm to 70 cm. It was found that the breaking strain and specific work of rupture decrease with increase in gauge length. Tenacity also decreases with increase in gauge length in both types of yarns, the decrease being more pronounced for ring spun yarns.

Cybulska and Goswami [14] have studied the tensile behavior of air-jet spun yarn (29 Tex), rotor spun yarn (30 Tex) and ring spun yarn (24 Tex). All the three yarns were produced from a 50:50 polyester/cotton blend. From the above study, the authors have concluded that the tensile behavior of staple yarn is strongly influenced by its structure. The distribution of fibers along the yarn length provides significant information about the tensile properties of yarns. The higher the number of fibers in the yarn cross-section, the higher is the breaking load, elongation and energy-to-break. The structure of staple yarn should help in better understanding of its tensile behavior and the effect of disposition of fibers in the yarn on its strength.

The effect of rate of extension of the tensile properties of a spun yarn was investigated by Radhakrishnaiah and Huang [15] Cotton yarns of 18s Ne were spun on the ring, rotor and friction spinning systems. Similarly, cotton/polyester (50:50) yarns of the same count were produced on ring, rotor, friction and air-jet spinning systems. These yarns were tested at gauge lengths of 45 mm and 500 mm and at test speeds varying from 15 mm/min to 2000 mm/min. Based upon the analysis of failure modes of the yarns, it was concluded that there are major differences in stress-strain behaviors of cotton yarns representing the three spinning systems. The average stress-strain curves of the cotton/polyester yarns representing the three spinning systems were found to be somewhat similar up to the yield point.

The traverse rate appears to have a similar effect on the stress-strain responses of three cotton yarns. The polyester/cotton yarns representing the three different spinning systems, however, fail to show a similar change in stress-strain responses with the change in traverse rate. Further, all six experimental yarns show catastrophic failure at 500 mm gauge length. At 45 mm gauge length, ring spun yarns show most catastrophic failures while the rotor, air-jet and friction spun yarns show mostly non-catastrophic failure. In view of these observations, the present research work has been planned to investigate the tensile behavior of yarns spun on most common spinning systems, at different specimen lengths.

According to Ghosh *et.al.*,, the tensile strength of a spun yarn depends on its structure, gauge length and extension rate employed during measurement[16]. Balasubramanian *et.al.*, explained that, the tensile strength of a yarn is influenced, among other factors, by the number of fibers that break in the region of yarn rupture. This number mainly depends on the yarn twist, length of the fibers and the rate of straining[17]. Tallant *et.al.*, explained that, there should be minimum fiber length for significantly contributing to yarn strength. To find this minimum fiber length, he proposed a mathematical model for translation of fiber bundle strength to yarn tenacity Equation given below:

$$Y = a \times f(l, x) \times s + b$$

Where, Y is the single-yarn tenacity; S, fiber bundle strength; l, length distribution of cotton; x, critical or minimum length of fiber; f (l, x), effective weight and a & b , are the constants. It was found that the fibers shorter than about 3/8 inch do not contribute to yarn tenacity and a 3/8 inch portion of each longer fiber is ineffective. It is implied that on an average, the 3/16 inch tip at each end of each fiber doesn't contribute to yarn tenacity. Their investigation gave interesting findings that the "zero" gauge fiber bundle test is superior to the 1/8 inch gauge length test as a criterion for relating bundle to yarn tenacity, if the gauge length value is modified by the effective weight[18]. Gulati, and Turner observed that the fibers below 0.5 inch length don't contribute to yarn strength[19].

Hearle described that the mechanical properties of yarn depends on the complex interrelation between the fiber arrangement and properties. It should however be possible to predict the yarn stress-strain properties from knowledge of the fiber stress-strain properties, if we know the arrangement of fibers in the yarn. He derived a mathematical formula to express its yarn structure, based on the distribution of fiber segments, diameter shrinkage function, yarn twist and number of fibers in yarn cross-section[20].

Moreover, with the increasing awareness of the considerable impact that variations in fiber properties have in determining their mechanical behavior and structures made from them, theoretical approaches to specify the statistical distribution of the fiber properties have become desirable [21, 22]. Many have turned to the Weibull distribution. This model has been shown to be valid for brittle fibers, as these fibers are close to the so-called classic fibers on which the Weibull theory for fiber strength was derived [23]. The application of this model has been expanded to polymeric fibers whose behavior is notoriously time dependent, and has a high probability that some long range property variations may exist due to manufacturing irregularities, thus violating the assumption of the classic fiber. Therefore, the validity of the Weibull model for these fibers has to be tested.

Krause, and Soliman analyzed the tensile behavior of air-jet spun yarns. He tried a mathematical approach to calculate and predict the strength of false twist yarn, spun by means of a single air- jet, based on an idealized yarn structure model. The strength of wrapping fibers, the core fibers and the frictional resistance of the slipping fibers in the core is the load bearing components of the yarn. Their equation indicated to what extent yarn strength depends on the following major parameters: position of the wrapping fibers, average wrapping length, the angle, fiber strain, fiber-to-fiber friction and fiber slenderness[24]. Tyagi, Goyal, and Salhotra studied the effect of various process parameters on the sheath slippage resistance of air-jet spun yarns. They claimed that the higher first nozzle pressure is advantageous for improving sheath-slippage resistance. Higher spinning speed and wider condenser significantly improves the tenacity, breaking extension, initial modulus and sheath slippage resistance, but adversely affect yarn hairiness, mass irregularity and flexural rigidity[25]. Chasmawala, Hansen, and Jayaraman divided the wrapping fibers in to five classes- core, wrapper, wild, core-wild and wrapper wild. They showed that, yarn strength depends on the proportion of each class of fibers in the yarn structure and that yarn strength decreases with an increasing number of wild and wrapper wild fibers and increases with an increasing number of core, wrapper & core-wild wrapper fibers[26]. Chasmawala claimed that the air-jet spun yarn displays two distinct failure modes – catastrophic and non-catastrophic[27]. Lawrence, and Baqui divided the structure of air-jet spun yarn into three classes, according to the properties of wrapper fibers. Class-I, characterized by uniform wrapping angle; class-II, with wrapper fibers at different wrapping angles and class-III, with no wrapper fibers[28]. Rajamanickam, Hansen, and Jayaraman analyzed three kinds of tensile fracture behavior in air-jet spun yarns. Catastrophic, when all fibers in the failure region slip and break at the same load, Non catastrophic, if fibers do not break or slip completely at the same load and failure by total fiber slippage. They showed that yarn strength increases with high frequency of class I structure and decreases with a high frequency of the class III structure, especially if these sections are agglomerated in some particular regions of the yarn length[29]. Lawrence et al. and Rajamanickam explained air-jet spun yarns produced using different fiber, yarn, and process parameters exhibit different tensile properties and yarn tensile failure modes. This difference may be attributed to variations in yarn structure, yarn count, and fiber properties[28,29].

The present work is to investigate the stress-strain responses and failure modes of structurally different Ring spun, Rotor spun, Air-jet spun and DREF-3 Friction spun yarns at high strain rates and different gauge lengths so that more appropriate yarn engineering and utilization techniques can be established. This specific work is mainly designed to study the influence of high strain rate and varying specimen length on stress-strain responses of cotton and polyester yarns spun on ring, rotor, air-jet and DREF3 friction spinning systems and to analyze the nature of stress-strain curves of individual yarns at different gauge lengths and strain rates and drawing inferences.

2. Experimental Procedure

2.1 Preparation of Yarn Samples

The yarn samples representing Ring, Rotor, Air-jet, and DREF-3 Friction spinning systems were prepared from Cotton fibers of S6 variety and Polyester fibers of 44 mm and 1.55 dtex. Yarns of 20 Ne and 30 Ne were produced from cotton and polyester on a laboratory model G 5/1 Ring frame. Similarly, 20 Ne and 30 Ne yarns were spun from cotton and polyester on a laboratory model Air-jet spinning machine MJS 802. In Rotor spinning, only cotton yarns of 10 Ne and 20 Ne were produced on a commercial Rotor spinning machine BD 200A, and due to unavailability of facilities, polyester rotor yarns could not be spun. The DREF-3 friction spun yarns of 6 Ne and 10 Ne were produced from cotton and polyester respectively on a laboratory model DREF 3 friction spinner. The yarn sample preparation plan and the process parameters used is given in Table 2.

2.2 Measurement of Yarn Tensile Properties

All the yarn samples were tested on Tensomax 7000 and Tensojet 4 for tensile characteristics, like breaking force, tenacity, breaking elongation, breaking work, and modulus at 1% extension and 3% extension. The yarn samples were tested at varying gauge lengths of 150 mm, 250 mm, 350 mm and 500 mm using a constant test speed of 5 m /min. In each case, 50 tests were conducted and the average values of breaking time, breaking force, tenacity, breaking elongation, breaking work, and modulus is computed.

Table 2. Particulars of Yarn Sample Preparation

Ring Spun Yarns	*Spindle Speed (r/min)*	*Break Draft*	*Twist Multiplier*	*Traveler*
20Ne Cotton	15000	1.23	4	2/O
30Ne Cotton	15000	1.23	4	2/O
20Ne Polyester	15000	1.23	3.5	2/O
30Ne Polyester	15000	1.23	3.5	1/O
Air-jet Spun Yarns	*N_1 Pressure (kg/cm²)*	*N_2 Pressure (kg/cm²)*	*Delivery Speed (m/min)*	*Total Draft*
20Ne Cotton	2.0	4.5	180	152
30Ne Cotton	2.0	4.5	180	225
20Ne Polyester	2.0	4.5	180	119
30Ne Polyester	2.0	4.5	180	184
Rotor Spun Yarns	*Feed Rate (m/min)*	*Opening Roller Speed (r/min)*	*Rotor Speed (r/min)*	*Delivery Rate (m/min)*
10Ne Cotton	1.31	8000	70000	112
20Ne Cotton	0.42	8000	70000	73.7
DREF-3 Friction Spun Yarns	*Core-Sheath Ratio*	*Delivery Rate (m/min)*	*Spinning Drum Speed (r/min)*	*Suction Pressure (mbar)*
6Ne Cotton	60:40	150	5000	20
10Ne Polyester	60:40	250	5000	20

3. Results and Discussion

The results of all yarns were analyzed and the variations tensile properties of yarns caused due to increase in gauge length and strain rate are subjected to tests of significance at 95% confidence level and inferences are drawn.

3.1 Influence of Gauge Length on Yarn Tensile Properties

3.1.1 Ring Spun Yarns

It can be understood from the analysis of results given in Table 3 for ring spun yarns that an increase in gauge length from 150 mm to 500 mm decreases the yarn tenacity and breaking extension but increases the breaking work, breaking time and modulus at both 1% and 3% extensions. Typical graphs showing these trends for 20 Ne polyester ring spun yarn are given in Figures 1-3. The reduction in tenacity and the extension can be attributed to the well-known weak-link effect (Midgeley and Pierce 1926), according to which the probability of presence of weakest link is greater in a longer specimen, which thus breaks early and results in lower strength and extension. The reduction in tenacity of 20 Ne and 30Ne polyester ring spun yarns is significant at 5% confidence level. Considering all the four samples of ring spun yarns, on an average, the tenacity and extension drop by 5-7.5% and 10.5-12.5% respectively.

Table 3. Effect of Gauge Length on Tensile Properties of Ring Spun Yarns

20 Ne Cotton					**30 Ne Cotton**				
L	150	250	350	500	***L***	150	250	350	500
T	0.1	0.1	0.2	0.2	***t***	0.1	0.1	0.2	0.2
F	551	549	524	531	***F***	355	353	337	338
T	18.7	18.6	17.8	17.8	***T***	18.1	17.9	17.1	17.1
E	4.8	4.6	4.3	4.2	***E***	5.1	4.9	4.6	4.5
W	204	336	418	608	***W***	146	231	287	408
M_1	2.1	2.6	3.2	4.4	M_1	2.2	2.7	3.2	4.5
M_3	2.7	4.6	5.9	6.5	M_3	2.2	4.4	5.0	5.1
20 Ne Polyester					**30 Ne Polyester**				
L	150	250	350	500	***L***	150	250	350	500
T	0.3	0.4	0.5	0.8	***t***	0.2	0.3	0.5	0.7
F	1197	1170	1131	1121	***F***	778	750	740	719
T	40.5	39.6	38.3	38.0[a]	***T***	39.5	38.1	37.6	36.5[a]
E	15.4	14.6	14.1	13.7	***E***	13.3	12.5	12.3	11.9
W	1191	1828	2370	3364	***W***	747	1106	1527	2029
M_1	1.6	1.7	2.2	3.2	M_1	2.3	2.5	2.7	3.3
M_3	1.6	3.5	4.2	5.1	M_3	2.5	4.7	5.2	5.7

L: Gauge Length (mm); t: Breaking Time (sec); F: Breaking Force (cN);
E: Breaking Extension (%); T: Tenacity (cN/tex); W: Breaking Work (kgf.m);
M_1: Modulus (N/tex) at 1% extn.; M_3: Modulus (N/tex) at 3% extn;
[a] reduction in tenacity is significant at 95% confidence level

The breaking work is a function of the product of breaking force and elongation (actual increase in the length of original specimen). The higher breaking work of a longer specimen of yarn as observed from Table 3 is due to the great increase in the length of the original specimen during extension. For instance, in case of 20 Ne cotton ring spun yarn, the elongation of 150 mm specimen is 7.2 mm whereas the same for 500 mm specimen is 21 mm.

The modulus refers to the resistance offered by the yarn to extend and is determined by the ratio of stress to strain. The modulus measured at 1% extension is often referred to as the initial modulus. The modulus at 3% extension indicates the resistance offered by the yarn when it is subjected to such an extension level during post-spinning, weaving or knitting operations. From Table 3, it is observed that the modulus (at both 1% extension and 3% extension) increases with an increase in the gauge length of the yarn. In a shorter specimen, as it is strained initially, the instantaneous tension builds up results in quicker fiber straightening and ready extension, thus showing lower modulus. This effect can be understood from the nature of the force-elongation curve shown in Figure 4. On the contrary, the longer specimen exhibits lower extension owing to delayed tension build up, perhaps caused by partial relaxation of the applied stress and thus registering a relatively higher modulus. The nature of the load - elongation curve (Figure 5) of a longer specimen is essentially different from that of a shorter specimen. The modulus at 1% extension is relatively higher for finer yarns as compared to the coarser yarns. This can be attributed to the fact that finer yarns with a relatively higher twist and enhanced structural cohesion offer greater resistance to extension and thus exhibit higher modulus.

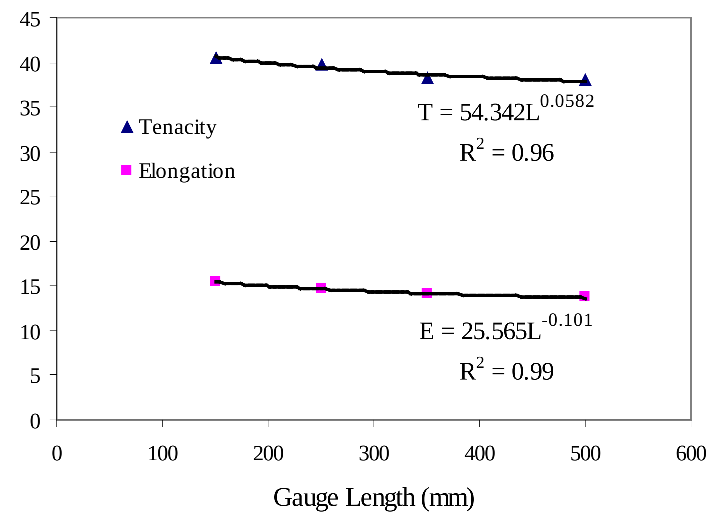

Figure 1. Effect of Gauge Length on Tenacity and Elongation (%) (20 Ne Polyester Ring Spun Yarn)

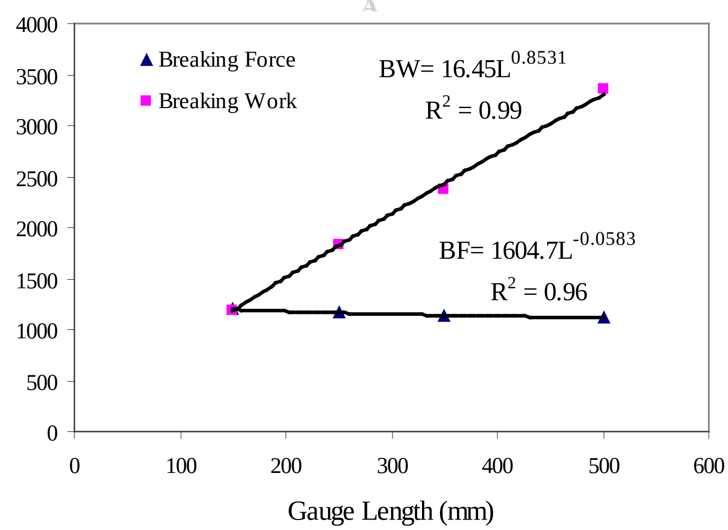

Figure 2. Effect of Gauge Length on Breaking Force and Breaking Work

(20 Ne Polyester Ring Spun Yarn)

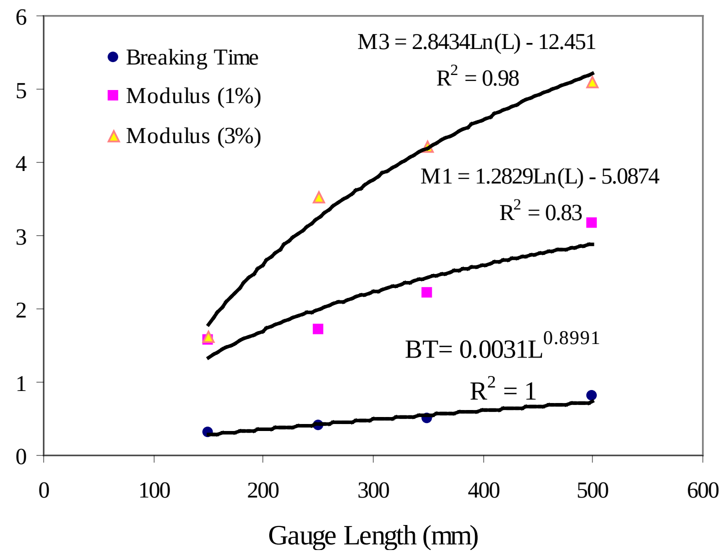

Figure 3. Effect of Gauge Length on Modulus and Breaking Time (20 Ne Polyester Ring Spun Yarn)

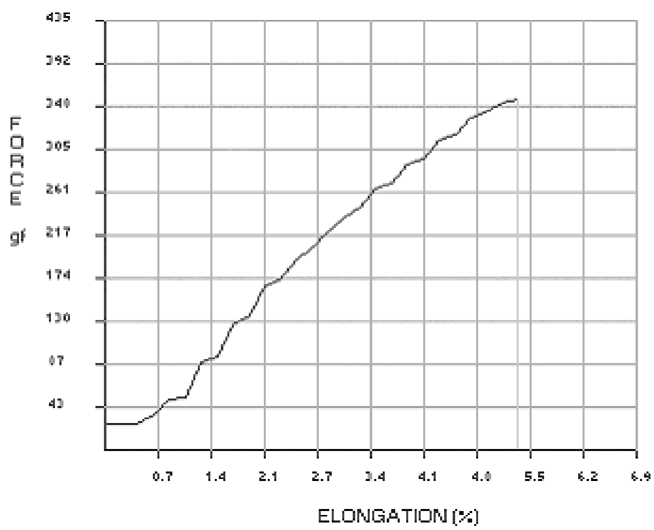

Figure 4. Force-Elongation Curve for 20Ne Cotton Ring Yarn at 150 mm

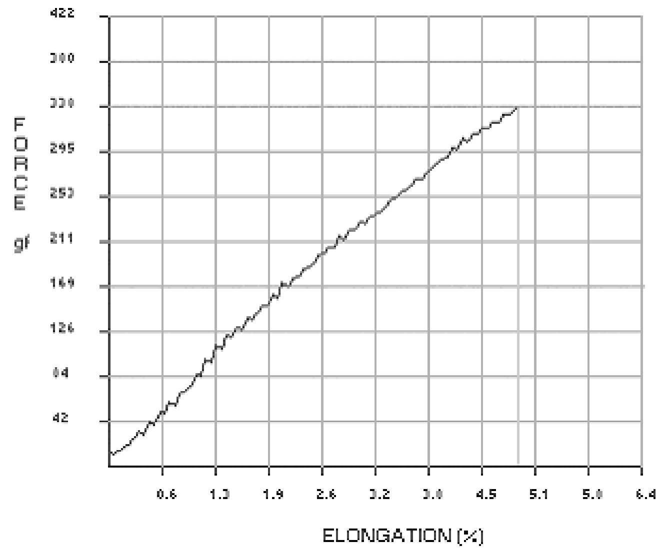

Figure 5. Force-Elongation Curve for 20Ne Cotton Ring Yarn at 500 mm

3.1.2 Air-jet Spun Yarns

It can be seen from Table 4 that the influence of gauge length of tensile characteristics of air-jet spun yarns is almost similar as in the case of ring spun yarns discussed above. However, as compared to ring spun yarns, the air-jet spun yarns register a slightly higher reduction in tenacity (8-12%) and extension (11-18%) due to increase in gauge length from 150 mm to 500 mm. The percentage drop in tenacity and extension is found to be relatively higher in case of cotton air-jet spun yarns as compared to polyester air-jet spun yarns. The nature of stress-strain curves for cotton air-jet spun yarns differs considerably from that of polyester air-jet spun yarns, which is clearly evident from Figures 6-7. It can be visualized from the stress-strain curves that the cotton air-jet yarns exhibit greater fiber slippage as compared to the polyester air-jet spun yarns. The cotton fibers owing to their shorter length might not have produced effective and tighter wrapping as compared to the polyester fibers, which are relatively long and expected to result in longer wrapper extent and firm wrappings in the yarn. Due this reason, the cotton air-jet spun yarns exhibit very low strength as compared to their polyester counterparts, which is very clear from the results given in Table 4.

Table 4. Effect of Gauge Length on Tensile Properties of Air-jet Spun Yarns

20 Ne Cotton					**30 Ne Cotton**				
L	150	250	350	500	***L***	150	250	350	500
t	0.1	0.1	0.2	0.3	***t***	0.1	0.1	0.2	0.3
F	252	239	234	226	***F***	171	169	161	154
T	8.5	8.1	7.9	7.6	***T***	8.7	8.6	8.2	7.8
E	6.0	5.5	5.2	4.9	***E***	5.5	5.4	5.3	4.8
W	127	185	244	326	***W***	87	131	192	218
M_1	1.2	1.4	2.0	2.4	M_1	1.6	1.7	1.8	2.5
M_3	1.3	2.3	2.6	2.8	M_3	1.9	2.6	2.8	3.2
20 Ne Polyester					**30 Ne Polyester**				
L	150	250	350	500	***L***	150	250	350	500
t	0.2	0.3	0.4	0.6	***t***	0.2	0.4	0.5	0.7
F	811	798	744	713	***F***	511	498	494	470
T	27.5	27.0	25.2	24.2[a]	***T***	26.0	25.3	25.0	23.9[a]
E	13.1	12.4	11.5	11.3	***E***	13.9	13.4	13.0	12.4
W	710	1104	1378	1828	***W***	479	750	1011	1335
M_1	1.1	1.3	1.9	2.2	M_1	1.3	1.4	1.8	2.2
M_3	1.2	1.6	2.2	2.5	M_3	1.2	1.6	2.0	2.6

[a] reduction in tenacity is significant at 95% confidence level

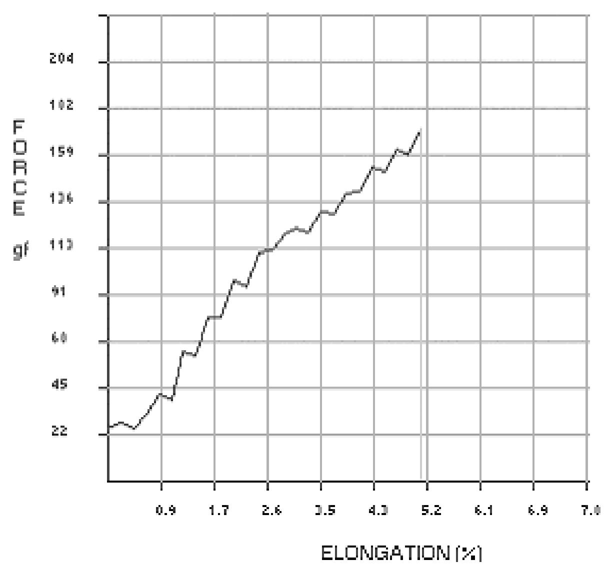

Figure 6. Force-Elongation Curve for 30s Cotton MJS Yarn at 150mm

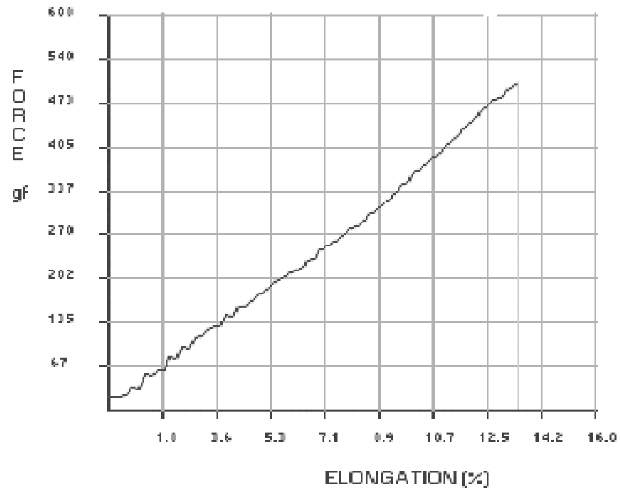

Figure 7. Force-Elongation Curve For 30s Polyester MJS Yarn at 150mm

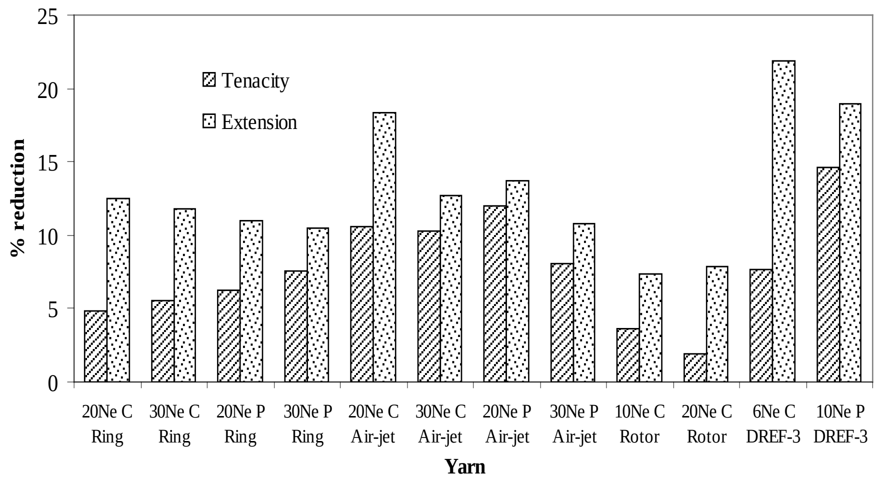

Figure 8. Reduction in Yarn Tenacity and Extension as a function of Gauge Length

3.1.3 Rotor Spun and DREF-3 Friction Spun Yarns

The rotor spun yarns and DREF-3 friction spun yarns also depict similar tensile behavior against variation in gauge length (Table 5) as already observed for ring spun and air-jet spun yarns. But interestingly, the drop in the tenacity and extension of longer specimen (500 mm) is most minimum in rotor spun yarns, say about 2.7% and 7.7% as compared to a shorter specimen (150 mm). This is clearly evident from Figure 8. The 6 Ne cotton and 10 Ne polyester DREF-3 friction spun yarns show a relatively higher reduction in tenacity and breaking extension with an increase in gauge length; a similar effect already discussed in the case of air-jet spun yarns. This can be attributed to the fact that both the air-jet spun and DREF-3 friction spun yarns exhibit core-sheath type structures, wherein the probability of occurrence of irregular wrapped portions (weak zones) is expected to be more in longer specimens of such yarns. The irregularly wrapped zone in a longer specimen can be treated as a weak zone, wherein the core fibers might slip readily at higher levels of stress, thus causing a higher drop in tenacity and extension.

Table 5. Effect of Gauge Length on Tensile Properties of Rotor Spun and DREF-3 Friction Spun Yarns

Rotor Spun Yarns									
10 Ne Cotton					**20 Ne Cotton**				
L	150	250	350	500	***L***	150	250	350	500
t	0.1	0.2	0.3	0.4	***t***	0.1	0.2	0.3	0.4
F	982	972	951	947	***F***	464	468	465	463
T	16.6	16.5	16.1	16.0	***T***	15.9	15.7	15.7	15.6
E	6.8	6.7	6.5	6.3	***E***	7.6	7.4	7.1	7.0
W	495	795	1062	1141	***W***	254	414	569	808
M_1	1.6	2.3	2.4	2.5	M_1	1.2	1.5	2.1	2.6
M_3	1.7	3.0	3.0	3.1	M_3	1.8	1.9	2.5	2.9
DREF-3 Friction Spun Yarns									
6 Ne Cotton					**10 Ne Polyester**				
L	150	250	350	500	***L***	150	250	350	500
t	0.1	0.1	0.1	0.2	***t***	0.2	0.3	0.4	0.6
F	1396	1390	1315	1288	***F***	1698	1683	1489	1452
T	14.2	14.1	13.4	13.1	***T***	28.8	28.5	25.2	24.6[a]
E	4.1	3.7	3.4	3.2	***E***	12.1	11.2	10.1	9.8
W	422	684	866	1159	***W***	1405	2161	2531	3430
M_1	1.5	2.6	3.8	4.6	M_1	1.1	1.7	2.6	3.0
M_3	1.8	4.9	5.7	6.8	M_3	0.9	3.7	4.8	5.1

[a] reduction in tenacity is significant at 95% confidence level

When the tensile characteristics of 20 Ne cotton ring spun, rotor spun and air-jet spun yarns are compared, it is observed that at all levels of gauge length, the ring spun yarn exhibits higher strength and modulus followed by rotor spun yarn and air-jet spun yarn. The rotor spun yarn has highest breaking extension and breaking work. The ring spun yarn shows lowest breaking extension while the air-jet spun yarn lies in between the rotor spun and ring spun yarns in this respect. These differences in tensile characteristics of above yarns are ascribed to marked differences amongst their structural features. Finally, by plotting the values of breaking force, tenacity, breaking extension, breaking work and modulus of all yarns against the values of gauge length, it is deduced that breaking force, tenacity, breaking extension, and breaking work are power law functions of gauge length while the modulus is preferably a logarithmic function of gauge length. The regression equations and coefficients of determination for all the yarns are given in Table 6 and Figure 9.

Table 6. Regression Equations and Coefficients of Determination for Yarn Tenacity as a function of Gauge Length

Yarn Type	*Count*	*Regression Equation*	R^2
Ring spun	20 Ne Cotton	$T = 13.389L^{-0.0902}$	0.99
	30 Ne Cotton	$T= 23.128L^{-0.0487}$	0.81
	20 Ne Polyester	$T = 54.34L^{0.0582}$	0.96
	30 Ne Polyester	$T = 54.141L^{-0.063}$	0.99
Air-jet spun	20 Ne Cotton	$T = 13.389L^{-0.0902}$	0.99
	30 Ne Cotton	$T = 13.92L^{-0.0909}$	0.89
	20 Ne Polyester	$T= 48.647L^{0.1114}$	0.91
	30 Ne Polyester	$T = 36.203L^{-0.0653}$	0.93
Rotor spun	10 Ne Cotton	$T = 19.729L^{-0.0337}$	0.93
	20 Ne Cotton	$T = 16.53L^{-0.0083}$	0.99
DREF-3 friction spun	6 Ne Cotton	$T = 20.7L^{-0.0733}$	0.86
	10 Ne Polyester	$T = 61L^{-0.1462}$	0.84

The above mentioned regression equation and coefficients of determination for yarn Tenacity as a function of Gauge Length could clearly explain the relationship among tenacity and gauge length where T: Tenacity of yarn (cN/tex); L: Gauge Length (mm).

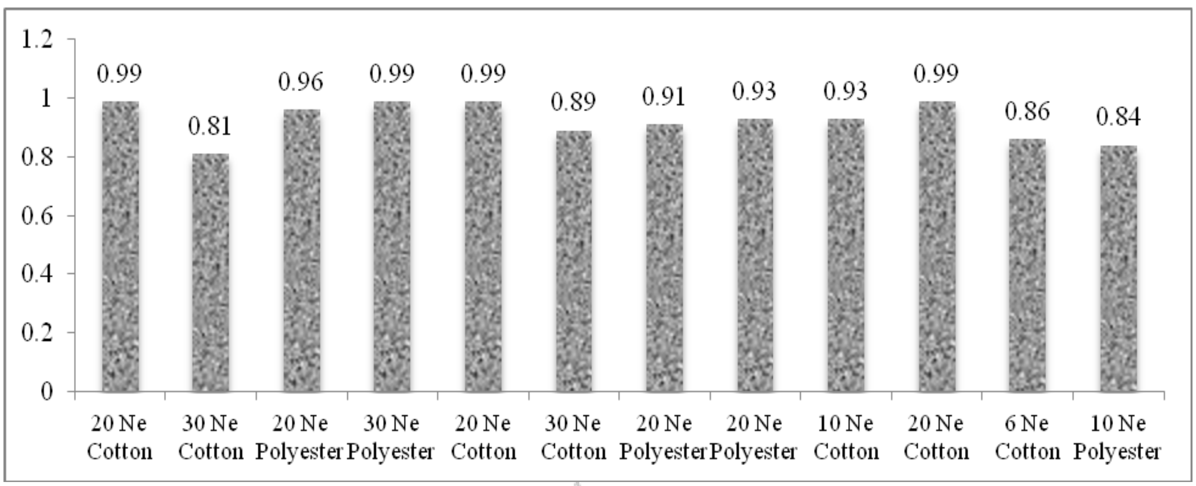

Figure 9. Coefficients of Determination for Yarn Tenacity as a function of Gauge Length

Further, an attempt has been made to understand the sigmoidal transfer function of the real values of independent and dependent variable is studied and it helps the researcher to understand how the load is distributed in the specified specimen length. The following sigmoidal equation is proposed to understand the impact of gauge length over yarn tenacity .

$$y = \frac{a}{1+e^{-\left(\frac{x-x_0}{b}\right)}}$$

Where a, b is a coefficient, x is specimen length and y is the tenacity of the spun yarns.

The regression analysis is also performed using this above mentioned equation. It was determined through the Coefficient of the Determination. The following table 7 would detail the regression analysis of sigmoidal transfer function for yarn tenacity and gauge length.

Table 7. Coefficients of Determination for Yarn Tenacity as a function of Gauge Length using Sigmoidal Transfer function

Yarn Type	*Count*	R^2
Ring spun	20 Ne Cotton	0.80
	30 Ne Cotton	0.82
	20 Ne Polyester	0.96
	30 Ne Polyester	0.90
Air-jet spun	20 Ne Cotton	0.97
	30 Ne Cotton	0.98
	20 Ne Polyester	0.95
	30 Ne Polyester	0.98
Rotor spun	10 Ne Cotton	0.90
	20 Ne Cotton	0.82
DREF-3 friction spun	6 Ne Cotton	0.92
	10 Ne Polyester	0.86

4. Conclusions

The increase in gauge length of yarn continually decreases its tenacity, breaking extension but increases the breaking time, breaking work and modulus at 1% extension and 3% extension. The air-jet spun yarns show higher drop (10%) in tenacity while the rotor spun yarns record minimum reduction (3%) in tenacity. The ring spun yarns exhibit highest modulus followed by rotor spun and air-jet spun yarns. The modulus is relatively higher for finer yarns as compared to that for coarser yarns. The yarn tenacity, breaking extension, and breaking work are power law functions of gauge length while the modulus is preferably a logarithmic function of gauge length. The increase in tenacity ranges from 9.5-34%, 14-22%, 8.5-20%, 15-36% for ring spun, rotor spun, air-jet spun and DREF-3 friction spun yarns respectively. The percentage increase in tenacity is highest in case of 20 Ne cotton ring spun yarn followed by the corresponding rotor spun and air-jet spun yarns. The findings of the present work will be of great use to the spinners and quality control personnel to select suitable gauge lengths for different types of yarns to depict high tenacity, extension and breaking work depending upon the application. This study also helps to understand the performance of yarns, which are subjected to various strain rates during post-spinning, weaving and knitting operations.

5. References

1. Midgeley E., and Pierce F.T., Tensile Tests for Cotton Yarns, the Rate of loading, Journal of Textile Institute. 17, T330-T341 (1926).
2. Meredith R., The Effect of Rate of Extension on the strength and Extension of Cotton Yarn, Journal of Textile Institute 41, T199-T224 (1950).
3. Kaushik R.C.D., Salhotra K.R., and Tyagi G.K., Influence of Extension Rate and Specimen Length on Tenacity and Breaking Extension of Acrylic/Viscose Rayon Rotor Spun Yarns, Textile Research Journal 59 (2), 97-100 (1989).
4. Hearle J.W.S., and Thakur V.M., The Breakage of Twisted Yarns, Journal of Textile Institute 52, T149-T163 (1961).
5. Realff M.L., Seo M., Boyce M.C., Schwartz P., and Backer S., Mechanical Properties of Fabrics Woven from Yarns Produced by Different Spinning Technologies: Yarn Failure as a Function of Gauge Length, Textile Research Journal 61 (9), 517-530 (1991).
6. Hearle J W S, Grosberg P and Backer S, Structural Mechanics of Fibers, Yarns,

and Fabrics Vol. 1, New York, Wiley-Interscience (1969).

7. Oxenham W., Zhu R.Y., Leaf G.A.V., observations on the tensile properties of Friction spun yarns, Journal of Textile Institute, 83,621-623, (1992).
8. Peirce F.T., Tensile Tests for cotton yarns, part V: The Weak Link Theorems on the strength of Long and composite specimens, Journal of Textile Institute, 17, T355-T368 (1926).
9. Grant J.N, Morlier O.E.,Relation of Specific Strength of Cotton Fibre to Fibre Length and Testing Method, Textile Research journal, 18, 1948,PP 481-487.
10. Pillay K.P.R, Fibre Strength at finite Gauge Length of raw material and Mercerised cotton: A study of Bundles in "Proc. Seventh Tech. Conference ATIRA,BTRA and SITRA," sec. A, PP. 15-30(1965).
11. Kapadia D.F, Single-Thread Strength Testing of yarns at various lengths of Test specimens. Journal of Textile Institute, 26, T142-T266 (1935).
12. Hattenschwiler P., Pfeiffer R., Schaufelberger J., The Tensile Strength of Yarns-Latest Reports from Mill Practice. Milliand Textilberichte [Eng.Ed.], 21-23, 1984.
13. Hussain G.F.S., Nachane R.P., Krishna Iyer.K.R., and Srinathan B., Weak-Link Effect on Tensile Properties of Cotton Yarns, Textile Research Journal, No.2, 1990, PP 69-77.
14. Maria Cybulska and Bhuvenesh c. Goswami, Tensile Behavior of Staple Yarns, Journal of Textile Institute, 2001,92 part 3 ©Textile institute.
15. Radhakrishnaiah P.and Gan Huang, Georgia Institute of Technology, The Tensile and Rupture Behavior Of Spun Yarns Representing Different Spinning Systems, School of Textile & Fibre Engineering, Atlanta, GA 30332-0295 (1997).
16. Horrocks, A.R. and Anand, S.C. (*eds*), Heat and Flame Protection, Handbook of Technical Textiles, Woodhead Publishing Limited, pp.224-228.
17. Rengasamy, R.S.; Ishtiaque, S.M.; Ghosh, A.; Prediction of Spun Yarn Strength at Different Gauge Lengths using Weibull Distribution; Indian Journal of Fiber &Textile Research, 30, 283-289(2005).
18. Salhotra, K.R.; Balasubramanian, P.; Estimation of Minimum Fiber Length Contributing to Tenacity of Rotor Spun Yarns; Indian Journal of Fiber & Textile Research Journal, 11, 11-14,(1986).
19. Tallant, J.D.; Fiori, L.A.; Little, H.W.; Castillan, A.V.; Investigation of the Minimum Length of Cotton Fiber Effective in Single Yarn Tenacity; Textile Research Journal 1963, 33, 1005-1012.
20. Gulati, A.N.; Turner, A.J.; The Foundations of Yarn-strength and Yarn-extension, Part IV: The Influence of Yarn- twist on the Diameters of Cotton Yarns and on the Proportions of Fiber Slippage and Fiber Rupture in Yarn Breakage; Journal of Textile Institute, 21, T561-T582,(1930).
21. Hearle, J.W.S.; Sakai, T.; On the Extended Theory of Mechanics of Twisted Yarns; Journal of Textile Machinery Society of Japan, 25, 68-72,(1979).
22. L. J. Knox and J. C. Whitwell, Textile Res. J. 41, 510,(1971).
23. S. Watson and R. L. Smith, J. Mater. Sci. 20, 3260,(1985).
24. D. Colman, J. Mech. Phys. Solids 7, PP 60 to70,(1958).
25. Krause, H.W.; Soliman, H.A.; Theoretical Study on the Strength of Single Jet False Twist Spun Yarns; Textile Research Journal, 60, 309-318(1990).
26. Tyagi, G.K.; Goyal, A.; Salhotra, K.R.; Sheath-slippage Resistance and Other Properties of Polyester-Viscose MJS Core-spun Yarns; Indian Journal of Fiber & Textile Research, 28,170-176,(2003).
27. Chasmawala, R.J.; Hansen, S.M.; Jayaraman, S.; Structure and Properties of Air-jet Spun Yarns; Textile Research Journal, 60, 61-69,(1990).

28. Chasmawala, R.J.; Structures and Properties of Air-jet Spun Yarns; Masters Thesis, School of Textile Engineering, Georgia Institute of Technology, Atlanta, Georgia,(1988).
29. Lawrence, C.A.; Baqui, M.A.; Effect of Machine Variables on the Structure and Properties of Air-jet Fasciated Yarns; Textile Research Journal, 61, 123-130(1991).
30. Rajamanickam, R.; Hansen, S.M.; Jayaraman, S.A.; A Model for the Tensile Fracture Behavior of Air-jet Spun Yarns; Textile Research Journal, 68, 655-662(1998).