Tensile Behaviour of Spun Yarns under Static State

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ABSTRACT

The tensile properties of spun yarn are accepted as one of the most important parameters for assessment of yarn quality. The tensile properties decide the performance of post spinning operations; warping, weaving and knitting and the properties of the final textile structure; hence its accurate technical evaluation carries much importance in industrial applications. There is no doubt that all the studies related to tensile behaviour of spun yarns are invaluable both in theory and practice. In this article, a critical review of the theoretical and practical aspect of static tensile behaviour of staple yarns has been discussed.

Keywords: interaction effect, spun yarn, tensile properties, yarn strength.

INTRODUCTION

Standard measurement of yarn strength is executed on a gauge length of 500 mm. A clamped yarn breaks in its weakest place according to the so-called principle of the weakest link and this strength value is assigned to the whole length. As the test sample is gripped at the two ends and maintains that static state during the testing process, the evaluated tensile properties are often treated as static tensile properties and the strength measured by single thread tensile test method is referred to as static yarn strength[1]. Among the measurable tensile properties of spun yarn, considerable attention has been paid on the evaluation of tensile strength and breaking extension, as these properties of the spun yarns influence the efficiency of weaving and knitting machines and the quality of the fabric produced from them. However, the tensile strength and breaking extension of the yarns are not the unique functions, but they depend on the rate of extension and gauge length. From the practical point of view, it is desirable that the effect of operating speed and gauge length on the tensile properties of yarn should be known, so that the results obtained from the instruments running at different speeds and gauge lengths can be correlated and compared.

Morton, and Hearle have shown, in general that if the stress-strain curves are nonlinear, there will also be a difference between the constant rate of loading (CRL) and constant rate of extension (CRE) tests as a result of the different proportions of time spent on different parts of the stress-strain curves. Thus, in studying time effects of yarn breaks, it is important to indicate if the tester uses the CRL or CRE method[36]. According to Midgley & Pierce, rapid test produces a higher breaking load than a slow test and they have also established relationship between the strength values obtained and the breaking time[2]. Meredith tested yarns over a million-fold range of rates of extension and found that the relationship between yarn tenacity and logarithm of rate of extension is approximately linear. For breaking times ranging between a second and an hour, the proposed formula is expressed in Eq. (1):

$$F_1 - F_2 = -KF_1 \log_{10}\left(\frac{t_2}{t_1}\right) \qquad (1)$$

Where, F_1 is the breaking load in time t_1; F_2, the breaking load in time t_2 and K, the strength-time coefficient[3]. Ghosh, Ishtiaque, and Rengasamy found that yarn tenacity increases continuously with the extension rate for all spinning systems. The increase in the tenacity with the increase in the extension rate is due to the consequent increase in the proportion of fiber breakage[4]. Chattopadhyay showed that, with an increase in the strain rate, the tenacity initially increased up to 10 mm/s for both ring and air-jet spun yarns and then followed by a sharp reduction[5]. Oxenham, Zhu, and Leaf compared the effect of gauge length on the strength of ring spun and open end friction spun yarns and found that the strength of ring spun yarns shows a sharp drop, as the gauge length increases from 1mm to 40 mm (which was approximately the fiber length). The strength of friction spun yarns also drops sharply as gauge length increases from 1mm to 20 mm (Which was almost equal to the fiber extent in the yarn). For gauge length greater than 40 mm, the strength of ring spun yarns appear fairly constant, whereas the strength of friction spun yarns reduced continuously with increase in the gauge length, reflecting the discontinuities in the yarn formation zone in friction spinning[6]. Hussain, Nachane, and Krishna found a significant difference in gauge length effect on the strength of ring and rotor spun yarns. The length effect, which they expressed as a ratio between the tenacity of a given gauge and that of a 1cm length, showed no difference between ring versus rotor spun yarns at relatively short lengths. But the difference was statistically significant at long lengths[7]. Realff et al (1991) proposed that the mechanism of failure might also change due to a decrease in the test length. They observed different range of failure zone size for ring spun and air-jet spun yarns for different gauge lengths *(Table I)*. According to their observation, as compared to the air-jet spun yarns, ring spun yarns yield higher strength, many broken fibers and a small failure zone size at longer gauge lengths. But, at gauge lengths well below the fiber staple length, 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 the core fibers of air-jet yarn. While comparing the influence of gauge length on yarn failure for ring spun and open-end spun yarn, they found that the ring spun yarns fail by fiber breakage at both long and short gauge lengths. But the open-end yarns show a change in breakage mechanism from a fiber slippage dominant failure at long gauge length (127 mm) to a fiber breakage dominant failure at short gauge lengths (12.7 mm and < 2 mm)[35].

TABLE I. Range of failure zone size for different gauge lengths[35]

Yarn system	Gauge length, mm	Failure zone size*, mm
Ring spun	127	<3
Ring spun	76.2	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

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[8].

According to Rengasamy, Ishtiaque, and Ghosh, the tensile strength of a spun yarn depends on its structure, gauge length and extension rate employed during measurement[9]. Salhotra, and Balasubramanian 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[10]. Tallant, Fiori, Little, and Castillan 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 Eq. (2):

$$Y = a \times f(l, x) \times S + b \qquad (2)$$

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[11]. Gulati, and Turner observed that the fibers below 0.5 inch length don't contribute to yarn strength[12].

TENSILE BEHAVIOUR OF PURE STAPLE YARNS

Majumdar tested 100% cotton yarns on Uster Tensorapid-3 & Uster Tensojet for determining its breaking load & extension and work of rupture. Although the actual values of tenacity is not equal for Tensorapid-3 and Tensojet, but there exists very good correlation between the two values (r = 0.99). The regression equation used to calculate the correlation is as follows Eq. (3):

$$T_j = 1.06 T_R + 1.80 \qquad (3)$$

Where, T_J and T_R are the corresponding tenacity reported by Tensojet and Tensorapid-3 respectively. The average yarn breaking times for Tensorapid-3 and Tensojet are 0.355^{s} and 0.004^{s} respectively, which may have allowed more relaxation of stress in the case of Tensorapid-3, causing lower yarn tenacity. He also found a very good correlation of yarn breaking extension and work of rupture measured by Tensorapid-3 and Tensojet. The coefficient of correlation for yarn breaking extension and work of rupture were (r = 0.95) and (r = 0.99) respectively. The regression equations explaining their relationship are as follows Eq. (4) & Eq. (5):

$$E_J = 0.86 E_R + 0.99 \quad (4)$$

$$W_J = 1.04 W_R - 2.25 \quad (5)$$

Where, E_J & E_R are the breaking extensions and W_J & W_R are the work of rupture measured by Tensojet and Tensorapid-3 respectively. The values of work of rupture measured by Tensorapid-3 and Tensojet are closer to each other, because the lower yarn breaking force obtained from Tensorapid-3 is compensated by the corresponding higher values of breaking extension. His experiment also concluded that the effect of rate of extension on breaking extension is smaller than its effect on strength. The average values of strength- time coefficients of cotton yarns lies between -0.069 to -0.076 and extension-time coefficient lies between -0.07 to -0.063. His results are supported by Meredith's similar experiments on viscose rayon yarns[13, 3].

Luca, and Thibodeuax were the pioneers to show analytically how low or high speed testing affects yarn tenacity. They used USDA Acala cotton as a test sample and the tested speeds were ranging from 100 mm/min to 5000 mm/min. They found that, as the rate of extension increased, yarn tenacity increased linearly with the logarithm of the rate of extension from 0.1 m/min to 1m/min. At 2 m/min, yarn tenacity increased slightly, reached a maximum and then at 5 m/min, it decreased or remained constant. However, there are several limitations in their research. They only tested speeds ranging from 0.1 m/min to 5 m/min, which are relatively low speeds compared to the testing speeds employed for USTER Tensojet and used 100% cotton yarn, which has larger deviation than the blended yarns or man-made yarns[14]. The similar results were claimed by Kaushik *et al.* (1989) and Salhotra *et al.* (1985). Kaushik, Salhotra, and Tyagi studied the influence of extension rate and test length on the tenacity and breaking extension of acrylic and viscose rotor spun yarns and their blends. They used extension range of 50 mm/min to 1000 mm/min and test length of 100 mm and 500 mm. The open end yarns showed maximum yarn strength at an extension rate of 200 mm/min (100 mm test length). The strength remained the same or drops slightly, when the extension rate is increased to 1000 mm/min[15]. This finding is in agreement with the results obtained by Salhotra and Balasubramanian on ring and rotor spun cotton yarns. According to Salhotra, and Balasubramanian, the increase in tenacity with an increase in extension rates can be accounted for two factors, the percentage of ruptured fibers and the realignment of fibers during tensile loading. When a yarn specimen is strained during tensile loading, the interfiber pressure tends to increase, which leads to build up of frictional resistance owing to an increase in transverse forces. As the rate of extension increases, the percentage of ruptured fibers increases, resulting in a higher breaking strength (i.e. greater numbers of fibers are contributing to the breaking load). At slow rate of extension, these authors attributed the lower tenacity to the non-catastrophic nature of the yarn break (i.e. dominance of fiber slippage). On the other hand, yarn strength appears to decrease slightly, when tested it at very high rates of extension. This trend was due to the low contribution of individual fibers, owing to an insufficient time for realignment of fibers. This loss in yarn strength may more than offset any increase caused by a higher percentage of ruptured fibers. The time dependence of this mechanism is further strengthened, when one observes that the maximum tenacity for the 500 mm test length was measured at the 1000 mm/min extension rate. This value was either equal to or slightly higher than the tenacity value observed at 500 mm/min. The breaking extension is low in yarns tested at the longer lengths, which was attributed to the increased probability of weak spots in a longer specimen, as indicated by the weak link theory. Breaking extension increases with increasing rate of extension and tends to reach the elongation of the fiber bundle. Increased breaking extension at a higher rate of extension can be ascribed to an increase in the proportion of ruptured fibers[16].

Oxeham, Kurz, and Lee, investigated how the yarns react differently according to the different testing machines; the preliminary trials are done by testing cotton, acrylic, and polyester/cotton spun yarns. USTER Tensojet showed consistently higher value of yarn tenacity for 100% cotton yarn than USTER Tensorapid, however, in the case of 50/50 polyester/cotton yarn, the tenacity value did not show the same trend as that of 100% cotton yarn. The tenacity value from USTER Tensojet and USTER Tensorapid has revealed no significant difference in case of 50/50 polyester/cotton spun yarns. It was found that the elongation values from the USTER Tensorapid are 1% to 1.5 % higher than those from the USTER Tensojet and that trend was consistent across all the samples tested in their research. It was possible to obtain a stronger correlation of the elongation value than that of the tenacity between the two testing machines. Their research clearly demonstrated that the force depends on the testing speed and that the amount of force is proportion to the logarithm of the speed[17]. These findings are contradictory to the observations of Luca and Thibodeaux, Kaushik *et al.* and Salhotra *et al.* [14-16]. The formers found that, yarn tenacity increases up to a certain testing speed. However, in this research, the yarn tenacity shows a continuous increase with the logarithm of the testing speed. Aggarwal developed a mathematical model to estimate the breaking extension of ring spun yarns from the fiber characteristics. The model was of the form Eq. (6):

$$E_y = E_f\,(1 + BTM^2) \tag{6}$$

Where, E_y is the yarn extension at break (%); E_f, fiber bundle elongation at 1/8 inch gauge length (%); *B*, fiber obliquity parameter and *TM*, twist multiplier. The accuracy of estimation of the model was very high and the model was applicable to both carded and combed cotton of particular type[18]. Bogdan suggested that for cotton yarns, the value of *B* is 0.014[19]. Aggarwal modified his previous model to apply his model for mixtures of cottons Eq. (7).

$$E_y = 0.90\,E_f\,(1 + 0.014TM^2) \times \left(1 - \frac{0.023W}{\sqrt{N}}\right) \tag{7}$$

Where, *W*= toughness index, *N* = number of fibers in yarn cross section.

Krause, and Soliman analysed the tensile behaviour 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[20]. 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[21]. 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[22]. Chasmawala claimed that the air-jet spun yarn displays two distinct failure modes – catastrophic and non catastrophic[23]. 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[24]. 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[25]. 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.

TENSILE BEHAVIOUR OF BLENDED STAPLE YARNS

The first theoretical work published concerning the mechanics of blended yarn was by Hamburger. He was concerned with the fact that the blended yarns have breaking strengths lower than those expected from the summation of the proportioned constituent fiber component strengths. Considering the two components *A* and *B* (with *A* representing viscose and *B* representing polyester), to have independent load elongation curves and to be under tension in parallel, he predicted the behaviour of the blended yarn from the tensile behaviour of its components. The tensile behaviour of the viscose and polyester fiber used in his research is shown in *Figure 1*. For a blended yarn, the tensile resistance will correspond to the blend-proportion weighed average of the tensile resistance of the two components up to the limit of strain, at which the less extensible component *A* failed. At strains beyond this point, yarn resistance is fully corresponds to the resistance of the unbroken component. Thus a blended yarn was expected to have two breaking points- one for its less extensible component and the other for its more extensible one. The breaking strength of the blend was reported as the higher of these two values. The first rupture level would be maximum for a yarn made of 100 % of fiber *A*, and its minimum would occur in a yarn containing no portion of fiber *A*. The first rupture point would never fall to zero in the absence of component *A*. Similarly, the second rupture level will be maximum for a yarn containing 100% of fiber *B* and would be minimum for yarns containing less or no portion of fiber *B*. The solid lines of *Figure 2* reflect the generally reported variations of breaking strength with blend levels. In general the first and second ruptures are as given below Eq. (8) and Eq. (9):

$$P_1 = \frac{bD}{100}(aS_A + bS_B) \qquad (8)$$

$$P_2 = \frac{bD}{100}S_B \qquad (9)$$

Where, P_1 = first rupture, P_2 = second rupture, D = total yarn denier, S_A= breaking tenacity of fiber *A*, S_B = breaking tenacity of fiber *B*, and *a* & *b* are weighted ratios of fiber *A* and *B* in the yarn[26].

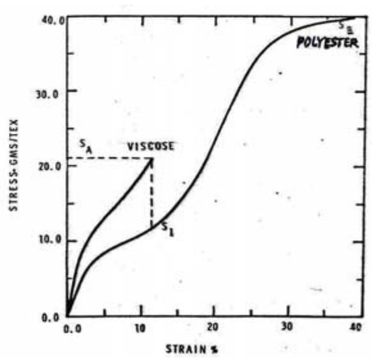

FIGURE 1. Stress-strain curves of viscose and polyester fibers[26]

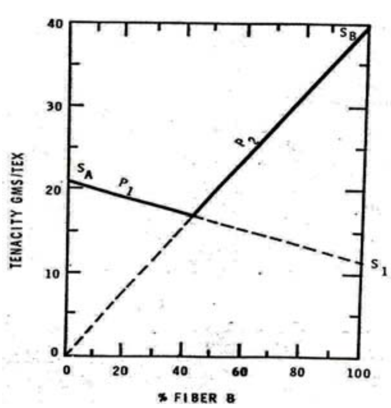

FIGURE 2. Theoretical effect of blend proportion on yarn strength[26]

Kemp and Owen investigated the stress-strain characteristics and cotton fiber breakage during tensile failure of a series of nylon/cotton blended yarns. At strains above the breaking strain of all cotton, the stress–strain curve of the 60/40 and 80/20 nylon/cotton blended yarns did not follow the predictions of Hamburger, nor did the plot of yarn tenacity versus blend ratio produce a linear relationship as predicted by hamburger. They developed a similar equation in the form Eq. (10):

$$\sigma y = \left(\frac{y}{100}\right)\sigma_n + \left(1 - \frac{y}{100}\right)\sigma_c \qquad (10)$$

Where, σ_n , σ_c and σy are the stresses in the nylon, cotton, and nylon/cotton blended yarns containing *y* percent of nylon. The predicted values fit the experimental values up to 7.5% strain level. The cotton fibers contribute to an amount of σ_{cf} to the blended yarn stress over the rupture strain of the all cotton yarn, so the cotton contribution σ_{cf} estimated by modifying the above equation to the form Eq. (11):

$$\sigma_{cf} = \left[y - \left(\frac{y}{100}\right)\sigma_n\right]\left(1 - \frac{y}{100}\right) \qquad (11)$$

The cotton fibers in the blended yarns sustain a high stress at strains above which all cotton yarns break. This stress, in fact rises considerably above the breaking stress of all cotton yarns. They have found that at high strains, the cotton fibers often broke more than once[27]**.** Owen presented a scheme for predicting the tensile properties of blends. The scheme requires; the single-fiber stress-strain curves for each component & the stress-strain curves for yarns spun from 100% of each component of lower breaking strain. The methodology used was primarily graphic, but it produced predictions that agreed reasonably well with the experimental results[28]**.**

Machida carried out the most extensive experimental investigation on the mechanics of rupture of blended yarns. His investigation was concerned with the transfer of stresses from low elongation fiber components to the high elongation fiber component. He produced gross-model yarns consisting of ninety-one component yarns twisted, without migration, in five helical layers about a central core yarn. In many models the occurrence of a break in one cotton element was accompanied by breaks in adjacent cotton element across a narrow zone of rupture. This occurrence was dependent on the direct contact between elements and sufficient lateral pressure to transmit the forces on the first element to the other elements. If the cotton elements were sufficiently congregated, propagation of element rupture across a narrow zone caused failure of the entire model at strains lower than those sustained by uniformly blended models. His observation also claims that at low twist level, the low elongation components "dropped out" (slipped) after they started to rupture. As a result, at strains above the breaking strain of the low elongation component, the yarn properties became highly dependent on the properties of the high elongation component[29].

Shiekh studied the various properties like tenacity, elongation, initial modulus, dynamic modulus of polyester/viscose blended yarns by using different blend proportions. He compared the experimentally observed tenacity values with the values predicted from the mixture theory proposed by Hamburger. Here the agreement appears to be fairly good at the extreme points, but appreciable differences are present at the transition regions, as shown in *Figure 3*. The reason for this discrepancy was explained by Kemp and Owen and later by Machida, to be due to the multi-breakage of the low elongation components[27,29]. The effect of twist is to lower the percentage of high tenacity fiber (polyester) in the yarn, at which the blended yarn strength starts to increase. At this critical percentage the yarn has its lowest tenacity. The effect of blend levels on elongation follows the prediction of Hamburger at high twist levels. At low twist level, however, the elongation at break is independent of the blend level, where the yarn elongation is mainly due to the fiber slippage rather than fiber extension. The modulus of blended yarn has been thought to follow the mixture theory as given below Eq. (12):

$$E_b = \frac{aE_A + bE_B}{a+b} \quad (12)$$

Where, E_b is the modulus of the blended yarn; $E_{A,}$ modulus of yarn made of 100% fiber *A*; $E_{B,}$ modulus of yarn made of 100% fiber *B*; *a*, fraction of fiber *A* in the blend; b fraction of fiber *B* in the blend. The experimental result showed an abnormal trend, where the modulus has a consistent maximum value at the 10% level of polyester (low modulus fiber). This could be due to a sudden increase in the drafting forces at this level, but the relative measurements of the drafting forces of the ten blends were made on a cohesion tester proved that the drafting forces increased with increasing the percentage of polyester component. The increase of modulus at 10% polyester probably could be due to fiber clustering in the yarn cross-section[30].

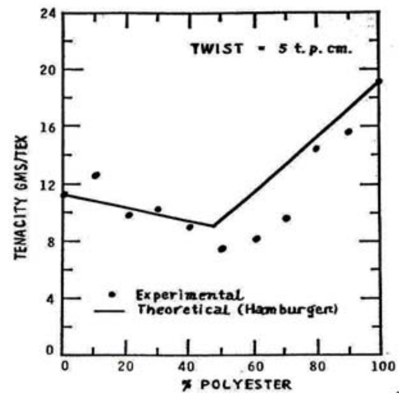

FIGURE 3. Effect of blend level on yarn tenacity; comparison of theoretical and experimental results[30]

Pan, and Chen explained that, in a blended system or mixture, the overall properties of the system are related to the proportion and corresponding properties of each component. If the mixture is not uniform, the distribution or local concentration of each constituent plays an important role in determining some aspects of the system's behaviour. The remaining factor has to with the interactions of the components themselves, which complicate an otherwise much simpler relationship between the blend system and its component properties[31]. Many properties of a material mixed or blended from two or more different components can be calculated using the simple rule of mixture (ROM); such properties include the elastic moduli, electrical and thermal conductivities, dialectical constant and thermal expansion coefficients. However, there are other properties of a material, like its overall strength or elastic lifetime, which are influenced by the interaction of the different components in the system and therefore, cannot be accurately predicted by the simple ROM. According to Nielsen, if we have a mixture of two different constituents, type 1 and 2 in general, the system property X_s can be calculated by a general ROM:

$$\begin{aligned} X_S &= X_1W_1 + X_2W_2 + IW_1W_2 \\ &= X_1W_1 + X_2(1-W_1) + IW_1(1-W_1) \end{aligned} \quad (13)$$

Where, X_i and W_i are the corresponding property and the volume fraction of the constituents i =1 & 2, and I is a coefficient representing the intensity of interactions of the two constituents[32]. There are three cases based on the value of I: for I >0, the interactions of the constituents 1 and 2 will enhance the overall system property and lead to a synergetic effect, I<0 represents a case where the interactions actually reduce system property and I=0 means that the interaction does not exist, so that the Eq. (13) degenerates in to the simple ROM. The expression for I can be expressed as Eq. (14):

$$I = 4X_{50\%} - 2(X_1 + X_2) = 4[X_{50\%} - 0.5(X_1 + X_2)] = 4[X_{50\%} - \langle x \rangle] = 4\Delta X \quad (14)$$

Where, $X_{50\%}$ is the actual system property X_s, when the $W_1 = W_2 = 0.5$ and $\langle x \rangle = 0.5\ X_1 + 0.5\ X_2$ are the arithmetic mean of the property for homogeneous constituents composed of X_1 and X_2 alone. If there are no interactions of the two constituents, there will be $X_{50\%} = \langle x \rangle$, so that $\Delta X = 0$ and $I = 0$.

Marom, Fischer, Tuler, and Wagner explained that the alteration of the system's overall properties caused by the interaction of the different constituents can be specified by using the concept of hybrid effect. One definition of the hybrid effect is given as the deviation of behavior of hybrid structure from the ROM. A positive hybrid effect means the synergetic case, and the actual property is above the ROM prediction, where as a negative hybrid effect means the property is below the prediction. Therefore, numerically the value of ΔX can used to indicate the hybrid effect and can be written from Eq. (14) as:

$$\Delta X = X_{50\%} - \langle x \rangle = X_{50\%} - (0.5X_1 + 0.5X_2) \quad (15)$$

The Eq. (13) can be normalized to eliminate the effect of twist as follows Eq. (16):

$$X_{sn} = \frac{X_s}{X_2} = \frac{X_1}{X_2} W_1 + (1 - W_1) + \frac{I}{X_2} W_1 (1 - W_1) \quad (16)$$

The more efficient way of normalizing the Eq. (13) to eliminate the effect of twist to develop the relationship between relative tenacity and blend ratio is as follows Eq. (17):

$$X_{sn\%} = \frac{X_s}{X_{50\%}} = \frac{X_1}{X_{50\%}} W_1 + \frac{I}{X_{50\%}} (1 - W_1) + \frac{I}{X_{50\%}} (1 - W_1) \quad (17)$$

[$X_{50\%}$ include the effect of both twist and interactions], the model indicated good correlation with the practical observations. The nature and results of the interactions of different fiber types are determined by their properties, such as the tensile modulus. The increase in modulus ratio leads to increase in interaction effect[33].

Pan, and Postle derived a statistical model for prediction of blended yarn strength. He explained that the blended yarn strength σ_y is a statistical variable with a normal distribution function $H(y)$, which can be expressed as Eq. (18):

$$H(\sigma_y) = \frac{1}{\sqrt{2\pi\theta_y}} \exp[- \frac{(\sigma_y - \bar{\sigma}_y)}{2\theta_y^{\,2}} \quad (18)$$

Where, $\bar{\sigma}_y$ is the average strength of blended yarn and $\theta_y^{\,2}$ is the variance of yarn strength. The distribution parameters can be calculated, according to the statistical theory as follows Eq. (19) and Eq. (20).

$$\bar{\sigma}_y = \eta_q \left(V_1 + V_2 \frac{E_{f2}}{E_{f1}} \right) (l_{c1}\alpha_1\beta_1)^{\frac{-1}{\beta_1}} \exp\left(-\frac{1}{\beta_1} \right) \quad (19)$$

$$\theta_y^{\,2} = \eta_q^{\,2} \left[V_1 + V_2 \frac{E_{f2}}{E_{f1}} \right] (l_{c1}\alpha_1\beta_1)^{\frac{-2}{\beta_1}} \left[\exp\left(-\frac{1}{\beta_1} \right) \right] \times \left[1 - \exp\left(-\frac{1}{\beta_1} \right) \right] . (a_1 N)^{-1} \quad (20)$$

Where, η_q is called the orientation efficiency factor; V_1 & V_2, fiber volume fractions of type 1 & 2; E_{f1} and E_{f2} are the tensile modulus of type 1 & 2 fibers; l_{c1} is the fiber length; α_1 & β_1 are the scale & shape parameter of fibers respectively; a_1, N are the number proportion of fiber 1 and total number of fibers respectively. According to the hypothesis on estimating the maximum range of statistical distribution, based on this normality of the strength distribution, there is a 99% chance that the actual blended yarn strength will fall in to the range of $\bar{\sigma}_y \pm 3\theta_y$. He also quantified the strength hybrid effect by a new parameter ϑ_y, which predicts the deviation of the actual yarn strength from the strength predicted by the Rule of Mixture. This can be expressed as Eq. (21):

$$\vartheta_y = \left(\frac{l_{c1}}{l_f} \right)^{-\frac{1}{\beta_1}} \quad (21)$$

Where, l_{c1} is the critical fiber length and l_f is original fiber length[34].

CONCLUSION

The foregoing discussion gives an overview of the theoretical and experimental aspects of the static tensile behaviour of staple spun yarns that have been reported so far in the literature, since the interest of this topic made a beginning. The yarns representing different spinning technologies and made of pure & blended spun yarns have also been concerned in this article. The various material, spinning and testing parameters influencing the static tensile properties are summarized**.** Finally, an inference may be drawn that the discussions made in this article is useful for textile researchers as a tool for further research in the area of tensile properties of spun yarns.

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