Zhaopeng Xia,
*Jianyong Yu,
Longdi Cheng,
Lifang Liu,
**Weiming Wang

Key Lab of Textile Science & Technology, Ministry of Education, Donghua University,
Shanghai, 201620, P.R.China

[*]**Modern Textile Institute, Donghua University,**
Shanghai 200051, P. R. China

[**]**College of Chemistry, Chemical Engineering and Biotechnology, Donghua University,**
Shanghai, 201620, P.R.China

Scale Effect on Jute/Cotton Fibres and their Blended Yarns

Abstract
The tenacities of jute and cotton fibres as well as their blended yarns at different gauge lengths were investigated in this paper. Based on Weibull distribution, the tenacity of the fibres and their blended yarns at a testing gauge length from 5 mm to 500 mm was studied. The tenacity of jute and cotton fibres is more dependent on the gauge length than that of their blended yarns. The blended yarn tenacity with a high jute content is more sensitive to the gauge length than that of a yarn with a low jute content.

Key words: *jute fibre, blended yarn, Weibull distribution, tenacity, fragmentation process.*

Introduction

The strength of a material depends on its scale or testing length due to the increased probability of a larger specimen containing a flaw large enough to lead to failure [1]. Numerous studies dealing with the scale effect on the mechanical behaviour of textile fibres and fibrous structures have been published [2 - 9]. Some of them are related to the scale effect on the strength of spun yarns manufactured by different spinning technologies [3 - 7]. Using empirical equations, Hussain [3] and Regasamy [4] reported that the strength of ring, rotor, friction and air-jet spun yarns decreases as the gauge length increases. Realff [5], Regasamy [6], and Raghunathan [7] studied the effect of the gauge length on tensile properties with the employment of Weibull distribution. Yet, Pan studied a series of test samples of fibres and yarns and concluded that the strength of yarn has less dependence on its gauge length than that of fibres [8].

However, few research papers deal with the scale effect on the mechanical properties between fibres and their blended yarns. In this paper, the scale effect on the breaking tenacity of jute/cotton fibres and their blended yarns spun at different jute/cotton blended ratios is investigated using equations derived from a two parameter Weibull distribution model.

Weibull distribution

Recently, Weibull distribution has been used to describe the strength of fibre of a brittle nature, [9, 10] which can also be used for textile yarns [5 - 7]. Based on the weakest link theory, the distribution of material strength σ is given by

$$P = 1 - \exp[-L(\frac{\sigma}{\sigma_0})^m] \qquad (1)$$

where P is the failure probability of the material, m is the Weibull modulus, σ_0 is the characteristic strength, and L is the fibre length. From the Weibull distribution, the average value of σ can be obtained:

$$\overline{\sigma} = \sigma_0 (L)^{-\frac{1}{m}} \Gamma(1 + \frac{1}{m}) \qquad (2)$$

where Γ is the gamma function.

From Equation (2) the average value of σ_2 at a gauge length of L_2 can be calculated from σ_1 at a gauge length of L_1:

$$\overline{\sigma}_2 = \overline{\sigma}_1 (\frac{L_2}{L_1})^{-\frac{1}{m}} \qquad (3)$$

Rearranging the equation (1), we get the following equation:

$$\ln[-\ln(1-P)] = m\ln\sigma - m\ln\sigma_0 + \ln L \qquad (4)$$

Thus the Weibull modulus m and characteristic strength σ_0 can be obtained from raw data.

***Table 1.** Tensile properties of cotton and degummed jute fibres.*

Fibre	Gauge length, mm	Tenacity, cN/tex	Elongation at break, %
Degummed jute	10	29.64	3.66
Cotton	10	20.98	8.94

***Table 2.** Tensile properties of jute/cotton blended yarns.*

Blended ratio	Gauge length, mm	Tenacity, cN/tex	Elongation at break, %
J30/C70	250	13.49	7.21
	500	12.67	6.16
J50/C50	250	9.08	4.90
	500	8.04	2.76
J70/C30	250	4.74	2.70
	500	4.04	2.11

***Table 3.** Uster evenness of jute/cotton blended yarns.*

Blending ratio	Mass irregularity, %	Thin places (-50%)	Thick places (+50%)
J30/C70	22.89	171	635
J50/C50	29.33	1142	1163
J70/C30	37.07	2268	2052

***Table 4.** Weibull parameters of jute and cotton fibres at a 10 mm gauge length.*

Fibre	Gauge length, mm	Weibull modulus M	Characteristic tenacity σ_0, cN/tex
Degummed jute	10 mm	2.18	33.78
Cotton	10 mm	1.97	22.06

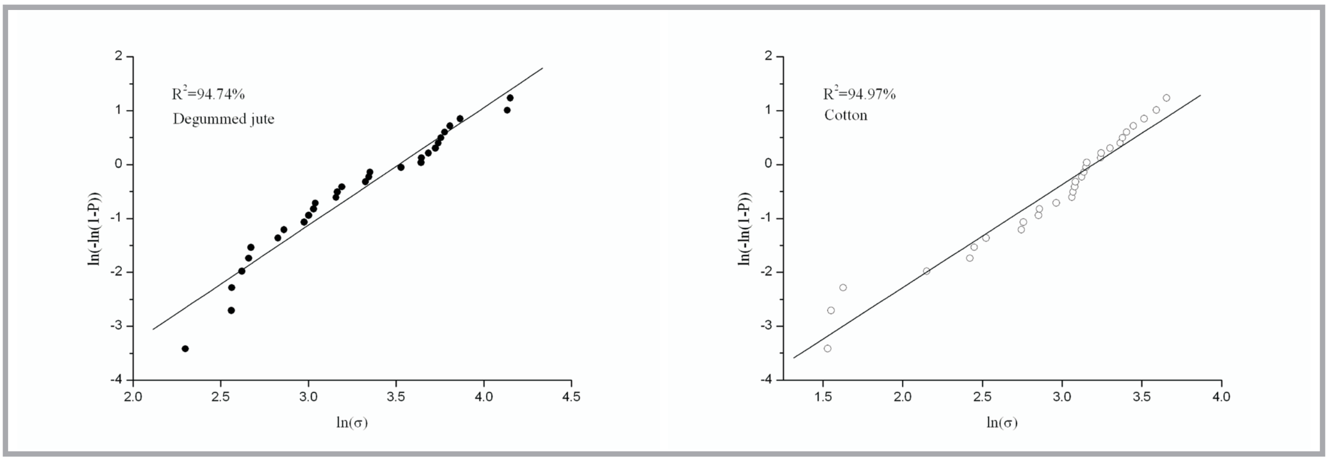

Figure 1. *Weibull plots of the tenacity at a gauge length of 10 mm for degummed jute and cotton fibres.*

Experimental

Spinning methods

Chemical degummed jute fibres were piling pretreated at 50 °C for 60 minutes with jute batching oil and then successively processed through two A186D Flat Card Frames (a breaker card followed by a finisher card). The jute fibres were carded into 100% jute slivers on a finisher card frame and then blended with carded cotton slivers during the first stage of the drawing process. The blended slivers were spun into rovings, which were spun into 27.8 tex blended yarns with 850 twists/m at a jute/cotton blending ratio of J30/C70, J50/C50, and J70/C30.

Testing methods

The tensile properties of the jute fibres were based on ASTM D 3822-07 at a gauge length of 10 mm. The tensile properties of blended yarns were evaluated on a YG061 Tensile Tester according to ASTM D2256 with a testing gauge length of 250mm and 500mm. We studied the mass irregularity of the jute/cotton blended yarns on an Uster Tester-II at a test speed of 400 m/min

Results and discussion

Fibre and yarn properties

Tensile properties of the fibres

The tensile properties of degummed jute and cotton fibres at a gauge length of 10 mm are provided in ***Table 1***. The degummed jute fibre has a higher tenacity and lower elongation at break than the cotton fibre.

Tensile properties of the yarns

The tensile properties of jute/cotton blended yarns are provided in ***Table 2***. Both the tenacity and elongation at break strain decrease with an increase in the amount of jute. The tenacity values at a gauge length of 500 mm are slightly lower than those at a gauge length of 250 mm, which shows the scale effect on the blended yarn tenacity.

Uster evenness of blended yarns

The Uster evenness of jute/cotton blended yarns is shown in ***Table 3***. The mass irregularity, thin places and thick places of blended yarns increase as we add jute to the blended yarns.

Weibull plots and Weibull parameters

Based on equation (4), Weibull plots for the tenacity at a gauge length of 10 mm for degummed jute and cotton fibres are shown in ***Figure 1***. The correlation coefficients are from 94.74% to 94.97%, respectively, which indicates a good degree of linearity.

The Weibull parameters of jute and cotton fibres at a 10 mm gauge length are shown in ***Table 4***. Based on equation (3) and a tenacity tested at 10 mm, the tenacity σ at different lengths can be obtained from the following equations:

$$\sigma_{jute} = 85.23L^{-0.46} \quad (5)$$

$$\sigma_{\mathrm{cotton}} = 67.52L^{-0.51} \quad (6)$$

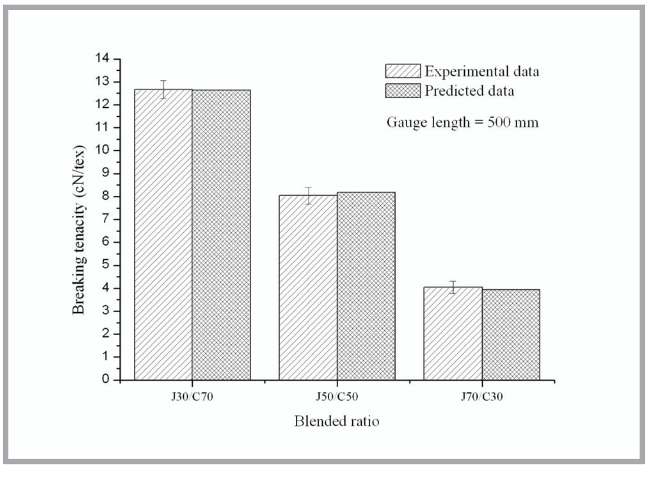

Figure 2. *Experimental and predicted values of the tenacity of blended yarns (experimental values are plotted at a 95% confidence interval, and predicted values are based on the tenacity at a 250 mm gauge length).*

Table 5. *Weibull parameters of jute/cotton blended yarns.*

Blending ratio	Gauge length, mm	Weibull modulus, m	Characteristic tenaity σ_0, cN/tex	Correlation coefficient R^2, %
J30/C70	250	10.54	14.13	97.29
	500	9.24	13.35	98.67
J50/C50	250	6.61	9.73	98.17
	500	6.22	8.64	96.76
J70/C30	250	3.69	5.25	96.76
	500	4.14	4.45	98.32

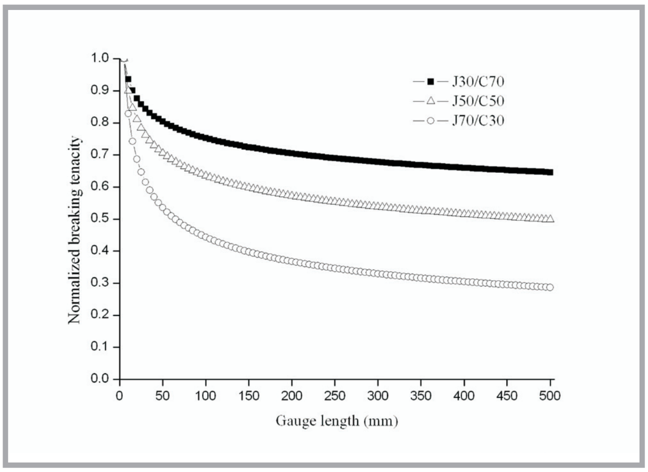

Figure 3. Normalized tenacities of blended yarns at a gauge length from 5 to 500 mm.

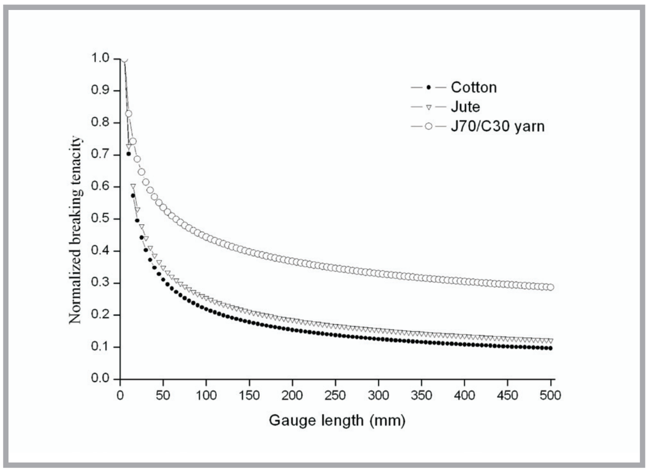

Figure 4. Normalized tenacities of fibres and blended yarns at a gauge length from 5 mm to 500 mm.

The Weibull parameters of jute/cotton blended yarns are provided in ***Table 5***, all of which show a high correlation coefficient (from 96.76% to 98.67%). Based on equation (3) and an experimental tenacity at 250 mm, the tenacity σ at different lengths can be obtained from the following equations:

$$\sigma_{J30/C70} = 22.78L^{-0.094} \quad (6)$$

$$\sigma_{J50/C50} = 20.93L^{-0.15} \quad (7)$$

$$\sigma_{J70/C30} = 19.11L^{-0.25} \quad (8)$$

The experimental and predicted values of the tenacity of the blended yarns are shown in ***Figure 2***. In all cases the predicted tenacity values have a good approximation to experimental data, which indicates that the model can predict the tenacity of blended yarns accurately.

Scale effect

With the purpose of facilitating researching on the scale effect on the tenacity of jute and cotton fibres and their blended yarns, the tenacities are normalised using each respective value at a gauge length of 5 mm. The normalised tenacities of blended yarns at a gauge length from 5 mm to 500 mm is provided in ***Figure 3***. The normalised breaking load for J70/C30 blended yarn decreases significantly as the gauge length increases. The breaking tenacity of blended yarn J50/C50 also declines with an increase in the gauge length but not as steeply as that of J70/C30 yarn. In the case of J30/C70 yarn, the tenacity drops slightly with an increase in the gauge length. The reason is that the number of thin places rises with an increase in jute content in the blended yarn (shown in ***Table 3***), which indicates that the blended yarn J70/C30 contains more weak points than that of other yarns. Therefore, the breaking tenacity of J70/C30 blended yarn is more sensitive to the gauge length.

The normalised tenacities of fibres and blended yarns at a gauge length from 5 mm to 500 mm is shown in ***Figure 4***. The normalised tenacity of cotton fibre decreases more sharply than that of jute fibre as the gauge length increases. The normalised tenacity of J70/C30 yarn declines with an increase in the gauge length but not more steeply than that of jute and cotton fibres. Therefore, we can conclude that the tenacities of jute and cotton fibres are more sensitive to the testing gauge length than their blended yarns. The reason is that no constrained materials such as neighbouring fibres or resins hold the fibre, therefore there is no fragmentation process taking place, in which jute and cotton fibres show the most significant scale effect [8]. However, in the case of yarn, the fibre in the yarn will break repeatedly with increasing tensile strength, and hence the fragmentation process takes place.

Conclusions

The scale effect between the tenacity and gauge length is different in a jute and cotton fibre structure and their blended yarn structure.

The tenacity of jute and cotton fibres is more sensitive to the gauge length than that of their blended yarns because the fragmentation process takes place during the yarn extension.

As the jute content increases, the tenacity of jute/cotton blended yarns becomes more and more sensitive to the gauge length.

References

1. *Sutherland, L. S., Shenoi, R. A., and Lewis, S. M.: Compos Sci Technol. Vol. 59, February 1999, pp. 209-220.*
2. *Pierce F. T. Tensile tests for cotton yarn. V.: Journal of the Textile Institute. Vol. 17, 1926, pp. T355-368.*
3. *Hussain, G. F. S., Nachane, R.P., Krishna, Iyer K.R., and Srinathan, B.: Textile Res. J. Vol. 60, February 1990, pp. 69-77.*
4. *Regasamy, R. S., Ishtiaque, S M., Ghosh, A., and Patnaik, A.: Processings, the 83rd Textile Institute World Conference. Textile Institute, Manchester, May 2004, pp. 411-414.*
5. *Realff, M. L., Seo, M., Boyce, M.C., and Backer, S.: Textile Res. J. Vol. 61, September 1991, pp. 517-530.*
6. *Regasamy, R. S., Ishtiaque, S. M., and Ghosh A.: Indian J Text Res. Vol. 30, September 2005, pp. 283-289.*
7. *Raghunathan, K., Subramaniam, V., and Srinivasamoorthy, V. R.: Indian J Text Res. Vol. 27, December 2002, pp. 358-361.*
8. *Pan N., Zhao S M., and Hua T.: Polymer Composites, Vol. 21, April 2000, pp. 187-195.*
9. *Pickering, K. L., Beckermann, G. W., Alam, S. N., and Foreman, N. J. Compos Part A. Vol. 38, February 2007, pp. 461-468.*
10. *Doan, T. T. L., Gao, S. L., and Mader, E.: Compos Sci Technol. Vol. 66, June 2006, pp. 952-963.*

Received 04.04.2008 Reviewed 12.09.2008