

A Simple Method of Measuring Flexural Rigidity of Jute Fibre

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Flexural rigidity of jute fibre bundle have been measured by designing a simple method following the principle of bending of a beam as a cantilever method with the help of a suitably developed apparatus. In the apparatus developed for the purpose, a fibre bundle was mounted on a horizontal platform in such a way that it overhangs, like a cantilever. A vertical load was put at the extreme of the free-end of the fibre bundle. The fibre bundle bends downwards both for its own weight and for the additional load applied at the free-end. The bending rigidity in terms of flexural rigidity was evaluated from the angular deflection of the fibre bundle using an appropriate mathematical expression formulated for this purpose from standard engineering formulæ considering necessary assumptions and conditions applicable for jute fibre bundle. Testing parameters have also been standardized. The efficacy of this method of measuring flexural rigidity of jute fibre was examined from correlation coefficient between flexural rigidity of (raw and differently treated) jute fibres and different structural and property parameters including packing fraction of the yarn samples spun from corresponding raw and differently treated jute fibres.

Keywords : Bending of beam; Bending modulus; Cantilever; Correlation coefficient; Flexural rigidity; Jute fibre; Packing fraction; Testing apparatus

NOTATION

E	:	elastic modulus
$E I$:	flexural rigidity
I	:	moment of inertia
L	:	length of beam or fibre bundle overhung, mm
P	:	transverse load at the extreme end of beam or fibre bundle, mg
TD3	:	Tosha Daise Jute of grade 3
w	:	weight of beam or fibre bundle, mg/mm
g	:	correlation coefficient
$\alpha, \alpha_1, \alpha_2$:	angular deflections, radian
s_1	:	vertical deflection
f	:	packing fraction

INTRODUCTION

The precise measurement of important properties of fibres are essential for the appropriate design of newer textiles, technical textiles and fibre reinforced composite material. Despite the remarkable achievement made in textile technology; the jute industry is still experience — preceding industry from technical viewpoint. Proper knowledge and data base of different fibre properties are essentially important in solving many problems in the engineered design of product and also in solving many problems in jute processing. Some simple instruments like, jute fibre fineness tester, bundle strength tester, lustre meter, bulk density tester^{1,2} are now being used commonly. However, no such instrument is available for assessment of softness (a relative indication of flexural rigidity) property of jute fibre and hence softness of jute fibre is still judged subjectively through touch and feel by hand only.

Flexural (bending) rigidity plays an important role in deciding the structure and property of yarn³. Efforts on measuring bending rigidity or flexural rigidity of fibre were made earlier by several workers⁴⁻¹⁰. Pierce⁴ and Carlene^{5,6} developed the method of measuring flexural rigidity of yarns by ring loop method suitable for monofilament or continuous filament or spun yarns. Finlayson⁷ observes that the flexural rigidity of fibre may be evaluated following the principle of bending of a beam as a cantilever caused to bend under its own weight. He however, did not considered for bending of the beams or fibres due to external load applied. Meredith and Hsu⁸ measured flexural rigidity dynamically which need a sophisticated instrumental arrangement. The bending modulus of jute filaments in terms of Young's modulus was reported by Sen⁹. Sur, *et al*¹⁰, developed a method of measuring flexural rigidity of fungal treated jute fibre based on the method developed by Sen. Later,

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Vivekanandan, *et al*¹¹, followed the method developed by Meredith and Hsu⁸ to measure flexural rigidity of single filament of different lingo-cellulosic fibres dynamically.

In the present work, a very simple and quicker method of measuring flexural rigidity of jute fibre bundle was designed adopting the principle of bending of a beam as a cantilever applying an appropriate vertical load at the free-end of the fibre bundle. Necessary theoretical expression has been formulated using relevant standard engineering formulae. The validity/suitability of this method of measuring flexural rigidity of jute fibre was examined from correlation coefficient between flexural rigidity of raw and differently treated/ modified jute fibres and some important physical property and structural parameters.

METHODOLOGY

Mathematical Expression for Design of the Apparatus

Flexural rigidity of jute fibre was measured by cantilever method. A fibre bundle of jute fibres was mounted on a horizontal platform in such a way that it overhangs, like a cantilever. A known transverse/ vertical load was put at the extreme of the free-end of the fibre bundle by using a pre-weighed (P) synthetic adhesive tape, so that, the fibre bundle bends downward to a small extent partially due to its own weight distributed at uniform intensity over its length (causing an angular deflection of α_1 radian) and partially due to the vertical concentrated load applied at the free-end of the fibre bundle (causing another angular deflection of α_2 radian). The bending rigidity in terms of flexural rigidity can be evaluated from the total angular deflection (say, $\alpha = \alpha_1 + \alpha_2$) of the fibre bundle, using the engineering formulae applicable for bending of a beam as a cantilever, with necessary assumptions and conditions applicable for jute fibres.

As per the theory of Deflection of Beams, in case of a cantilever type beam with a uniform load of intensity due to its own weight, w (in mg/mm), over its length (L) of the cantilever portion, the angular deflection α_1 (Figure 1(a)) is given by the following formula¹²

$$\alpha_1 = \frac{wL^3}{6EI} \quad (1)$$

or

$$EI = \frac{wL^3}{6\alpha_1} \quad (2)$$

and, the maximum deflection at the end,

$$\delta_1 = \frac{wL^4}{8EI} \quad (3)$$

where α_1 is the angular deflection (in radian) of the beam due to its own weight; L , the length of the beam overhung as a cantilever, mm; E , the elastic modulus and I being the moment of inertia, where the quantity EI is called as 'Flexural Rigidity' of the beam.

Similarly, when a concentrated transverse/vertical load is sub-

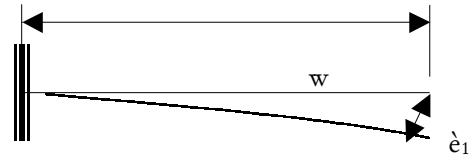


Figure 1(a) Angular deflection on subjecting load to the length of the cantilever of beam

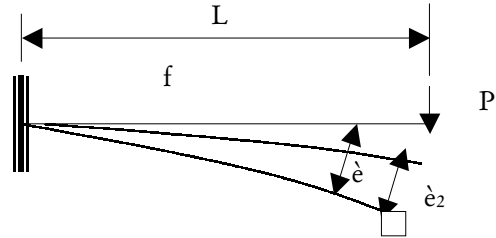


Figure 1(b) Angular deflection on subjecting load to the free-end of the cantilever of beam

jected to the free-end of a cantilever of a beam, then the angular deflection α_2 (Figure 1(b)) is given by the following formula¹²

$$\alpha_2 = \frac{PL^2}{2EI} \quad (4)$$

or,

$$EI = \frac{PL^2}{2\alpha_2} \quad (5)$$

The maximum vertical deflection,

$$\delta_2 = \frac{PL^3}{3EI} \quad (6)$$

where α_2 being the angular deflection (in radian) of the beam, due to the applied concentrated load P in mg.

The method of obtaining a resultant effect by adding together partial effects is called the 'method of superposition'¹². In this method, the resultant effect is obtained by adding the bending moments produced by each load acting separately. Therefore, in this case the resultant deflection can be given by the following relationship obtained by method of superimposition applied in this case

$$\delta = \delta_1 + \delta_2 \quad (7)$$

and

$$\begin{aligned} \alpha &= \alpha_1 + \alpha_2 = \frac{wL^3}{6EI} + \frac{PL^2}{2EI} \\ &= \frac{L^2}{2EI} \left[P + \frac{wL}{3} \right] \end{aligned}$$

or

$$EI = \frac{L^2}{2\alpha} \left[P + \frac{wL}{3} \right] \quad (8)$$

Now, applying this general engineering principle and formulae for bending of a beam as a cantilever, for jute fibre

bundle (jute fibre being rigid in nature, it much simulates the condition of having a small extent of bending of a beam as discussed above.) with necessary assumptions and conditions applicable, the mathematical relationship for calculating flexural rigidity of jute fibre bundle is given hereunder.

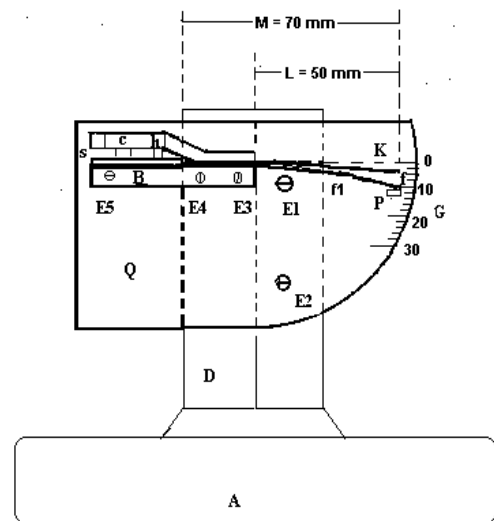
Considering, L , the length of the overhung fibre bundle (acting as a cantilever) in mm; α , the total small deflection of fibre bundle from its horizontal plane in radian; P , the transverse load applied at the extreme free-end of the fibre bundle in mg; and w , the weight of fibre bundle in mg/mm; the flexural rigidity of the jute fibre bundle can be calculated from the following expression.

$$\begin{aligned} & \text{Flexural rigidity in mg} \cdot \text{mm}^2 \\ &= \frac{(\text{Length of overhung fibre bundle in mm})^2}{2 \times \text{Angular deflection in radian}} \\ & \times \left[\text{Transverse load in mg} + \frac{\text{Weight of fibre bundle in mg/mm} \times \text{Length of overhung fibre bundle in mm}}{3} \right] \quad (9) \end{aligned}$$

Assumptions and Conditions Applicable

1. Under an appropriate known vertical load at the extreme free-end of the fibre bundle, the deflection of fibre bundle is to be very small (5° - 20°). However, for a rigid fibre like jute, the above formula may be applicable, where the total angular deflection, under the standardized vertical load, is low and within 5° - 20° .
2. Effect of cross-sectional shape of the fibre on flexural rigidity has been ignored.
3. Weight of fibre bundle per cross-section is considered to be uniform across its length.
4. Effect of inter-fibre friction has been ignored and is not considered during the mathematical formulation.
5. Jute is hygroscopic in nature. Variation in moisture regain of the fibre sample may affect proper evaluation of flexural rigidity value. So, it is essential to condition the fibre sample in standard atmosphere¹³.

Jute fibres are mesh-like in structure. Even after passing through all the stages of processing, jute filaments are not free from meshes and branches. Bending of a fibre during spinning process is a complex phenomenon. The complexity arises from the frictional resistances offered by the neighbouring fibres in addition to inherent bending modulus of individual fibres. Hence, instead of taking observations on single filaments after removing these branches, it was considered more appropriate to study the properties on clean, hand-combed fibre bundles in the form of a beam containing remnants of mesh structure. However, in this case effect of frictional resistance and effect of



A : bottom base; B : horizontal platform; C : clamp to hold fibre bundle; D : vertical stand ; E1-E5 : screws; f : fibre bundle bends due to its own weight; f1 : fibre bundle bends both due to its own weight and a vertical load put at the free-end of the fibre bundle; G : graduated quadrant scale to measure angular deflection; h : hinge of the clamp; K : zero line for measuring angular deflection; M : total length of the fibre bundle of known and fixed weight; L : length of fibre bundle overhung like a cantilever; P : transverse / vertical load hanged at the free-end of the fibre bundle; S : spring for the clamp.

Figure 2 Schematic diagram of flexural rigidity tester for jute fibre

non-uniform diameter or mass per unit length were ignored. Moreover, bundling of filaments improves the regularity in weight per cross-sectional area across the length of the beam of the fibre bundle. For the above said reasons, the estimation of flexural rigidity of jute fibre was made taking fibre bundle instead of single fibre.

Design of the Apparatus and Testing

A schematic diagram of the flexural rigidity tester for jute fibre as designed in the present work is shown in Figure 2. It is a very simple, handy and table model instrument requiring no electrical connection and is fairly small in size. Some of the test parameters were standardized in the present work, which are (i) total length of the fibre bundle to be taken, is 70 mm among which 50 mm will overhung as a cantilever; (ii) total weight of the jute fibre bundle is to be 5 mg, and (iii) an appropriate known vertical load, to be hanged at the free-end of the fibre bundle is to be 25 mg. A clean, hand-combed fibre bundles in form of beam (f) of 70 mm (cut using a template) in length ($M = 70$ mm) weighing 5 mg was clamped on the horizontal platform (B) with the help of a clamp (C) in such a way that 50 mm length ($L = 50$ mm) of fibre bundle overhangs like a cantilever. A self adhesive synthetic tape weighing 25 mg (of 2 mm width) was stuck at the extreme free-end of the fibre bundle for application of the known transverse / vertical load. After 1 min, the angle of deflection (α) was recorded from a graduated scale (G) engraved on the quadrant scale plate (Q) erected on a vertical stand (D) fitted on a horizontal base (A) at the bottom. The weight of adhesive tape was chosen in such a way that the total angular deflection of fibre bundle was maintained to a very small extent (about 5° - 20°) from its horizontal zero

Table 1 Properties of Raw and Treated Jute Fibres and Yarns Spun from Corresponding Fibres

Sl No	Treatment of Fibre	Fibre Propertie				Yarn Properties				
		Linear Density, tex	Bundle Tenacity, cN/tex	Flexural Rigidity cN-mm ²	Coefficient of Friction (Fibre to Fibre-parallel)	Packing Fraction	Breaking Tenacity, cN/tex	Breaking Elongation, %	Initial Modulus, cN/tex	Specific Flexural Rigidity (mN-mm ² /tex ² ×1000)
1.	Untreated Jute	3.58	29.77	61.19	0.32	0.34	11.00	1.86	732.00	126.20
2.	Treatment with Steam of Wet Jute Fibre at 121°C (1.1 kg/cm ²) for 30 min	3.20	30.48	68.16	0.33	0.33	12.25	1.71	867.30	108.30
3.	Treatment with 3% H ₂ O ₂ at 85°C for 2 h (pH 11)	2.62	27.58	41.40	0.31	0.35	10.95	1.90	703.10	130.40
4.	Treatment with 0.5% NaOH Solution at 30°C for 60 min	2.98	30.48	46.49	0.28	0.40	13.08	2.03	811.90	142.70
5.	Treatment with 0.5% NaOH Solution at Boil (100°C) for 30 min	2.82	29.18	44.90	0.27	0.43	11.54	1.71	754.30	98.40
6.	Treatment with Plain Water at Boil for 30 min	3.10	30.27	46.70	0.36	0.37	11.82	1.98	751.90	136.90
7.	Sequential Treatment with 0.5% NaOH Solution at 30°C for 60 min Followed by 4% Mixed Enzyme at 55°C for 2 h (pH 4.8)	1.93	25.80	40.60	0.27	0.39	10.10	1.59	801.90	136.70
8.	Sequential Treatment with 0.5% NaOH Solution at Boil for 30 min Followed by 4% Mixed Enzyme (Cellulase, Xylanase and Pectinase) at 55°C for 2 h (pH 4.8)	1.72	17.48	40.80	0.28	0.41	8.84	1.49	779.00	127.60
9.	Treatment with 8% Ethylene Glycol by Pad (100% Wet Pick-up)-Dry-cum-Cure (at 125°C for 10 min) Method on Oxy-jute K ₂ S ₂ O ₈ -treated) Fibre	2.75	30.29	54.95	0.34	0.38	13.39	1.75	898.13	120.65

line (K). Before testing, the jute fibre samples was conditioned at $27 \pm 2^\circ\text{C}$ and at $65 \pm 2\%$ relative humidity as per BIS specification¹³. The recorded angular deflection of fibre bundle measured in degree is to be converted in radian for calculation of the flexural rigidity of the fibre bundle by using the equation (9). An average of ten such readings were taken for each fibre sample.

Fibres and Chemicals

The middle region of the raw jute reed of Tossa Daisee (*Corchorus Olitorius*) variety (grade TD3) was taken for the present study. Relevant chemicals taken were of laboratory reagent grade. Commercial grade 50% H₂O₂ from local market was used. A mixed enzyme preparation from Biocon India Ltd was used.

Treatments of Fibres

Relevant treatment conditions are mentioned in Table 1.

Preparation of Yarn Sample

Raw jute (control fibre) and some selectively treated jute fibres were subjected to spinning for yarn making maintaining an average of 1.5% oil content and nearly 35% moisture, respectively (on weight of fibre). The fibres were then kept in separate bins for piling or conditioning for 24 h. After 24 h, the

fibres were successively processed through two miniature carding machines (a Breaker card followed by a Finisher card) and three miniature jute drawing machines to obtain a uniform sliver of desired weight per unit length. The sliver from the third drawing machine was further processed in a standard commercial finisher drawing machine to get much finer and more uniform sliver. This sliver was finally spun into yarn of a linear density of nearly 165 tex using Mackie's standard apron draft jute spinning machine imparting optimum level of twist (215 twist/m) using a flyer speed of 3800 rpm.

Evaluation Linear Density of Fibre

The fineness of untreated and treated jute fibres was measured by using standard gravimetric method¹⁴ taking cut length as 2 mm after giving an exhaustive hand combing to the jute reeds on fine gill pins.

Evaluation Bundle Tenacity of Fibre

The bundle strength of jute fibre was measured at standard condition using JTRL-jute fibre bundle strength tester following the usual test method¹⁵. For each test, the fibre bundle was of 0.25 mg in weight and 12.5 cm in length from which a standard test length of 5 cm was maintained between the clamps holding the fibre bundles.

Evaluation of Coefficient of Friction of Fibre

Fibre to fibre coefficient of friction of specified jute fibres (raw or treated) was measured following the principle of inclined plane friction tester^{16,17}. The coefficient of friction data of jute fibres shown in Table 1 was determined by calculating corresponding value of $\tan\alpha$, where α is the required angle of the inclined plane at which downward slide of the top sliding plate was found to occur first.

Evaluation of Tensile Properties of Yarn

The tensile properties such as tenacity, breaking elongation and initial modulus of yarns made from untreated and treated jute fibres were evaluated as per IS: 1670-1970 method¹⁸ using Instron universal tensile tester, model 4411 after conditioning¹³ the yarn samples appropriately. The gauge-length and crosshead speed were maintained as 610 mm and 300 mm/min, respectively

Assessment of Flexural Rigidity of Yarn

The bending rigidity of yarn expressed as specific flexural rigidity was measured by the ring-loop method¹⁹. The yarn ring diameter was taken as 3.12 cm with the help of a mandrel and a load of 0.004 g/tex²⁰ as suspended on the yarn ring for 60 s. Specific flexural rigidity of the test yarn was then calculated measuring undistorted and distorted diameter of the yarn loops following the standard method²¹.

Determination of Diameter and Packing Fraction of Yarn

The packing fraction (f) of the yarn was calculated²² from the knowledge of fibre density and apparent yarn density on duly accounting for its linear density and diameter. The fibre density was taken as 1.48 g/cm³ in the present study. The yarn diameter was measured using Leitz microscope with a magnification of 30X under a constant tension of 0.02 g/tex. The packing fraction f is expressed as:

$$f = (\text{Apparent yarn density}) / (\text{Fibre density}).$$

RESULTS AND DISCUSSION

Flexural Rigidity of Raw and Differently Treated Jute Fibres and their Correlation with Different Properties of Yarn

Flexural Rigidity of raw and differently treated jute fibres was measured by the method developed in the present work and results obtained are shown in Table 1. There is a noticeable reduction in flexural rigidity by all the treatments studied in the present work, except the steam treatment where the same is rather, found to be increased. There is also measurable reduction in fibre fineness (linear density) to a varying extent, altering their bundle tenacity and coefficient of friction values. It is expected that lower is the flexural rigidity (bending rigidity), higher will be the compactness (packing fraction) in the resultant yarns at comparable condition, if changes in any other property parameters of treated/modified fibres do not overrules or

Table 2 Correlation Coefficient between Flexural Rigidity of Jute Fibre and Selected Properties of Yarns

Correlating Parameters	Correlation Coefficient, r	t-value*
Flexural Rigidity of Fibre and Packing Fraction of Yarn	0.67	2.41
Flexural Rigidity of Fibre and Breaking Tenacity of Yarn	0.47	1.41
Flexural Rigidity of Fibre and Breaking Elongation of Yarn	0.12	0.33
Flexural Rigidity of Fibre and Initial Modulus of Yarn	0.45	1.34
Flexural Rigidity of Fibre and Specific Flexural Rigidity of Yarn	0.41	1.18

For significant correlation coefficient, the corresponding value of 't', for 7degree of freedom (for N= 9), should be ≤ 2.365 at 5% confidence level²³.

influences to downsize the said effect of reduction/ increase in flexural rigidity of fibres. The observed results of flexural rigidity of untreated and differently treated fibres, Table 1, measured by the method developed in the present work, show a similar trend as expected for the measured packing fraction values of the corresponding yarns.

To examine the validity and suitability of the method of measuring flexural rigidity developed by us, the correlation coefficients between the observed flexural rigidity of untreated and differently treated jute fibres and the packing fraction, breaking tenacity, breaking elongation, initial modulus and specific flexural rigidity values of yarns spun from the corresponding jute fibre samples was calculated and the results are given in Table 2. Significance of the correlation coefficient value was tested by the method recommended by Chambers²³. The correlation coefficient between flexural rigidity of untreated and treated jute fibre and packing fraction of corresponding yarns is found to be 0.67 and is also significant at the 5% confidence level. However, it should be borne in mind that difference in other property parameters of fibre like fineness, bundle tenacity, coefficient of friction of fibres might also have influenced the other property parameters of yarn which have not been considered here. The observed other property parameters of those yarns, *ie*, breaking tenacity, breaking elongation, initial modulus, and specific flexural rigidity of yarn samples expectedly show a corresponding low value of correlation coefficient (0.12 to 0.47, Table 2) with flexural rigidity data of corresponding untreated and treated jute fibres and are not significant also. Effect of different treatments on properties of jute fibres and properties of corresponding yarns made from those fibres and their process performances including spinnability are discussed in our earlier publication²⁴.

CONCLUSION

The method of measuring flexural rigidity of jute fibre (may also be applicable for similar stiff / rigid fibre) developed in the present work is very simple and very useful for quicker assessment of flexural rigidity of jute fibre. The data of flexural rigidity of untreated and treated jute fibres obtained by this

method is in well tune with the packing fraction data of jute yarns spun from corresponding untreated and treated jute fibres. Moreover, validity and suitability of this method of measuring flexural rigidity of jute fibre was established from the correlation coefficient value ($r = 0.67$, which is also found to be significant at 5% confidence level) between flexural rigidity of untreated and differently treated jute fibres and packing fraction data of the yarn samples spun from corresponding untreated and differently treated jute fibres. However, chances of influences of variation in other property parameters of fibres (caused due to different treatments) like fineness, bundle tenacity and coefficient of friction of fibres on the structural parameters (packing fraction) of yarn can not be ruled out.

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REFERENCES

1. 'Assessment of Quality of Jute Fibre; Instrumental Method'. *Jute Technological Research Laboratories*, Kolkata, India, 1983.
2. C G Jarman. 'The Retting of Jute'. *FAO Agricultural Services Bulletin* 60, Food and Agriculture Organization of The United Nations, Rome, 1985, p 49.
3. S Kawabata and M Niwa. 'Influence of of Fibre and Process Parameters on Product Performance'. 'Fibre to Finished Fabrics, Proc Fibre Sci / Dyeing and Finishing Groups, Joint Conference'. *The Textile Institute International*, U K, December 8 and 9, 1998, p 1.
4. F T Pierce. 'The Handle of Cloth as a Measurable Quantity'. *J Text Inst*, vol 21, 1930, p T377.
5. P W Carlene. 'The Measurement of the Bending Modulus of Monofil'. *J Text Inst*, vol 38, 1947, p T38.
6. P W Carlene. 'The Relation Between the Fibre and Yarn Flexural Rigidity in Continuous Filament Viscose Yarns'. *J Text Inst*, vol 41, 1950, p T159.
7. D Finlayson. 'Yarns for Special Purposes – Effect of Filament Size'. *J Text Inst*, vol 37, 1946, p 168.
8. R Meredith and Bay-Sung Hsu. 'Dynamic Bending Properties of Fibres: Effect of Temperature on Nylon 66, Terylene, Orlon and Viscose Rayon'. *J Polym Sci*, vol 61, 1962, p 271.
9. K R Sen. 'The Elastic Properties of Single Jute Filaments, I Measurement and Study of Young's Modulus by Flexure'. *J Text Inst*, vol 39, 1948, p T339.
10. D Sur, S K Bhattacharyya and M K Basu. 'A Simple Method of Assessing Microbial Softening of Barky Jute'. *J Text Assoc*, July, 1983, p 128.
11. M V Vivekanandan, P B Iyer, S Sreenivasan and K R Krishna Iyer. 'Torsional and Flexural Properties of Lignocellulosic Fibres'. *Book of Papers, Int Seminar on Jute and Allied Fibres: Changing Global Scenario, National Institute of Research on Jute and Allied Fibre Technology*, Kolkata, India, January, 1998, p 74.
12. S Timoshenko and G H MacCullough, 'Elements of Strength of Materials'. 3rd edn, *D Van Nostrand Co Inc*, New York, USA, 1949, p 167.
13. Indian Standard, IS:6359-1971. 'Method for Conditioning of Textiles'. *Bureau of Indian Standards*, New Delhi, India, April 1972.
14. S B Bandyopadhyay. *Text Res J*, vol 38, no 2, 1968, p 135.
15. IS: 7032 (Part VII)-1975/1986. 'Physical Methods of Test for White, Tossa and Daisee Uncut Indian Jute: Bundle Strength'. *ISI Handbook of Textile Testing, Bureau of Indian Standards*, New Delhi, India, 1981, p 106.
16. S B Bandyopadhyay. *Text Res J*, vol 21, 1951, p 659.
17. D Das, A K Samanta and P C Dasgupta. *Indian J Fibre Text Res*, vol 22, 1997, p 53.
18. IS : 1670-1970. 'Determination of Breaking Load, Elongation at Break and Tenacity of Yarns'. *ISI Handbook of Textile Testing, Bureau of Indian Standards*, New Delhi, India, 1982, p 137.
19. R B Beevers. 'Experiments in Fibre Physics'. *Butterworth and Co Ltd*, London, U K, 1970, p 193.
20. A K Sinha and G Basu. 'Studies on Physical Properties of Jjute-acrylic Blended Bulked Yarns'. *Indian J Fibre Text Res*, vol 26, 2001, p 268.
21. W E Morton and J W S Hearle. 'Physical Properties of Textile Fibres'. *The Textile Institute*, Manchester, U K, 1986, p 402.
22. J E Booth. 'Textile Mathematics'. *The Textile Institute*, Manchester, U K, vol 2, 1975, p 330.
23. E G Chambers. 'Statistical Calculation for Beginners'. *University Press*, Cambridge, U K, 1958, p 37.
24. P Ghosh, A K Samanta and G Basu. 'Effect of Selective Chemical Treatments of Jute Fibres Aimed at Improving its Textile Related Properties and Processibility'. *Ind J Fibre and Text Res*, 2004 (In Press).