Mechanical Behaviour of Jute Ply Yarns

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Two, three and four ply jute yarns have been prepared with fine (163 tex) and coarse (344 tex) component single yarns and low (15.92) and high (25.75) ply twist multiplier. It is observed that as the number of ply increases, the tenacity, breaking elongation, specific work of rupture and packing factor increases, but specific flexural rigidity decreases except for coarse component yarn and high twist level. Wetting of ply yarn decreases tenacity and specific flexural rigidity when improves breaking elongation and specific work of rupture. The effect of wetting on ply yarns having coarse component yarns are more pronounced compared to those of finer component yarns. As revealed by the stress relaxation and cyclic loading of ply yarns, the stress decay and permanent set increase with the increase in number of ply at low deformation level, while at high extension level, the stress decay decreases. The coarser component yarn or high twist of ply yarn enhances the stress decay and permanent set indicating lower elasticity.

Keywords: Extension cycling; Jute; Packing factor; Ply yarn; Specific flexural rigidity; Specific work of rupture; Stress relaxation

NOTATION

BE : breaking elongation
C : coarse component yarn (344 tex)
F : fine component yarn (163 tex)
H : high ply twist (25.75 twist multiplier)
L : low ply twist (15.92 twist multiplier)
S : single yarn
X : two-ply yarn
Y : three-ply yarn
Z : four-ply yarn

INTRODUCTION

Jute is a coarse, strong, rigid natural bast fibre and an important cash crop of Eastern India. It is spun into the yarn which is traditionally used in packaging and carpet backing. Now-a days, it is also used in various diversified areas namely, floor-coverings, household textiles, technical textiles, reinforced plastics, handicrafts etc[1]. In most of the fabrics, jute are woven in single yarn form and the use of ply yarns are mainly limited to floor-coverings, bag stitching yarns and diversified areas. In cotton and worsted sector, use of ply yarn is well accepted due to improved uniformity and strength, lower hairiness which results lower end breaks in subsequent processes producing better quality yarn, as well as fabric[2].

In jute sector, demand of diversified uses and improved quality may lead to higher use of ply yarn in various applications as stated earlier. Before going to applications, there is a need to explore the mechanical behaviour of jute ply yarns. Hence, in the present study an attempt has been made to investigate the responses of jute ply yarn under various deformations and loads.

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MATERIALS AND METHODS

Materials

Tossa jute (grade TD-5)[3] with linear density 2.14 was used for spinning of yarns. the tenacity and elongation-at-break of jute fibre is 30.1 cN/tex and 1.55% respectively.

Methods

The raw jute fibre was passed through a softener machine, sprayed with 2.5% oil in emulsion and binned for 24 hours. Sliver of jute was prepared in a JF-2 breaker card and then JF-4 finisher card. The sliver from finisher card was passed through three passages of Mackie's gill drawing frames, and the yarn was spun on a Mackie's apron draft spinning frame having spindle speed 4300 rpm with two linear densities of 163 tex (F) and 344 tex (C) and twist multiplier 26.9. Plying of both these single yarns (S) was done in two-, three-, and four-ply yarns (X, Y and Z) with 15.92 (L) and 25.75 (H) twist multiplier using ring doubler. The construction details of ply yarns are shown in Table 1.

Determination of Tensile Properties

The tensile properties of yarns were determined at 65% RH and $22^\circ C - 25^\circ C$ on an Instron Tensile Tester. Yarns were tested in 30 cm test length and 25 cm/min cross-head speed. Wet tests were carried out after wetting the yarn in water containing 0.1% anionic wetting agent for 30 mins. For each yarn samples 20 tests were performed. The master stress-strain

Table 1 Constructional details of jute ply yarn

Sample Code	Number of Ply	Single Yarn Count Tex	Ply Yarn Count Tex	Ply Twist tpcm
S_F	1	163	—	—
$X_{F,L}$	2	163	340	0.98
$Y_{F,L}$	3	163	527	0.78
$Z_{F,L}$	4	163	708	0.67
$X_{F,H}$	2	163	352	1.55
$Y_{F,H}$	3	163	541	1.25
$Z_{F,H}$	4	163	747	1.05
S_C	1	344	—	—
$X_{C,L}$	2	344	737	0.58
$Y_{C,L}$	3	344	1135	0.47
$Z_{C,L}$	4	344	1536	0.41
$X_{C,H}$	2	344	807	0.91
$Y_{C,H}$	3	344	1206	0.74
$Z_{C,H}$	4	344	1655	0.63

S : Single yarn; X : 2-ply; Y : 3-ply; Z : 4-ply; F : Fine; C : Coarse; L : Low twist; and H : High twist

curves (Figures 1 and 2) were drawn from the load-elongation curves by adopting the technique suggested by Meredith[4].

Stress relaxation of the yarn samples was determined by stretching the yarns to 30% (0.3 BE) or 70% (0.7 BE) of their average breaking extensions and allowing them to relax for 5 min at the extended condition. The stress decay,

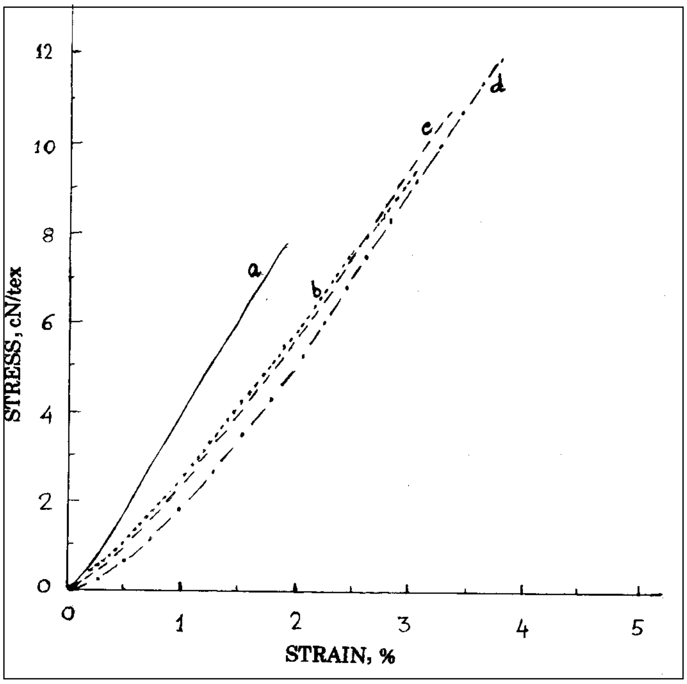

Figure 1 Stress-strain curves of yarns : (a) jute single yarn with 163 tex; (b) 2-ply yarn with low twist; (c) 3-ply yarn with low twist; and (d) 4-ply yarn with low twist

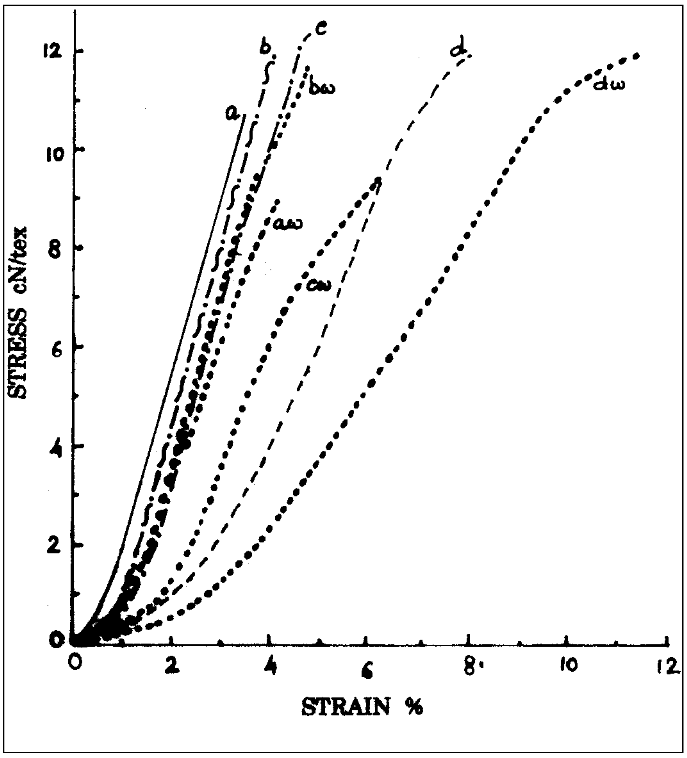

Figure 2 Stress-strain curves of 3-ply yarns : (a) with fine yarn and low twist; (b) with fine yarn and high twist; (c) with coarse yarn and low twist; and (d) with coarse yarn and high twist

characterizing the stress relaxation, was calculated as follows:

$$\text{Stress decay} = \frac{T_1 - T_2}{T_1} \times 100$$

where T_1 and T_2 are the loads on the yarn at the onset of the stress decay and after stress decay for 5 min respectively. The yarn samples were further extended to break after stress relaxation and the respective breaking load and extension values were evaluated.

Yarn samples from each specimen were also subjected to extension cycling at 30% of average breaking extension for 10 cycles before straining them to break. Permanent set (%) on extension cycling was taken to be equivalent to the percent strain at zero load condition after extension cycling. In each case, the average of 10 set results has been reported after testing the statistical significance of the difference between the mean values at 5% level.

The work of rupture was calculated by the area under the stress strain curve taking up to the maximum load value and then dividing it by the tex value to make the parameter independent of linear density.

Determination of Linear Density

Yarns of 100 m length were weighed and the average of 10 such readings was taken as a measure of linear density using standard method[5].

Determination of Flexural Rigidity

Specific flexural rigidity of the yarn samples was determined by the standard ring-loop method[6].

Determination of Packing Factor

The diameter of yarn samples was measured with a projection microscope (magnification, 10 X). Average of 30 readings taken at random was taken. Packing factor was calculated[7] from the yarn diameter and considering the density of jute fibre 1.48.

RESULTS AND DISCUSSION

Physical Properties of Jute Ply Yarns

Table 2 shows the effect of plying on the physical properties of jute ply yarn in two different twist levels, (*ie*, twist multiplier 15.92 and 25.75) and two different single yarn counts (163 tex and 344 tex). It is observed that the higher the number of ply, the higher is the tenacity, breaking elongation, specific work of rupture, packing factor and the lower is the specific flexural rigidity. As the number of ply increases, the change in structure improves the regularity and inter yarn radial forces, which, in turn, improve the effective contribution of fibre length towards the tenacity. Higher packing in higher number of ply is the result of higher radial forces between component yarns. A pressure is developed to the outside of each single component during tensile deformation. Ply yarn thus utilises the contribution of the ineffective fibres of single yarn outer layer towards strength. Moreover, in the plying operation, the weak placed of one component yarn is protected by the strong place of other component yarns, thus improving the regularity (better breaking load cv%) and mechanical properties of yarn. On the contrary, the bending deformation is a low load phenomenon where the role of radial forces is insignificant, and, therefore, relative fibre mobility within and between the component yarns in higher as the number of ply increases which is reflected in lower specific flexural rigidity.

Table 2 Physical properties of jute ply yarn

Sample Code	Tenacity, cN/tex	Breaking Load, cv%	Breaking Extension, %	Specific Work of Rupture, mJ/tex.m	Packing Factor	Specific Flexural Rigidity, cNcm²/tex²
S_F	7.91	25.71	1.85	0.885	0.134	0.445
$X_{F,L}$	9.73	16.23	3.10	0.728	0.119	0.937
$Y_{F,L}$	10.76	13.95	3.33	0.837	0.127	0.821
$Z_{F,L}$	12.09	9.07	3.70	0.952	0.136	0.536
$X_{F,H}$	11.02	14.33	3.64	0.913	0.138	1.299
$Y_{F,H}$	11.97	10.56	4.00	1.053	0.146	0.861
$Z_{F,H}$	13.54	8.29	4.77	1.211	0.155	0.576
S_C	10.47	24.18	1.96	0.739	0.149	1.872
$X_{C,L}$	10.82	17.93	3.80	0.748	0.145	6.702
$Y_{C,L}$	12.38	14.37	4.53	1.113	0.152	4.227
$Z_{C,L}$	14.62	11.02	6.97	1.560	0.159	3.137
$X_{C,H}$	13.23	13.65	5.23	1.233	0.155	3.166
$Y_{C,H}$	12.10	10.59	7.97	1.441	0.162	5.778
$Z_{C,H}$	10.56	9.21	9.39	1.663	0.177	6.929

In case of coarse component yarn and high twist level, the tenacity and specific flexural rigidity behave in the reverse way as stated in other cases, though the trends of breaking extension, specific work of rupture and packing factor with the change in number of ply, remain same. Tenacity decreases with increase in number of ply due to the obliquity effect[8] of the single yarns owing to high twist. But as the breaking extension increases and in the overall effect of tenacity and extension, the work of rupture increases. Packing factor increases due to higher radial forces. The specific flexural rigidity increases with increase in ply, is due to more compact structure of ply yarn because of high radial forces between the component yarns, which in turn, decreases the possibility of relative fibre mobility within and between the component yarns. This can be substantiated by the very high value of packing factor.

Figure 1 shows the stress-strain curves of singles, 2-ply, 3-ply and 4-ply jute yarns (single yarn count 163 tex and ply twist multiplier 15.92) which clearly demonstrate the tensile behaviour of these yarns at different extension levels. The stress-strain curves of 3-ply yarns with two different twist levels and linear dencities are shown in Figure 2.

Physical Properties of Wet Jute Ply Yarns

The physical properties of wet jute 3-ply yarn and its comparison with normal ply yarns are shown in Table 3. It is observed from the table that the single yarn count and twist level play a very vital role with respect to the properties of ply yarn. In case of low twist level, the wetting decreases tenacity and specific flexural rigidity, but increases breaking elongation and hence, specific work of rupture. Chakravorty[9] reported

Table 3 Effect of wetting on properties of 3-ply jute yarn

Sample Code	Sample Condition	Tenacity, cN/tex	Breaking Elongation, %	Specific Work of Rupture, mJ/tex m	Specific Flexural Rigidity, cNm²/tex²
$Y_{F,L}$	Dry	10.76	3.33	0.837	0.821
	Wet	8.95	4.03	0.926	0.789
$Y_{F,H}$	Dry	11.97	4.00	1.053	0.861
	Wet	11.86	4.76	1.332	0.876
$Y_{C,L}$	Dry	12.38	4.53	1.113	4.227
	Wet	9.23	6.16	1.317	4.019
$Y_{C,H}$	Dry	12.10	7.97	1.441	5.778
	Wet	12.15	11.24	1.848	7.107

that the wet strength of jute fibre is lower than its dry strength. Hence, at lower twist, the decrease in strength of fibre after wetting was reflected in the decrease in strength. The increase in breaking extension and decrease in specific flexural rigidity is due to controlled slippage of fibres is low load condition where water molecules acts as a lubricant. It is also seen that the effect of wetting on ply yarns having coarse component yarns are more pronounced compared to those of finer component yarns.

After wetting, the strength retention of high twisted ply yarn is higher compared to low twisted ply yarn. Wetting of jute play yarn is expected to bring about increase in inter-fibre friction in the yarn. With the increase in twist, lateral pressure within the yarn increases and the inter-fibre friction plays a more dominant role. In coarse component yarn and high twist, wetting increases rigidity. This is due to swelling of fibres and increase in inter-fibre friction in the component yarns.

Stress Relaxation of Jute Ply Yarns

Table 4 shows the stress relaxation behaviour of jute ply yarn in two different extension levels, *ie*, 30% and 70% of breaking extension (0.3 BE and 0.7 BE). The effect of ply has been shown with fine component yarn and low twist level. It is observed that stress decay increases at 0.3 BE, whereas it decreases at 0.7 BE with the increase in number of ply. The increase of stress decay at 0.3 BE level is, apparently, due to the variation in yarn structure which leads to difference in modulus values of component yarns and hence, the decrease in elasticity. On the contrary, at 0.7 BE level, *ie*, in case of high tensile deformation, the stress relaxation leads to partial disruption of the compact and interlocked yarn structure due to some irrecoverable flow among the fibre elements. This flow is obviously higher for lesser number of ply due to its higher modulus. High twisted 3-ply yarn from fine component yarn shows no such significant difference in stress decay at 0.3 BE with respect to its low twist counterpart, but at 0.7 BE the decrease of stress decay is significant.

In general, 3-ply yarn from coarse component yarn shows higher stress decay compared to its fine counter part in both the extension levels. The coarse yarn should have higher modulus value compared to fine yarn which leads to higher non-recoverable flow in the fibre component resulting in lower elasticity.

In most of the cases with fine component yarn, the tenacity increases after stress relaxation whereas with coarse component yarn, tenacity decreases stress relaxation leads to higher extension in all the cases. When the yarns are ruptured after being subjected to stress relaxation, the tenacity and breaking elongation shows deviation in all the cases with respect to those without stress relaxation. When a yarn is held at a particular extension for some time controlled shearing (flow) between fibre and yarn elements is expected to take place to minimise the localised stress concentration as far as possible and this is manifested in stress decay. Due to the redistribution of stress concentration, the yarn is expected to rupture at higher load, and elongation. But when ply yarn is deformed to a large extent and allowed to relax stress, the irrecoverable flow between fibre elements occurs and this might be responsible for the reduction in breaking stress of ply yarns on stress relaxation.

Cyclic Loading of Jute Ply Yarns

When jute ply yarns are subjected to ten cyclic loading between zero to 30% of breaking extension (0.3 BE), some deformation in the yarn as well as changes in elasticity takes place. The permanent set due to cyclic loading, tenacity and elongation after rupture of that yarn are tabulated in Table 4. It is observed that the elasticity decreases as ply of yarn increases which is evident from the higher permanent set values. Coarser component ply yarn or higher twist level deteriorates the elasticity as indicated by increased permanent set values. In low load cyclic deformation of ply yarn, flow of fibre element results in redistribution of stress concentrations, making the yarn structure more compact which is reflected in higher tenacity and elongation-at-break after cyclic loading with respect to rupture without cyclic deformation. Only in case of coarse component yarn and high twist ply yarn, tenacity deteriorates after cyclic deformation because of destruction of structure even in low load cyclic deformation.

Table 4 Stress relaxation and cyclic deformation of jute ply yarn

Sample Code	Stress Relaxation						Extension Cycling		
	Stress Decay, %		Tenacity, cN/tex		Breaking Elongation, %		Permanent Set, %	Tenacity, cN/Tex	Breaking Elongation, %
	0.3 BE	0.7 BE	0.3 BE	0.7 BE	0.3 BE	0.7 BE			
$X_{F,L}$	28.25	43.63	12.79	12.22	3.97	3.72	0.10	10.55	3.93
$Y_{F,L}$	30.88	40.12	12.41	11.01	4.10	4.00	0.17	12.23	3.90
$Z_{F,L}$	34.16	36.29	12.38	10.44	4.39	4.93	0.36	12.57	4.12
$Y_{F,H}$	30.77	35.25	14.26	10.88	4.47	4.23	0.24	13.53	4.73
$Y_{C,L}$	32.85	51.21	10.64	11.28	5.86	5.19	0.43	13.79	5.82
$Y_{C,H}$	40.57	46.59	8.36	11.91	8.83	8.17	0.97	11.19	9.53

CONCLUSIONS

1. With the increase in number of ply generally tenacity, breaking elongation, specific work of rupture, packing increases, except for coarse component yarn (344 tex) and high twist level (TM = 25.75). For such yarns tenacity decreases remaining the trend of other properties same as above.

2. As number of ply increases, specific flexural rigidity decreases for most of the cases. For coarse component yarn and high twist level rigidity increases with the increase of ply.

3. In case of low twist level (TM = 15.92 tex) the wetting decreases tenacity, specific flexural rigidity but increases breaking elongation and specific work of rupture. The strength retention of high twisted ply yarn is higher compared to low twisted ply yarn.

4. The effect of wetting on ply yarns having coarse component yarns are more pronounced compared to those of finer component yarns. In coarse component yarn and high twist, wetting increases rigidity of ply yarn.

5. Stress relaxation leads to increase in stress decay at low level of deformation whereas decrease in stress decay at high deformation level with increase in number of ply. In general, 3-ply yarn from coarse component yarn shows higher stress decay compared to its fine counterpart.

6. With increase in number of ply, cyclic loading results higher permanent set, *ie*, lower elasticity. Coarser component yarn and higher twist also leads to higher permanent set in the ply yarn.

7. When the yarns are ruptured after stress relaxation and cyclic loading, breaking elongation increases with respect to any pre-deformation in all the cases, but tenacity increase/ decrease depending on the effect of pre-deformation on structure of yarn.

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