



Time-dependent Mechanical Behaviour of Jute Yarn

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Abstract: The visco-elastic and elastic-plastic nature of jute yarn is described in this paper. Different mechanical properties like tenacity, initial modulus, breaking extension and specific work of rupture at different test speeds, stress relaxation, creep, and elastic-plastic nature of the jute yarn under cyclic loading have been studied in this paper. The tenacity of jute yarn initially increases with the increase in test speed but above 300 mm/min speed it shows a decreasing trend. The strength-time coefficient (K) for the yarn is calculated. Studies have been made on the decay in load, i.e., stress relaxation, and increase in elongation, i.e., creep, in 10 min time interval at three different levels of extensions and loads respectively. Cyclic loading of the yarn have been done to study the elastic and plastic deformation. Jute fibres are having fringed-fibrillar structure where chances of chain slippages are very low. The decay in stress and increase in elongation after 10mins interval are not very high. It has been found that plastic extension has increased and elastic extension has decreased from 1st to 10th cycle. The strength-time coefficient has increased at higher test speed and decreased at lower test speed. An approximate value of K in case of jute yarn has been derived which is nearly equal to the value proposed by Meredith(1950).

Keywords: Time-dependent mechanical behaviour, visco-elastic behaviour, stress-relaxation, creep, strength-time coefficient, cyclic loading.

I. Introduction

Mechanical behaviour expresses the responses of a material to applied force and deformation. It is associated with elastic or inelastic reaction of the materials when a force is applied and involves the relationship between stress and strain. Mechanical behaviour is expressed by means of the properties like tenacity, elongation, modulus, toughness etc. The stress-strain curve of jute yarn is non-linear and hence its mechanical properties deviate from that of elastic materials. Moreover, their mechanical behaviour is time-dependent which is known as the visco-elastic behaviour. Knowledge on time dependent mechanical behaviour and elastic-plastic nature of jute yarn are useful since they are subjected to load or deformation over a certain period of time, such as stacked filled bag, rope, geo-textiles, etc., and sometimes cyclic loading also, especially during weaving. Jute yarns are having very low extensibility and the shed depth in jute weaving is high that may cause permanent deformation in the yarn and thereby lowering the yarn strength. These behaviours are well studied in case of fibres and polymers but lacking in case of jute yarns. The tenacity of a yarn depends upon two important testing parameters, namely, the gauge length and the test speed. The tenacity has been reported either to increase (Midgley and Pierce, 1926; Meredith, 1950) or to show a rising tendency at the start followed by a fall with an increasing strain rate (Kaushik *et al.*, 1989; Peirce, 1926; Salhotra and Balasubramanian, 1985). The breaking extension, on the other hand, has been found to increase in some cases and to decrease monotonically in others with an increasing strain rate (Meredith, 1950). When a yarn specimen is strained during a tensile test, the inter-fiber pressure increases due to the transverse forces, this leading to a build-up of frictional resistance. In addition, the fibers are realigned to a certain extent, depending on the packing and the position of the fibers in the yarn. This realignment maximizes the contribution to the breaking load of the yarn from the individual fibers; however, the failure of yarn in a slow strain rate test is not catastrophic, which indicates that fiber

slippage is dominating the tenacity. As the strain rate increases, (Singh and Sengupta 1977) observed that the percentage of fiber rupture increases.

Meredith (1950) proposed the following empirical relation between breaking load and time to break during tensile testing:

$$F_2 - F_1 = K F_1 \log_{10} (t_1/t_2) \quad (1)$$

Where F_1 = the breaking load for a time to break at t_1 seconds, F_2 = the breaking load for a time to break at t_2 seconds and K = strength-time coefficient. The tenacity and breaking extension provide information only about the terminal point of the stress-strain curve. Other tensile properties like initial modulus, work of rupture, stress relaxation, creep, and elastic-plastic deformation under cyclic loading are also important to judge the performance of the yarn. Jute yarns have low extensibility and are subjected to various types of force during processing and use. These properties of jute yarn are studied in this paper.

II. Materials and methods

Jute yarn of count 276 tex spun in conventional jute spinning system, with 28.9 tex twist factor is selected for present work. The tensile properties of the yarn are measured with Zwick Roell 010 tensile tester. The testing is carried out at the gauge length of 500 mm with seven different test speeds, which are 10 mm/min, 50 mm/min, 100 mm/min, 200 mm/min, 300 mm/min, 600 mm/min and 1000 mm/min with 100 specimen measurements. The results are given in Table 1. Stress relaxation and creep behavior of the yarn are studied at three different levels, 25%, 50%, and 75% of breaking extension and breaking load respectively. The decay in stress and increase in elongation after 10 minutes time interval are given in Table 2. Cyclic loading of the yarn is done at three different levels, 25%, 50%, and 75% of breaking extension. The plastic and elastic extensions (%) are determined in the 1st cycle and 10th cycle. The values are given in Table 3.

III. RESULTS AND DISCUSSIONS

Table 1. Tensile properties of yarn at different test speeds

Test speed (mm/min)	Tenacity (cN/tex)	Breaking extension (%)	Initial Modulus (N/tex)	Specific work of rupture (mN/tex)	Test time (s)
10	10.03	1.55	5.42	0.75	46.92
50	10.30	1.52	5.72	0.75	9.39
100	10.41	1.62	5.27	0.79	5.17
200	10.56	1.73	5.05	0.86	2.88
300	10.66	1.59	5.32	0.81	1.87
600	10.31	1.50	5.66	0.75	1.04
1000	8.96	1.38	5.47	0.62	0.70

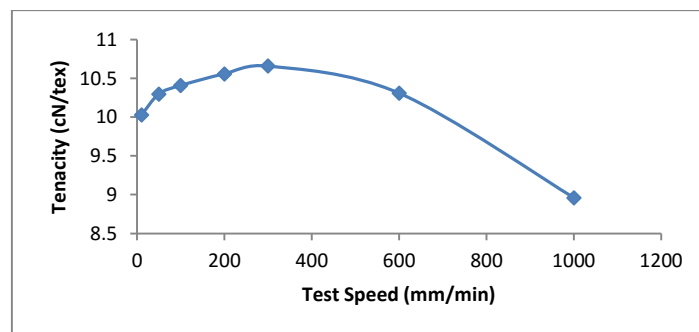


Fig 1: The variation in tenacities with test speeds

Figure 1 shows that with the increase in test speed the tenacity values increase upto 300 mm/min and then decreases. When a yarn specimen is strained during a tensile test, the inter-fibre pressure increases due to transverse forces, thus leading to the build up of frictional resistance. In addition the fibres are realigned to certain extent depending on the packing and the position of the fibres in the yarn. This realignment maximizes the contribution of breaking load of the yarn from the individual fibres. As the test speed increases the time for stress relaxation decreases resulting in an increase in tenacity. But when the test speed is higher than 300 mm/min time to break is too short for the realignment of fibres. This factor could therefore cause a drop in

tenacity because of the low contribution to tenacity of individual fibres which offsets the effect of stress relaxation. The net effect is that a very high test speed results in a low tenacity (1985). At the test speed of 300 mm/min and 10 mm/min, breaking load values, F_2 and F_1 , are 29.44 N and 27.69 N and the corresponding time to break in seconds, t_2 and t_1 , are 1.87 and 46.92 respectively.

$$\frac{F_2 - F_1}{F_1} = K \log \left(\frac{t_1}{t_2} \right)$$

$$\frac{29.44 - 27.69}{27.69} = K \log \left(\frac{46.92}{1.87} \right)$$

$$K = 0.045$$

The approximate value of K in case of different textile fibres is 0.1 as proposed by Meredith(1950). The value is lower in case of jute yarn which may be due to slippage of fibres in the yarn.

At the test speed of 300 mm/min and 1000 mm/min, breaking load values, F_2 and F_1 , are 29.44 N and 24.73 N and the corresponding time to break in seconds, t_2 and t_1 , are 0.7 and 1.87 respectively.

$$\frac{F_2 - F_1}{F_1} = K \log \left(\frac{t_1}{t_2} \right)$$

$$\frac{29.44 - 24.73}{24.73} = K \log \left(\frac{1.87}{0.7} \right)$$

$$K = 0.452$$

It is seen that the value of strength-time coefficient (K) has increased at the test speed from 300 mm/sec to 1000 mm/sec and the coefficient has decreased at the test speed from 300 mm/sec to 10 mm/sec. Strength time coefficient is higher when calculated at the test speeds of 300 mm/min and 1000 mm/min that may be due to insufficient time for stress relaxation and creep to occur.

The effect of test speed on breaking extension, initial modulus, and specific work of rupture is insignificant.

Table 2. Stress relaxation and creep after 10mins at different extensions and stress levels.

Level of extension (% of maximum extension)	Stress relaxation (%) $= \left(\frac{f_0 - f_{10}}{f_0} \times 100 \right)$	Level of load (% of maximum load)	Creep (%) $= \left(\frac{\epsilon_{10} - \epsilon_0}{\epsilon_0} \times 100 \right)$
25	8.0	25	28.8
50	7.2	50	23.7
75	8.5	75	20.0

f_0 = load at time $t = 0$ min

f_{10} = load at time $t = 10$ min

ϵ_0 = elongation at time $t = 0$ min

ϵ_{10} = elongation at time $t = 10$ min

Table 2 shows that stress relaxation (%) values at three different extension levels remain almost same and the decay in force is very low which is due to low extensibility of jute yarn. The creep (%) values decrease with the increase in load levels which is due to greater instantaneous deformation since the ultimate breaking extension of the yarn is low. This low value of stress relaxation and creep suit jute yarn for packaging, since filled in jute bags are stacked for a long time in the ware houses and hence the distortion of the bag will be low. These properties are also advantageous in case of jute geo-textiles.

Table 3. Plastic extension % and elastic extension % of total extension for 1st and 10th cycle at different extensions.

Level of extension (%)	Cycle index	Plastic extension (%)	Elastic extension (%)
25	1 st	50.8	49.7
	10 th	59.5	39.9
50	1 st	37.7	62.3
	10 th	47.8	52.1
75	1 st	43.5	56.6
	10 th	53.9	46.1

Table 3 shows that the proportion of plastic strain and elastic strain are almost equal but at the 10th cycle the proportion of plastic strain increases. So cyclic loading increases the permanent deformation of the jute yarn (10).

IV. CONCLUSION

Test speed has a profound effect on jute yarn tenacity. Yarn tenacity increases from 10 mm/min to 300 mm/min test speed and then it decreases with the increase in speed. Test speed has practically no effect on breaking extension, initial modulus, and specific work of rupture. Stress relaxation and creep values are very low in case of jute yarn. The permanent deformation is almost equal to elastic deformation and increases with the increase in number of cycles in cyclic loading.

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