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RUPTURE MECHANISM OF JUTE FIBRE

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The bast fibres such as ramie, hemp, flax and jute, in which the tiny cellulose ultimates are embedded in a cementing matrix including hemicelluloses, lignin and pectin, can be classed as two phase materials.[1] The existance of a two-phase structure within the cortex of wool has also been suggested.[2]

The strength of such composite materials where the cellulose units are very short (in case of jute it is 2–5 mm) must be determined largely by the extent to which the cementing materials i.e. lignin and hemicelluloses are capable of cementing them together. Some work has been done on the possible contribution of the cementing materials i.e. lignin and hemicelluloses of jute fibre on its tensile properties both in dry and wet coditions, but the subject is still a matter of conjecture.[3,4,5]

Failure and rupture mechanism of composite structures is very complex, it depends on various properties of the individual constituents, and the condition under which the fracture has occurred. It is of considerable interest to study the fracture mechanism of jute fibre, both from the technological view point and structural considerations.

Experimental

Materials.—A superior quality (Pak White Special) jute (*C. Capsularis*) was used for this study. Sample was taken from the mid portion of the strand and the individual fibres were combed out and finally by zoning method a numerical sample was drawn.

Methods.—The linear density (fineness) of the individual fibre was determined by weighing 10 cm length of fibre in a sensitive torsion balance. All fibres were conditioned at 20°C and 65% R.H. from dry state at least for 48 hr and tested under these conditions. Stress–strain properties were measured on an Instron Tensile Tester with a 5 cm test length and four different rate of extensions, 0.2, 0.5, 1.0 and 3.0 cm/min. At least 100 fibres were tested for each group. The stress–strain curves were plotted following Meredith's construction[6] and the initial Young's modulus was calculated at 0.5% extension.

An optical microscope was used for studying the fractured ends of the fibres and the diameter of the fractured point.

Results and Discussions

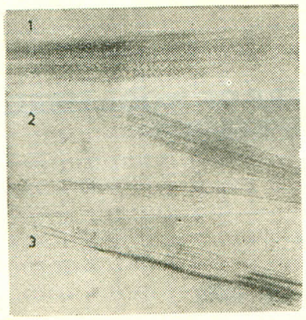
The stress–strain properties of jute at different rate of strain i.e. 0.04, 0.10, 0.20 and 0.60 cm/cm/min at standard condition are reported in Table 1. It will be seen that the specific stress (tenacity) and initial Young's modulus increased with the increase in rate of strain. For example, on increasing the rate of strain by 15 times the specific stress increased by about 36% and initial Young's modulus by 41%. The breaking extension practically remained unaltered with the increase in rate of strain. The linear nature of stress–strain curve for raw jute fibre suggests that the breakage of the fibres occurs within the elastic limit, and Hook's law of elasticity is roughly applicable in any part of the curve.[7] Though the increase in strength and modulus of jute fibre with the increase in rate of strain is very high compared to other textile fibres, it is not surprising at all considering its very little extensibility, (jute 1% compared to 10–15% for other textile fibres) orientation factor and composite structure of the jute fibre.

When a fibre is subjected to an unaxial stress it breaks at its weakest point.[8] Once an ultimate cell of the jute fibre is broken, the possibility of a catastrophic failure increases due to concentration of stress pattern at the edge of the broken ends. It is interesting to note that the probability of a clean cut or a catastrophic failure or breaking of all ultimates at a particular point increased with the increase of rate of strain and conversely the chance of slippage or the pulling out of ultimates proportionately decreased.

After the fibre is broken in tensile tests the broken ends of the fibres were examined under the microscope.

Table 1.—The Effect of Rate of Strain on Stress–Strain Properties of Jute Fibre.

Rate of strain cm/cm/min	Linear density (tex)	Specific stress ($gf\text{-}tex^{-1}$)	S.E.	Initial modulus ($gf\text{-}tex^{-1}$)	S.E.	Extension at break (%)
0.04	1.8	32.6	1.2	2376	247	1.3
0.10	1.9	38.2	1.19	3042	242	1.4
0.20	1.9	41.8	1.0	3308	198	1.4
0.60	1.9	44.4	2.0	3353	153	1.2



Plates 1–3.— 1. Clean rupture; 2. Slippage or pulled out; 3. Combination of the both.

Three typical rupture ends are shown in Plates 1,2 and 3 respectively. Plate 1 shows the clear rupture i.e. breaking of all ultimates at a particular point. This type of breakage almost always occurred at the weakest point along the fibre. Plate 2 demonstrates the slippage or pulled out of ultimate fibres from the cementing materials and Plate 3 is the combination of both i.e. breakage of few ultimates and slippage of the rest and this included in the latter group. This slippage of ultimates suggests that the cementing material is weaker than the ultimates and fails much earlier at a stress which could be realised by the ultimates if they were bound by a stronger matrix. It would be expected that the tenacity of the fibre ruptured by breaking all the ultimates at one point as shown in the Plate 1 should register a higher value than the fibre ruptured by slippage of ultimates (Plates 2 and 3); but curiously enough no significant difference in tenacity was observed between the two types of rupture.

In a composite fibre, such as jute, the ultimate strength of the fibre depends on the properties of the cellulosic ultimates, their number per unit cross-sectional area, spatial distribution and orientation, as well as on the cementing matrix composed of hemicellulose, lignin and other incrusting materials—their proportions and ability to bind the ultimates together. In jute fibre incrusting materials comes to about 40%. It has been shown by Roy[3] and Ridge *et al.*[5] that the strength of the jute fibre decreased when either of the incrusting materials i.e. hemicellulose or lignin is removed from it, more specially in wet condition.

It will be seen in Table 3 that the wet strength of jute fibre is less than the dry strength.

TABLE 2.—THE EFFECT OF RATE OF STRAIN ON RUPTURE.

Rate of strain cm/cm/min.	Linear density (tex)	Type of rupture	
		Clean cut (%)	Slippage (%)
0.04	1.8	33.3	66.7
0.10	1.9	38.7	61.2
0.20	1.9	63.6	36.4
0.60	1.9	75.0	25.0

TABLE 3.—STRESS–STRAIN PROPERTIES OF JUTE FIBRES ON DRY AND WET CONDITION.

Type of sample	Rate of strain cm/cm/min	Linear density (tex)	Tenacity (gf-tex^{-1})	S.E.	Extension at break (%)
Dry	0.20	1.9	41.8	1.0	1.4
Wet	0.20	1.7	31.3	1.25	1.1

It was also observed that the percentage slippage was more in wet condition than in dry, as could be expected. This decrease in strength on wetting is not due to weakening of the cellulose ultimates but to a swelling and softening action of the water on the cementing materials. Chakravarty and Hearle[9] have shown that the ultimate cells of the plant fibres have a greater strength and extensibility and lower modulus than the natural (composite) fibre. This suggests that the cellulose ultimates in a jute fibre cannot realise the full individual strength and hence slippage occurs.

References

1. H.M. Elder, J. Ferguson and A.W. Khandaker, J. Textile Inst., **61,** 166 (1970).
2. A. Robson, Textile Inst. Ind., **4,** 37 (1966).
3. M.M. Roy, J. Textile Inst., **50,** T 45 (1953).
4. P.B. Sarker, A.K. Mazumder and K.B. Pal, J. Textile Inst., **39,** T45 (1948).
5. B.P. Ridge, A.H. Little and J. Wharton, J. Textile Inst., **34,** T93 (1943).
6. R. Meredith, J. Textile Inst., **36,** T107 (1945).
7. R.R. Mukherjee, M.K. Sen and H. J. Woods, J. Textile Inst., **39,** T241 (1948).
8. F.T. Pierce, J. Textile Inst., **17,** T355 (1926).
9. A.C. Chakravarty and J. W.S.Hearle, J. Textile Inst., **58,** T651 (1967).