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Short Communications

Effect of lateral crushing on tensile property of bamboo, modal and tencel fibres

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The effect of lateral crushing on the tensile properties of bamboo, modal and tencel fibres has been investigated. A fibre crushing apparatus has been used for the purpose of lateral crushing of fibres. The influence of transverse compression on the axial mechanical properties of these fibres has been analysed. The study reveals that modal fibre sustained a higher loss in tensile properties compared to bamboo and tencel. The general phenomenon obtained from the study is that the percentage loss of strength and breaking extension varies from one fibre to another based on the fibre type and morphology.

Keywords: Bamboo, Crushing instrument, Lateral deformation, Modal, Tencel, Tensile property

Textile fibres may be considered elastic when subjected to very small strain, but when the strains become large, viscoelastic and permanent deformations occur[1]. Under the influence of tensile stresses, fibres may be damaged or broken by mechanical forces that are more or less transverse to the fibre axis. The effect of lateral crushing on the tensile properties of various textile fibres has been investigated by Lai and Onions[2]. This was the only concentrated research on lateral crushing and the loss in tensile strength was observed due to lateral crushing. The data on wool, silk, viscose and acrylic fibres after crushing were provided by Lai and Onions[2]. With the advent of new types of fibres, it is imperative that the effects of lateral crushing on the properties of these fibres are studied. The notable omissions by Lai and Onions[2] are bamboo, tencel and modal. Hence, a study on the loss in tensile strength due to lateral crushing of these fibres is needed. The present study has addressed all these issues.

In this study, to apply the crushing force, the fibre crushing apparatus[3] has been used. With this apparatus, the influence of transverse compression on the axial mechanical properties of bamboo, tencel and modal fibres has been studied. Lai and Onions[2] first reported studies on the lateral crushing of fibres which are very relevant to the area of carpet wear. Subsequently, Onions[4] presented data on the effect of crushing them for some more fibres which were omitted initially by them. Onions[4] work was more concerned with the wear of carpets which are subjected to crushing during their regular use. They have provided useful data on the loss in tensile strength of fibres such as wool, viscose and acrylic due to lateral crushing. Ozipek[5] went a step further and demonstrated how the data on crushing force of acrylic fibres could be used for explaining spinning behaviour in particular fibre rupture by opening rollers in rotor spinning and yarn properties. It was further shown that crushing test could also predict the trend of work of rupture during processing and could rationalize the application of fibres. Although the application of crushing force has been carried out on acrylic fibres because of their use in carpets, the other areas where it can be fruitfully used have not been explored. Murugan *et al.*[6] predicted the tensile behavior of laterally crushed filaments using finite element method and highlighted the importance of this process with respect to fishing net applications. The uniqueness of the study is the fact that for bamboo, modal and tencel fibres, data are provided for the first time.

Experimental

The tencel and modal fibres were sourced from M/s Lenzing AG, Coimbatore and bamboo fibres were purchased from local spinning mill. Fibre properties of tencel, bamboo and modal are shown in Table 1. Fibre properties were measured using HVI (ASTM D5867). The fibres were compressed by loads of 200, 400, 600, 800 and 1000 gf respectively in the crushing instrument. The deformed fibre specimen was studied for bundle fibre strength and elongation as it is more representative than single fibre strength. A rate of loading at 1 kg/s and

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gauge length 3.2 mm were maintained in Stelometer (ASTM D1445-05). Minimum ten readings were taken for each sample.

Fibre Crushing Apparatus

The forces were applied on a bundle of fibres by rolling a narrow steel wheel under load, across the fibres mounted on a hard flat surface[3]. A little trolley with a central steel wheel with a narrow run was driven on the fibres. The front view of the crushing apparatus is shown in Fig. 1. After placing the fibre specimen over base plate, crushing wheel was lowered and then brought into contact in a direction perpendicular to the fibre axis (or transverse direction) with the fibre specimen. The required load may be adjusted, as seen on the display. The base plate was now given forward and backward strokes of upto 60 mm. The deformed fibre specimen was then removed and taken for further testing. The lateral deformation of fibres is shown in Fig. 2.

Results and Discussion

The tensile properties of crushed fibres are summarized in Table 2. The influence of crushing load on tenacity and elongation of fibres are shown in Figs 3 and 4 respectively. The percentage weakening of the fibres after crushing is more in the case of modal followed by bamboo and tencel fibres. This is due to high degree of crystallinity in the structure of tencel as compared to other fibres. While testing with stelometer, due to low cohesive property of bamboo fibre, slippage of fibres was observed. This could be a reason for higher elongation values and reduced drop in elongation of bamboo fibres as compared to tencel and modal fibres. The loss in tensile properties of crushed fibre samples are well correlated with all the crushing loads (Table 3). The fibres become weaker and break at lower extensions as the applied loads are increased. With the strength of uncrushed fibre taken as the basis, the percentage loss in breaking strength and breaking extension at each successive load is calculated (Table 2).

The wall of bamboo fibres is many layered. An outermost thin layer is composed of cellulose chains making an angle of 35° to cell length and this is followed by other inner layers where the angle steadily decreases from outer to inner layers, first to about 20° and then to about 10°. These layers are separated by thicker layers[7]. The lateral crushing could alter the cell angles, trying to decrease them from outer to inner layers steadily. This will cause changes in the orientation of polymer which is reflected as a loss in tensile strength and elongation.

Tencel, although a cellulosic fibre, has a very high molecular orientation having higher crystallinity[8]. The degree of polymerization of tencel in terms of molar mass is 21% higher than those of modal fibres. Molecular orientation in tencel fibre is the highest and it exceeds the orientation factor of viscose fibres by 18%. Modal fibres show a compact external structure with very small pores and some large pores towards the centre. In Lyocell fibres, a more homogenous distribution of small pores is seen[9]. Tencel fibres show lesser loss in their tensile properties after

Table 1 — Properties of raw material used in fibre crushing

Fibre	Fineness den	2.5% Span length, mm	Tenacity g/tex	Elongation %
Bamboo	1.2	38	33.95	18.10
Tencel	1.3	38	43.20	15.60
Modal	1.3	38	40.61	19.40

Fig. 1 — Photograph of fibre crushing instrument[6]

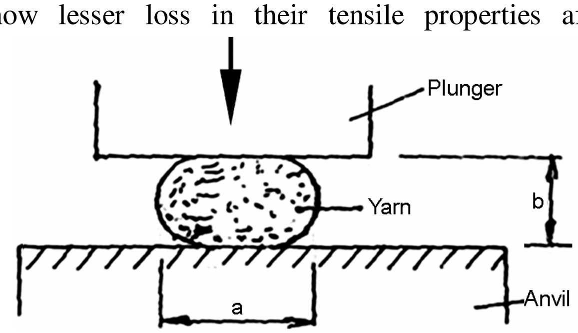

Fig. 2 — Lateral deformation of fibres during compression

Table 2 —Tensile properties of crushed fibres

Fibre fineness	Crushing load, gf	Tenacity, g/tex	% Reduction in tenacity after crushing	Elongation, %	% Reduction in elongation after crushing
Bamboo (1.2 den)	0	33.95	-	18.1	-
	200	29.98	11.6	17.8	1.7
	400	28.46	16.2	17.7	2.2
	600	27.13	20.1	17.6	2.8
	800	26.38	22.3	17.2	5.0
	1000	26.29	22.6	17.0	6.0
Modal (1.3 den)	0	40.61	-	19.4	-
	200	36.97	9.0	17.6	9.2
	400	34.44	15.2	17.4	10.3
	600	32.92	18.9	16.6	14.4
	800	31.44	22.6	16.4	15.5
	1000	31.30	22.9	16.2	16.5
Tencel (1.3 den)	0	43.20	-	15.6	-
	200	38.57	10.7	12.8	17.9
	400	37.83	12.4	12.3	21.2
	600	36.60	15.3	12.2	21.8
	800	36.58	15.3	11.7	25.0
	1000	36.18	16.3	11.4	26.9

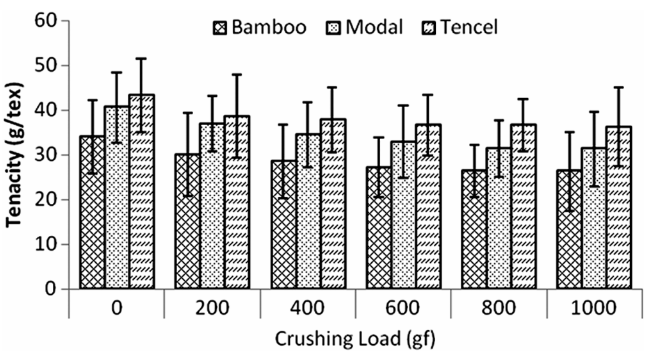

Fig. 3 — Influence of crushing load on tenacity

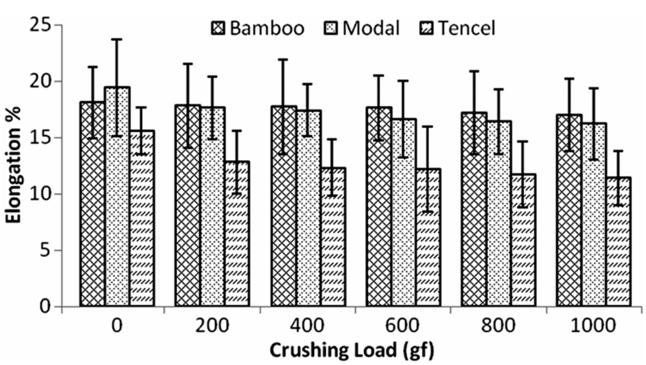

Fig. 4 — Influence of crushing load on elongation

crushing. This can be attributed to compact fibre centre. In modal, fibre centre has more number of pores and hence greater loss in strength becomes inevitable with an increase in crushing load.

Extension of covalent bonds, hydrogen bonds and to some degree, Van der Waals bonds might occur

Table 3 — Linear regression equations for tenacity and elongation at different crushing loads for various fibres

Fibre	Fibre fineness den	Tenacity		Elongation	
		Regression equations	R^2	Regression equations	R^2
Bamboo	1.2	$Y = -0.0072x + 32.300$	0.847	$Z = -0.0011x + 18.095$	0.962
Modal	1.3	$Y = -0.0092x + 39.232$	0.912	$Z = -0.0029x + 18.724$	0.848
Tencel	1.3	$Y = -0.0060x + 41.181$	0.740	$Z = -0.0035x + 14.410$	0.739

x — Crushing load (gf), *Y* — Tenacity (g/tex), *Z*— Elongation (%).

when strains are small. The fibre tries to recover its original state due to increase in internal energy accompanying the transverse deformation. If the deformation is small, the fibre recovers and can be considered elastic in the Hookean region.

When the strains are large arising due to high crushing loads, stress induced transformation from one crystalline form to another occurs in certain fibre structures. Here the structure switches from stable equilibrium to a meta-stable state corresponding to a slightly higher, minimum local energy. In this extended state, the external force is balanced by an internal restoring force. Due to the sluggish nature of the fibre in this state, the recovery from deformation will be delayed. In other words, the behavior is more viscoelastic than elastic.

When crushing loads are increased, the prevailing lateral forces may remain intact, and provide a restoring force sufficient to return the fibre to its original shape once the stress is removed. As the loading conditions become increasingly severe, it is found that the mechanical properties are dominated by plastic or flow-type processes. If the stress is removed at this point, there will no longer be a driving force for recovery, and so the deformation occurs. It does not mean that viscoelastic processes no longer occur, but they play a relatively less significant role.

The effect of lateral crushing on the tensile property of some recent fibres such as tencel, modal and bamboo has been investigated to provide some new data. It is found that modal fibre sustains a higher loss in tensile properties in comparison with bamboo and tencel. The percentage loss of strength and breaking extension varies from one fibre to another, depending on fibre type and morphology. This information could be used while spinning the yarns from these fibres on ring and rotor spinning, and also to know the potential of these fibres. It will also enable the manufacturers to consider redesigning of the various parts.

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