Cleavage analysis of Bamboo : a natural composite

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Abstract
Dry bamboo samples of dendrocalamus strictus species were splitted along the fiber direction to make slats using single point cutting tools with different included angles to get suitable cutting tool. Shear force required to split (cleave) the bamboo decreases from botom to top along fiber direction. Cutting tools of 15° to 25° included angles were found suitable for safe and low load input. Shear force required to split the bamboo culm to make slats decreases in the range of 2.20-1.45 KN from bottom to top and to make slivers from slats increases in the range of 1.70-2.01KN from inner to outer region of bamboo culm along fiber direction.

Keywords: Slats; Slivers; Included angle; Shear Force.

1. Introduction
Among plants, bamboo is a structurally smart plant and functionally gradient materials, which resembles a long cylindrical fiber-reinforced composite with several internodes and nodes along its length [1]. There are over 1000 species of bamboo and for certain varieties, a tensile strength of 370 MPa was reported [2]. The establishment of the INBAR contributed to the renewed intrest in research on bamboo for development of new products and to increase of usability of bamboo[3]. Mechanical properties of bamboo culms for different species have been reported by researchers [4-8]. Bamboo does not have radial cells along fiber direction i.e. axis of bamboo culm, which is present in trees to increase their shear strength parallel to axis. This is the reason why bamboo culm split easly. This could be a disadvantages for nailing bamboo but it could also be a great advantages for other applications. The maximum load required to shear the bamboo specimens in such a manner that the moving portion (cutting tool) has completely cleared the stationary portion (bamboo samples) is called shear resistance of bamboo. Variation of shear force and effective cutting tool geometry required in sliver making from different regions of bamboo culms is hardly reported . Therefore we report here the variation of shear forces required to split the bamboo culm to make slats and to split slats to make slivers with different included angle of cutting tools and found effective cutting tool geometry.

2. Materials and methods
Four year old green bamboo (Dendrocalamus strictus species) culms were obtained from TERI Gram , District Gurgaon (Haryana), India. Moisture content of green bamboo collected were 37% at the time of felling (Digital moisture meter model MD-4G). Moisture content is then reduced to 10-12% by sundrying to make dry bamboo. A full length bamboo was labeled at nodes and internodes as shown in Fig. 1. A raw bamboo culm was crosscut perpendicular to axis of bamboo using hacksaw to make samples of 12 cm length of without nodes.Eight samples were prepared and labeled 1 to 8 from bottom to top. Each samples were manually spitted into two halves along axis of bamboo i.e. the fiber direction for easy splitting of slats on radial drilling machine as shown in Fig.2. Fixture of mild steel rod was prepared as shown in Fig. 3 to hold cutting tool on radial drilling machine . Cutting tool with 50^o included angle were prepared with suitable geometry from mild steel plate of 5mm thickness as shown in Fig.4 . Other geometry of cutting tools were prepared using grinding machine by reducing angle of previous cutting tool used. Angle of cutting tools were measured by bevel protector.

3. Testing
To evaluate effective cutting tool geometry and shear force to split the dry bamboo along fiber derection , cutting tool of 50^o included angle (Fig.4) was placed first into the fixture (Fig.3) and tightly screwed. This fixture was tightened on radial drilling machine. Samples were vertically placed on the weighing machine (Sansui SPP series, capacity max. 300 kg, min. 5 grams, accuracy 5 grams) for shear force measurement. Shear forces was applied manually by drilling machine to split the dry bamboo samples along fiber direction to make slats as shown in Fig.2 for cutting tool of 50^o included angle to get maximum shear force . Further maximum shear force have been also evaluated for other angles of cutting tools (Table 1) so that effective cutting tool could be found on the basis of safe and low load input for splitting of bamboo. A typical curve for variation of shear force with distance of cutting too travel along fiber direction from bootom to top during splitting the bamboo samples to make slats is shown in

Fig. 5. Slats obtained from each samples from previous experiments were further splitted for making slivers using cutting tool of 20° included angle along fiber direction from inner to outer of bamboo culm. The maximum shear force required to split the slat to make slivers is given in Table 2.

Table 1
Shear force (KN) to split dry bamboo into slats

Sample	Included angle of cutting tools							
	50^o	45^o	40^o	35^o	30^o	25^o	20^o	15^o
1	2.55	2.54	2.54	2.30	2.22	2.20	2.10	1.95
2	2.53	2.50	2.50	2.30	2.20	2.13	2.08	1.88
3	2.45	2.45	2.42	2.28	2.12	2.08	1.97	1.82
4	2.10	2.09	2.08	2.00	1.97	1.91	1.87	1.70
5	1.90	1.83	1.80	1.72	1.71	1.69	1.65	1.65
6	1.88	1.88	1.82	1.71	1.68	1.65	1.59	1.55
7	1.74	1.73	1.70	1.67	1.60	1.54	1.53	1.53
8	1.64	1.60	1.58	1.55	1.49	1.45	1.34	1.30

Length of testing materials: 12cm

Table 2
Shear force (KN) to split slats into slivers with cutting tool of 20^o included angle

Sample No.	Regions of bamboo culms		
	inner	Middle	outer
1	1.90	1.92	2.01
2	1.88	1.91	1.99
3	1.82	1.85	1.89
4	1.80	1.82	1.88
5	1.80	1.82	1.87
6	1.75	1.79	1.87
7	1.72	1.75	1.86
8	1.70	1.75	1.80

Length of testing materials: 12cm

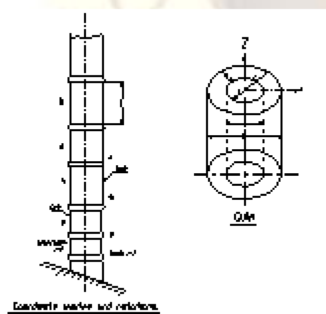

Fig. 1. Bamboo culms and sample.

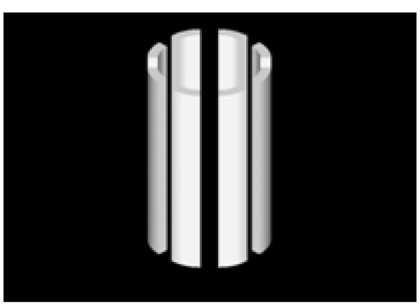

Fig. 2. 3D View of sectional slats.

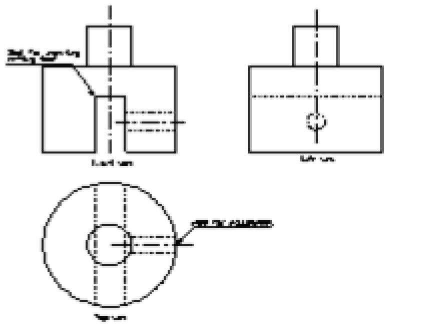

Fig. 3. Fixture for holding cutting tools.

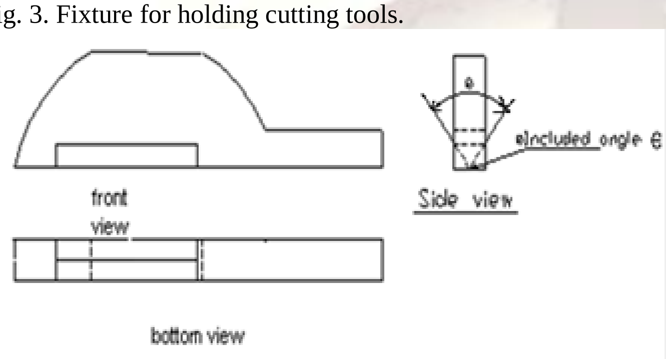

Fig. 4. Geometry of cutting tools.

4.Results and Discussion

It was observed that the dry bamboo culm were splitted completely into two slats after certain distance travel of cutting tool along fiber direction where shear force required to split the dry bamboo culm to make slats decreases with decrease in included angle of cutting tools but distance traveled by cutting tools along fiber direction increases with decrease in included angle. Distance above which shear force were drastically reduced to low level is known as critical distance and after this distance shear force was continue at low level just before of end of split and finally become zero to split the dry bamboo culm into slats (Fig. 5) . It were observed that critical distance were less than depth of cutting tool included angle (i.e. depth = 2.5 mm/tan10^{o}= 14mm).

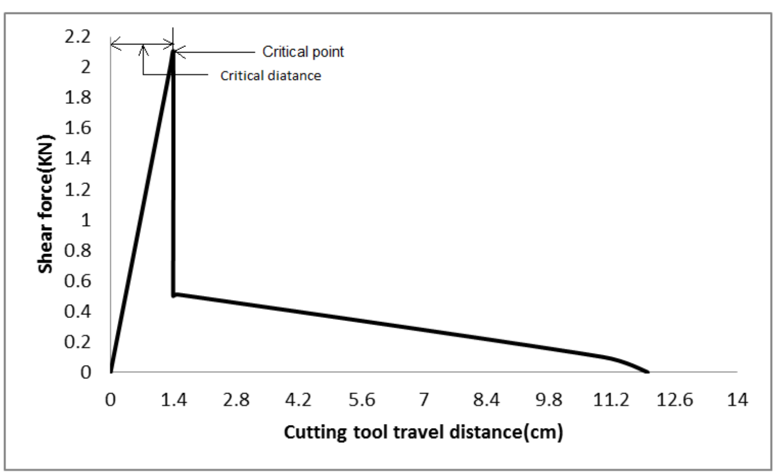

Fig.5. A typical curve for variation of shear force with cutting tool travel distance along fiber direction from bottom to top of bamboo culm.

Furthermore it is analysed that shear force required to split the dry bamboo to make slats decreases from bottom to top along fiber direction with all cutting tools due to increase in volume fraction of fibers and decrease in thickness of bamboo culms (Table 1). During experimental investigation it was observrd that shear force is low in case of low cutiing tool angle but tool approches to fail below 15° included angle. Shear force was high above 25° included angle where bamboo slats were came out with force which may hurt the operator. Thus it is concluded that for safe operation effective cutting tool angle varies from 15° to 25° for splitting the bamboo along fiber direction. It is easy to split the bamboo along fiber direction than across fiber direction using suggested single point cutting tool because less number of fibers come across during splitting in former cases, in which hard cellulosic fibers bind by soft lignin matrix where matrix fails easily . It is difficult to split the bamboo across fiber direction due to large number of fibers come across which is difficult to split/cut by single point cutting tool. For this, multipoint cutting tool such as hacksaw is suitable. Shear force required to split the bamboo slats to make slivers decreases from bottom to top of bamboo due to increase in volume fraction of fibers and shear force required to split slats to make slivers increases from inner surface to outer surface due to increase in fiber density and silica content which is hard to split inspite of increase in volume fraction of fibers from inner to outer surface. Shear force required with cutting tool of 20° included angle to split bamboo to make slats decreases in the range of 2.20 -1.45KN from bottom to top and to split slats to make slivers increases in the range of 1.70-2.01kN from inner to outer region of bamboo culm along fiber direction (Table 2).

5. Conclusions

1. Dry bamboo culm splits completely into two slats after certain distance travel of cutting tool along fiber direction where distance traveled by cutting tools along fiber direction increases with decrease in included angle. Distance above which shear force were drastically reduced to low level is known as critical distance and after this distance shear force was continue at low level just before of end of split and finally become zero to split the dry bamboo culm into slats.
2. Effective cutting tool angle varies from 15^o to 25^o for splitting dry bamboo to make slats and slivers and finally laminas.
3. Shear force to split the bamboo along fiber direction decreases in the range of 2.20- 1.45KN from bottom to top and increases in the range of 1.70-2.01KN from inner to outer region.

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Figure captions

Fig. 1. Bamboo culms and sample.
Fig. 2. 3D View of sectional slats.
Fig. 3. Fixture for holding cutting tools.
Fig. 4. Geometry of cutting tools.
Fig.5. A typical curve for variation of shear force with cutting tool travel distance along fiber direction from bottom to top of bamboo culm.

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