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Creep behaviour of *Bambusa blumeana* in bending

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Abstract: Long-term bending tests on *Bambusa blumeana* culms with a free span of 4.5 m have been performed to study the creep (deformation under long-term loading) in bending. The Burger's model has been used to describe the results and the parameters have been determined. Influence of the diaphragm and the outer skin of the culm and relative humidity (RH) on creep has been studied.

Key words: Creep, bending, Burger's model, *Bambusa blumeana*.

INTRODUCTION

Creep (deformation under long-term loading) in bending is an important phenomenon. Creep in timber has been well studied but no information is available on the behaviour of bamboo culms under long-term loading. The validity of Burger's model has been tested to describe the creep phenomenon in bamboo.

The aim of the study was to find out whether creep and recovery are important phenomena in bamboo, to determine the parameters in the stress-strain formula of the Burger's model and to study the influence of diaphragm, outer skin, and relative humidity.

The mathematical formula for the stress-strain relationship, based on Burger's model is given by equation (1).

$$\varepsilon\,(t) = \frac{\sigma}{E_1} + \frac{\sigma}{E_2} + \frac{\sigma}{\eta_1}t - \frac{\sigma}{E_2}e^{-E_2 t/\eta_2} \qquad (1)$$

in which:
ε = strain, dimensionless,
σ = stress, in N/mm^2,
t = the time, in sec,

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E_1 and E_2 = modulus of elasticity, in N/mm^2,
η_1 and η_2 = viscosity, in mm^2/N sec.

Amada and Lakes (1997) have reported the viscoelastic properties of bamboo. The deformation under a repetition of wetting and drying has been reported by Saito and Arima (2002). However, these articles deal with very small specimens of 3 x 3 mm by 52 mm, and 1 x 5 mm by 110 mm. Obataya *et al.* (2007) and Yoko *et al.* (2002) have published interesting data on creep in bamboo from a fundamental point of view.

MATERIALS AND METHODS

The bending tests were carried out on full length culms of *Bambusa blumeana* obtained from the Philippines. The culms were conditioned at RH 70 per cent and 20 °C. This resulted in a moisture content (MC) of 12 per cent. The mean density was 823 kg/m^3 with a standard deviation of 119 kg/m^3. A four-point bending test with a free span of 4.5 m was employed as it represents the actual building practice closely. Concrete blocks and steel disks were used as load. The deformation was measured at mid span with a potentiometer. The load was applied in such a way that the initial strain was 0.002. The reason for this initial strain is to have an initial deformation of about 100 mm, which allowed measurement of creep and recovery accurately. However, a disadvantage of this was loading up to 55 per cent of the assumed short-term strength resulting in failure of some culms. The culms were loaded for two months, followed by one and a half month recovery (unloaded); this was repeated three times. The total test period was 14 months.

Table 1 provides details of all long-term tests performed. "No diaphragms" means culms with the diaphragms removed, and "skin removed" means the outer skin of about 1 mm removed.

RESULTS

An example of a strain-time diagram is given in Figure 1. In about 400 days the creep caused an increase of the strain from 0.0022 to almost 0.003 during recovery, the strain was as low as 0.0002 to 0.0004. Most culms showed less deformation than this.

Table 1. Timetable of tests

Period	Type of tests	No. of culms	RH (%)
Oct. 1981 - May 1983	Normal culms	8	70
May 1983 - Oct. 1984	No diaphragms	5	70
June 1983 - Oct. 1984	Skin removed	3	70
Jan. 1985 - July 1985	Normal culms	8	60

(initial strain = 0.002)

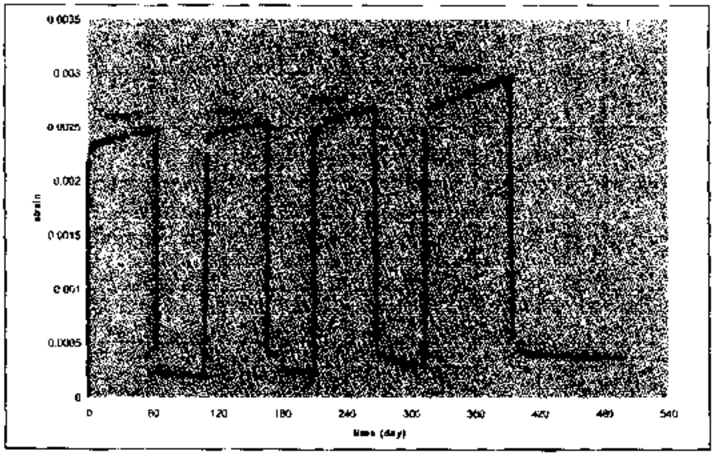

Figure 1. An example of a strain-time diagram.

The results from the first series of tests, on normal culms, are given in Table 2. For the eight culms, the deformation at mid-span is given in mm at the end of each of the four creep periods, and at the end of each of the four recovery periods. The deformation increases from 100 per cent initial to average values of 112, 115, 117 and 119 per cent at the end of the creep periods. The permanent deformation at the end of the four recovery periods is as low as 3, 3, 4 and 6 per cent. Table 3 gives the values for E_1, E_2, η_1 and η_2.

The results of the tests on culms without diaphragms are given in Tables 4 and 5. Remarkably, the creep increases less than that of normal culms. The permanent deformation at the end of five recovery periods is nearly the same. Table 5 gives the values for E and η. The removal of diaphragms has only a small influence on the deformation and on E_t and η_t. One would expect the diaphragms to act as a type

Table 2. Deformation of normal culms (n = 8)/at mid-span

Culm No.	Initial value (mm)	Deformation at mid-span (mm)							
		Creep 1	Creep 2	Creep 3	Creep 4	Recov. 1	Recov. 2	Recov. 3	Recov. 4
2	99.8	116.9	119.8	124.1	125.1	2.7	3.4	6	7.6
3	96.6	107.2	109	111.7	113.1	2.7	2.7	6	5.3
4	112.4	128	135	137.9	134.4	3.4	7.5	10	8.2
5	110.4	118.8	121.9	122.4	119.1	0.5	1.6	3.5	0
6	116.8	127.8	129.9	131.3	132.9	4.3	3.9	4.4	5.9
7B	103.5	112.2	114.5	114	110.4	1.3	2.1	4	0
8	106	115.2	118.2	120	119.9	2	1.3	2.5	3.6
9	86.5	104.7	107.7	112.7	125.9	8.4	9.8	13.2	16.1

Table 3. Modulus of elasticity and viscosity of normal culms (n=8)

	Creep 1	Recov. 1	Creep 2	Recov. 2	Creep 3	Recov. 3	Creep 4	Recov. 4	Total
E_1, Mean	21180		19790		19790		20280		20260
SD.	2080		1840		1920		1930		1936
CV%	10		9		10		10		10
E_2, Mean	342000	720000	802000	501000	530000	414000	487000	395000	523875
SD.	198000	1148000	346000	317000	178000	175000	185000	199000	343250
CV%	58	159	43	63	34	42	38	50	66
η_1, Mean	2.53E+12	3.44E+12	3.11E+12	3.20E+12	3.09E+12	6.64E+12	3.91E+12	8.07E+12	4.25E+12
SD	8.64E+11	9.29E+11	1.46E+12	1.26E+12	1.80E+12	6.49E+12	2.14E+12	3.96E+12	2.36E+12
CV%	34	27	47	39	58	98	55	49	56
η_2 Mean	6.80E+10	1.13E+11	3.74E+11	2.32E+11	1.45E+11	1.32E+11	1.19E+11	4.97E+10	1.54E+11
SD	9.32E+10	1.77E+11	2.13E+11	1.97E+11	9.96E+10	1.86E+11	5.29E+10	7.54E+10	1.37E+11
CV%	137	157	57	85	69	141	44	152	89

Table 4. Deformation of culms with diaphragms removed (n=5)

Culm No.	Initial value (mm)	Deformation at mid-span (mm)									
		Creep 1	Creep2	Creep 3	Creep 4	Creep 5	Recov.1	Recov. 2	Recov.3	Recov.4	Recov.5
2B	115.8	125.2	128.9	132.2	134.6	134.4	0	2.8	6.1	5.7	7.3
3B	102.4	107.8	110.4	111.9	112.8	112.7	3.7	4.4	7.4	6.5	8.1
6B	113.6	124.9	132.4	136.7	137.7	failed	0.8	2.7	6.9	6.3	failed
8B	90.1	99.7	102.1	102.1	102.9	103.7	1	2.2	4.4	3.6	4.6
9B	109.5	124.7	128	129.5	130.7	131.3	2.7	4.3	7	5.7	7.5

Table 5. Modulus of elasticity and viscosity of culms with diaphragm removed (n=5)

	Creep 1	Recov. 1	Creep 2	Recov. 2	Creep 3	Recov. 3	Creep 4	Recov. 4	Total
E_1, Mean	21010		21120		20950		20875		20930
SD	1610		1530		1620		1760		1460
CV%	8		7		8		8		7
E_2, Mean	470950	478680	365570	323180	308195	535470	359920	412020	410180
SD	147815	77595	62680	134645	71605	80755	98760	75800	113620
CV%	31	16	17	42	23	15	27	18	28
η_1, Mean	1.86E+12	4.25E+12	2.21E+12	3.98E+12	4.61E+12	4.27E+12	4.49E+12	8.27E+12	4.44E+12
SD	5.46E+11	7.76E+11	5.39E+11	5.15E+11	2.02E+12	1.06E+12	9.04E+11	2.85E+12	2.29E+12
CV%	29	18	24	13	44	25	20	34	52
η_2, Mean	1.06E+11	1.04E+11	7.40E+10	5.21E+10	6.04E+10	5.01E+10	7.42E+10	1.21E+11	9.01E+10
SD	7.08E+10	1.61E+10	2.47E+10	2.81E+10	1.38E+10	1.10E+10	2.38E+10	4.36E+10	5.50E+10
CV%	67	15	33	54	23	22	32	36	61

Table 6. Deformation of culms with skin removed (n=3)

Culm No.	Initial (mm)	Deformation at mid-span (mm)							
		Creep 1	Creep 2	Creep 3	Ceep 4	Recov.1	Recov. 2	Recov.3	Recov.4
4B	96.7	109.0	110.8	111.4	112.0	4.9	8.4	7.2	8.7
5B	88.1	101.2	103.7	104.0	103.9	7.7	10.7	9.8	11.1
7C	89.9	100.2	100.6	101.1	102.2	3.4	5.8	5.5	5.1

ofdowel keeping the upper and lower halves of the cross section together during bending; however, this is not supported by the test results.

Table 6 shows the results of the tests on culms without outer skin. The number of culms was limited to three as removal of 1 mm outer skin manually, without damaging the culm, was cumbersome. The results, not much different from those for normal culms, are quite surprising. One would normally expect that the outer skin with its high content of silica would diminish the creep and recovery, but it was not so.

Tables 7 and 8 give the results of the tests carried out at RH 60 per cent. Table 7 gives the strain instead of the deformation at mid-span. Comparing these values with the

Table 7. Strain values of culms tested at 60% RH (n=8)

Culm	Initial ε	Strain at mid-span (x10^{-3})				
		Creep 1	Creep 2	Recov. 1	Recov. 2	Recov. 3 (RH 78%)
4D	1.73	2.12	2.20	0.21	0.28	0.17
5D	1.71	1.89	1.94	0.07	0.11	0.04
6D	1.82	2.10	2.16	0.13	0.17	0.07
7D	1.99	2.25	2.32	0.11	0.15	0.06
8D	1.89	2.16	2.19	0.16	0.19	0.10
9D	2.05	2.43	2.49	0.17	0.22	0.14
10D	2.19	2.65	2.74	0.27	0.34	0.20
11D	2.12	2.50	2.56	0.22	0.27	0.13

Table 8. Modulus of elasticity and viscosity values of culms tested at RH 60% (n=8)

	Creep 1	Recov. 1	Creep 2	Recov. 2	Total
E_1, Mean	24210		21590		22900
SD	2785		2390		2587.5
CV%	12		11		11
E_2, Mean	191530	503370	472640	545540	428270
SD	84990	122130	107490	98880	103372.5
CV%	44	24	23	18	27
η_1, Mean	1.48E+12	2.69E+12	1.63E+12	2.34E+12	2.035E+12
SD	4.74E+11	7.61E+11	3.16E+11	4.54E+11	5.013E+11
CV%	32	28	19	19	25
η_2, Mean	3.69E+10	5.04E+10	3.71E+10	5.21E+10	4.413E+10
SD	3.30E+10	1.31E+10	9.43E+09	1.74E+10	1.823E+10
CV%	89	26	25	33	44

values for the normal culms tested at RH 70 per cent, there is no significant difference; normally, a lower RH should result in less deformation, which is not the case here.

Table 7 provides values after an extra period of recovery at RH 78 per cent. This resulted in a decrease of the strain. Table 8 gives the values for E and η, which should be compared with those for normal culms. The value for E_1 is 13 per cent higher, which makes sense. It is difficult to find any logic in the other comparisons.

DISCUSSION

The creep and recovery are important phenomena in bamboo. In view of the fact that bamboo is becoming an accepted engineering material, knowledge about these phenomena is important. Further tests are warranted to find out reasons why creep in bamboo is less than in timber.

CONCLUSIONS

In these tests, creep in bamboo is up to 20 per cent of the immediate deformation, and the permanent deformation is 6 per cent or less. The hypothesis that the diaphragms influence the creep is not supported by these tests. The same applies for the outer skin of the culm. Differences in relative humidity did not result in a significant difference in creep.

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