Effect of Beating on the Visco-elastic Properties of Bamboo Paper

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SUMMARY

Effect of beating on the visco-elastic properties of paper has been studied. It is observed that recovery is always less than deformation at all level of freeness. Deformation and recovery decrease with increase on beating. Visco elastic nature of the paper is confirmed as total deformation is more pronounced than total rec overy which in turn is less pronounced than permanent set. Sheet formation and fibre bonding effect the Visco-elastic properties of paper as indicated by the negative linear relationship between breaking length and total deformation and net recovery at different freeness levels.

INTRODUCTION

Paper has been classified as a visco-elastic material[1] i.e. it possesses both plastic as well as elastic properties. If a load smaller than the elastic limit is applied to paper sheet, it suffers an instantaneous elastic (recoverable or reversible) deformation followed by a prolonged plastic deformation (irrecoverable or irreversible) which is dependent upon the time. The irrecoverable or irreversible component of the time dependent deformation procured under a constant load level below the elastic limit is called creep. Thus after a certain period, if the constant load is removed, the deformation (strain) may only be partly recovered (elastic recovery). The part that is irrecoverable is the permanent set associated with creep.

If, on the other hand, a constant load larger than the elastic limit is applied, both elastic strain and permanent set are developed instantaneously with a much larger proportion of the latter type in the total strain. In addition, the permanent set grows with time. To differentiate gross permanent set caused by load levels above the elastic limit from permanent set caused by load levels below the elastic limit the term plastic flow is used for the former and 'creep" for the latter effect.

The first descriptions of the viscoelastic behaviour of paper were drawn from the load-deformation tests. The work of Gibbon[2] and Farebrother[3] established that the early deformation at low stress levels in a load deformation test stress was largely elastic and increased linearly with the stress but that at higher loads, the specimen was more easily deformable in a manner indicating flow that is. it showed larger increases of strain for a given increase of stress than in the earlier stages. The later deformation was largely non-recoverable. Andersson and Berkyto[4] studied the effect of relative humidity and temperature on the load-deformation properties of paper.

A high rate of strain recovery is desirable in printing papers[5] to ensure reproducible positioning of the paper under various printing plates. In recent years increased attention is being directed to study the pre-rupture mechanical behaviour of paper chiefly by means of load deformation tests.

Van den Akker[6] has related the mechanical properties of paper to the structural characteristics of sheet. Therefore a preliminary study has been carried out on plastic flow properties of bamboo papers obtained at different freeness.

EXPERIMENTAL

BEATING AND SHEET MAKING OF BAMBOO PULP

Bleached bamboo pulp was used in the preparation of standard sheets. The pulp was beaten to a desired level of freeness i. e. 550, 400, 250 and 100 ml. (C.S.F.) in valley beater at 1.57% consistency at 25°C temperature. Sheets of 60 g.s.m. were made and dried in ring and plates. Specimen strips were cut to 120×15 mm for creep study. The sheets were also tested for breaking length, burst factor and tear factor.

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LOAD-DEFORMATION TESTER

A load–deformation tester was designed and fabricated at F.R.I. for studying the creep properties of paper (Fig.1). Six units were mounted on a single frame. The units were designed to deliver a constant dead load (275 g) to a paper specimen (100×15 mm) to keep it in a constant stretched position. The paper strip was fixed between the two clamps. The elongation of the strip was measured by the shift of cross mark on the strip. The shift was measured with the help of a travelling micro scope with a least count of 0.001 cm.

To calculate the maximum load to be applied, initial set of experiments were conducted with the application of 20, 40, 60 and 80 % of the breaking load which was determined by a tensile tester. It was observed that the application of load beyond 60% of breaking load causes rupture of sheet within 3 hours. Loads below 60% of breaking load, deformation after 3 hours, was negligible. Hence the applied load was taken as 60% of breaking load and total time of experiments was kept as 6 hours i.e. 3 hours for deformation and 3 hours for recovery.

CALCULATION FOR DEFORMATION AND RECOVERY

Deformation and recovery have been expressed in percentage. These have been calculated by the ratio of change in length and original length.

DEFORMATION

Instantnaneous deformation (d_i) delayed deformation (d_d) due to maximum applied load were calculated as follows:—

$$d_i, \% = \frac{L_1 - L}{L} \times 100 \quad \text{.........1}$$

$$d_d, \% = \frac{L_2 - L_1}{L} \times 100 \quad \text{......... 2}$$

$$d_t, \% = \frac{L_2 - L}{L} \times 100 \quad \text{......... 3}$$

Where L = Original length of strip (10 cm)

L_1 = Length of elongated strip after about 5 seconds with maximum applied load.

L_2 = Length of elongated strip after 3 hours with maximum applied load.

Total deformation (d_t) can also be obtained by adding d_i and d_d.

$$d_t = d_i + d_d \quad \text{......... 4}$$

RECOVERY

Instantaneous recovery (R_i), delayed recovery (R_d) and total recovery (R_t) were calculated by the similar expressions as (5), (6), (7).

$$R_i, \% = \frac{L_2 - L_3}{L} \times 100 \quad \text{......... 5}$$

$$R_d, \% = \frac{L_3 - L_4}{L} \times 100 \quad \text{......... 6}$$

$$R_t, \% = \frac{L_2 - L_4}{L} \times 100 \quad \text{......... 7}$$

Where

L_3 = Length of elongated strip immediately after removing maximum applied load.

L_4 = Length of elongated strip after 6 hours without maximum applied load.

Net recovery (R_n) was computed by equation (8).

$$R_n\% = d_t\% - R_t\% = \frac{L_4 - L}{L} \times 100 \quad \text{......... 8}$$

R_n gave the permanent set caused after 3 hrs. loading followed by 3 hrs. delayed recovery.

RESULTS AND DISCUSSION

The strength properties of bleached bamboo pulp sheets beaten to different freeness, are recorded in Table I. It is observed that breaking length, tear factor, burst factor increase as the freeness falls while bulk shows an inverse order with freeness.

Deformation and recovery at different time intervals and freenes have been given in Table II. A typical calculation for deformation and recovery at 250 freeness has been done in Table III. Similar deformation and recovery have been calculated and recorded in Table IV. It is observed that recovery is always less than deformation with increase in beating.

Elongation has been found from Table–II by substracting the original length of strip. Elongation at the different freeness has been plotted

TABLE—I STRENGTH PROPERTIES OF BLEACHED BAMBOO PULP SHEETS BEATEN TO DIFFERENT FREENESS

Sl.	Freeness ml. (CSF)	Breaking length m	Burst factor	Tear factor	Bulk (cm^3/g)
1.	550	500	1.47	64.7	2.40
2.	400	1500	9.68	109.7	2.12
3.	250	2670	13.24	82.4	1.91
4.	100	3820	17.65	82.3	1 70

TABLE—II LENGTH OF STRIP OF PAPER WITH AND WITHOUT LOAD AT DIFFERENT TIME INTERVAL AND FREENESS (original length of strip L=10 cm. and initial dead load 275 g.)

Sl. No.	Time mts.	Freeness (CSF) 550 ml.	400 ml.	250 ml.	100 ml.	Remarks
		Deformation				
1.	0 (5 secs)	10.236	10.199	10.160	10.130	L_1=length of strip with maximum load after 5 secs of loading.
2.	5	10.312	10.269	10.206	10 162	
3.	20	10.323	10 283	10.221	10.179	
4.	40	10.337	10 293	10.234	10.187	
5.	60	10.340	10.299	10.242	10.193	
6.	100	10.348	10.302	10.246	10 200	
7.	140	10.352	10.303	10.249	10.202	
8.	180	10.355	10.304	10.250	10.203	L_2=length of strip with maximum load after 180 minutes.
		Recovery				
9.	180	10.315	10.260	10.203	10.152	L_3=length of strip immediately after removal of load.
10.	200	10.286	10.243	10 86	10.140	
11.	240	10 276	10.236	10 184	10.138	
12.	280	10.272	10.234	10.182	10.137	
13.	320	10.271	10.230	10.180	10.136	
14.	360	10.271	10 225	10.178	10.135	L_4=length of strip without load after 180 mts. of removing max. load.

against time of loading in Fig. 2. Fig 2 shows that all the curves follow the same trend and elongation is reduced by improved bonding lower freeness) resulting from the increase interfirber bonding on beating.

Deformation and recovery (from Table IV) have been plotted against freeness in Fig. 3 and 4 respectively.

Plastic flow as evidenced by permanent set is considerably reduced (to as much as 50%) by increased beating due to better fibre to fibre bonding.

Change in permanent set is greater than change in total deformation whieh in turn is greater than total recoveryi.e.$\triangle R_n > \triangle d_t > \triangle R_t$. This indicates that at the stress level of 60% the major part of total deformation d_t is plastic in nature because change in d_t is almost equal to change in permanent set. Also total recovery R_t (combined elastic and plastic recovery) forms only a small percentage of the total deformation again indicating major part of d_t being irrecoverable plastic deformation. This indicates that the experiments were carried out in the stress range of plastic flow.

Total deformation and permanent set of pulp sheets at different freeness have been plotted in Fig. 5, against breaking length. Total deformation and permanent set have a negative linear relationship with breaking length. Both lines have approximately same slope. This clearly indicates that creep properties of pulp sheets depends upon the sheet formation and fibre to fibre bonding.

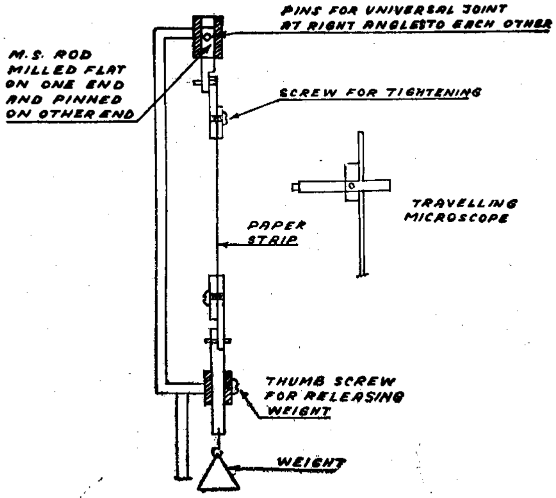

FIG 1. LOAD-DEFORMATION TESTER

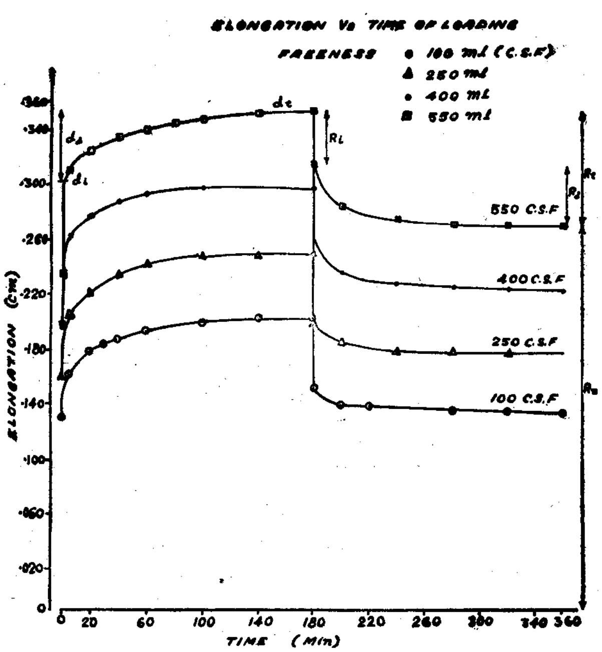

FIG. 2 CREEP CURVES OF PAPER OF DIFFERENT FREENESSES

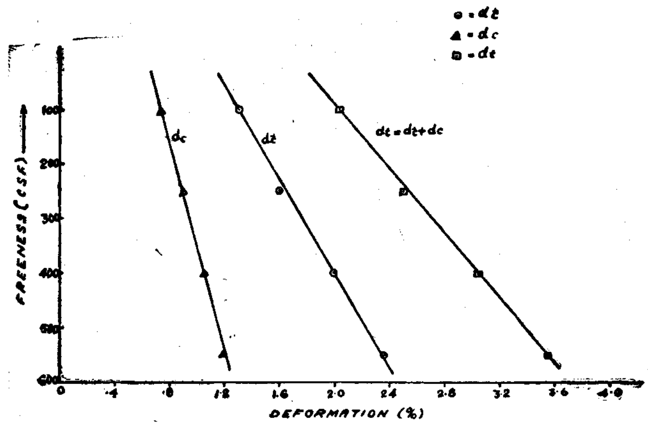

FIG. 3. EFFECT OF BEATING (FREENESS) ON DEFORMATION

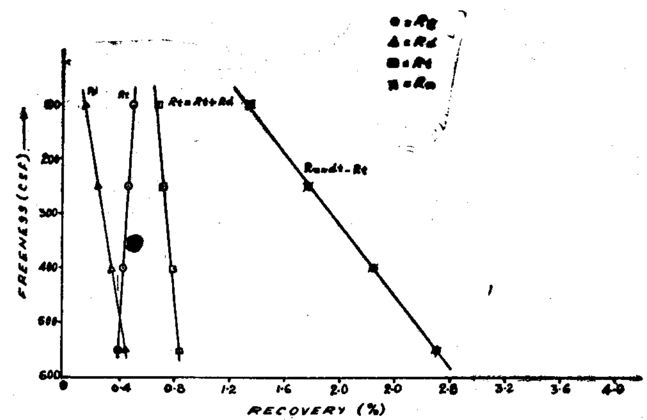

FIG 4 EFFECT OF BEATING (FREENESS) ON RECOVERY

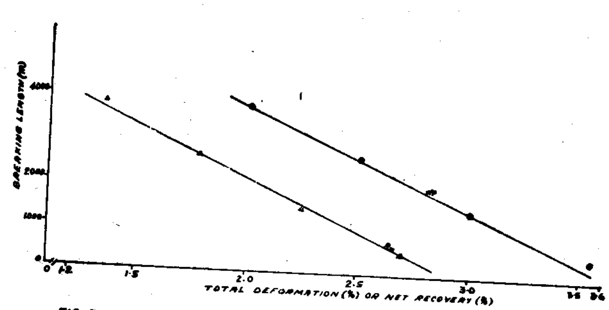

FIG. 5 TOTAL DEFORMATION AND NET RECOVERY Vs BREAKING LENGTH

TABLE –III TYPICAL CALCULATION OF DEFORMATION AND RECOVERY AT 250 FREENESS

From Table - II

$L = 10.00$ cm.
$L_1 = 10.160$ cm.
$L_2 = 10.250$ cm.
$L_3 = 10.203$ cm.
$L_4 = 10.178$ cm.

Deformation

$$d_i,\ \% = \frac{(L_1-L)}{L} \times 100 = \frac{(10.160-10.00)}{10} \times 100 = 1.60$$

$$d_d,\ \% = \frac{(L_2-L_1)}{L} \times 100 = \frac{(10.250-10.160)}{10} \times 100 = 0.90$$

$$d_t,\ \% = d_i + d_d = 1.60 + 0.90 = 2.50$$

Recovery

$$R_i,\ \% = \frac{(L_2-L_3)}{L} \times 100 = \frac{(10.250-10.203)}{10} \times 100 = 0.47$$

$$R_d,\ \% = \frac{(L_3-L_4)}{L} \times 100 = \frac{(10.203-10.178)}{10} \times 100 = 0.25$$

$$R_t,\ \% = R_i + R_d$$

$$= 0.47 + 0.25 = 0.72$$

$$R_n,\ \% = d_t - R_t$$

$$= 2.50 - 0.72 = 1.78$$

TABLE—IV DEFORMATION AND RECOVERY OF BAMBOO SHEETS BEATEN TO DIFFERENT FREENESSES

Sl. No.	Beating Freeness ml. (CSF)	Deformation upto 3 hours d_i %	d_d %	d_t %	Recovery after 3 hours R_i %	R_d %	R_t %	R_n%
1.	550	2.36	1.19	3.55	0.40	0.44	0.84	2.71
2.	400	1.99	1.05	3.04	0.44	0.35	0.79	2.25
3.	250	1.60	0.90	2.50	0.47	0.25	0.72	1.78
4.	100	1.30	0.73	2.03	0.51	0.17	0.68	1.35

Where d_i = Instantaneous deformation
d_d = Delayed deformation
d_t = Total deformation.
R_i = Instantaneous recovery
R_d = Delayed recovery
R_t = Total recovery
R_n = Permanant set

CONCLUSIONS

The following conclusions have been drawn from the study of creep properties of bamboo paper :—

(1) Recovery is always less than deformation at all level of freeness.

(2) Deformation and recovery decrease with increased beating, indicating that the plastic flow has been reduced by beating. This may be due to the fact that the individual fibres become less stiff on beating.

(3) Creep curves (Elongation Vs time of loading) follow the same trend, and confirms the findings No. 1 & 2.

(4) Total deformation is more pronounced than total recovery which in turn, is less pronounced than permanent set indicating the viscoelastic nature of the paper.

(5) Total deformation and permanent set of pulp sheets at different freeness have a negative linear relationship with breaking length. Both lines have approximately same slope confirming that sheet formation & afibre bonding affects the viscoelastic properties of paper.

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