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SUMMARY AND TABLES

from

A STUDY OF THE EFFECT OF FIBER AND PROCESS VARIABLES ON THE MECHANICAL PROPERTIES OF THE COMPONENTS OF COMBINED BOARD

PART I. EFFECT OF PROCESS VARIABLES ON HANDSHEETS IN COMMERCIAL WEIGHTS

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A STUDY OF THE EFFECT OF FIBER AND PROCESS VARIABLES ON THE MECHANICAL PROPERTIES OF THE COMPONENTS OF COMBINED BOARD

PART I. EFFECT OF PROCESS VARIABLES ON HANDSHEETS IN COMMERCIAL WEIGHTS

SUMMARY

Past research has been concerned mainly with the relationship between box compression and the associated mechanical properties of combined board and components. That work has identified the important component properties and established the relative importance among the several properties.

Progress in the abovementioned research has made it possible to enter a new phase of research directed to improving component quality during manufacture. This report describes the initial studies in this area. The following process variables are studied in terms of the pertinent mechanical properties of three-ply, wet-laminated handsheets in commercially significant weights, formed from unbleached kraft pulp:

a) basis weight

b) degree of refining

c) additives

   1. guar

   2. polyethyleneimine

   3. a cationic protein dispersion (Kaysoy 200D)

   4. tamarind seed gum

   5. starch

   6. deacetylated karaya gum

d) refining and additives in the secondary stock system

e) wet pressing

f) dry pressing

g) drying temperature

h) exposure to high moisture

The mechanical properties studied and their relative importance to top- and end-load box compression are as follows:

Property	Relative Importance to: Top-Load	End-Load
Edgewise compression strength	1	--
Extensional Stiffness, Et	2	2
Flexural Stiffness, $\sim Et^3$	3	1
Modulus of elasticity, E	*	*
Caliper, t	*	*
Z-direction tensile strength	--	--
Regular tensile strength	--	--
Stretch	--	--
Basis weight	--	--
Density	--	--

* Important to the degree that it governs extensional stiffness and flexural stiffness.

A summary of the major effects of each of the process variables is given in the following paragraphs.

EFFECT OF BASIS WEIGHT AND DEGREE OF REFINING

Three-ply, wet-laminated handsheets were formed in nominal basis weights of 33, 42, 51, 69, and 90 lb./1000 ft.^{2} at three degrees of refining (700, 600 and

500 cc. Canadian standard freeness); the 42-lb. handsheets were also made at 400 and 300 cc. freeness. Among the conclusions reached in this phase of the study were the following:

1. Edgewise compression strength (as measured by modified ring strength), extensional stiffness (Et), regular tensile strength and caliper (t) were directly proportional to basis weight at a given level of refining. These results indicate that the per cent improvement in these properties is equal to the per cent increase in basis weight. This proportionality permits adjusting these properties (by calculation) to correct for unavoidable variations in basis weight in the subsequent phases of this research program.

2. Modulus of elasticity, E, was sensibly independent of basis weight, indicating that the effect of weight on extensional stiffness (Et) is through caliper. No adjustment of modulus for spurious variations in basis weight is required.

3. Flexural stiffness ($\sim Et^3$), as measured by Taber stiffness, increased non-linearly with basis weight because of the strong influence of increased caliper (as the third power). Adjustments to flexural stiffness for unavoidable fluctuations in basis weight are made by adjusting caliper (by calculation).

4. Z-direction tensile strength is a measure of internal bonding. It is somewhat sensitive to basis weight, presumably because of fiber flexing and peeling of bonds during the test. Z-direction tensile strength is correlated with modified ring compression, apparently because the latter involves delamination of the sheet (and hence bond failure in the Z-direction of the sheet).

5. An increase in basis weight of liners should improve both top- and end-load box compression because of increased edgewise compression, extensional stiffness and flexural stiffness.

6. Increased refining in the range of 700 to 300 cc. Canadian standard freeness (at constant basis weight) increased edgewise compression, extensional stiffness, modulus of elasticity, Z-direction tensile strength, regular tensile strength and stretch, indicating improved bonding.

7. In all cases the foregoing mechanical properties appeared to reach a maximum (or level out) in the range of 500 to 300 cc., indicating that increased refining of a 100% kraft pulp by the method used herein reaches a point of diminishing returns in this range.

8. Caliper decreased with increased refining and hence density increased. Modulus of elasticity increased approximately linearly (though not proportionally) with increase in density at a given basis weight. It is believed, however, that density should not be regarded as an independent variable governing modulus and/or other mechanical properties; density is an associated variable which, like modulus, is affected by certain process variables.

9. Flexural stiffness decreased slightly with increased refining, because the decrease in caliper more than offset the increase in modulus of elasticity.

10. Increased refining in the range of 700 to 500 cc. freeness should increase top-load compression because of the increased edgewise compression and extensional stiffness of the liners. There will probably be minimal change in end-load compression because the increase in extensional stiffness should be offset by the decrease in flexural stiffness. In the range of 500 to 300 cc. freeness, refining can be expected to have little effect on both top-load and end-load compression.

11. A comparison of single-ply and multi-ply handsheets over the 33 to 90-lb. weight range at one degree of refining (600 cc.) revealed that both types of sheets show the same trends in properties important to box compression. This result justifies three-ply handsheets as an experimental technique.

EFFECT OF ADDITIVES

A number of beater additives (and one interply additive) were tried at various levels of addition in each ply of three-ply, wet-laminated handsheets. The salient effects of each additive are summarized below, followed by a comparison of the several additives in terms of their projected effect on box compression.

12. Guar added in concentrations of 0.25, 0.75 and 1.25% by weight increased edgewise compression by as much as 10% at the 0.75 level. Z-direction tensile, regular tensile and stretch increased correspondingly. Extensional stiffness increased only modestly (4.5% at 1.25% addition) because a sizeable increase in modulus was compensated by a decrease in caliper. For the same reason, flexural stiffness decreased slightly.

13. Polyethyleneimine (PEI) at 0.25, 0.75 and 1.25% addition levels caused marked improvement in all of the ultimate strength properties of the handsheets. The optimum level of addition was 0.75%, giving nearly 17% increase in edgewise compression. No important improvements were experienced in the elastic stiffnesses (extensional and flexural) because a decrease in caliper compensated for an increase in modulus of elasticity.

14. Increasing levels of addition (0, 2, 4, 6%) of a cationic protein dispersion (Kaysoy 200D) caused progressive increases in all mechanical properties except flexural stiffness. Edgewise compression increased by 8-1/2% and extensional stiffness by nearly 6% at 6% addition. Higher levels of addition possibly may give even greater improvement.

15. There were no important increases in the mechanical properties of handsheets resulting from addition of tamarind seed gum (T.S.G.) at levels up to 1.25%. The lack of orderly trends makes it questionable whether higher levels of addition would lead to favorable increases in the mechanical properties.

16. A starch blend was applied between plies of three-ply handsheets as an interply bonding agent; 2.5% of the total sheet weight was added at each interface. The ultimate strength properties were improved markedly (edgewise compression by 10-1/2%); however, the elastic stiffness properties showed no improvement and may have decreased slightly.

17. A deflocculating agent, 1% deacetylated karaya gum (D.K.G.), produced virtually no change in the mechanical properties and possibly caused a slight reduction in edgewise compression. This result indicates that the presumably better formation with a deflocculated stock does not enhance the mechanical properties important to box compression. On the other hand, 1% addition of polyethyleneimine caused visible flocculation of the stock and produced significant improvements in the ultimate strength properties (comparable to those mentioned above in Item 13).

18. By way of summary, the estimated improvement in box compression through the use of the above additives is as follows:

	Per Cent Change in Box Compression					
	PEI (0.75)	Guar (0.75%)	Kaysoy (6%)	Starch (5%)	D.K.G. (1%)	T.S.G. (1.25%)
Top-load:	+13.6	+7.7	+7.9	+6.6	+3.5	-2.6
End-load:	+ 1.8	+0.4	+0.4	-5.4	-0.7	+1.2

PEI appears to be the most favorable additive, followed by guar and Kaysoy 200D. Starch between plies can be expected to improve top-load but decreases end-load compression because of a loss in flexural stiffness. Deacetylated karaya gum and tamarind seed gum in the concentrations studied should have little or no effect on box compression. None of the additives offers any marked improvement in end-load compression. PEI, guar and Kaysoy 200D offer a real improvement in top-load with no loss in end-load compression.

EFFECT OF ADDITIONAL REFINING AND ADDITIVES ON THE SECONDARY STOCK

Additional refining of the third ply and varying distribution of guar additive among the plies were studied in sinulation of the manipulation of stock properties which is possible when using a secondary stock system. The results were as follows:

19. Additional refining of the third ply (outer ply) to 300 cc. freeness (remaining two plies at 500 cc.) did not improve the mechanical properties and may have decreased interply bonding slightly because of a differential freeness effect between the middle ply and the highly refined ply.

20. Addition of 0.75% guar to the third ply resulted in modest improvement in the strength properties. A high concentration of 2.25% in the third ply offered no further improvement, evidently because 0.75% addition is about optimum for this additive.

21. It was much more effective to distribute a given addition of guar uniformly throughout the three plies than to concentrate it all in the outer ply.

EFFECT OF WET AND DRY PRESSING

Handsheet samples were subjected to wet pressing at three levels (25, 50 and 100 p.s.i.) and subsequently dry pressed at two levels (no pressing and pressing sufficiently to reduce the caliper by 2.5 points). The following effects were noted:

22. Dry pressing was detrimental to all strength and stiffness properties (except for an inconsequential increase in modulus of elasticity). Edgewise compression decreased by about 8%. Thus, improvement in surface finish achieved by dry calendering is at the expense of mechanical properties important to box compression.

23. Wet pressing improved the ultimate strength properties of the sheet. Edgewise compression increased (by nearly 6%) over the range from 25 to 100 p.s.i., but only if the sheet was not subsequently dry calendered. Wet pressing decreased flexural stiffness and caused no important change in extensional stiffness. Modulus of elasticity increased with wet pressing but only because of the increased density; consequently the loss in caliper negates the value of the increased modulus in terms of container performance.

EFFECT OF DRYING TEMPERATURE

24. An increase in drying temperature in the range of 150 to 450°F. caused no change in the ultimate strength and stiffness properties of three-ply, wet-laminated handsheets, with the exceptions that flexural stiffness increased by 16% and stretch decreased by 16%.

EFFECT OF EXPOSURE TO HIGH MOISTURE

Samples of handsheets were subjected to high humidity (92% R.H.) and immersion in water prior to standard conditioning, in simulation of the excursions to high moisture which may be encountered in converting and service.

25. All strength and stiffness properties (except stretch) tended to decrease with increase in degree of exposure to high moisture. The effects were relatively minor at 92% R.H. but were appreciable with immersion. Stretch increased markedly as a result of exposure to high moisture -- by 46% following water immersion -- which may be attributed to unrestrained shrinkage during subsequent drying.

TABLE II

EFFECT OF BASIS WEIGHT AND DEGREE OF REFINING ON MECHANICAL PROPERTIES OF HANDSHEETS

Canadian Standard Freeness, cc.	Basis Weight, lb./1000 ft.^{2}	Caliper, t, pts.	Apparent Density, lb./pt.	Modified Ring Compression, lb./in.	Z-Direction Tensile Strength, kg./cm.^{2}	Taber Stiffness, units	Modulus of Elasticity, E, 10^3 lb./in.^{2}	Extensional Stiffness, Et, lb./in.	Tensile Strength, lb./in.	Stretch, %
Multi-Ply Sheets										
700	32.3	11.1	2.91	14.3	5.41	34	506.8	5,624	47.6	2.4
	44.4	14.8	2.99	18.6	3.75	77	495.6	7,361	67.0	2.8
	53.1	17.5	3.03	23.0	3.66	132	488.7	8,508	80.3	2.9
	67.7	23.0	2.95	28.0	3.29	265	451.4	10,337	97.7	3.0
	90.6	29.8	3.04	37.0	3.00	568	499.2	14,889	132.9	3.1
600	32.1	10.3	3.12	16.8	5.84	31	602.9	6,210	60.0	3.0
	42.5	12.9	3.29	20.6	5.61	61	606.3	7,900	80.8	3.3
	55.0	16.1	3.42	28.6	5.79	126	612.7	10,010	106.9	3.4
	71.0	21.2	3.36	36.2	5.46	286	592.9	12,506	132.6	3.5
	98.4	28.4	3.46	51.0	5.43	598	589.0	16,758	165.2	3.8
500	32.2	9.5	3.39	19.1	7.28	28	718.6	6,759	67.8	3.1
	42.4	12.2	3.46	22.8	6.82	61	722.9	8,883	92.8	3.3
	50.9	14.3	3.56	28.4	6.93	99	694.7	9,964	109.4	3.4
	71.1	19.6	3.62	39.0	6.78	260	686.1	13,524	145.2	3.7
	89.3	24.6	3.63	50.0	6.58	500	703.8	17,332	188.9	3.5
400	42.0	11.8	3.56	22.1	7.50	57	772.3	8,997	96.1	3.4
300	42.7	11.8	3.63	23.0	7.86	59	801.1	9,333	101.1	3.4
Single-Ply Sheets										
600	32.5	9.8	3.30	18.7	7.78	25	612.3	6,004	58.8	3.1
	44.5	13.2	3.36	22.6	7.29	66	610.4	8,104	77.2	2.9
	51.5	15.1	3.41	27.1	7.35	98	604.9	9,165	86.5	2.8
	69.5	20.0	3.48	37.5	7.20	232	584.3	11,649	106.8	2.8
	81.8	23.7	3.45	44.4	7.12	382	589.0	13,742	121.6	2.8

TABLE III

EFFECT OF GUAR ADDED TO EACH PLY

	Per Cent Additive			
	0	0.25	0.75	1.25
Basis Weight, lb./1000 ft.^{2}	42.5	43.4	43.5	43.8
Caliper, pt.	12.9	12.6	12.6	12.7
Adjusted[a]	12.7	12.2	12.2	12.2
Diff., %	--	- 3.9	- 3.9	- 3.9
Apparent Density, lb./pt.	3.29	3.46	3.44	3.45
Diff., %	--	+ 5.2	+ 4.6	+ 4.9
Modified Ring Compression, lb./in.[b]	20.6	22.7	23.2	22.9
Adjusted[a]	20.4	22.0	22.4	22.0
Diff., %	--	+ 7.8	+ 9.8	+ 7.8
Z-Direction Tensile, kg./cm.^{2}	5.61	6.60	6.74	7.02
Diff., %	--	+17.6	+20.1	+25.1
Taber Stiffness, units	61	63	65	65
Adjusted[a]	59	57	59	57
Diff., %	--	- 3	0	- 3
Modulus of Elasticity, 10^3 lb./in.^{2}	606.3	656.7	649.3	665.5
Diff., %	--	+ 8.3	+ 7.1	+ 9.8
Extensional Stiffness, lb./in.	7900	8279	8226	8512
Adjusted[a]	7807	8012	7942	8162
Diff., %	--	+ 2.6	+ 1.7	+ 4.5
Tensile Strength, lb./in.	80.8	90.9	91.3	94.9
Adjusted[a]	79.8	88.0	88.2	91.0
Diff., %	--	+10.3	+10.5	+14.0
Stretch, %	3.3	3.6	3.6	3.6
Diff., %	--	+ 9	+ 9	+ 9

[a] Adjusted to 42 lb./1000 ft.^{2}

[b] Six-inch modified ring

TABLE IV

EFFECT OF POLYETHYLENEIMINE ADDED TO EACH PLY

	Per Cent Additive			
	0	0.25	0.75	1.25
Basis Weight, lb./1000 ft.^{2}	42.5	45.1	45.5	44.7
Caliper, pt.	12.9	13.3	13.2	13.2
Adjusted[a]	12.7	12.4	12.2	12.4
Diff., %	--	- 2.4	- 3.9	- 2.4
Apparent Density, lb./pt.	3.29	3.39	3.45	3.37
Diff., %	--	+ 3.0	+ 4.9	+ 2.4
Modified Ring Compression, lb./in.[b]	20.6	23.8	25.8	24.5
Adjusted[a]	20.4	22.2	23.8	23.0
Diff., %	--	+ 8.8	+16.7	+12.7
Z-Direction Tensile, kg./cm.^{2}	5.61	6.79	10.37	10.42
Diff., %	--	+21.0	+84.8	+85.7
Taber Stiffness, units	61	72	76	69
Adjusted[a]	59	58	60	57
Diff., %	--	- 2	+ 2	- 3
Modulus of Elasticity, 10^3 lb./in.^{2}	606.3	641.7	666.6	656.1
Diff., %	--	+ 5.8	+ 9.9	+ 8.2
Extensional Stiffness, lb./in.	7900	8567	8874	8731
Adjusted[a]	7807	7978	8191	8204
Diff., %	--	+ 2.2	+ 4.9	+ 5.1
Tensile Strength, lb./in.	80.8	95.8	109.1	104.7
Adjusted[a]	79.8	89.2	100.7	98.4
Diff., %	--	+11.8	+26.2	+23.3
Stretch, %	3.3	3.5	3.7	3.8
Diff., %	--	+ 6	+ 12	+ 15

[a] Adjusted to 42 lb./1000 ft.^{2}

[b] Six-inch modified ring

TABLE V

EFFECT OF A CATIONIC PROTEIN DISPERSION ADDED TO EACH PLY
(Kaysoy 200D)

	Per Cent Additive			
	0	2	4	6
Basis Weight, lb./1000 ft.^{2}	42.3	43.8	41.7	42.8
Caliper, pt.	12.0	12.3	11.6	12.0
Adjusted[a]	11.9	11.8	11.7	11.8
Diff., %	--	- 0.8	- 1.7	- 0.8
Apparent Density, lb./pt.	3.52	3.56	3.59	3.57
Diff., %	--	+ 1.1	+ 2.0	+ 1.4
Modified Ring Compression, lb./in.	26.8	27.9	27.2	29.6
Adjusted[a]	26.7	26.8	27.4	29.0
Diff., %	--	+ 0.4	+ 2.6	+ 8.6
Z-Direction Tensile, kg./cm.^{2}	6.94	7.09	8.38	9.00
Diff., %	--	+ 2.2	+20.7	+29.7
Taber Stiffness, units	57	63	53	58
Adjusted[a]	56	56	54	55
Diff., %	--	0	- 4	- 2
Modulus of Elasticity, 10^3 lb./in.^{2}	683.5	697.5	704.4	724.1
Diff., %	--	+ 2.0	+ 3.1	+ 5.9
Extensional Stiffness, lb./in.	8182	8631	8330	8747
Adjusted[a]	8124	8276	8390	8584
Diff., %	--	+ 1.9	+ 3.3	+ 5.7
Tensile Strength, lb./in.	92.8	95.4	97.4	102.4
Adjusted[a]	92.1	91.5	98.1	100.5
Diff., %	--	- 0.7	+ 6.5	+ 9.1
Stretch, %	3.5	3.5	3.6	3.7
Diff., %	--	0	+ 3	+ 6

[a] Adjusted to 42 lb./1000 ft.^{2}

TABLE VI

EFFECT OF TAMARIND SEED GUM ADDED TO EACH PLY

	Per Cent Additive			
	0	0.25	0.75	1.25
Basis Weight, lb./1000 ft.^{2}	42.5	43.4	43.1	42.5
Caliper, pt.	12.8	12.7	13.0	12.4
Adjusted[a]	12.6	12.3	12.7	12.3
Diff., %	--	- 2.4	+ 0.8	- 2.4
Apparent Density, lb./pt.	3.32	3.42	3.32	3.43
Diff., %	--	+ 3.0	0.0	+ 3.3
Modified Ring Compression, lb./in.	26.0	27.4	26.6	27.0
Adjusted[a]	25.7	26.5	25.9	26.7
Diff., %	--	+ 3.1	+ 0.8	+ 3.9
Z-Direction Tensile, kg./cm.^{2}	5.75	6.19	6.02	6.27
Diff., %	--	+ 7.7	+ 4.7	+ 9.0
Taber Stiffness, units	64	67	68	62
Adjusted[a]	62	60	63	60
Diff., %	--	- 3	+ 2	- 3
Modulus of Elasticity, 10^3 lb./in.^{2}	617.3	651.2	627.3	638.8
Diff., %	--	+ 5.5	+ 1.6	+ 3.5
Extensional Stiffness, lb./in.	7945	8329	8193	8123
Adjusted[a]	7852	8060	7984	8027
Diff., %	--	+ 2.6	+ 1.7	+ 2.2
Tensile Strength, lb./in.	91.1	93.2	94.8	97.6
Adjusted[a]	90.0	90.2	92.4	96.5
Diff., %	--	+ 0.2	+ 2.7	+ 7.2
Stretch, %	3.6	3.5	3.6	3.7
Diff., %	--	- 3	0	+ 3

[a] Adjusted to 42 lb./1000 ft.^{2}

TABLE VII

EFFECT OF STARCH ADDED BETWEEN PLIES

	Per Cent Additive	
	0	2.5[a]
Basis Weight, lb./1000 ft.^{2}	41.8	44.6
Caliper, pt.	14.1	14.4
Adjusted[b]	14.2	13.6
Diff., %	--	- 4.2
Apparent Density, lb./pt.	2.96	3.10
Diff., %	--	+ 4.7
Modified Ring Compression, lb./in.	24.4	28.8
Adjusted[b]	24.5	27.1
Diff., %	--	+10.6
Z-Direction Tensile, kg./cm.^{2}	5.40	7.61
Diff., %	--	+40.9
Taber Stiffness, units	63	68
Adjusted[b]	64	57
Diff., %	--	- 11
Modulus of Elasticity, 10^3 lb./in.^{2}	497.9	497.4
Diff., %	--	- 0.1
Extensional Stiffness, lb./in.	7100	7246
Adjusted[b]	7134	6824
Diff., %	--	- 4.3
Tensile Strength, lb./in.	83.8	94.4
Adjusted[b]	84.2	88.9
Diff., %	--	+ 5.6
Stretch, %	3.9	4.6
Diff., %	--	+ 18

[a] At each interface

[b] Adjusted to 42 lb./1000 ft.^{2}

TABLE VIII

EFFECT OF FLOCCULATING AND DEFLOCCULATING AGENTS

	Deflocculating Agent[a]	Control	Flocculating Agent[b]
Basis Weight, lb./1000 ft.^{2}	43.3	43.1	42.3
Caliper, pt.	13.2	13.0	13.0
Adjusted[c]	12.8	12.7	12.9
Diff., %	+ 0.8	--	+ 1.6
Apparent Density, lb./pt.	3.28	3.32	3.25
Diff., %	- 1.2	--	- 2.1
Modified Ring Compression, lb./in.	25.5	26.3	30.3
Adjusted[c]	24.7	25.6	30.0
Diff., %	- 3.5	--	+17.2
Z-Direction Tensile, kg./cm.^{2}	5.51	5.50	9.95
Diff., %	+ 0.2	--	+80.9
Taber Stiffness, units	69	66	64
Adjusted[c]	63	61	63
Diff., %	+ 3	--	+ 3
Modulus of Elasticity, 10^3 lb./in.^{2}	613.1	624.3	615.1
Diff., %	- 1.8	--	- 1.5
Extensional Stiffness, lb./in.	8203	8167	8098
Adjusted[c]	7957	7959	8041
Diff., %	0.0	--	+ 1.0
Tensile Strength, lb./in.	93.7	94.2	103.2
Adjusted[c]	90.9	91.8	102.5
Diff., %	- 1.0	--	+11.7
Stretch, %	3.6	3.6	3.8
Diff., %	0	--	+ 6

[a] 5% dispersion of deacetylated karaya gum (D.K.G.) added to each ply (1% by weight)

[b] 5% solution of polyethyleneimine (P.E.I.) added to each ply (1% by weight)

[c] Adjusted to 42 lb./1000 ft.^{2}

TABLE IX

SUMMARY OF EFFECT OF ADDITIVES

Additive:	Guar	PEI	C.P.D.	Tamarind Seed Gum	Starch Between Plies	D.K.G. (deflocculant)
	Per Cent Difference[a]					
Level of Addition:	0.75%	0.75%	6%	1.25%	5%	1%
Modified Ring Compression	+ 9.8	+16.7	+ 8.6	+ 3.9	+10.6	- 3.5
Z-Direction Tensile	+20.1	+84.8	+29.7	+ 9.0	+40.9	+ 0.2
Taber Stiffness	0	+ 2	- 2	- 3	- 11	+ 3
Modulus of Elasticity	+ 7.1	+ 9.9	+ 5.9	+ 3.5	- 0.1	- 1.8
Extensional Stiffness	+ 1.7	+ 4.9	+ 5.7	+ 2.2	- 4.3	0.0
Tensile Strength	+10.5	+26.2	+ 9.1	+ 7.2	+ 5.6	- 1.0
Stretch	+ 9	+ 12	+ 6	+ 3	+ 18	0
Caliper	- 3.9	- 3.9	- 0.8	- 2.4	- 4.2	+ 0.8
Top-Load Compression (Estimated)	+ 7.7	+13.6	+ 7.9	+ 3.5	+ 6.6	- 2.6
End-Load Compression (Estimated)	+ 0.4	+ 1.8	+ 0.4	- 0.7	- 5.4	+ 1.2

[a] Based on no additive

TABLE X

EFFECT OF ADDITIONAL REFINING AND ADDITIVES
ON THE SECONDARY STOCK SYSTEM

	Experiment				
	A	B	C	D	E
Canadian Standard Freeness, cc., of Ply 3[a]	500	300	300	300	300
% Guar Additive in Ply 3	0	0	0.75	2.25	0.75
% Guar Additive in Plies 1 and 2	0	0	0	0	0.75
Basis Weight, lb./1000 ft.^{2}	43.0	42.1	43.2	42.1	42.5
Caliper, pt.	12.1	11.8	11.7	11.4	11.3
Adjusted[b]	11.8	11.8	11.4	11.4	11.2
Diff., %	0	--	- 3.4	- 3.4	- 5.1
Apparent Density, lb./pt.	3.55	3.57	3.69	3.69	3.76
Diff., %	- 0.6	--	+ 3.4	+ 3.4	+ 5.3
Modified Ring Compression, lb/in.	27.6	26.5	28.3	27.6	29.2
Adjusted[b]	27.0	26.4	27.5	27.5	28.9
Diff., %	+ 2.3	--	+ 4.2	+ 4.2	+ 9.5
Z-Direction Tensile, kg./cm.^{2}	6.89	6.22	6.83	6.79	7.70
Diff., %	+10.8	--	+ 9.8	+ 9.2	+23.8
Taber Stiffness, units	60	56	58	55	52
Adjusted[b]	56	56	53	55	50
Diff., %	0	--	- 5	- 2	- 11
Modulus of Elasticity, 10^3 lb./in.^{2}	694.4	707.6	716.3	717.4	778.8
Diff., %	- 1.9	--	+ 1.2	+ 1.4	+10.1
Extensional Stiffness, lb./in.	8499	8410	8509	8309	8848
Adjusted[b]	8301	8390	8273	8289	8744
Diff., %	- 1.1	--	- 1.4	- 1.2	+ 4.2
Tensile Strength, lb./in.	90.9	91.4	96.8	94.2	99.6
Adjusted[b]	88.8	91.2	94.1	94.0	98.4
Diff., %	- 2.6	--	+ 3.2	+ 3.1	+ 7.9
Stretch, %	3.3	3.4	3.5	3.5	3.7
Diff., %	- 3	--	+ 3	+ 3	+ 9

a Remaining plies at 500 cc. freeness
b Adjusted to 42 lb./1000 ft.^{2}

TABLE XI

EFFECT OF WET PRESSING AND DRY PRESSING

	Dry Calender Pressure					
	None			High		
Wet Pressing Pressure, p.s.i.	25	50	100	25	50	100
Basis Weight, lb./1000 ft.^{2}	42.2	40.8	42.9	43.8	42.2	42.8
Caliper, pt.	13.8	12.6	12.0	11.2	10.2	9.4
Adjusted[a]	13.7	13.0	11.7	10.7	10.2	9.2
Diff., %	+ 5.4	--	-10.0	-17.7	-21.5	-29.2
Apparent Density, lb./pt.	3.06	3.24	3.58	3.91	4.14	4.55
Diff., %	- 5.6	--	+10.5	+20.7	+27.8	+40.4
Modified Ring Compression, lb./in.	24.7	24.6	26.4	24.8	23.1	23.6
Adjusted[a]	24.6	25.4	26.0	23.8	23.0	23.2
Diff., %	- 3.1	--	+ 2.4	- 6.3	- 9.4	- 8.7
Z-Direction Tensile, kg./cm.^{2}	5.53	5.90	6.40	4.19	4.57	5.36
Diff., %	- 6.3	--	+ 9.2	-29.0	-22.5	- 9.2
Taber Stiffness, units	74	59	57	48	39	35
Adjusted[a]	73	64	53	42	38	33
Diff., %	+ 14	--	- 17	- 34	- 41	- 48
Modulus of Elasticity, 10^3 lb./in.^{2}	591.5	629.2	703.3	645.2	697.3	771.6
Diff., %	- 6.0	--	+11.8	+ 2.5	+10.8	+22.6
Extensional Stiffness, lb./in.	8282	7934	8598	7264	7148	7272
Adjusted[a]	8243	8167	8418	6965	7114	7136
Diff., %	+ 0.9	--	+ 3.1	-14.7	-12.9	-12.6
Tensile Strength, lb./in.	87.4	86.8	95.4	87.5	87.3	89.2
Adjusted[a]	87.0	89.4	93.4	83.9	86.9	87.5
Diff., %	- 2.7	--	+ 4.5	- 6.2	- 2.8	- 2.1
Stretch, %	3.5	3.5	3.5	3.7	3.5	3.3
Diff., %	0	--	0	+ 6	0	- 6

[a] Adjusted to 42 lb./1000 ft.^{2}

TABLE XII

EFFECT OF PRESSING ON MODIFIED RING COMPRESSION
(Adjusted to 42 lb./1000 ft.^{2})

		Wet Pressing Pressure, p.s.i.			
		25	50	100	Av.
Dry Calender Pressure	None	24.6	25.4	26.0	25.3
	High	23.8	23.0	23.2	23.3
	Av.	24.2	24.2	24.6	24.3

TABLE XIII

EFFECT OF DRYING TEMPERATURE

	Drying Temperature, °F.			
	150	250	350	450
Basis Weight, lb./1000 ft.^{2}	44.1	42.0	42.5	42.4
Caliper, pt.	14.3	14.0	14.0	14.2
Adjusted[a]	13.6	14.0	13.8	14.1
Diff., %	- 2.9	--	- 1.4	+ 0.7
Apparent Density, lb./pt.	3.08	3.00	3.04	2.99
Diff., %	+ 2.7	--	+ 1.3	- 0.3
Modified Ring Compression, lb./in.	24.6	24.2	24.5	24.7
Adjusted[a]	23.5	24.2	24.2	24.5
Diff., %	- 2.9	--	0.0	+ 1.2
Z-Direction Tensile, kg./cm.^{2}	5.39	5.09	5.48	5.48
Diff., %	+ 5.9	--	+ 7.7	+ 7.7
Taber Stiffness, units	62	57	61	65
Adjusted[a]	54	57	59	63
Diff., %	- 5	--	+ 4	+ 11
Modulus of Elasticity, 10^3 lb./in.^{2}	489.1	499.3	503.1	492.2
Diff., %	- 2.0	--	+ 0.8	- 1.4
Extensional Stiffness, lb./in.	7048	6983	7080	7034
Adjusted[a]	6712	6983	6997	6968
Diff., %	- 3.9	--	+ 0.2	- 0.2
Tensile Strength, lb./in.	87.2	83.0	83.4	83.0
Adjusted[a]	83.0	83.0	82.4	82.2
Diff., %	0.0	--	- 0.7	- 1.0
Stretch, %	4.9	4.5	4.3	4.2
Diff., %	+ 9	--	- 4	- 7

[a] Adjusted to 42 lb./1000 ft.^{2}

TABLE XIV

EFFECT OF EXPOSURE TO HIGH MOISTURE

	Maximum Moisture Environment[a]		
	Standard Conditioning	92% R.H.	Liquid Water
Basis Weight, lb./1000 ft.^{2}	41.9	44.8	43.1
Caliper, pt.	12.0	12.8	13.0
Adjusted[b]	12.0	12.0	12.7
Diff., %	--	0.0	+ 5.8
Apparent Density, lb./pt.	3.49	3.50	3.32
Diff., %	--	+ 0.3	- 4.9
Modified Ring Compression, lb./in.	26.0	26.8	22.8
Adjusted[b]	26.1	25.1	22.2
Diff., %	--	- 3.8	-14.9
Z-Direction Tensile, kg./cm.^{2}	7.63	6.87	5.35
Diff., %	--	-10.0	-29.9
Taber Stiffness, units	59	64	51
Adjusted[b]	59	53	47
Diff., %	--	- 10	- 20
Modulus of Elasticity, 10^3 lb./in.^{2}	710.0	669.2	496.8
Diff., %	--	- 5.7	-30.0
Extensional Stiffness, lb./in.	8590	8712	6488
Adjusted[b]	8611	8168	6322
Diff., %	--	- 5.1	-26.6
Tensile Strength, lb./in.	96.6	101.8	88.1
Adjusted[b]	96.8	95.4	85.9
Diff., %	--	- 1.4	-11.3
Stretch, %	3.5	4.0	5.1
Diff., %	--	+ 14	+ 46

a Followed by standard conditioning prior to test

b Adjusted to 42 lb./1000 ft.^{2}