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The Effects of Selected Pilot Paper Machine Variables on Web Shrinkage

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THE EFFECTS OF SELECTED PILOT PAPER MACHINE VARIABLES ON WEB SHRINKAGE

by

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ABSTRACT

The purpose of this study was to determine the effects of certain machine variables on shrinkage and also to determine a shrinkage and strength profile across the width of the sheet. Machine conditions varied were the draws and the amount of pressure on the presses. Cross direction shrinkage was measured by using felt marking pens to mark three sections across the web. Machine direction shrinkage was determined by using a cogged wheel to punch a series of small holes into the sheet which could then be measured at the reel. Press loading was shown to have no effect on cross direction shrinkage. Cross direction shrinkage was shown to increase as the draw increased but inability to maintain constant draws eliminated the possibility of attaching much significance to a stepwise analysis. Tensile and percent elongation were run and compared with the literature to substantiate the shrinkage results.

TABLE OF CONTENTS

INTRODUCTION

It is a well known fact that cellulose fibers exhibit a certain amount of dimensional change during the drying process. This dimensional change, commonly referred to as shrinkage, is also transmitted to a sheet of paper as the paper is dried. Shrinkage has been shown to be dependent upon several variables during the drying process.

It was the purpose of this thesis to review shrinkage theory, review literature reports on the effects of variables upon which shrinkage is dependent, and to experimentally analyze the effects of selected pilot paper machine variables on shrinkage.

Shrinkage Theory

One of the earliest theories of shrinkage was that of surface tension as stated by Rance (1). It was proposed that web shrinkage is due to the forces created by the surface tension of the water as it was evaporated. As more water is evaporated the water bridge between fibers becomes shorter and the surface tension of the water brought the fibers closer together. A portion of the shrinkage was due to the transverse shrinkage of the individual fiber. This shrinkage of the individual fiber was transmitted to the web through the fiber to fiber bonds. The formation of fiber to fiber bonds was seen as the endpoint of intra-fiber contraction.

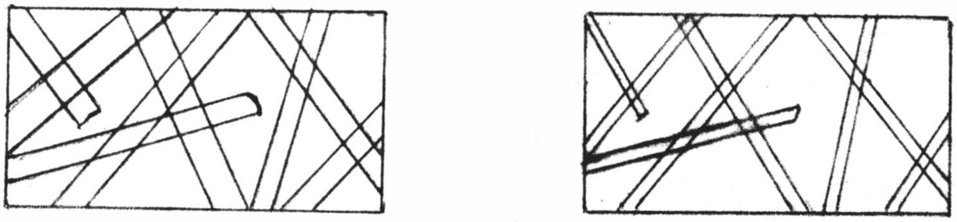
Page and Tydeman (2) observed that if the bond sites were considered to be stationary, which is generally accepted as being the case, the cross direction shrinkage should be independent of the transverse shrinkage of the individual fibers. This idea can easily be seen as illustrated in Figure 1.

From this they reasoned that either the bond sites actually did move or that the longitudinal shrinkage of the fiber was considerably more in the sheet than had been observed with individual fibers. Steenberg (3) had suggested that shrinkage might be caused by micro-creping of the fibers during drying. Micro-creping would not allow, though, that a well beaten pulp would produce more shrinkage than a lightly beaten pulp. The reason for this is that a highly beaten pulp would have a shorter fiber length and thus less potential

the fibers during drying. Micro-creping would not allow, though, that a well beaten pulp would produce more shrinkage than a lightly beaten pulp. The reason for this is that a highly beaten pulp would have a shorter fiber length and thus less potential shrinkage through microcreping. Since the relationship between refining and shrinkage was well known, Page and Tydeman ran some experiments and discovered that the longitudinal shrinkage of the fibers corresponded in every case to the amount of shrinkage that the sheet had undergone. They hypothesized that the transverse shrinkage of the fiber at the

Figure 1

Independence of Web Shrinkage To Individual Fiber Shrinkage



Before Shrinkage After Shrinkage

bond site creates a compressional force on the longitudinal direction of the fiber which can produce micro-creping and shrinkage in the longitudinal direction. According to Page and Tydeman there are four major structural factors that control the shrinkage of paper:

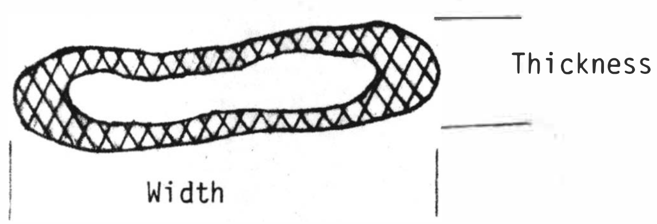
1. The intrinsic potential shrinkage of the fiber.
2. The resistance of the fiber to axial compression.
3. The strength and the extent of fiber to fiber bonding.
4. Fibrillation, which, when present, has shrinkage forces associated with it.

Smith (4) also recognized that shrinkage is primarily due to large compressional forces on the longitudinal axis of the fiber but states that the unbeaten fiber bonds are not strong enough to create the necessary forces.

Page, Tydeman, and Wembridge (5) supported the contention that the transverse shrinkage of the individual fibers is of a magnitude that would be capable of applying the compressional force needed. Width changes of 22-34% were reported for a spruce sulphite pulp. They also reported that if the cross-section of a fiber was said to approximate a rectangular shape, the fiber shrunk more in the width direction than in the thickness direction. This can be seen in Fig. 2 where the inside section is the dry fiber and the cross-hatched section is the amount of shrinkage that has taken place. It should be noted that a fiber deposited from a suspension

Figure 2

Individual Fiber Shrinkage



tends to lie with its largest cross-sectional area in the horizontal plane.

The Effect of Moisture Content on Shrinkage

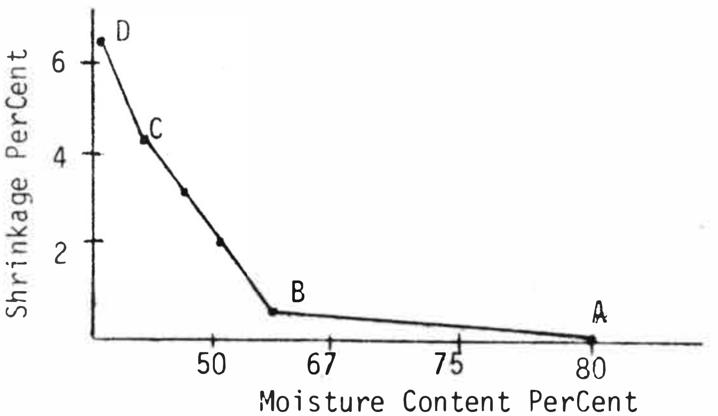
Lynn and Gallay (6) in some laboratory work discovered that the

shrinkage force started to develop at about 35% solids, increased slowly until about 55% solids and then increased rapidly up to a solids content of about 80%. Beating determined the moisture content at which the shrinkage tension starts to develop and also the maximum tension developed, but the rate of development of tension once it has begun is largely independent of beating. Rance (7) has also shown that the degree of beating causes shrinkage to begin at a higher moisture content.

Rance (1) subscribes to a three phase theory of shrinkage that is illustrated in Fig. 3. Phase AB is seen as a phase in which

Figure 3

Relation Between Moisture Content and Shrinkage of the Wet Web

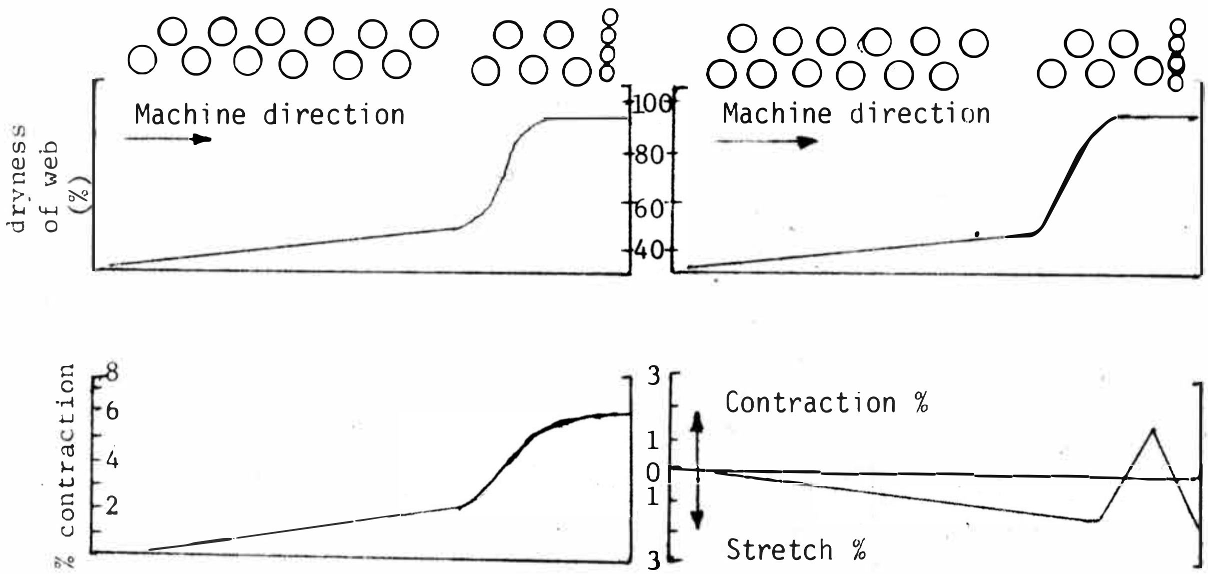


surface tension displays some effect, but very little, up to about 60% moisture. From 60% to approximately 20% moisture surface tension is thought to display more of an effect while below 20% moisture the effect of transverse shrinkage of the fibers takes place.

Arlov and Ivarsson (8) did a study which followed the development of shrinkage through the dryer section under four different conditions of felt tension and draws. Their findings about the relationship between shrinkage and percent dryness of the web can be summarized by Fig. 4. It appears that the majority of shrinkage

Figure 4

Development of Shrinkage Along the Paper Machine



occurs in the 50-90% dryness range. Arlov and Ivarsson also did some work on the effect of drying rate and found that it had no effect on the moisture content at which the most shrinkage occurred.

Smith (4) has stated that the maximum amount of shrinkage occurs

as the capillary bound water is being driven off. This observation generally agrees with the results given above.

Gallahue (9) reports a much narrower range, from 45-35% moisture, as being the zone in which the maximum amount of shrinkage occurs. He states that 50% of the shrinkage may occur in less than 10% of the dryer area.

Effect of Paper Machine Variables On Shrinkage

Smith (4) recognized that the papermaking process resulted in a dried in strain in both machine and cross machine direction. Smith defined dried in strain as percentage potential shrinkage minus percentage actual shrinkage. It was also reported that some of the dried in strain was recoverable on rewetting and drying the sheet in successive cycles, but that not all of the dried in strain could be recovered.

Arlov and Ivarsson (8) reported that machine direction draws force a cross direction shrinkage which can be off-set to some degree by the action of tight felts. Tensile strength in the machine direction was shown to increase with an increase in machine direction tension. In the first part of the dryer the sheet will allow a permanent stretch in the machine direction. This phenomenon will occur as long as the sheet contains free water. A machine direction shrinkage was observed in the 60-90% dryness range which appeared to be independent of the draw and felt tension.

Kenworthy (10) reported a laboratory simulation experiment involving the relationship between draws and shrinkage. Machine direction in this experiment was defined as the direction of tension on laboratory handsheets. By applying a tension in the machine direction along with a restraint to prevent shrinkage in the cross direction, to simulate a machine direction draw and the restraint contributed by the felt, it was shown that as the cross direction restraint is increased, the machine direction shrinkage is reduced. In other words, the greater the cross direction restraint, the greater is the permanent stretch in the machine direction produced by a machine direction tension.

Gallahue (9) reports a communication with John Buss in which the latter had shown that shrinkage was uneven from one edge of the sheet to the other. It was stated that the ratio between the edge shrinkage and the center of the sheet shrinkage was 4:1.

The Effect of Shrinkage on Strength

Gates and Kenworthy (11) have shown that changes in machine direction shrinkage cause little or no change in the cross direction tensile. The relationship between shrinkage and extension at break is not affected by fiber orientation, but the response of tensile strength to shrinkage is dependent on fiber orientation, increasing as more of the fibers become aligned in the machine direction. Shrinkage was also shown to be dependent on fiber orientation because as more fibers become aligned in the machine direction, cross direction

tension developed during drying becomes greater and machine direction less under the action of a given strain.

Sapp and Gillespie (12) examined the relationship between tension and strength properties and found that tensile strength increased in the direction of tension, stretch decreased in the direction of tension, tensile strength decreased in the cross direction, and that stretch increased in the cross direction.

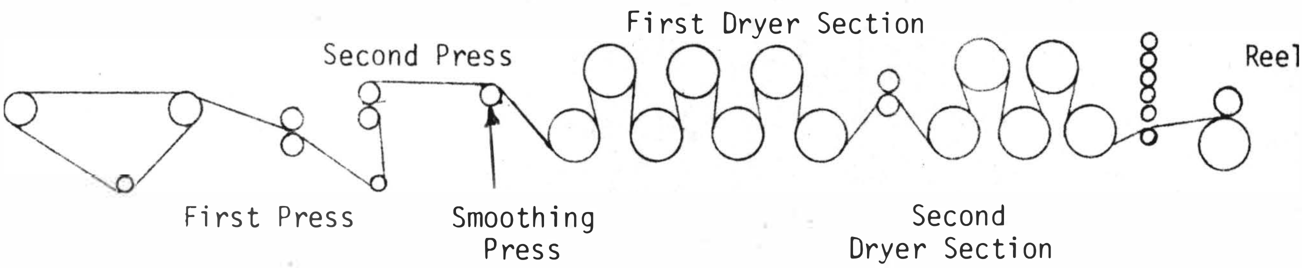
EXPERIMENTAL DESIGN

The facilities of the Paper Science and Engineering Department at Western Michigan University were used in this study. The pilot paper machine, a schematic of which is shown if Fig. 5, was run at approximately eighty feet per minute, making a 55 lb. (25 X 38-500) sheet from a furnish of seventy five percent softwood kraft and twenty five percent hardwood kraft beaten to approximately 275 CSF. Additives to the furnish were one percent rosin size and two percent alum. The size press was bypassed.

The machine variables studied were the draws between the smoothing press and the first dryer section, the amount of pressure on the first and second presses, and the draws between the first and second dryer section. Draws were varied from as slack as possible to as tight as possible to provide a total of four samples. Variation in press pressures, from 60 psig to 30 psig, was carried out for slack draws and for tight draws. The draw range available was ± 2.0 feet. Moisture samples were taken immediately after marking the sheet for shrinkage determination.

Figure 5

Schematic of Pilot Paper Machine



Machine direction in this report is defined as the plane of the sheet in the direction in which it is formed. Cross direction is defined as being normal to the machine direction, that is, from one edge of the sheet to the other as it is formed.

Cross direction shrinkage was measured by placing four felt marking pens on a rod which was then held in position at various places along the machine. The four pens divided the sheet into three sections, which allowed the measurement of the shrinkage profile. Percent shrinkage was obtained by measuring the distance between the lines at the reel and dividing by the known distance between the pens on the rod.

Machine direction shrinkage was measured using the same concept described by Arlov and Ivarsson (8). A cogged wheel was held against the sheet with the result that a series of small holes was punched into the sheet. One of the teeth on the wheel was flattened so that one revolution of the wheel could be easily distinguished. Percent machine direction shrinkage was calculated as the distance between two revolutions on the dry sheet divided by twice the circumference of the wheel.

Tensile, percent elongation, and moisture tests were run according to Tappi standards.

STATEMENT OF THE OBJECTIVES OF THE STUDY

Upon review of the literature there seems to be a void in actual paper machine study of the effects of draw and other machine variables on shrinkage.

Although the moisture content was somewhat high, the press section of the paper machine was selected as the area of primary concern. The reason for this being that a maximum range of draw changes was possible. In addition, tensile, and stretch tests were run and compared with the trends as stated in the literature as a basis for substantiating the results obtained in the shrinkage study.

Another area which it was felt has not received enough consideration was the cross direction shrinkage profile that has been reported in the literature. If the relationship between shrinkage and strength as stated in the literature is valid, a cross direction shrinkage profile should result in a strength profile as well.

DATA DISCUSSION

Shrinkage

Although the stepwise reduction of the draw between the smoother and first dryer section shows no distinct pattern, the tightest draw produced the highest total cross direction shrinkage. Changes in the draw between the dryer sections produced more shrinkage as the draw was decreased. Smith's (4) idea of dried in strain may account for this phenomenon. If the relaxation of the draw after the first dryer section allows the sheet to regain a portion of the dried-in strain, the cross direction shrinkage will increase.

The amount of pressure applied on the press rolls varied from 60 psig to 30 psig and it was shown to have no effect on cross direction shrinkage.

As reported previously by Gallahue (9) a shrinkage profile was obtained but not of the magnitude reported. There appears to be no discernible trend in the shrinkage profile. In some instances the middle shrinkage was lower by approximately one per cent with the front and back shrinkage nearly equal. In some cases the middle shrinkage was higher with the front and back again nearly equal. In some instances the profile did not exist with all three sections approximately equal. In some cases the profile showed the highest shrinkage in the back with the middle slightly lower than the back and the front slightly lower than the middle. This lack of consistency may be due

to the narrow width of the sheet which may not exhibit the shrinkage profile that has been reported on wider webs.

It would appear that Gallay and Lynn (6) have been correct in assigning the shrinkage forces as beginning to develop at approximately 35% solids. Under various press conditions the solids leaving the second press ranged from 36.7-41.8%. In this range and with tight draws the difference in total cross direction shrinkage before and after the second press showed that a shrinkage of about 0.3% occurs in this area. With slack draws this effect was not noticed as the shrinkage apparently began at higher solids.

Shrinkage measurements taken from approximately 68% solids to 95% solids concur with the findings of Arlov and Ivarsson (8) in their detailed study of the development of shrinkage along the paper machine. According to their graphs slightly less than half of the total shrinkage occurred at this solids range. Shrinkage after 68% solids in this study ranged from 4.6-5.6% while the total cross direction shrinkage ranged from 7.3-8.9%.

Inconclusive results were obtained in the machine direction shrinkage study. No machine direction shrinkage occurred after the first dryer section. Variation of the draws produced no changes in the machine direction shrinkage, probably because of the small draw range, plus or minus two feet, available.

Machine Direction Tensile & Elongation

Machine direction tensile strength was shown to increase when the draws were increased between the first and second dryer sections. As the draw was increased, the machine direction tensile increased as much as approximately twenty percent in some cases as can be seen in Table I. Sapp and Gillespie (12) have reported that tensile will increase in the direction of the applied tension.

Variation of draw between the smoothing press and the first dryer section produced various results in machine direction tensile. For the most part the difference between tight and slack draws was a 1.5-2.0% decrease in machine direction tensile which is insignificant in comparison to the approximate twenty percent change that occurred with the change in draw at a lower moisture content.

Elongation in the machine direction decreased with increasing tension as expected according to Sapp and Gillespie. (12) The range encountered was a decrease of from 0.9-1.2% in going from slack draws to tight draws. Again the effect is more noticeable at a lower moisture content. Variations of the draws between the smoothing press and the first dryer section increased the percent elongation 0.1-0.3% in going from slack draws to tight draws.

Analysis of the four different draws used in going from tight to slack draws gives mixed results. In some cases the relationship appears linear while in others there appears to be a certain draw at which the machine direction tensile takes a sudden jump and then

levels off. In still other cases the machine direction tensile increases. It is thought that these seemingly contradictory results may have been the result of inadequate control of the draw on the paper machine. The maximum draw range available in this study was plus or minus two feet. The speed of a given section was found to vary by plus or minus one foot per minute . Thus, although the tightest and slackest draw could vary with variations in machine speed with little chance of overlap, this variation could easily jumble the results near the middle of the range.

Cross-Machine Tensile And Elongation

Variation of the draw between the smoothing press and the first dryer section resulted in the cross direction tensile decreasing with an increase in draw. The decrease ranged from 2.2-9.3%. Variation in the draw between the first and second dryer sections generally resulted in an increase in cross direction tensile with an increase in draw. The range was a one to six percent increase in cross direction tensile in going from slack draws to tight draws.

Cross direction percent elongation increased in most cases as the draw decreased. The range of the decrease was from 0.1-1% in going from tight draws to slack draws. This behavior is not predicted by the literature but the majority of the changes seem insignificant. In most cases the cross direction percent elongation did rise as the draw increased and then fell below the percent elongation at the slack draw. In other words, there appeared to be a maximum machine

direction tension above which the cross direction elongation begins to diminish.

Tensile And Elongation Profile Variations

The cross direction tensile profile showed much the same randomness already noted in the cross direction shrinkage profile. At times the profile variation was non-existent with all three sections approximately equal. In some cases the breaking length decreased from front to back and in others increased from front to back. In still others the middle was slightly lower than the edges. In most cases the differences were less than six percent. As illustrated in Table I, there appears to be a qualitative relation between the cross direction shrinkage profile and the cross direction breaking length profile. From the similarity of the shrinkage profiles of samples three and four, five and six, seven and eight, it would be expected that the breaking length profiles would not be appreciably different.

As illustrated in Table II, the machine direction breaking length profile illustrates that the tensile in the center of the sheet was usually significantly higher than the edges of the sheet. According to the literature, this would indicate that the center of the sheet receives the greatest amount of tension under the action of a given draw. Since the shrinkage exhibited no such definite pattern it would also indicate that tensile is much more sensitive to changes in

TABLE I

Cross Direction Breaking Length and Shrinkage

Sample No.	Breaking Length (feet) Back	Middle	Front	Shrinkage (percent) Back	Middle	Front
1	10,300	9.800	9.400	8.3	9.0	9.6
2	9,900	10,400	10,600	7.3	8.1	10.5
3	10,600	10,200	10,400	8.3	8.1	8.4
4	10,500	10,200	10,400	8.3	8.1	8.4
5	10,500	10,200	9,700	5.2	5.4	5.3
6	10,200	10,200	10,300	5.2	5.4	5.3
7	10,500	9,900	10,200	5.2	6.3	5.3
8	9,900	9,800	10,100	5.2	6.3	5.3

TABLE II

Machine Direction Breaking Length (feet)

Back	Middle	Front
23,700	24,400	24,400
21,900	24,400	22,100
21,200	21,900	20,300
19,400	21,700	20,100
22,000	23,800	22,400
21,300	22,900	20,000
20,500	21,700	20,600
19,300	20,300	19,000

tension than is shrinkage.

Percent elongation in the machine direction showed little or no change from one edge of the sheet to the other. Percent elongation in the cross direction exhibited the randomness previously mentioned with regards to cross direction tensile.

CONCLUSIONS

Variation in the draw between the smoother and the first dryer section showed that total cross direction shrinkage increased as the draw was increased. Variation in the draw between the dryer sections resulted in a slight increase in shrinkage as the draw was decreased. Although contrary to the literature, this was substantiated by a decrease in cross direction tensile as the draw was decreased. The inability of the pilot paper machine to maintain a constant draw dismissed the analysis of a stepwise change in draw and its subsequent effect on cross direction shrinkage.

The amount of pressure on the presses was shown to have no effect on cross direction shrinkage.

The magnitude of the draw range available apparently was not sufficient to cause a significant change in machine direction shrinkage.

The existence of uneven sheet shrinkage from one edge of the sheet to the other was shown but there appeared to be no discernible trend.

Generally the strength test results were as predicted in the literature, thus giving a certain amount of reliability to the shrinkage results.

The apparent randomness of several of the tests would seem to indicate that other variables are controlling the amount of

shrinkage occurring on the machine.

With regards to control of cross direction shrinkage, the paper machine should be run with the draws as tight as possible in the dryer section for a minimum of cross direction shrinkage to occur. Draws in the press section should be as slack as possible to allow minimum cross direction shrinkage to occur.

RECOMMENDATIONS FOR FURTHER STUDY

It would be interesting to determine the effect of fiber orientation on cross direction shrinkage. The same method as used here could be used to determine shrinkage. Fiber orientation could be determined by tagging a small portion of the fibers and later examining the sheet with a microscope. Machine variables which could be varied include the machine shake, vacuum on the flat boxes, and headbox consistency.

Another area of more basic research could involve the effects of refining and different types of pulps on shrinkage. This would involve a great deal of laboratory work and a method that would allow the handsheets to dry without tension and yet prevent wrinkles would have to be devised.

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APPENDIX ONE

TABLE III

Per Cent Shrinkage

Cross Direction

Draw (feet)	Back	Middle	Front	Total	Machine Direction
Between Smoother and 1st Dryer					
+0.4	8.3	9.0	9.6	8.9	2.29
-0.3	7.3	8.1	10.5	7.6	2.29
-1.0	8.3	8.1	8.4	8.3	2.29
-1.4	8.3	8.1	8.4	8.3	2.3
+1.0	8.3	8.1	8.4	8.3	5.2
0.0	6.9	7.2	8.4	7.8	4.0
0.0	7.3	7.2	7.4	7.6	4.0
-2.0	7.3	7.2	7.4	7.3	4.6
Between Dryer Sections					
+1.9	5.2	5.4	5.3	5.3	0
+1.0	5.2	5.4	5.3	5.3	0
-0.2	5.2	6.3	5.3	5.6	0
-0.3	5.2	6.3	5.3	5.5	0
+1.0	5.7	4.5	3.7	4.6	0
-0.4	5.2	4.5	5.3	5.0	0
0.0	5.2	5.4	5.3	5.0	0
-0.7	5.2	5.4	4.2	5.0	0

TABLE IV

Per Cent Cross Direction

Total Shrinkage

Percent Dry	Before Second Press	After Second Press
	Slack Draws	
36.7	6.0	6.0
38.9	6.3	6.0
39.7	6.3	6.1
39.9	5.6	5.6
40.1	6.0	6.0
40.6	6.0	6.0
40.8	6.0	6.0
41.1	6.1	6.1
41.4	6.0	6.0
41.5	6.0	6.0
	Tight Draws	
38.4	6.0	5.6
38.7	6.0	5.6
39.7	6.0	5.6
39.7	6.0	5.3
39.9	6.0	5.6
41.0	6.0	5.3
41.3	5.6	5.3
41.4	6.0	6.0
41.8	6.0	6.0
42.6	6.0	5.6

TABLE V

Breaking Length And Per Cent Elongation

Back Section

	Machine Direction		Cross Machine Direction	
Draw (feet)	Breaking Length (feet)	PerCent Elongation	Breaking Length (feet)	PerCent Elongation
Between Smoother And 1st Dryer Section				
+0.4	24,800	2.2	10,300	8.4
-0.3	24,100	1.9	9,900	6.5
-1.0	23,000	1.8	10,600	7.1
-1.4	25,200	1.9	10,500	7.1
+1.0	21,800	1.8	9,200	6.2
0.0	22,400	1.7	9,600	6.6
0.0	18,800	1.4	10,000	7.3
-2.0	20,800	1.6	9,700	6.8
Between Dryer Sections				
+1.9	23,700	1.6	10,500	7.5
+1.0	21,900	2.0	10,200	7.5
-0.2	21,200	2.6	10,500	7.5
-0.3	19,400	2.7	9,900	6.9
+1.0	22,000	1.5	9,300	6.3
-0.4	21,300	1.9	9,700	6.8
0.0	20,500	2.2	9,700	7.0
-0.7	19,300	2.7	9,400	7.2

TABLE VI

Breaking Length And Per Cent Elongation

Middle Section

	Machine Direction		Cross Machine Direction	
Draw (feet)	Breaking Length (feet)	PerCent Elongation	Breaking Length (feet)	PerCent Elongation
	Between Smoother And 1st Dryer Section			
+0.4	25,500	2.1	9,800	6.8
-0.3	26,200	2.1	10,400	6.6
-1.0	25,200	2.1	10,200	6.4
-1.4	25,500	1.9	10,200	5.9
+1.0	22,900	1.7	9,300	5.6
0.0	24,000	1.8	9,600	6.1
0.0	21,200	1.7	9,900	5.8
-2.0	23,000	1.7	9,700	5.8
	Between Dryer Sections			
+1.9	24,400	1.6	10,200	6.6
+1.0	24,400	2.1	10,200	6.8
-0.2	21,900	2.5	9,900	6.6
-0.3	21,700	2.9	9,800	6.7
+1.0	23,800	1.6	9,500	5.5
+0.4	22,900	1.8	9,600	5.9
0.0	21,700	2.1	9,700	6.6
-0.7	20,300	2.6	9,300	6.6

TABLE VII

Breaking Length And Per Cent Elongation

Front Section

Draw (feet)	Machine Direction: Breaking Length (feet)	Machine Direction: PerCent Elongation	Cross Machine Direction: Breaking Length (feet)	Cross Machine Direction: PerCent Elongation
Between Smoother And 1st Dryer Section				
+0.4	23,100	2.1	9,400	6.4
-0.3	21,900	1.8	10,600	7.5
-1.0	23,700	1.9	10,400	8.0
-1.4	23,400	1.8	10,400	7.2
+1.0	21,500	1.7	8,900	6.3
0.0	22,400	1.8	9,300	6.8
0.0	21,200	1.7	9,500	6.9
-2.0	21,700	1.7	8,500	6.6
Between Dryer Sections				
+1.9	24,400	1.7	9,700	7.0
+1.0	22,100	2.0	10,300	7.4
-0.2	20,300	2.4	10,200	7.5
-0.3	20,100	2.9	10,100	7.5
+1.0	22,400	1.6	9,500	7.6
+0.4	20,000	1.7	9,300	6.4
0.0	20,600	2.2	9,700	7.2
-0.7	19,000	2.6	9,400	7.2

TABLE VIII

Breaking Length And Per Cent Elongation

Back Section

PerCent Dry	Machine Direction: Breaking Length (feet)	Machine Direction: PerCent Elongation	Cross Machine Direction: Breaking Length (feet)	Cross Machine Direction: PerCent Elongation
		Slack Draws		
36.6	15,400	2.4	7,800	5.0
38.9	14,500	2.4	7,900	5.2
39.7	15,000	2.3	7,700	4.7
39.9	14,700	2.3	7,600	4.9
40.1	14,400	2.4	8,000	5.2
40.6	15,400	2.3	8,100	5.0
40.8	15,000	2.4	8,100	4.9
41.1	15,300	2.3	8,100	4.9
41.4	14,700	2.4	8,200	5.2
41.5	15,200	2.2	8,200	5.2
		Tight Draws		
38.4	15,500	2.0	7,700	4.5
38.7	15,400	2.0	7,600	4.7
39.7	15,900	2.3	7,700	4.6
39.7	15,800	2.1	7,800	5.1
40.0	15,500	2.0	7,800	4.9
41.0	15,100	1.9	7,900	4.9
41.3	15,800	2.0	8,000	4.6
41.4	15,900	2.1	7,700	4.9
41.8	15,500	2.1	7,800	5.0
42.6	15,300	2.3	7,800	5.3

TABLE IX

Breaking Length And Per Cent Elongation

Middle Section

	Machine Direction		Cross Machine Direction	
PerCent Dry	Breaking Length (feet)	PerCent Elongation	Breaking Length (feet)	PerCent Elongation
		Slack Draws		
36.6	15,100	2.3	7,900	5.2
38.9	15,800	2.5	7,700	4.9
39.7	15,600	2.5	7,900	5.0
39.9	14,900	2.3	7,700	5.0
40.1	15,700	2.6	7,700	4.9
40.6	15,800	2.3	8,100	5.0
40.8	16,100	2.6	8,100	4.8
41.1	16,000	2.4	8,000	4.9
41.4	15,100	2.2	8,000	5.2
41.5	15,800	2.3	7,900	4.7
		Tight Draws		
38.4	16,000	2.0	7,600	4.5
38.7	16,300	2.1	7,600	4.4
39.7	16,300	2.2	7,600	4.6
39.7	16,400	2.2	7,600	4.7
40.0	15,700	2.0	7,600	4.7
41.0	16,500	2.2	7,800	4.6
41.3	16,200	2.1	7,700	4.3
41.4	16,400	2.1	7,800	4.8
41.8	15,900	2.1	7,700	4.7
42.6	16,800	2.3	7,600	4.7

TABLE X

Breaking Length And Per Cent Elongation

Front Section

	Machine Direction		Cross Machine Direction	
PerCent Dry	Breaking Length (feet)	PerCent Elongation	Breaking Length (feet)	PerCent Elongation
		Slack Draws		
36.6	15,400	2.2	7,900	5.3
38.9	15,200	2.4	7,500	5.0
39.7	15,400	2.2	7,800	5.1
39.9	14,800	2.1	7,200	4.8
40.1	14,800	2.4	7.800	5.2
40.6	15,400	2.2	7,700	4.9
40.8	15,600	2.4	7,900	5.4
41.1	15,200	2.3	7,900	5.4
41.4	15,100	2.4	7,700	5.0
41.5	16,300	2.3	8,100	5.2
		Tight Draws		
38.4	15,700	2.1	7,400	4.7
38.7	15,700	2.2	7,500	4.9
39.7	15,900	2.2	7,300	4.9
39.7	15,700	2.0	7,500	4.7
40.0	15,300	2.1	7,300	5.0
41.0	16,000	2.1	7,800	4.9
41.3	16,000	2.0	7,700	4.5
41.4	15,800	2.1	7,500	4.6
41.8	16,000	2.0	7,500	5.1
42.6	15,100	2.0	7,600	5.2