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The Effects of Stress During Drying Upon Physical Characteristics

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THE EFFECTS OF STRESS DURING DRYING

UPON PHYSICAL CHARACTERISTICS

by

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ABSTRACT

The purpose of this study was to determine the effects of stress during drying upon the strength of the paper.

This study consisted of two machine runs on a pilot paper machine. The machine was operated with minimum tension in all draws to provide a standard condition. For experimental conditions, tension was applied at various draws and increased until the sheet broke. Samples were taken from the standard condition sets and from all experimental sets for evaluation purposes. The samples were evaluated for machine and cross-machine direction elongation, machine and cross-machine direction tensile, mullen, and machine and cross-machine direction tensile energy absorption.

It was observed that machine direction elongation decreased, the machine direction tensile strength increased, and the mullen decreased when increased tension was applied. The machine direction tensile energy absorption (T. E. A.) decreased and the cross-machine direction T. E. A. increased when tension was applied to the drying paper.

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HISTORICAL BACKGROUND AND DEVELOPMENT OF PROBLEM

Historical Background

The effects of stress applied to a web of paper during its drying process on a paper machine have been studied during the past twenty years. These drying stresses have mainly resulted in changing the physical strength characteristics of the paper. The following section is a brief summary of the work that has been done in this area.

Sapp and Gillespie (1) used a paper machine to perform their studies. They concluded that mullen decreased rapidly, approximately a straight line function of the extent of stretching during drying. Sapp and Gillespie also stated that in their work that if paper was dried under minimum stress, the resulting paper had the best bursting strength.

Shulz (2) made handsheets and employed stress on these handsheets while they dried. Shulz found in his work that as stress in the machine direction was increased the resulting tensile strength of the dry sheet increased.

Brecht and Pothmann (3), Rance (4), and Brecht, Gerspach, and Hildenbrand (5) used a paper machine for the studies performed in their work. These authors stated that a drying stress was increased to give more tensile strength, in the dry sheet, the extensibility decreased proportionately to the amount of increased tensile strength.

When Arlov and Ivarrson (6) used a paper machine to study the effects of tension applied during drying, they found that the increase in tensile strength produced by stress was best developed when the paper entered the dryer section at approximately 30 to 35% solids and 65-70% moisture.

Development of Problem

Based on the results of the above mentioned studies, it was decided to further investigate these areas by varying the draw tensions at numerous points on the paper machine and evaluating the resulting paper for elongation, tensile, mullen, tensile energy absorption, and moisture content.

The primary purpose of this study was to determine if the literature conclusions would hold true in this work. The literature survey did not state any data on the effects of stress upon tensile energy absorption. Therefore, another objective of this study was to determine if stress applied during drying produced any effects on machine direction and cross-machine direction tensile energy absorption.

EXPERIMENTAL DESIGN AND PROCEDURE

The pilot paper machine at Western Michigan University was used for this study. The pilot plant beater was used to prepare the furnish in this study.

Stock Preparation

First machine run

The furnish for this run consisted of a mixture of pulp, 60% bleached softwood kraft and 40% bleached hardwood kraft, beaten at a consistency of 4% to a Canadian Standard freeness of 390 milliliters.

Second machine run

The pulp furnish for this run was 100% bleached softwood kraft beaten at a consistency of 4% to a Canadian Standard freeness of 400 milliliters.

Machine Operation

Standard conditions

The machine speed in both runs was maintained at 80 feet per minute. In an effort to reduce the number of variables the size press was not used and no sizing or alum was used. The paper machine was run with minimum tension in all draws to provide standard reference data. In each of the two runs the standard conditions are labeled as set 1.

An attempt was made to maintain the moisture content at approximately the same values in each of the machine runs. This was done by taking samples for the determination of moisture content at the same places in each run. The samples were taken at the following places: between the wire and the first press, between the first and second presses, between the second press and the smoothing roll, between the big dryer section and the little dryer section, and between the little dryer section and the calendar stack.

In all cases any draws that are not mentioned are kept under minimum tension while the stress is being applied in the stated draws. Also, samples were taken in each case after the web had broken.

Experimental conditions

First machine run

In set 2-3 the tension was increased between the wire and the first press until the web broke. Set 3-4 consisted of increasing tension between the first press and second press until the sheet broke. For set 4-5 the stress was increased between the second press and the smoothing roll until the web was broken. The paper made in set 5-6 had maximum tension applied between the smoothing roll and the big dryer section. Another variable, set 6-7, had the tension between the big dryer section and the little dryer section increased to a maximum. The final stress condition, set 8-9, consisted of increasing the stress in all draws between the wire and the little dryer section until the web broke.

Second machine run

In the first variable labeled as set 5-6, the tension between the smoothing roll and the big dryer section was increased until the sheet broke. Set 6-7 consisted of increasing the tension between the big dryer section and the little dryer section until the web failed. In set 7-8 the stress in all the draws between the smoothing roll and the little dryer section was increased until the sheet broke. The last stress condition, set 8-9, produced in this run consisted of increasing the tension in all draws between the wire and little dryer section until the sheet failed.

Evaluation of Samples

All the samples that were obtained for this study were conditioned for 24 hours under Tappi Standard Conditions.

The samples obtained in the first machine run were tested for moisture content, machine direction elongation, machine direction tensile, and mullen.

The samples from the second machine run were evaluated for the following: moisture content, machine and cross-machine direction elongation, machine and cross-machine direction tensile, mullen, and machine and cross-machine direction tensile energy absorption.

Moisture samples were tested according to Tappi Standard Procedure T-412 os63.

The Instron Testing Machine was used to test for machine and cross-machine direction elongation, machine and cross-machine direction tensile energy absorption (T. E. A.), and machine and cross-machine direction tensile. The samples for the Instron were 1 inch

(2.54 centimeters) wide and 10 centimeters long. A 20 kilogram full scale load was used in all tests. A 20 centimeter per minute chart speed and a 2 centimeter per minute crosshead speed was used for all testing. The Instron was calibrated and the integrator device was standardized according to the manufacturer's specifications. The values for the respective tests were read off the chart. The integrator readings were recorded for each sample so that T. E. A. values could be calculated using Tappi Standard T-494 su64.

Mullen tests were performed on all samples according to Tappi Standard T-403 ts 63.

The raw data obtained for tensile and mullen were converted to tensile factors (tensile/basis weight) and mullen factors (mullen/basis weight). These factors were employed to make the data more meaningful because there was some fluctuation in basis weight during the machine runs.

DISCUSSION OF EXPERIMENTAL DATA

The draw points at which tension was applied to the drying paper are listed for the first machine run and for the second machine run in Tables I and II, respectively.

Tables III and IV list the moisture content in the sheet at various points along the paper machine. Table III refers to the first machine run, and Table IV refers to the second machine run. The moisture samples were taken in an effort to control the moisture content of the paper going into the dryer section.

The amounts of stretch caused by tension applied at various draw conditions are listed in Tables V and VI for the first machine run and the second machine run, respectively.

Effects of Stress on Sheet Elongation

The discussion of elongation in the sheet caused by tension revolves around figures 1, 2, and 3. The general pattern observed from increased tension on machine direction elongation in both machine runs as shown in Figures 1 and 2 was a decrease in elongation. The explanation for the observed effects of stress upon machine direction elongation can be discussed in the following manner. When tension is applied in the machine direction, the fibers are strained so that they are dried in an extended state. This means that the amount of extensibility in the fibers has decreased by extension during drying. Since some of the extensibility has been destroyed, the amount of elongation remaining in the fibers is less than the elongation that fibers would have without stretching while drying. Therefore, when the sheet is subjected to an elongation test in the machine direction, the elongation decreases with increased machine direction stress applied to the paper during the drying process.

The cross-machine direction elongation was shown in Figure 3 to increase as machine direction stress was increased. This increase in elongation was attributed to the contraction in the cross direction to compensate for the extension in the machine direction. Therefore, with the paper contracted in the cross direction it will have a tendency to stretch more in the cross direction when it is subjected to an elongation test. The high data result in set 5-6 is partially attributed to a high basis weight in this set.

Effects of Stress on Tensile Factors

Figures 4, 5, and 6 show the effects of stress on tensile factors. Figure 4 is on the first machine run while Figures 5 and 6 are on the second machine run.

The effects of increased drying stress upon machine direction tensile strength as shown in Figures 4 and 5 resulted in a trend that the tensile load required to break the sample increased when the sheet was nearly dry and was not changed when the sheet was wet. There are two possible explanations for the results obtained. It is felt that no effects were received when the sheet was very wet because stretching affected the moisture content rather than the fibers. The reason for the increase in tensile strength when the sheet was nearly dry is explained by the theory that most of the bond formation is occurring at this point. The stress applied orients the fibers and improves bonding. This phenomenon would lead to a higher tensile strength.

Figure 6, the effects of stress upon cross-machine direction tensile factors, resulted in no clear-cut trend.

Effects of Stress on Mullen Factors

In both machine runs the general trend of the effects of stress on mullen factors, shown in Figures 7 and 8, were quite similar. This pattern was found to be that as stress in the machine direction was increased, the bursting strength decreased. This decrease was attributed to the decrease in machine direction elongation which resulted from increased stress in the machine direction.

Effects of Stress on Tensile Energy Absorption

Figures 9 and 10 show the effects of stress on machine direction and cross-machine direction tensile energy absorption (T. E. A.), respectively.

The over-all pattern of T. E. A. is explained by the decrease in machine direction elongation. T. E. A. is a measure of work which is force times distance. The elongation decreased with increased stress. Therefore, a decrease in elongation resulted in a shorter distance required to break the sample. A decreased elongation and a decreased distance gave less work required to break the sample which resulted in the decrease in T. E. A. with increased stress.

The general pattern of cross-machine T. E. A. shown in Figure 10 was a gradual increase as machine direction stress was increased. This result is explained on the basis of sample elongation. The increase in cross-direction elongation required an increase in distance. An increased elongation and increased distance gave increased work. Consequently, the increase in work gave an increase in T. E. A. when stress was increased.

This study has been quite successful in achieving the goals for which it was performed. It was found that the literature conclusions held true in this study for the effects of stress on elongation, tensile strength, and mullen. It was observed that stress applied in the machine direction has some effects on the tensile energy absorption of paper in both the machine direction and the cross-machine direction.

CONCLUSIONS AND SUMMARY

In both machine runs, the machine direction elongation decreased, the tensile strength increased, and the mullen decreased when increased tension was applied.

As stress was increased in the machine direction, the machine direction tensile energy absorption decreased and the cross-machine direction T. E. A. increased.

The data obtained from the effects of stress upon mullen coincide with the results of Sapp and Gillespie (1) in that mullen decreased with increased drying stress. The increase in machine direction tensile caused by increased tension observed in this work paralleled the work done by Shulz (2). The results of increased machine direction tensile strength as machine direction elongation decreased are similar to the conclusions obtained in previous studies (3, 4, 5).

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TABLE I DEFINITIONS OF SETS

Set No.	Conditions
1	Minimum Tension in all Draws on the Machine
2-3	Maximum Tension between Wire and 1st Press
3-4	Maximum Tension between 1st Press and 2nd Press
4-5	Maximum Tension between 2nd Press and Smoothing Roll
5-6	Maximum Tension between Smoothing Roll and Big Dryer Section
6-7	Maximum Tension between Big Dryer Section and Little Dryer Section
8-9	Maximum Tension between the Wire and Little Dryer Section

TABLE II DEFINITIONS OF SETS

Set No.	Conditions
1	Minimum Tension in all Draws on the Machine
5-6	Maximum Tension between Smoothing Roll and Big Dryer Section
6-7	Maximum Tension between Big Dryer Section and Little Dryer Section
7-8	Maximum Tension between Smoothing Roll and Little Dryer Section
8-9	Maximum Tension in all Draws

TABLE III MOISTURE CONTENT

Location	% Moisture
Between Wire and 1st Press	76.6%
Between 1st Press and 2nd Press	67.8%
Between 2nd Press and Smoothing Roll	59.7%
Between Big and Little Dryer Sections	11.8%
Between Little Dryer Section and Calendar	5.0%

TABLE IV MOISTURE CONTENT

Location	% Moisture
Between Wire and 1st Press	77.6%
Between 1st Press and 2nd Press	65.7%
Between 2nd Press and Smoothing Roll	63.4%
Between Big and Little Dryer Sections	9.8%
Between Little Dryer Section and Calendar	4.5%

TABLE V STRETCH DUE TO TENSION

Set No.	Amount of Stretch
1	2.2 feet stretch per 80 feet
2-3	1.3 feet stretch per 80 feet
3-4	2.3 feet stretch per 80 feet
4-5	2.5 feet stretch per 80 feet
5-6	1.8 feet stretch per 80 feet
6-7	1.7 feet stretch per 80 feet
8-9	4.8 feet stretch per 80 feet

TABLE VI STRETCH DUE TO TENSION

Set No.	Amount of Stretch
1	1.0 feet stretch per 80 feet
5-6	2.3 feet stretch per 80 feet
6-7	1.4 feet stretch per 80 feet
7-8	1.9 feet stretch per 80 feet
8-9	3.8 feet stretch per 80 feet

Figure 1 First Machine Run

Machine Direction Elongation

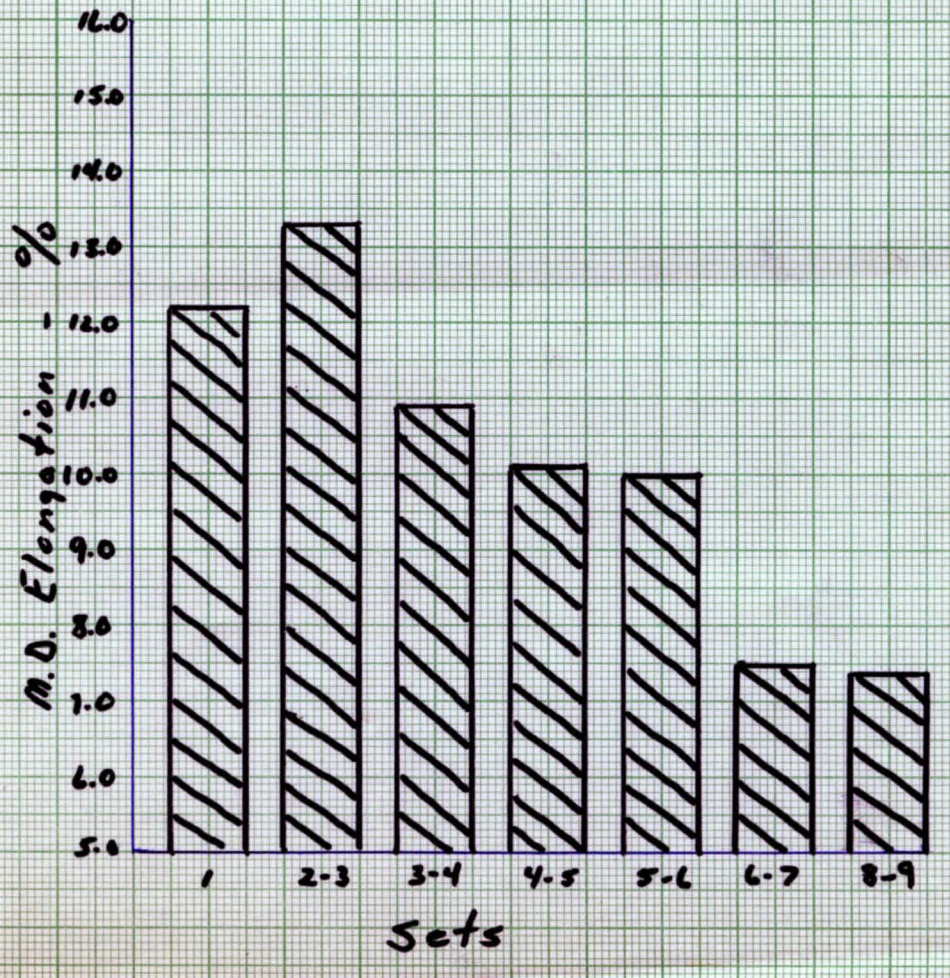

Figure 2 Second Machine Run

Machine Direction Elongation

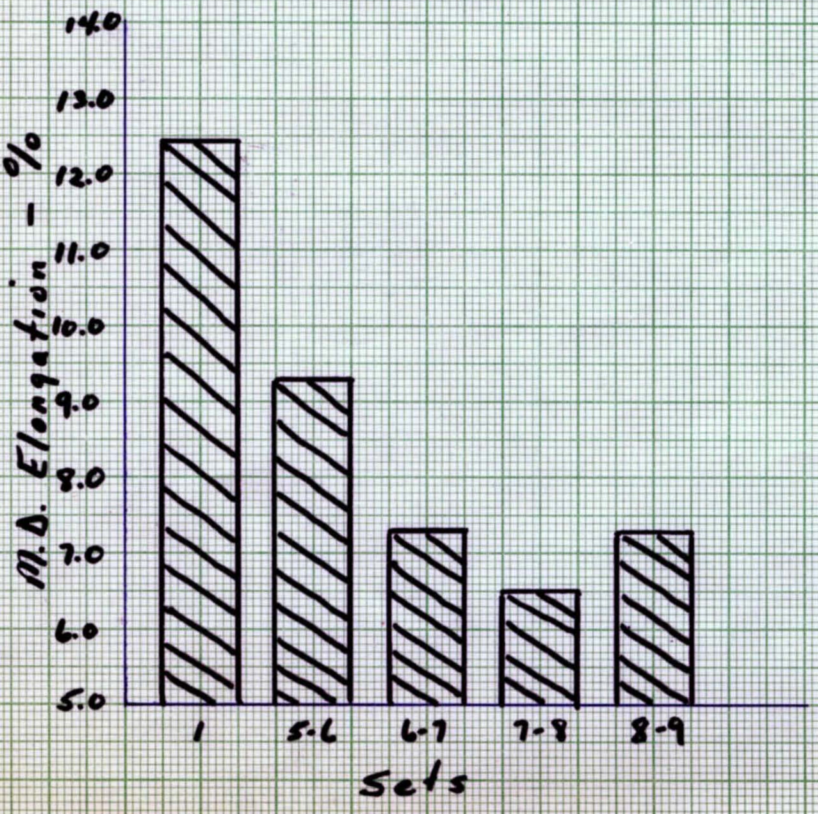

Figure 3 Second Machine Run

Cross Direction Elongation

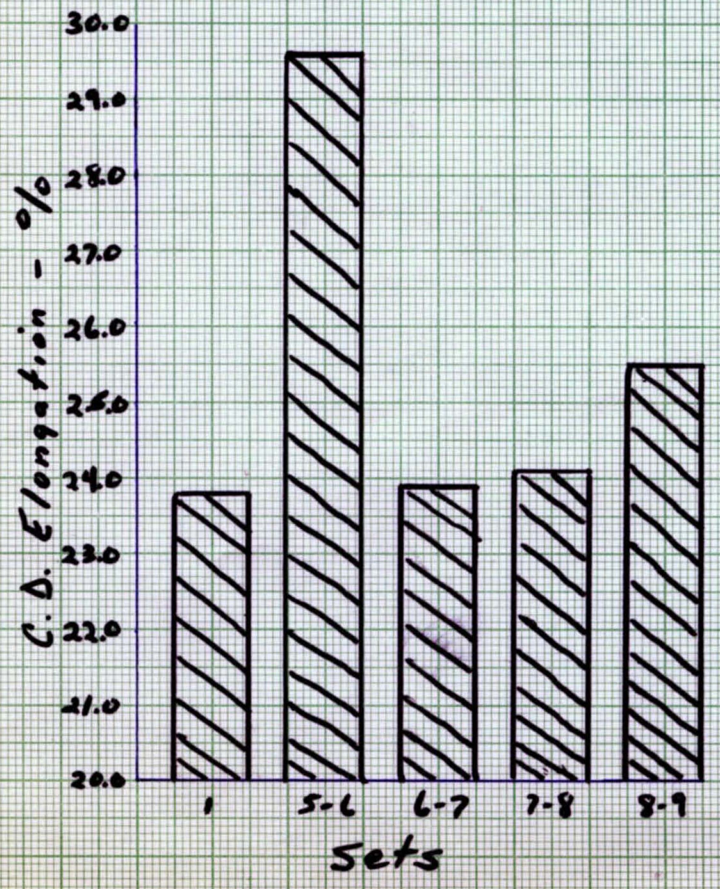

Figure 4 First Machine Run

Machine Direction Tensile Factor

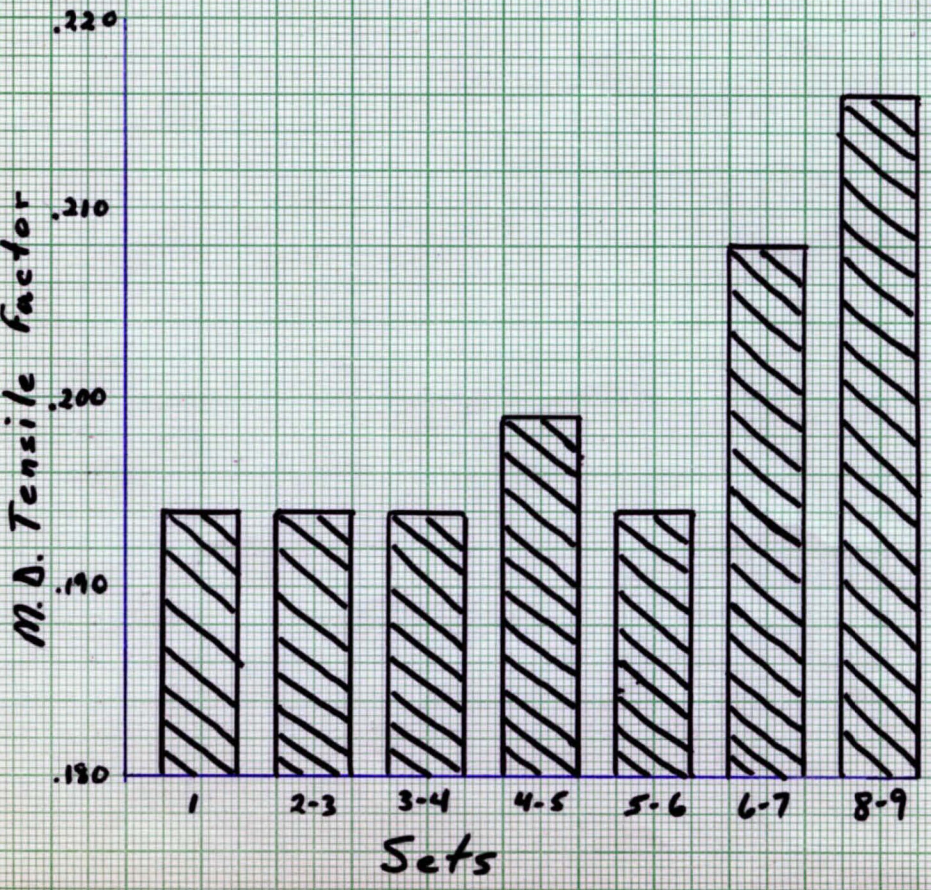

Figure 5 Second Machine Run

Machine Direction Tensile Factor

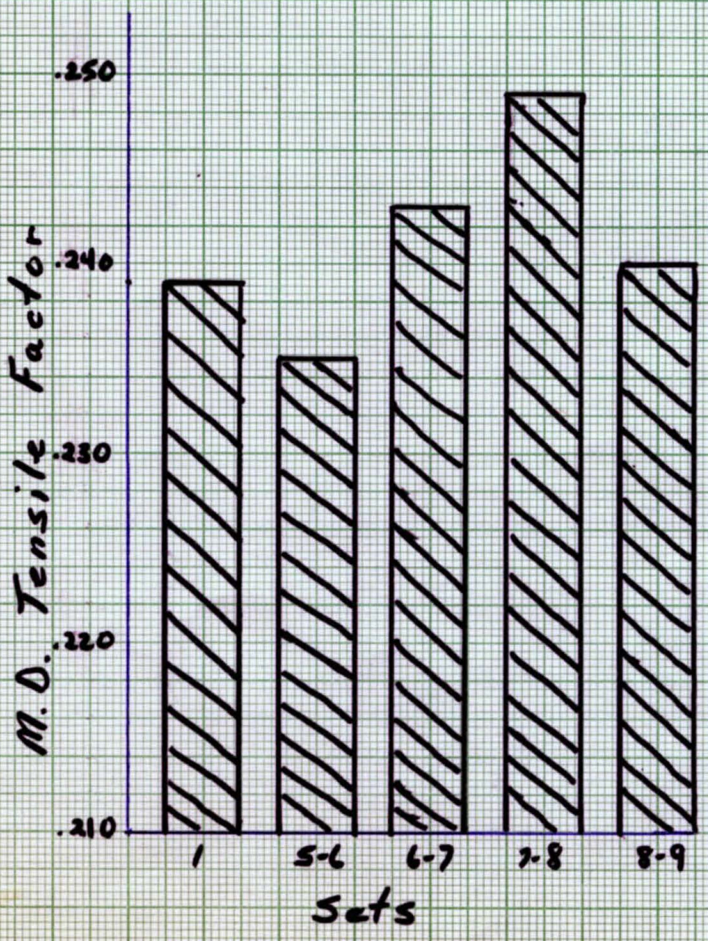

Figure 6 Second Machine Run

Cross-machine Direction Tensile Factor

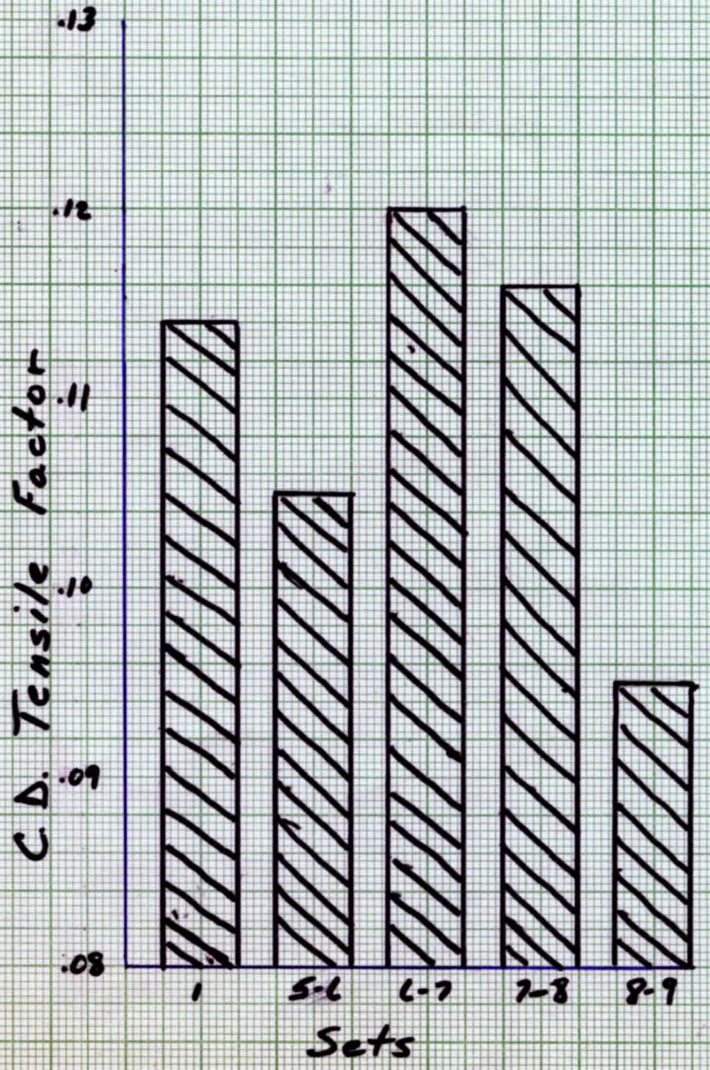

Figure 7 First Machine Run

Mullen Factor

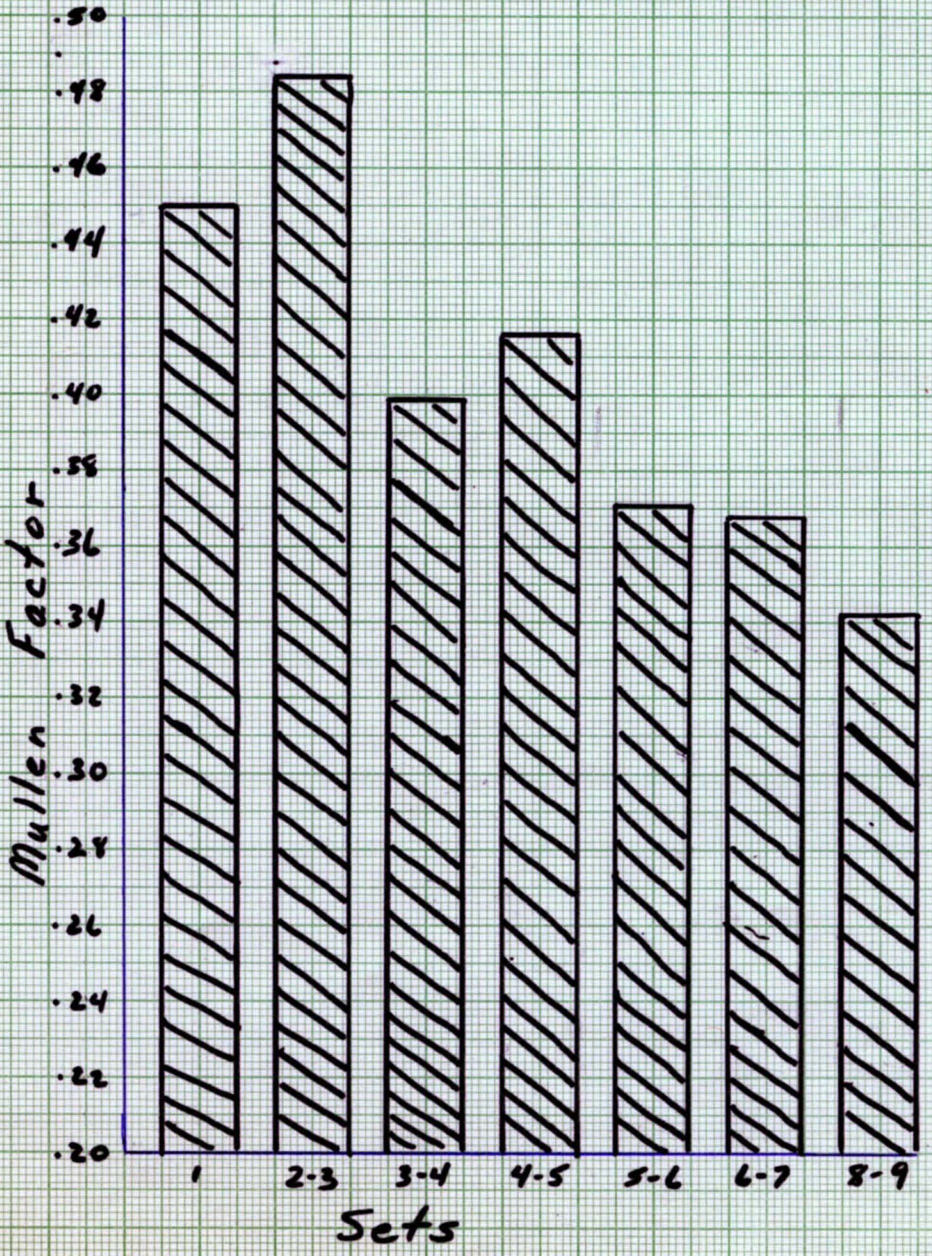

Figure 8 Second Machine Run

Mullen Factor

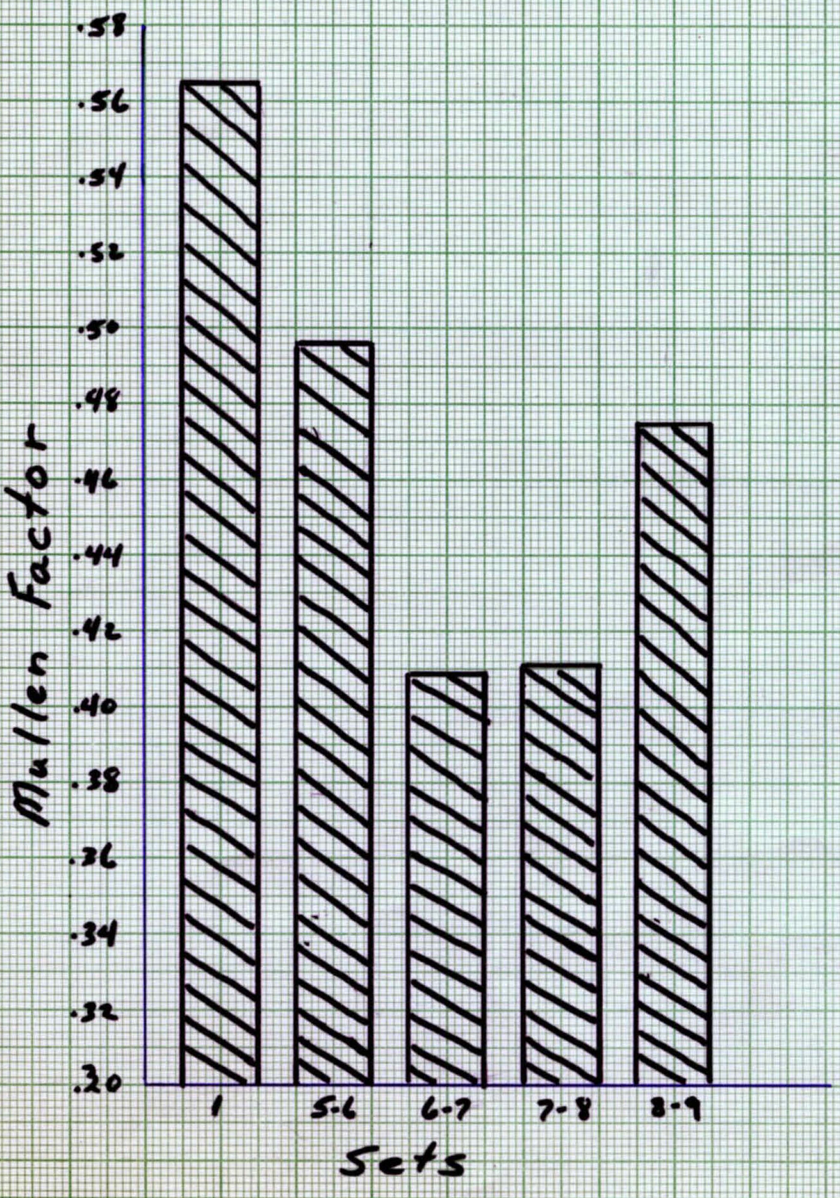

Figure 9 Second Machine Run

Machine Direction Tensile Energy Absorption

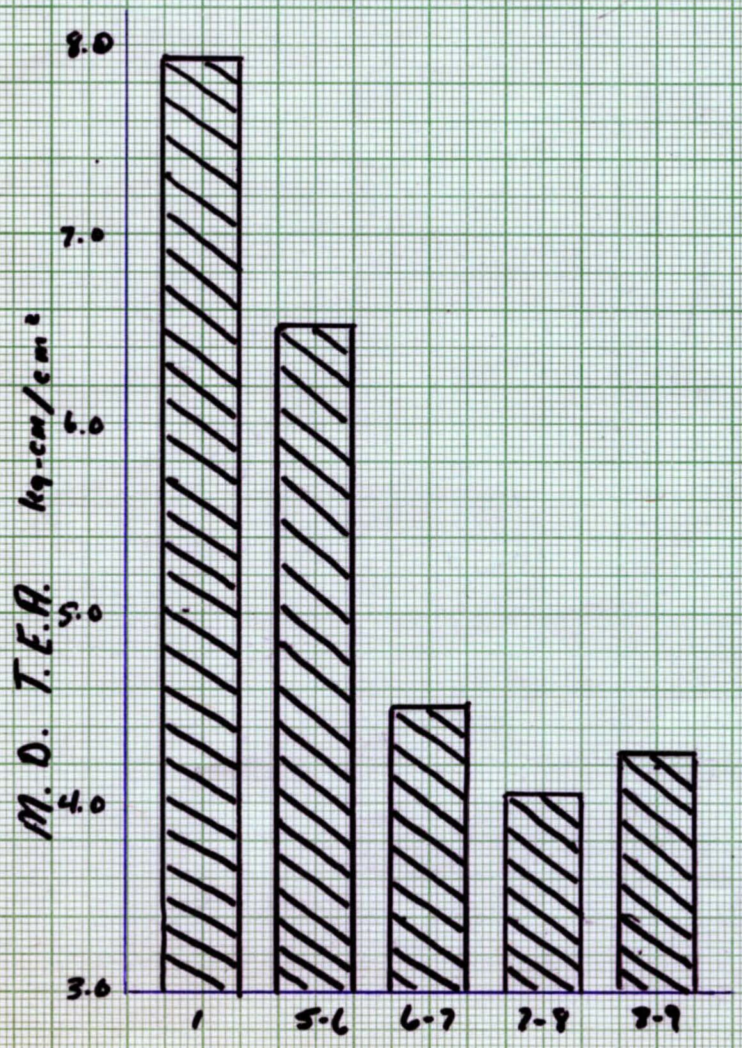

Figure 10 Second Machine Run

Cross-machine Direction Tensile Energy Ab

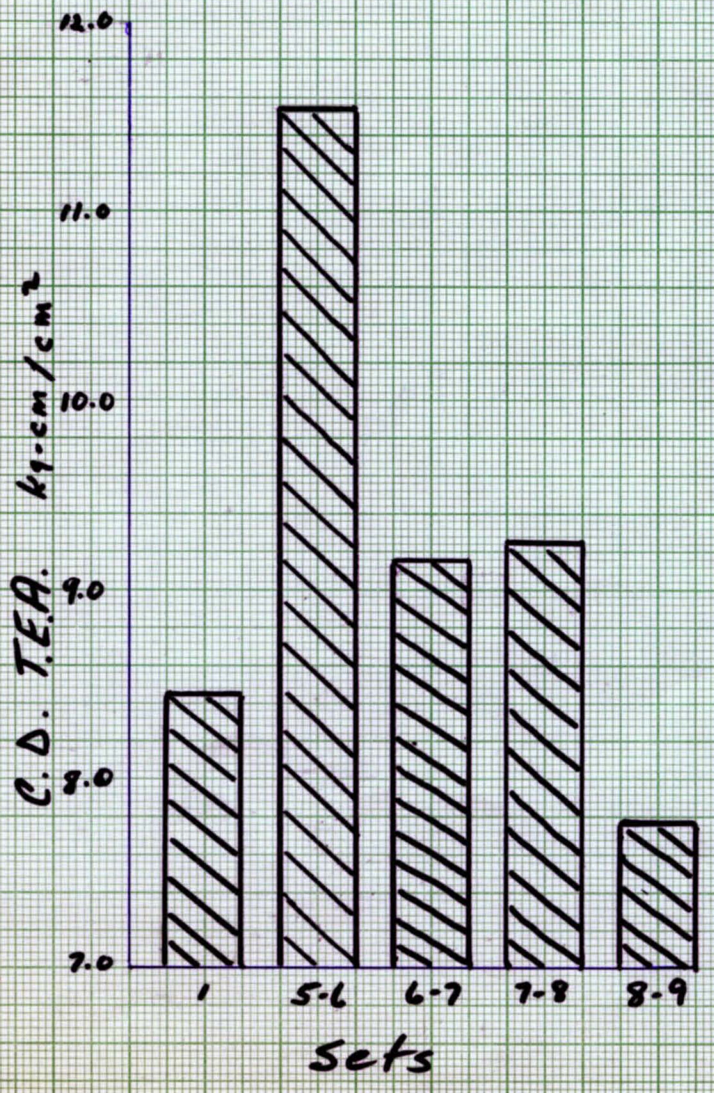

TABLE VII EXPERIMENTAL DATA

Set No.	Mullen Factor	M. D. Tensile Factor	M. D. Elongation	Basis Weight
1	.45	.194	12.2	46.3
2-3	.484	.194	13.3	50.0
3-4	.399	.194	10.9	50.7
4-5	.416	.199	10.1	49.2
5-6	.371	.194	10.0	49.6
6-7	.368	.208	7.5	48.1
8-9	.342	.216	7.4	47.4

TABLE VIII EXPERIMENTAL DATA

Set No.	Mullen Factor	M.D. Tensile Factor	C.D. Tensile Factor	M.D. Elong.	C.D. Elong.	M.D. T.E.A.	C.D. T.E.A.	Basis Weight
1	.565	.239	.114	12.45	23.8	7.94	8.45	45.0
5-6	.496	.235	.105	9.3	29.6	6.52	11.57	52.0
6-7	.409	.243	.120	7.3	23.9	4.51	9.16	46.0
7-8	.411	.249	.116	6.5	24.1	4.05	9.25	46.0
8-9	.475	.240	.095	7.3	25.5	4.28	7.79	44.0