M. LORENZ

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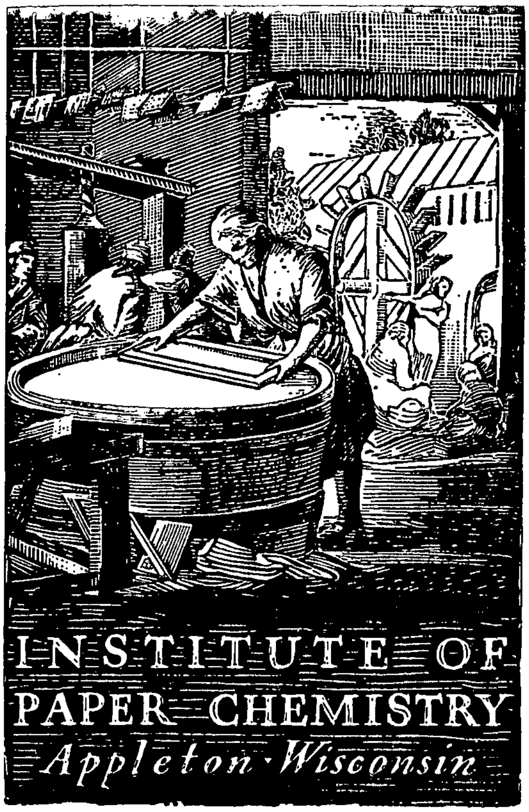

HIGH SPEED RUNNABILITY AND BONDING: EFFECTS OF MEDIUM AND CORRUGATOR CONDITIONS ON BOARD QUALITY

Project 2696-22

Report Two
A Progress Report
to
FOURDRINIER KRAFT BOARD GROUP
OF THE
AMERICAN PAPER INSTITUTE

May 1, 1989

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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W. J. Whitsitt and C. N. Smith

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

HIGH SPEED RUNNABILITY AND BONDING: EFFECTS OF MEDIUM AND CORRUGATOR CONDITIONS ON BOARD QUALITY

SUMMARY

This project is directed to identifying medium factors which will promote increases in corrugating speed and improve the quality of corrugated board. A major part of our current work has been concerned with the evaluation of the effects of moisture content and temperature during fluting. Optimizing roll moisture levels and corrugating moisture/temperature conditions can improve box plant quality and effect mill savings.

Corrugating trial results on a wide range of mediums have been analyzed to show a) the effects of medium nip moisture, nip temperature, roll moisture and speed on ECT, flat crush, pin adhesion and high-lows, b) how medium nip moisture and temperature are affected by the steam shower and preheat conditions, c) how medium properties affect combined board properties and, (d) medium nip moisture/temperature relationships.

The following results were obtained:

<u>Moisture/temperature/medium results</u>.

1. Roll and nip moisture content are major factors affecting flat crush. Increasing the roll and nip moisture content significantly increases flat crush. The nip temperature of the medium has only a minor effect on flat crush. Effective showering equipment on the corrugator is important to help keep the medium from becoming too dry. Higher mill moisture target levels could also be beneficial.

2. Pin adhesion strengths increase as medium nip moisture and nip temperature increase at a given speed. Higher medium moistures aid wetting and penetration, and higher temperatures should promote faster gelling of the starch. The analysis does indicate that the benefits of higher nip moistures reach a maximum at a moisture somewhat in excess of 10%; beyond that point pin adhesion may decrease.
3. Higher pin adhesion strengths at a given speed are promoted by rougher, more porous, and more wettable mediums. Greater porosity and wettability should aid in wetting and penetration of the starch adhesive. The roughness of the medium, measured by the difference between soft platen and TAPPI densities, appeared to significantly affect adhesion strengths. The rougher the medium, the greater the pin adhesion strength. These adhesion increases may be due to the greater surface area of the rougher mediums. The results also suggested that the effects of water absorptivity depend somewhat on the medium density, although not in a major way.
4. Higher nip temperatures and moistures generally decreased high-lows. Higher temperatures help plasticize the medium and, providing the medium is not too dry, promote fluting with less damage and dimensional instability. Mediums exhibiting higher hot friction and soft platen caliper and lower MD stretch exhibited more high-lows at a given speed.
5. ECT strengths increased as the STFI compression strength and basis weight of the medium were increased. The results also show that ECT strengths increased as pin adhesion strengths increased and

high-lows diminished. Thus the higher nip moistures and temperatures which increase adhesion and decrease high-lows should have a favorable effect on ECT.

However, the effects of changes in adhesion and high-lows were not very great unless extremes were present. Past work shows that ECT decreases rapidly when glue skips are present or adhesion strengths are low. Also, fractured flutes are known to reduce ECT.

6. In general, increasing roll and nip moisture tended to produce small decreases in single-face flute height.
7. Nip temperatures increased markedly with increased showering and were lowered somewhat as medium density increased.
8. The medium moisture at the entrance to the fluting nip is primarily dependent on the roll moisture and steam shower conditions as expected. The medium preheater reduces nip moisture. Medium properties which affected nip moisture included water drop, density and porosity.
9. These results emphasize the importance of effective steam showers for obtaining high medium temperatures with added moisture to help soften the medium and promote fluting and bonding.
10. The regression equations relating board quality to operating factors and medium properties can be used to assess the effects of changes in mill target property levels, corrugating practices, and for trouble-shooting problems. Used in this way the effects of many combinations of medium properties and corrugator conditions can be evaluated and optimized.

High temperature tensile properties

We also determined the tensile load-elongation properties of mediums from different sources after exposure to high temperature for short, controlled periods of time. These conditions simulate the temperature/moisture condition of the medium in the fluting nip.

At high temperatures the results indicate that

1. The MD stretch behavior of mediums significantly increases as temperature is increased, which favors higher runnability speeds. However, the amount of stretch increase varies from medium-to-medium, and the differences are great enough to affect runnability. For example, a green liquor medium exhibited much lower stretch increases than NSSC and caustic/carbonate mediums. These differences in stretch behavior are believed to be affected by the chemical composition of the medium, i.e., by the lignin and hemicellulose content.
2. Different medium types exhibit approximately equal tensile losses as the test temperature or initial moisture content were changed.
3. The results indicate that high temperature tensile tests should be helpful in explaining runnability differences and moisture/temperature preconditioning effects on the corrugator. In a current project we are investigating the effects of furnish composition on high temperature medium behavior.

Devron-Hercules Steam Shower

In general the Devron shower results showed no major strength or runnability advantages were obtained.

INTRODUCTION

This project was directed to identifying medium factors which promote increases in corrugating speed and improve the quality of corrugated board. It is part of a long-range plan to improve corrugator runnability. The first phase of the work was directed to (a) developing a runnability model to relate medium properties to strength retention, high-lows and flute fracture and (b) developing baseline information on the performance of current commercial mediums.

Report One summarized the results from the first phase. The research showed that critical speeds for high-lows and flute fracture depend on the following properties: MD tensile, MD stretch, hot friction and caliper. High-lows decrease as medium friction and thickness decrease, and MD tensile and stretch increase. Strength retention and flute fracture are affected in a similar way by these properties.

The second phase was concerned with the evaluation of the effects of medium properties, moisture content and temperature during fluting on board qualities. The board qualities evaluated were adhesion, flute height, high-lows, flat crush and ECT. Roll moisture levels and corrugating moisture/temperature conditions can greatly affect board quality. Optimizing these factors can improve box quality and effect mill savings. The results obtained in this phase are summarized in this report.

Currently we are extending this work to include consideration of green bond development on the single-facer as well as final bond. Emphasis is being given to the liner and medium properties affecting green and final bond.

A detailed review of the literature on runnability is contained in Report One. The literature on corrugator bonding was discussed in Project 2696-24, Report One, January 18, 1989.

MEDIUM SUPPLIERS

To study the effects of initial roll moisture content variations a number of mills supplied rolls made at lower than normal, normal, and higher than normal moisture levels. Mills submitting medium samples are listed in Table 1.

Table 1. List of mills submitting medium rolls.

Company	Mill	Moisture Levels Low	Moisture Levels Normal	Moisture Levels High
Boise Cascade Corp.	Wallula	--	X	X
Great Southern Paper Co.	Cedar Srings	X	X	X
Longview Fibre Corp.	Longview	X	X	X
Nekoosa Packaging Corp.	Big Island	X	X	X
MacMillan Bloedel, Inc.	Pine Hill	X	X	X
Stone Container Corp.	Hodge	X	X	X
Stone Container Corp.	York	X	X	X

These medium rolls were overwrapped in plastic by the mills. To try and retain the manufactured moisture content the rolls were not unwrapped until time of corrugating. Samples for test purposes were taken at that time.

The roll moisture contents taken during corrugating are shown in Table 2 under coded identity.

Table 2. Roll moisture contents.

Mill	Nominal Weight, lb/M sq ft	Moisture Content, % Low	Moisture Content, % Normal	Moisture Content, % High
D	33	4.2	5.6	7.2
I	26	4.4	6.0	7.8
K	26	2.6	6.0	14.3
R	26	5.8	7.6	9.6
R	33	--	--	10.8
AC	26	--	6.8	10.2
AF	26	--	6.4	11.3
AG	26	5.3	7.6	8.1

MEDIUM PROPERTIES

The physical characteristics of the mediums submitted for this phase of the work are shown in Tables 3 and 4. For each mill the results are shown separately for the two or three rolls made to different moisture contents. All test properties were evaluated after TAPPI standard conditioning.

For comparison purposes selected properties of the 26-lb medium rolls made to "normal" moisture content are illustrated in Fig. 1-5. It should be kept in mind that the results for the rolls made at different moisture contents often exhibit medium properties which are significantly higher or lower than obtained with the "normal" moisture content rolls.

Figure 1 shows that the MD tensile results ranged from a low of 37.7 lb for mills AC and R to 49.7 lb for mill AF. The MD stretch values ranged from 1.08% for mill AF to over 1.6% for mill AG. Mill K also exhibited a relatively low stretch value. In our runnability model high MD tensile and stretch promote better runnability, but stretch is somewhat more important. Thus, the advantages of a higher MD tensile strength can be counterbalanced by low MD stretch.

The hot friction coefficients ranged from about 0.24 for mill AG to 0.46 for mill K (Fig. 2). A low coefficient is desirable. Lower runnability would be expected for mill K medium, which exhibited high friction, low MD stretch and a relatively high thickness.

The mill R medium exhibited the lowest soft platen caliper, while the highest soft platen calipers were obtained for the mill K and AF mediums (Fig. 3). A lower caliper should promote better runnability.

Table 3. Test properties for mediums made at various moisture levels.

Mill:	AG	AG	AG	AF	AF	R	R	R	I	I	I
Roll No.	6771	6773	6775	6781	6782	6791	6793	6796	6797	6799	6801
Basis Weight, lb/Msq ft	25.7	26.4	26.8	24.9	25.6	27.1	26.3	27.0	25.1	25.4	25.7
Caliper (TAPPI), mil	9.42	8.82	9.63	9.44	9.84	9.25	8.76	8.94	9.54	8.89	9.55
Caliper (IPC), mil	184	182	190	200	195	175	170	165	182	177	180
Caliper (IPC), mil	7.25	7.18	7.49	7.87	7.65	6.87	6.71	6.48	7.16	6.98	7.09
Dens. (TAPPI), lb/rm-mil	2.73	2.99	2.78	2.64	2.60	2.93	3.00	3.02	2.63	2.86	2.69
Dens. (IPC), lb/rm-mil	3.54	3.68	3.58	3.17	3.35	3.94	3.92	4.16	3.51	3.64	3.62
MD Tensile, lb/inch	40.2	38.9	39.2	49.7	48.8	39.4	37.7	44.4	42.4	42.0	42.9
MD Stretch, %	1.57	1.64	1.59	1.08	1.25	1.28	1.26	1.80	1.23	1.30	1.30
MD Et, lb/inch	5032	4840	5060	6634	6306	5703	5418	5659	5833	5548	5779
MD TEA, ft lb/sq ft	4.83	4.93	4.83	3.77	4.42	3.85	3.54	6.27	3.84	4.04	4.13
MD STFI, lb/inch	21.7	21.3	20.9	27.3	26.0	25.8	22.1	26.0	24.3	24.1	25.4
CD STFI, lb/inch	14.0	13.2	12.6	13.7	12.5	15.3	14.0	16.0	15.0	14.5	14.9
MD Ring Crush, lb/6 inches	50.3	48.5	48.6	63.9	61.0	57.9	51.2	58.1	57.1	57.2	56.9
CD Ring Crush, lb/6 inches	36.1	39.0	36.4	43.1	39.5	41.3	39.3	43.7	41.3	41.6	42.5
Concora, lb	60.3	55.9	60.7	56.1	66.7	54.1	49.0	62.5	60.8	64.2	56.9
Friction (Hot), felt	0.22	0.25	0.24	0.40	0.39	0.38	0.40	0.30	0.27	0.29	0.27
Friction (Hot), wire	0.22	0.24	0.21	0.43	0.44	0.39	0.39	0.30	0.27	0.31	0.33
Porosity (Grly), sec/100 mL	22.1	17.1	22.4	7.1	15.1	19.4	14.3	41.1	9.3	8.7	10.0
Water drop (T819), sec	4	10	3	46	121	12	6	42	25	4	35
Roll Moisture, %	5.3	7.6	8.1	6.4	11.3	5.8	7.6	9.6	4.4	6.0	7.8

Table 4. Test properties for mediums made at various moisture levels.

Mill:	K	K	K	AC	AC	AC	D	D	D	R
Roll No.	6807	6805	6803	6809	6811	6813	6783	6785	6787	6795
Basis Weight, lb/Msq ft	26.2	26.8	26.8	25.7	26.1	26.0	34.3	33.1	33.8	34.3
Caliper (TAPPI), mil	10.96	10.10	10.66	10.06	9.51	9.93	12.98	12.15	12.76	11.54
Caliper (IPC), mil	193	193	190	182	183	179	249	249.3	253.7	221.1
Caliper (IPC), mil	7.59	7.58	7.46	7.14	7.19	7.04	9.81	9.81	9.98	8.70
Dens. (TAPPI), lb/rm-mil	2.39	2.65	2.51	2.55	2.74	2.62	2.54	2.72	2.65	2.32
Dens. (IPC), lb/rm-mil	3.45	3.54	3.59	3.60	3.63	3.69	3.36	3.37	3.39	3.58
MD Tensile, lb/inch	46.0	46.8	47.2	39.6	37.7	35.2	52.4	48.0	47.9	51.3
MD Stretch, %	1.03	1.15	1.49	1.39	1.33	1.56	1.22	1.29	1.33	1.62
MD Et, lb/inch	6496	6368	5838	5122	4934	4530	7342	6322	6398	6856
MD TEA, ft lb/sq ft	3.34	3.82	5.22	4.10	3.76	4.23	4.74	4.63	4.80	6.65
MD STFI, lb/inch	25.6	26.7	24.1	26.2	24.3	21.4	32.0	30.0	29.6	30.0
CD STFI, lb/inch	15.8	14.7	14.1	17.4	15.9	14.4	18.7	20.8	19.0	20.5
MD Ring Crush, lb/6 inches	60.2	65.2	55.6	54.9	57.1	47.0	89.8	91.5	91.9	85.8
CD Ring Crush, lb/6 inches	42.9	47.3	38.7	42.7	43.3	35.8	62.1	68.1	65.2	64.5
Concora, lb	57.7	60.9	63.3	66.3	60.5	59.2	71.2	76.8	67.1	78.2
Friction (Hot), felt	0.50	0.47	0.50	0.34	0.38	0.45	0.39	0.43	0.44	0.41
Friction (Hot), wire	0.48	0.46	0.50	0.38	0.38	0.44	0.36	0.43	0.40	0.40
Porosity (Grly), sec/100 mL	16.6	14.2	25.1	26.0	16.1	26.8	8.5	8.2	9.0	29.1
Water drop (T819), sec	6	125	17	20	12	18	20	8.9	22.1	52.1
Roll Moisture, %	2.6	6.0	14.3	3.2	6.8	10.2	4.2	5.6	7.2	20.8

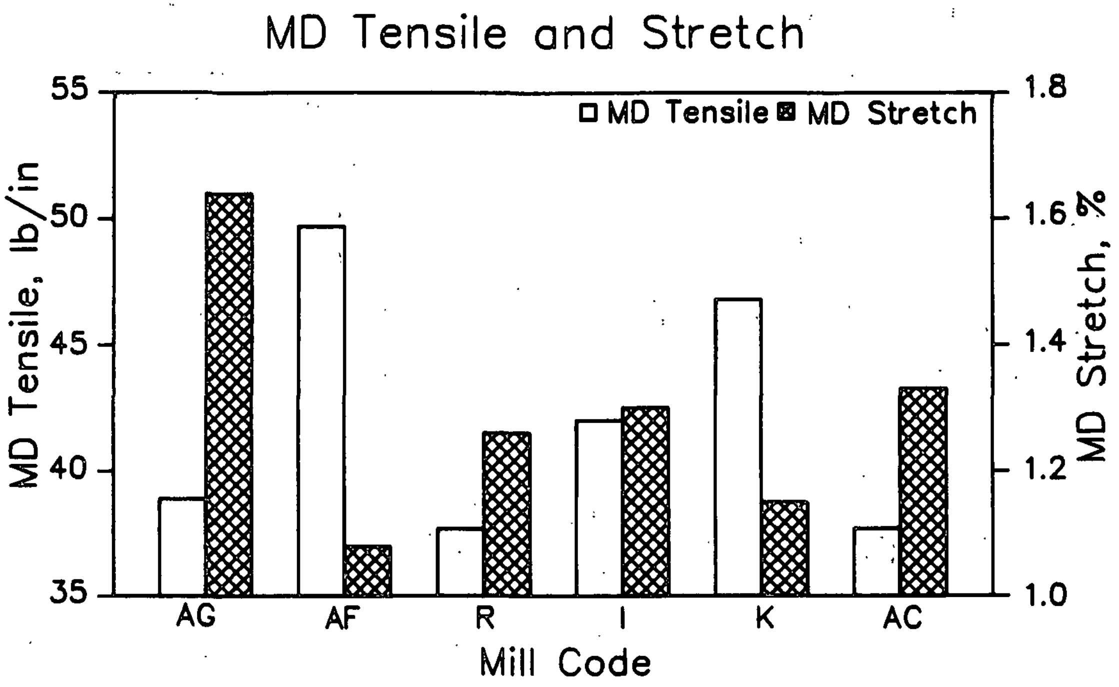


Figure 1. MD tensile and stretch results for "normal" moisture content 26-lb mediums.

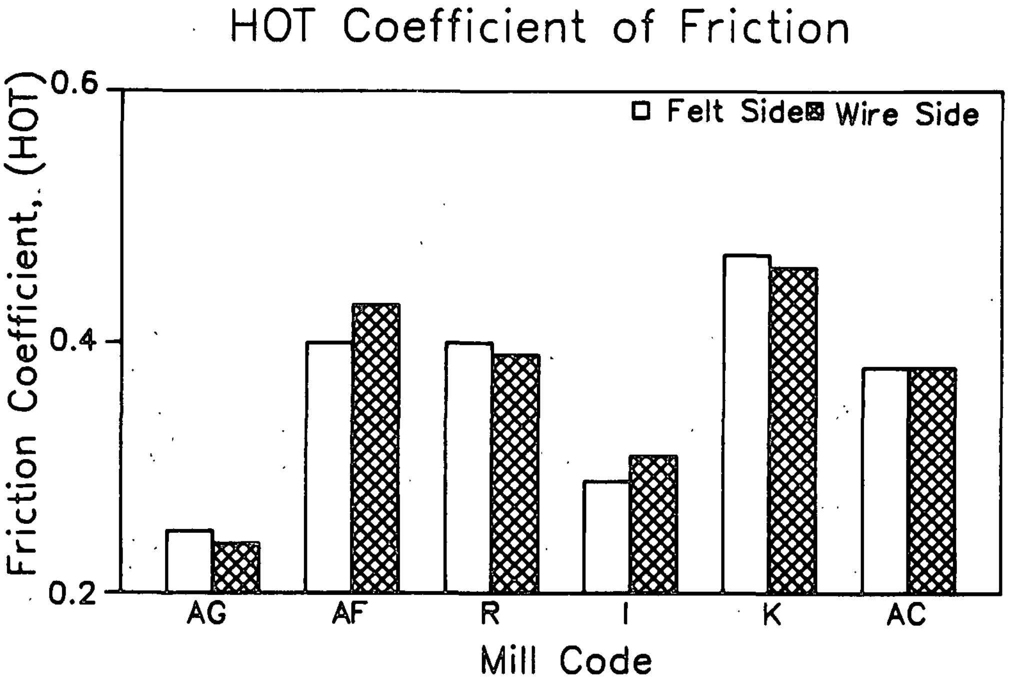


Figure 2. Hot friction results for "normal" moisture content 26-lb mediums.

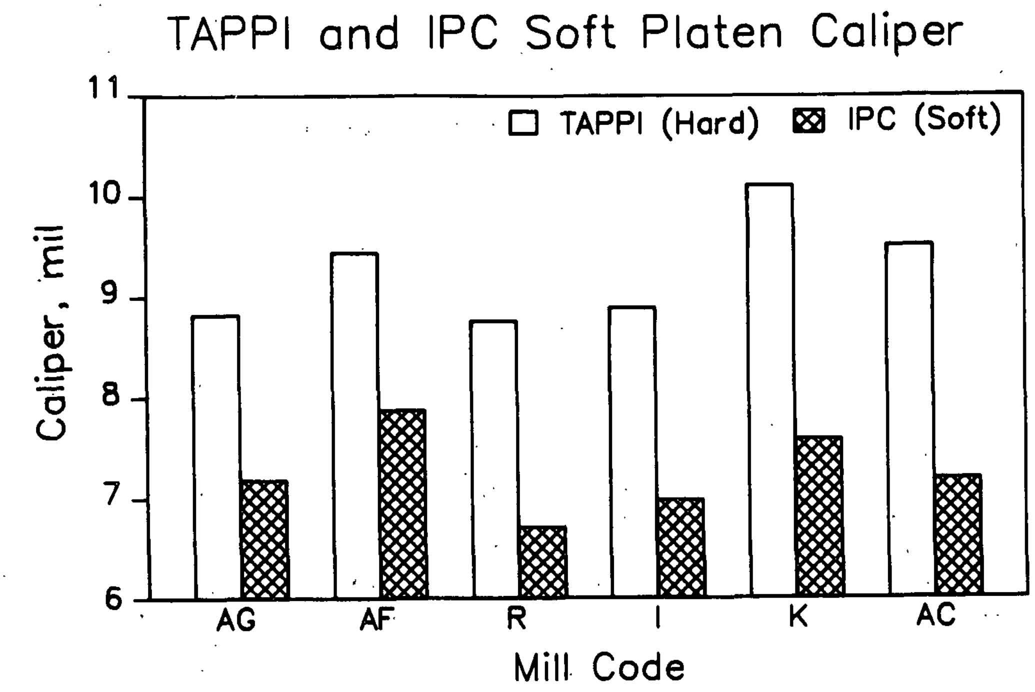


Figure 3. Caliper results for "normal" moisture content 26-lb mediums.

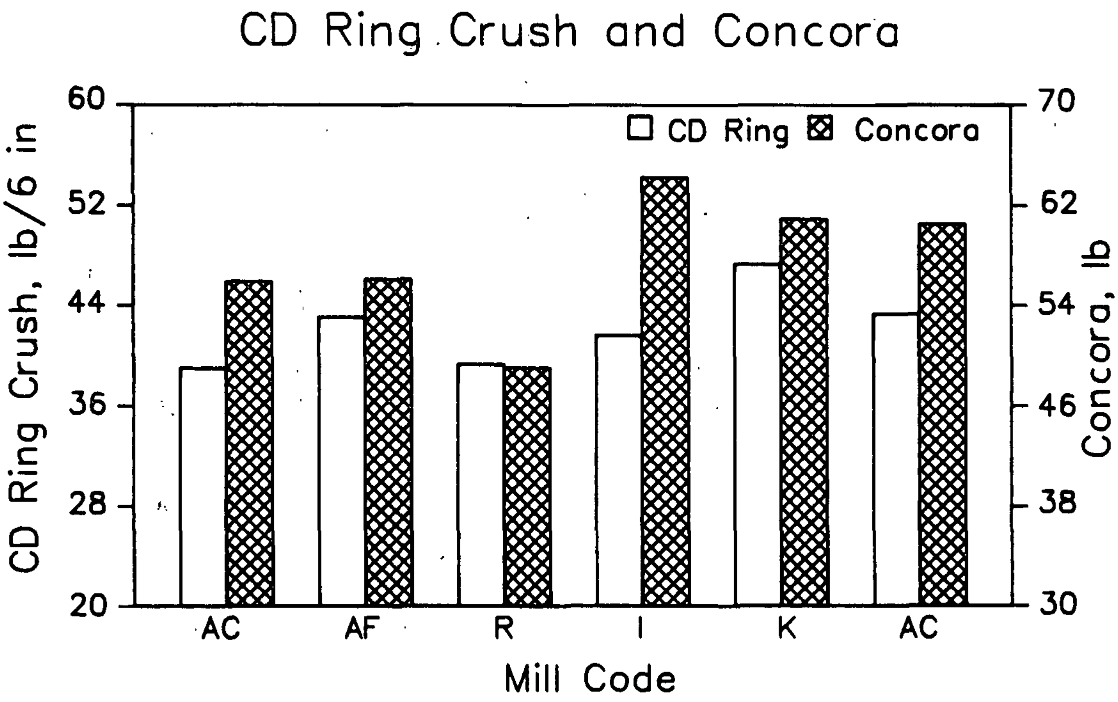


Figure 4. Ring crush and Concora results for "normal" moisture content 26-lb mediums.

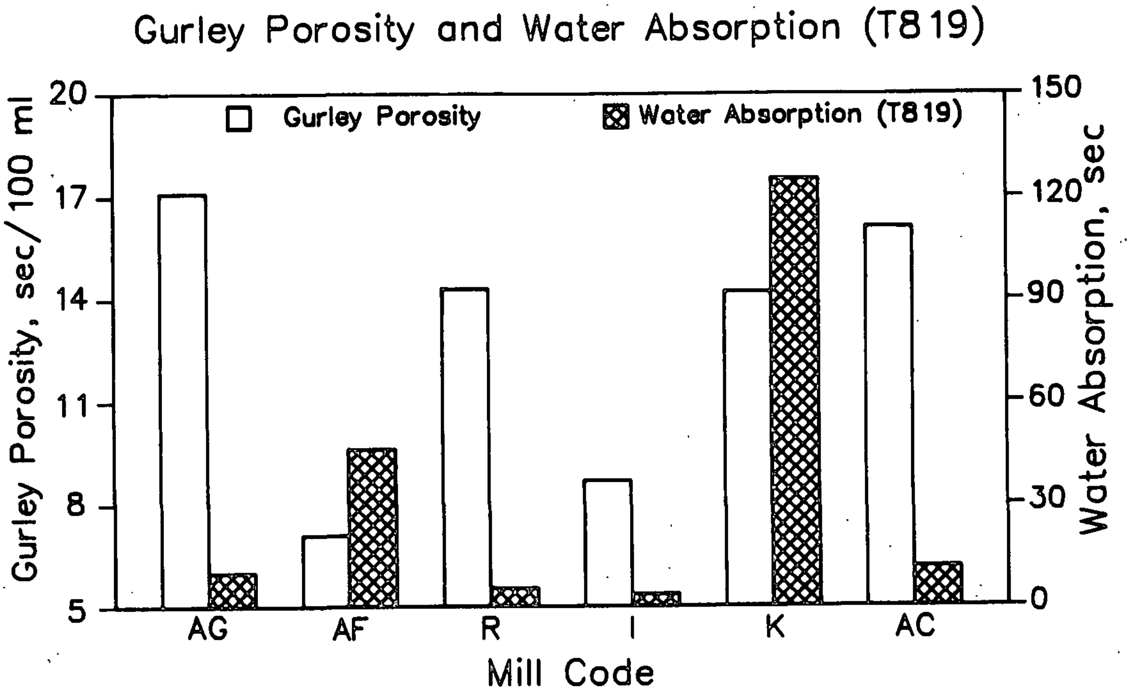


Figure 5. Porosity and water absorption results for "normal" moisture content mediums.

Concora strengths ranged from 49 lb for mill R to 64 lb for mill I (Fig. 4). CD ring crush values ranged from about 39 lb for mills AG and R to about 47 lb for mill K.

Adhesion on the corrugator can be affected by both porosity and water receptivity. Figure 5 shows Gurley porosity values ranging from 7 sec for AF to 17 sec for mill AG. Water absorptivity times ranged from a low of 4 sec for mill I to 125 sec for mill K. As mentioned previously, the other rolls made to higher or lower moisture targets often exhibit porosities or water absorptivity results which differ from those of the "normal moisture rolls.

CORRUGATING CONDITIONS AND RUN DATA

Each medium was corrugated under three sets of corrugating conditions to vary the moisture and temperature of the medium as it entered the fluting nip. The fluting conditions were:

a) maximum steam showers and full medium preheat,

b) no steam showers and full preheat,

c) maximum steam showers and half preheat.

During each run the medium moisture content and temperature were measured just before the fluting nip (termed nip moisture and temperature) at the operating speeds of 200, 400, 600, 800 and 1000 fpm. Roll moisture contents were taken at start and end of the runs. A schematic of the instrumentation and corrugator arrangements is shown in Fig. 6.

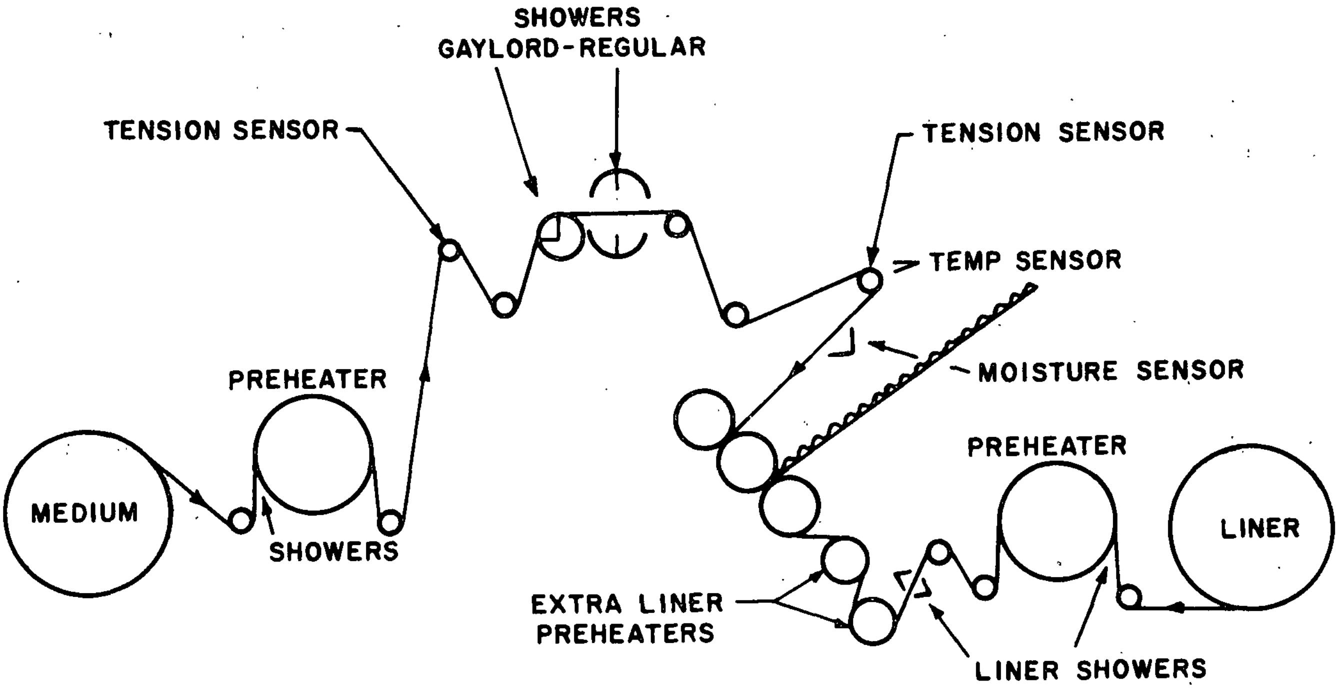


Figure 6. Instrumentation and corrugator arrangement.

Single-faced board samples were taken at each speed and condition, providing the medium adhered to the liner. The board samples were tested for pin adhesion, flat crush, high-lows, flute height, and ECT (on double-faced samples).

The corrugating run data are summarized in the Appendix (Table 14-34) for each medium roll.

DISCUSSION OF RESULTS

The test results were analyzed to

1. Determine the effects of nip moisture, temperature, roll moisture and speed on each of the board properties
2. Relate performance differences between mediums to the properties of the medium and operating conditions
3. Evaluate how nip moisture and temperature are affected by the shower and preheat conditions

The results should have applications for both mill and box plant. Some applications could involve mill moisture target levels, medium property targets, and optimum box plant shower and preheater use to increase quality.

The test results for each board property, pin adhesion, high-lows, flute height, flat crush and ECT, were statistically related to the following variables:

1. medium moisture before nip, termed nip moisture,
2. medium temperature before nip, termed nip temperature,
3. medium roll moisture content,
4. speed,
5. selected medium properties.

Nonlinear effects of each variable were allowed for as seemed statistically necessary; some property interactions were also considered.

The multiple regression equations were then used to predict the effects of changing the variables such as roll moisture content on each combined board property. Arbitrarily selected levels of each variable were used in the calculations to illustrate effects. Keep in mind that this may result in conditions which are difficult to achieve on the corrugator. In the illustrations which follow, the points shown on the graphs are calculated values for the selected levels of the variables in the regression equation; the actual fit to the experimental data can be judged from the predicted vs. experimental graphs.

The regression equations can be used to compare the effects of many combinations of medium properties and operating conditions on the corrugator. Used in this way the equations can be used to evaluate the potential impact of mill manufacturing and corrugator operating practices and equipment.

FLAT CRUSH

The best fitting relationship for the composited data is shown in Table 5. The regression explained about 82% of the variation in flat crush, which is quite favorable. Figure 7 compares the predicted and observed values and shows that the regression line gives a good fit to the data.

Figure 8 shows that flat crush results increase as roll moisture increases. At a given roll moisture content higher flat crush strengths are achieved when the medium moisture entering the nip is high. Thus, effective steam showers or other moisturizing equipment is needed on the corrugator to obtain the full flat crush potentials of medium. Low roll moisture contents coupled with inadequate showers can greatly reduce flat crush. These increases in flat crush with higher nip moisture contents are in accordance with past work which showed that increasing the nip moisture decreased the elastic stiffness of the medium and made it easier to form with less damage.

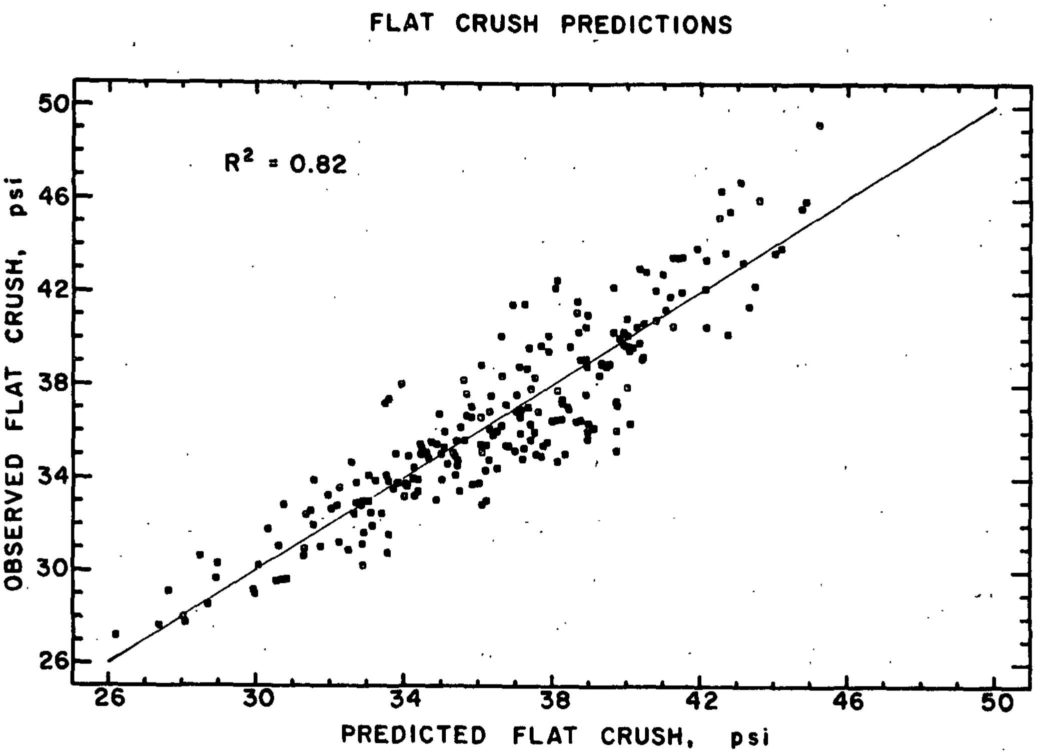


Figure 7. Comparison of observed and predicted flat crush results.

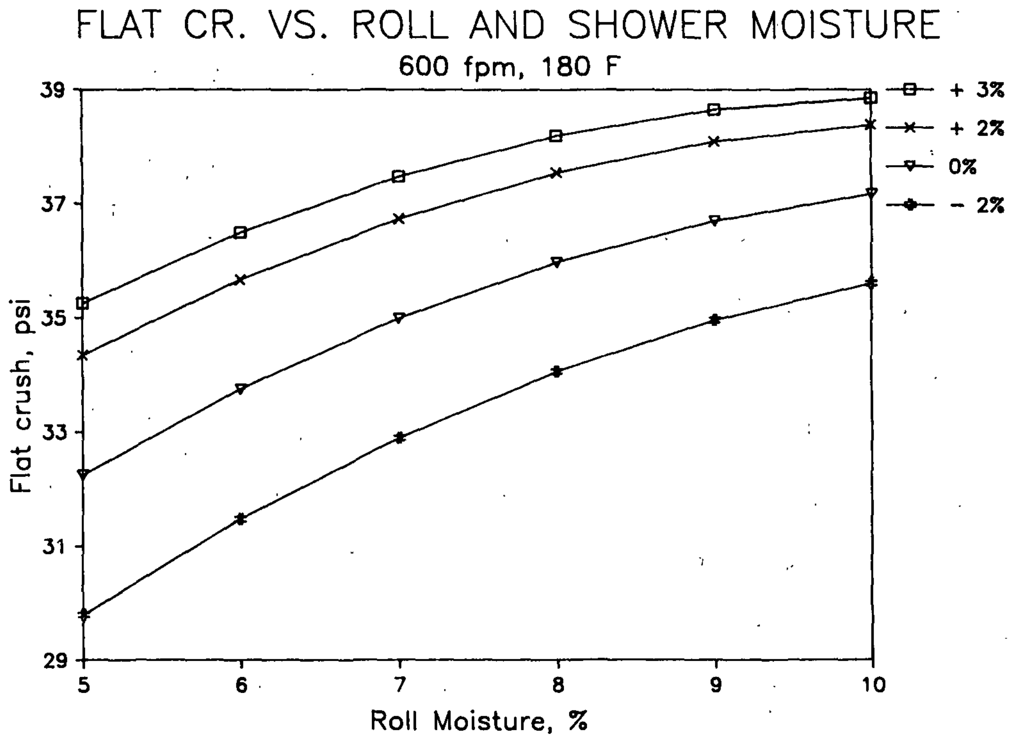


Figure 8. Flat crush increases as roll moisture and nip moisture increase. (Note: higher or lower nip moistures are shown as a difference, i.e., nip - roll moisture.)

Table 5. Flat crush relationship for composite data.

Property	Regression Coefficient	Significance
Speed	0.00168	0.01
Nip moisture	1.57700	0.01
Nip moisture squared	-0.04430	0.01
Nip temperature	0.29250	0.01
Nip temperature squared	0.00088	0.01
Roll moisture	1.34800	0.01
Roll moisture squared	-0.08540	0.01
Concora	0.55500	0.01
Constant	-37.52000	--

Note: R squared = 0.82.

At a given roll moisture content flat crush strengths were not greatly affected by the nip temperature of the medium (see Fig. 9). The highest flat crush strengths tended to be achieved with nip temperatures in the 155 to 185°F range; however, the flat crush differences in this range were small. Higher temperatures up to a point would be expected to help plasticize the lignin and hemicelluloses in medium and help fluting.

Figure 10 shows that flat crush strengths slightly increased with speed at a given roll and nip moisture content. The small increase with speed is usually obtained in our trials and appears to be due to the fact that slightly higher nip moisture contents are obtained at higher speed. However, it is known that decreases in flat crush at higher speed can be obtained as the fracture speed is approached. Also, if bad high-lows are present, flat crush variability normally increases and there may be some reduction in average flat crush. These observations suggest that flat crush strengths should pass through a maximum with increasing speed; however, when a nonlinear speed term was put into the regression it was not statistically significant. This may be due to the fact that samples with visibly fractured flutes were not tested.

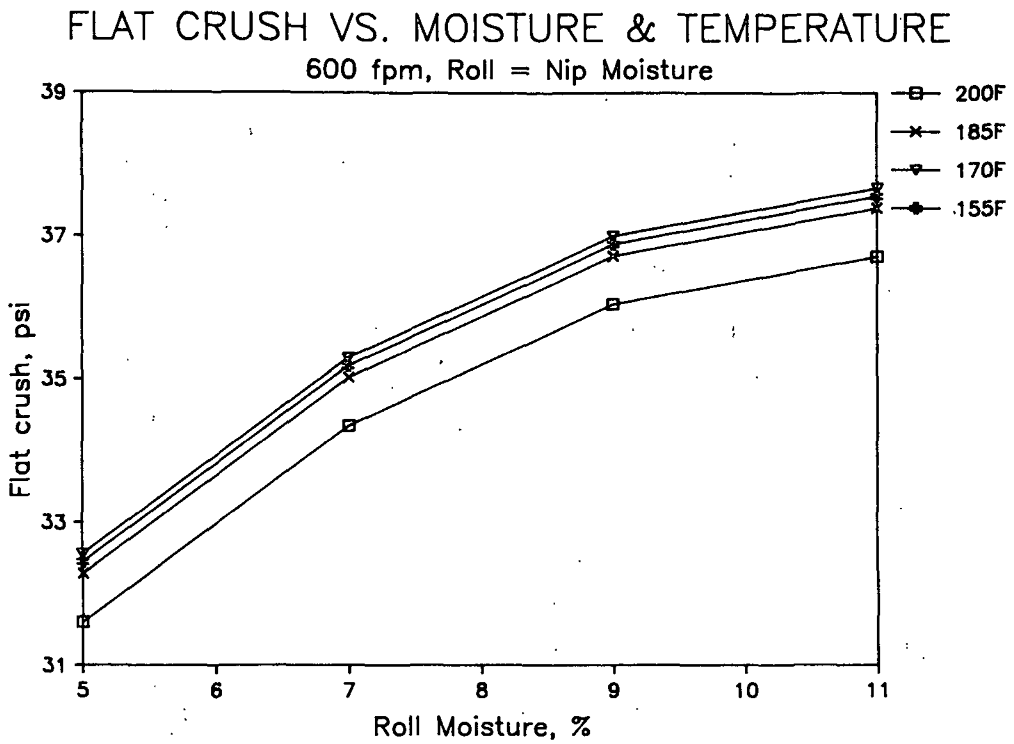


Figure 9. Flat crush strengths were not greatly affected by nip temperatures in the 155 to 185°F range.

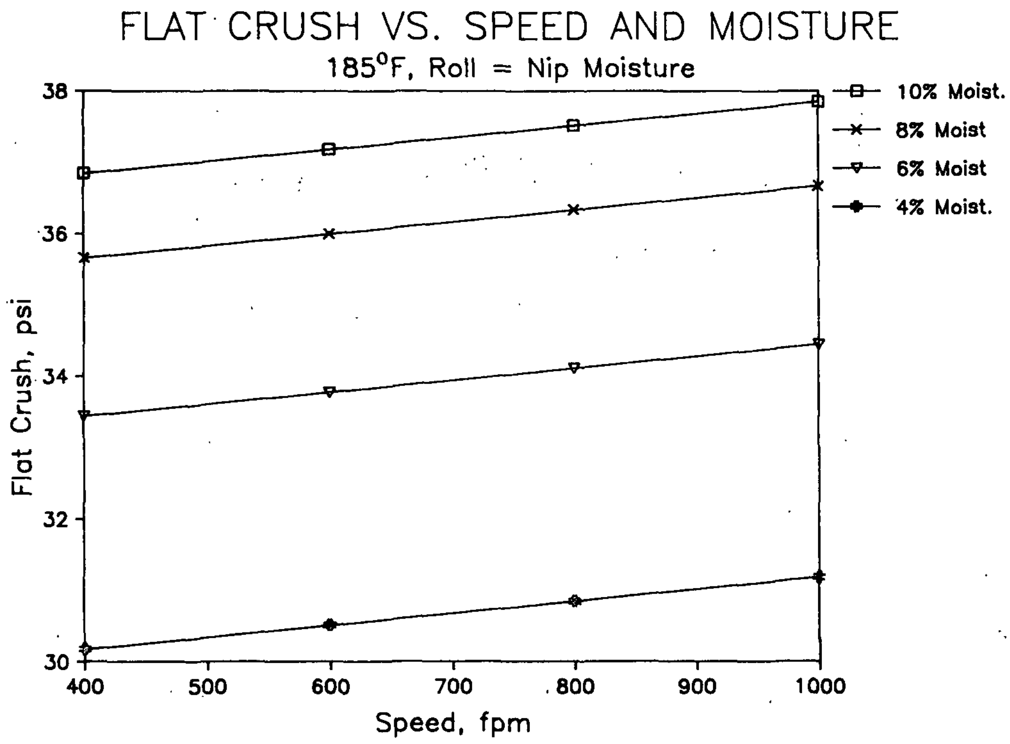


Figure 10. Effect of speed and roll moisture on flat crush.

There were indications that improvements in predictive ability could be achieved by including MD STFI or possibly MD ring crush in the relationships. Such improvements may arise because the Concora test does not entirely simulate the moisture/temperature conditions in the fluting process and uses an A-flute profile rather than the C-flute profile used in this work.

Briefly summarizing, it appears that medium roll and nip moisture content are major factors affecting flat crush. Increasing the medium roll and nip moisture content significantly increases flat crush. The nip temperature of the medium has less effect on flat crush and a maximum was reached near 185°F. Effective showering equipment on the corrugator is important to help keep the medium from becoming too dry. Higher mill moisture target levels could also be beneficial.

PIN ADHESION

Several alternative regression equations were developed for pin adhesion. The equation shown in Table 6 was one of the best, considering the sign of the coefficients, medium properties and R squared. The equation explained 89% of the variations in pin adhesion and all factors were statistically significant. Figure 11 shows that the predicted values compare well with the observed values.

Figure 12 shows that higher pin adhesion strengths were achieved as the nip moisture increased. It appears likely that the increase in adhesion strength is due to better penetration of the starch at higher moisture contents. A dry sponge is more difficult to wet than a moist sponge. This analysis does suggest that the benefits of higher nip moisture reach a maximum in excess of 10%. At very high moisture contents the water in the starch may penetrate too quickly, starving the starch for water and reducing adhesion strength. Higher

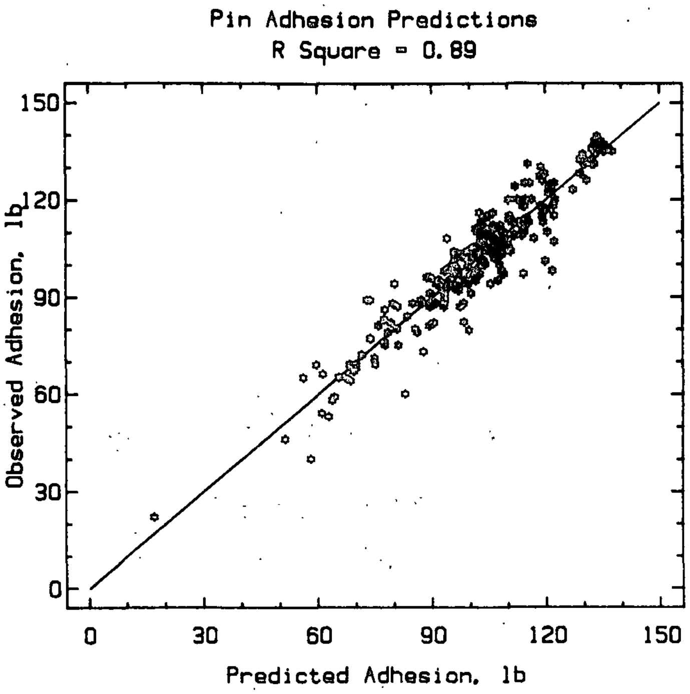


Figure 11. Observed vs. predicted pin adhesion strengths are in good agreement.

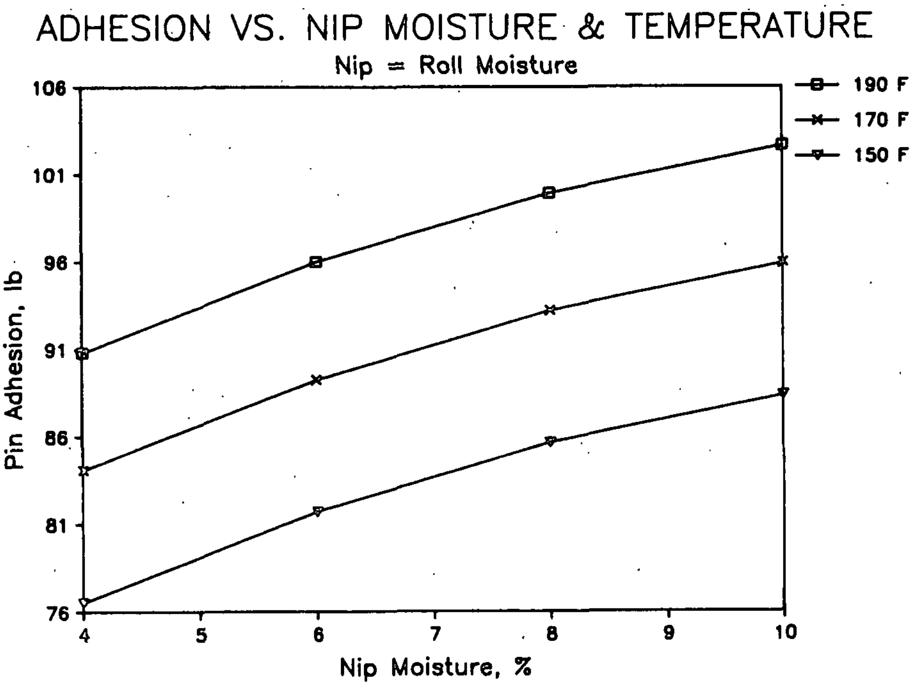


Figure 12. Pin adhesion strengths increase as the nip temperature and moisture content of the medium are increased.

pin adhesion strengths were also obtained as the nip temperatures were increased at a given roll moisture. Higher nip temperatures promote faster gelling of the starch and hence, higher pin adhesion strengths at high speed. Thus, effective steam showers combined with higher medium moisture contents (within limits) should help in obtaining higher adhesion strengths.

Table 6. Pin adhesion relationship for composited data.

Property	Regression Coefficient	Significance
Speed/100	-20.137	0.01
(Speed/100) cubed	-0.0439	0.01
(Nip Temp./100) squared	-10.058	0.01
(Temp./100) x (speed/100)	11.674	0.01
Water Penetr./100	-36.314	0.01
(W. Penetr./100) squared x IPC dens.	9.340	0.01
Porosity	-0.888	0.01
IPC-TAPPI dens.	-251.100	0.01
(IPC-TAPPI dens.) squared	185.000	0.01
Nip moisture	4.140	0.01
Nip moisture squared	-0.155	0.01
Basis weight	3.873	0.01
Constant	110.600	--

Note: R squared = 0.89.

Figure 13 shows that pin adhesion strengths decreased rapidly above 800 fpm for the liner, adhesive and operating conditions employed on our corrugator. Above 800 fpm we were not able to supply sufficient heat to the liner and medium to maintain the high adhesion levels obtained at lower speeds. Similar shaped curves would be expected to be obtained for other machines and conditions but shifted laterally or vertically depending on the specific board materials, adhesive, and corrugating conditions.

The effects of nip temperature and medium porosity are shown in Fig. 14. Higher pin adhesion strengths were obtained at lower Gurley porosity times (more porous mediums) at a given nip temperature. More penetration would be expected with the more porous mediums and hence, higher adhesion strengths."

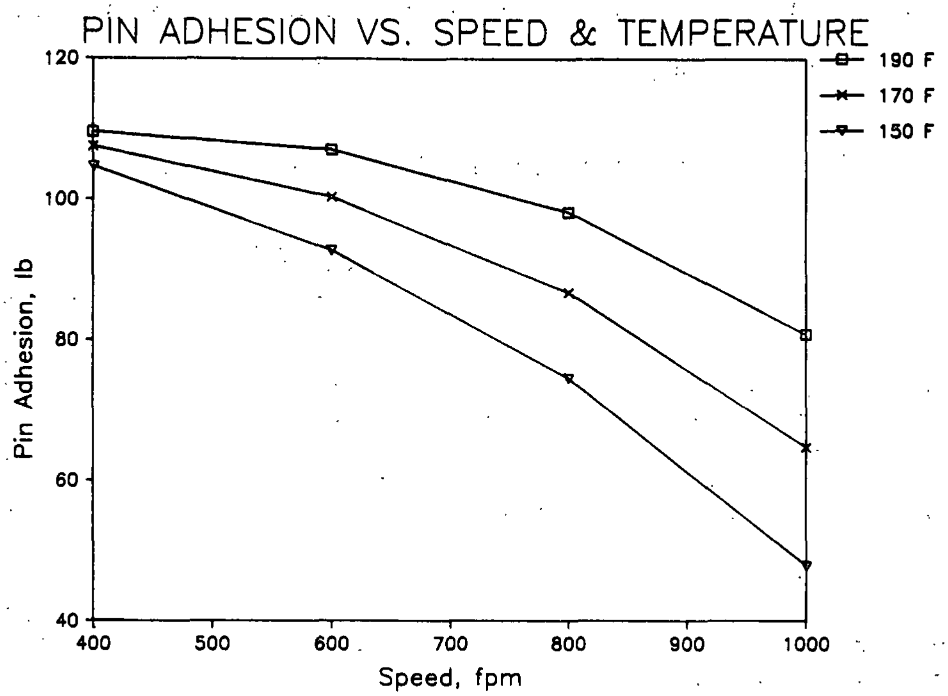


Figure 13. Pin adhesion strengths decrease as speed increases at a given nip temperature. High temperatures are needed for high speed operation.

Another medium factor which appeared to affect adhesion strengths was the difference between the soft platen (IPC) and TAPPI densities. This difference depends on the roughness of the medium, i.e, the greater the difference the greater the roughness. Figure 15 shows that the rougher the medium at a given porosity the higher the pin adhesion strength. The rougher mediums will have more surface area and hence, be more receptive to moisture/temperature transfer in the showers and also provide more surface area for adhesion. This analysis indicates that roughness effects were non-linear; thus roughness has a diminishing effect as the medium becomes smoother.

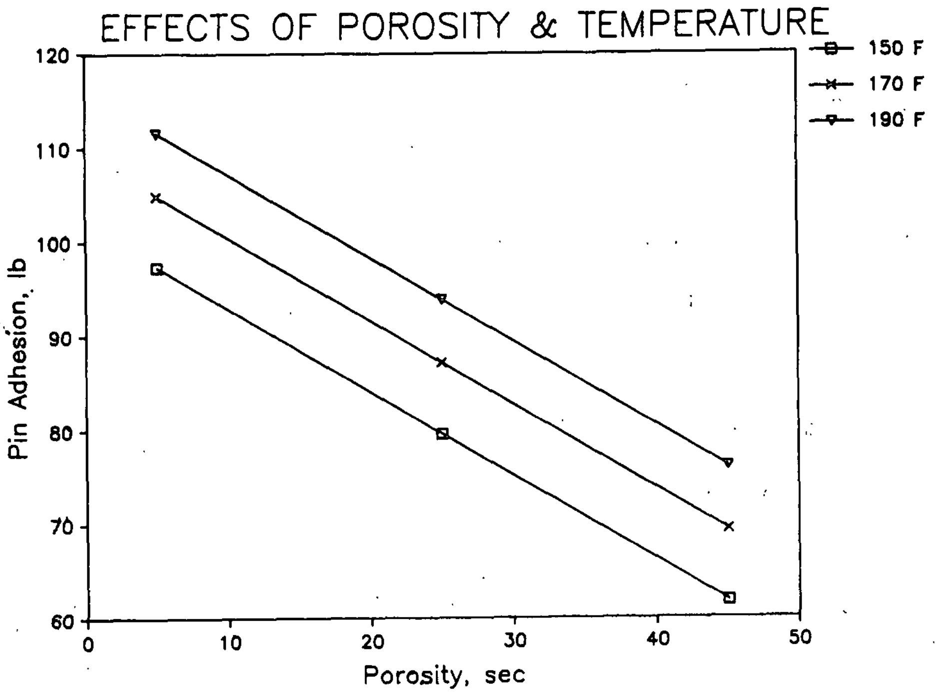


Figure 14. Higher pin adhesion strengths are achieved with more porous mediums at a given nip temperature.

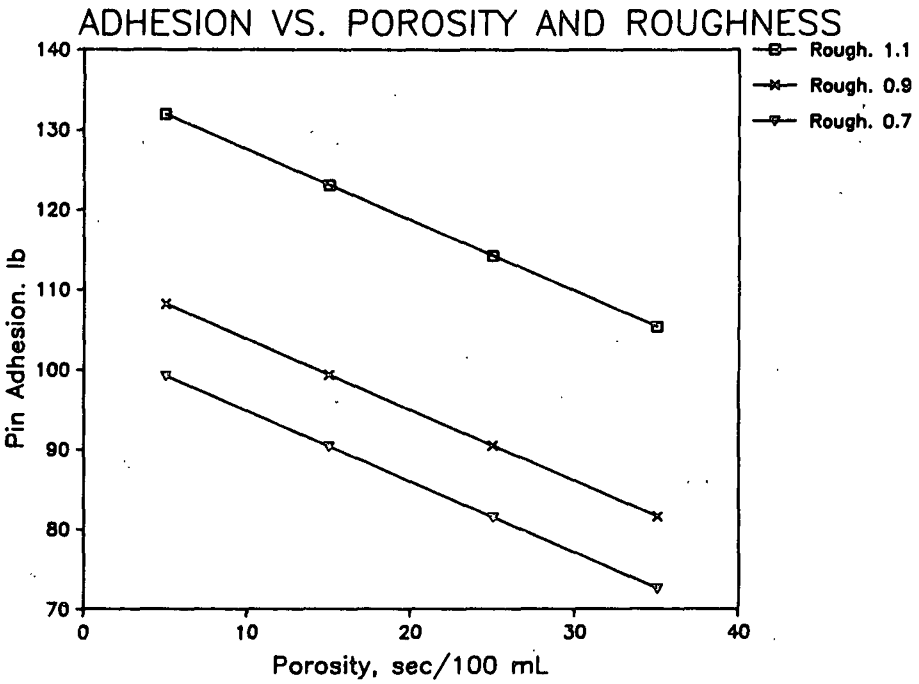


Figure 15. At a given medium porosity, pin adhesion strengths increased for the rougher medium.

Figure 16 shows that pin adhesion strengths decreased as water penetration times (TAPPI method T819) increased, as expected. However, the pin adhesion strengths were not very sensitive to relatively large changes in the water drop times. The analysis suggests that the water penetration effects depend somewhat on the medium density, although not in a major way. At low water penetration times density seemed to exert only small effects on adhesion strength. Curiously, higher densities were slightly favored for the less wettable sheets. The opposite might be expected; therefore, this effect will be checked in future work on green and final bond strength.

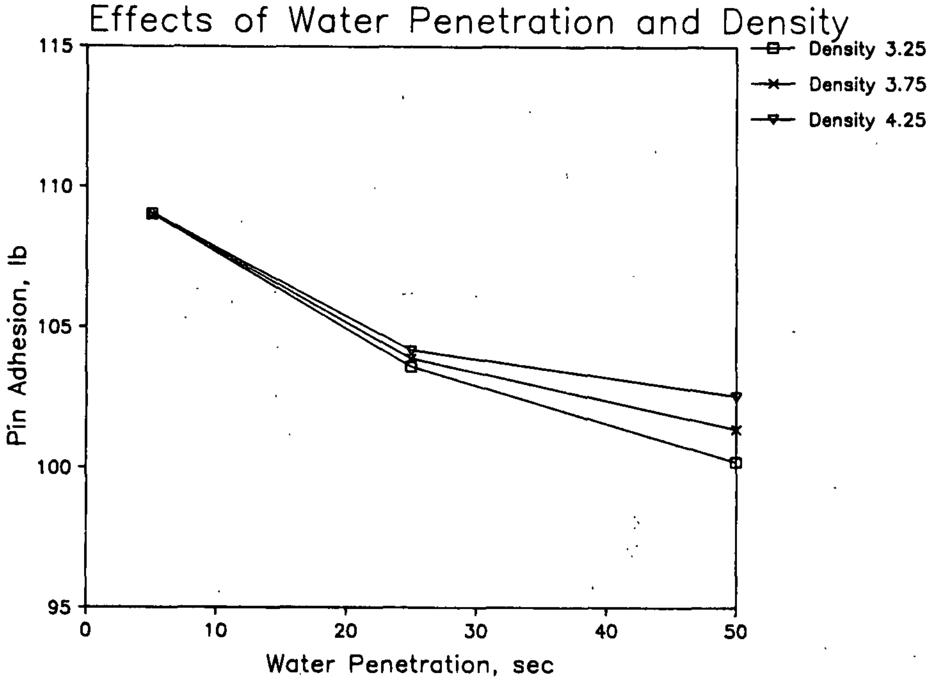


Figure 16. Pin adhesion strengths decrease with increasing water penetration times, T819 Flotation method.

During the development of the above regression model there were also some indications that porosity effects might also interact with sheet density. We could not clearly determine if this was a real effect or was due to interactions between density, porosity, and water penetration.

Briefly summarizing, pin adhesion strengths increase as nip moisture and nip temperature increase at a given speed. Higher medium moistures may aid wetting and penetration, and higher temperatures should promote faster gelling of the starch. More porous and wettable mediums gave higher adhesion strengths. Also, the roughness of the medium measured by the difference between soft platen and TAPPI densities appeared to affect adhesion strengths. The rougher the medium the greater the pin adhesion strength.

HIGH-LOWS

The best fitting relationship for the composited data is shown in Table 7. The relationship explained about 80% of the variation in high-lows which is quite good. Figure 17 compares the predicted and observed values and shows that the regression equation gives a good fit to the data.

Table 7. High-low relationships for composite data.

Property	Regression Coefficient	Significance
Speed	-0.02540	0.01
Speed squared	0.000046	0.01
Nip moisture	-4.05200	0.01
Nip moisture squared	0.19920	0.01
Nip temperature	-0.12230	0.01
Roll moisture	0.47200	0.10
Friction squared	26.48000	0.01
IPC caliper	4.56400	0.01
MD stretch	-151.73000	0.01
MD stretch squared	49.75000	0.01
Constant	120.15000	0.01

NOTE: R squared = 0.80.
No. of observations = 229.

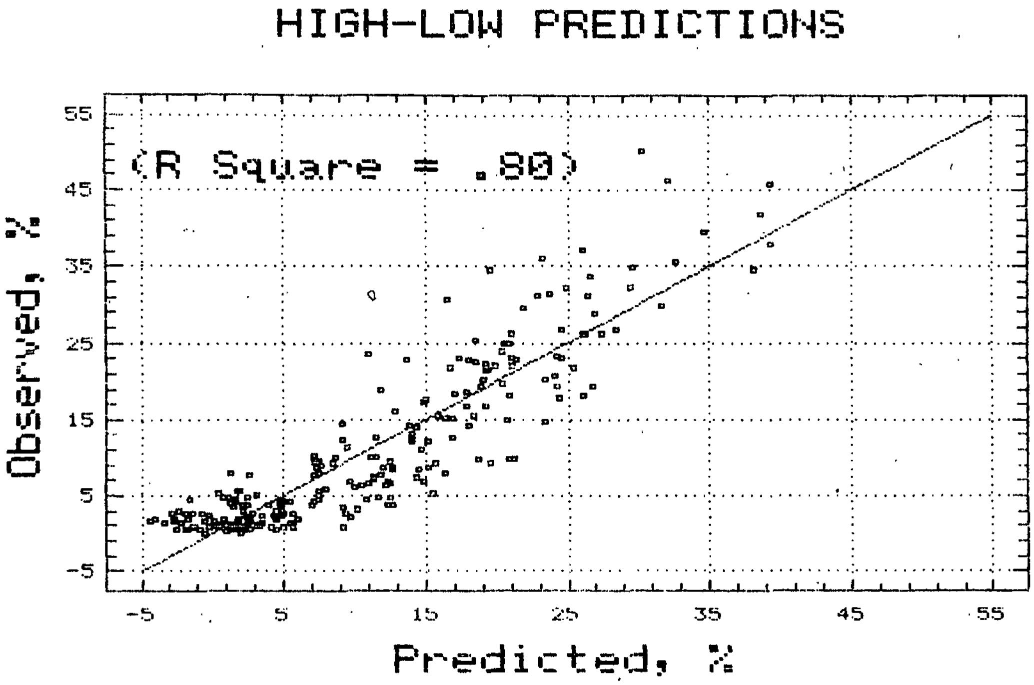


Figure 17. Comparison of observed and predicted high-low results.

Figure 18 shows that increasing medium nip temperature decreases high-lows at a given level of nip moisture. Increasing nip moisture in the range up to 8% decreased high-lows. Above 8% nip moisture the high-low levels remained sensibly constant. Higher temperatures help plasticize the medium provided the sheet is not too dry and hence, promote fluting with less damage and dimensional instability.

Figure 19 shows that if the medium moisture at the nip is less than the original roll moisture due to the drying effect of the medium preheater, the high-lows will be increased at a given roll moisture. As the amount of steam showering is increased to raise the medium nip moisture above that of the roll the high-lows diminish at a given roll moisture content. When the showers add 2% moisture the high-lows are nearly constant over the range of 5 to 9% roll moisture, although a shallow minimum in high-lows may occur for roll moistures

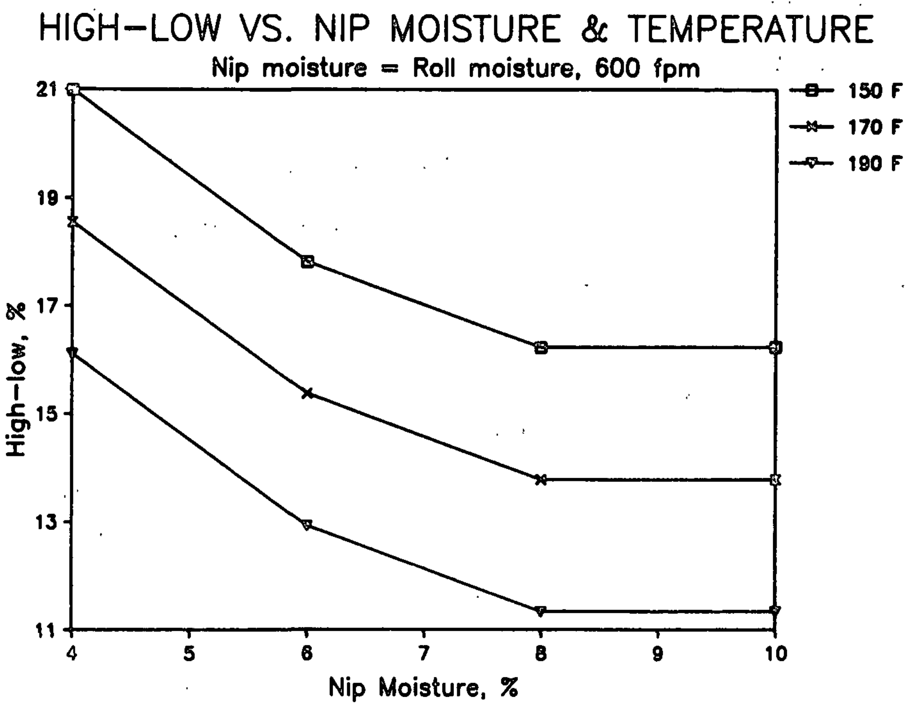


Figure 18. High-lows are decreased as the medium temperature is increased. Higher medium moistures at the fluting nip also decrease high-lows up to about 8%.

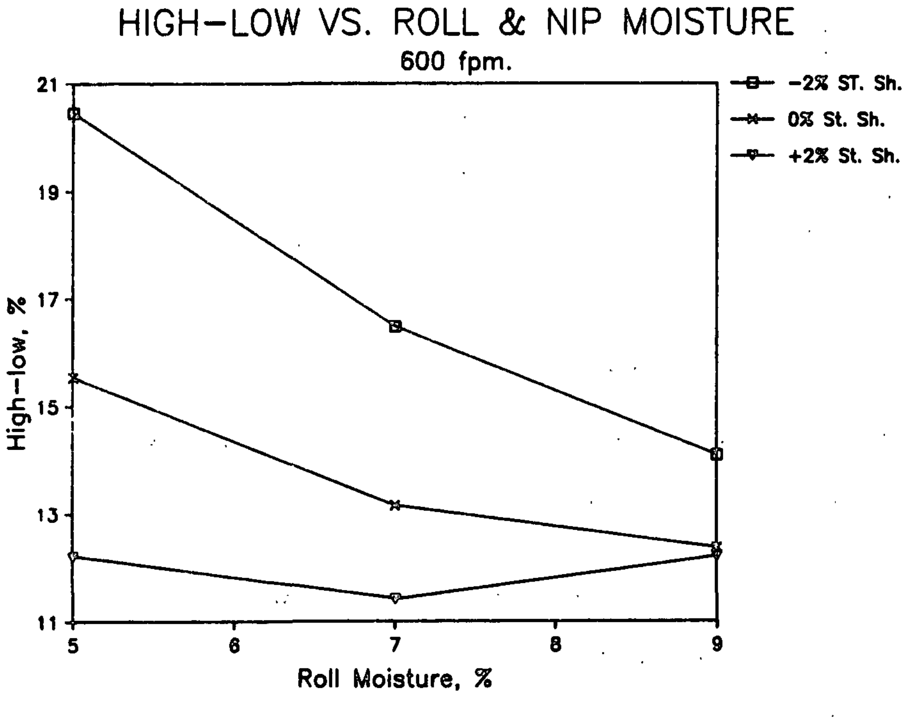


Figure 19. When the steam showers add moisture, the high-lows decrease. The optimum steam shower moisture addition is about 2% above the roll moisture.

near 7%. If extrapolated to even higher roll moistures or steam additions, the results suggest that high-lows could increase.

The effects of changes in nip moisture at a given roll moisture content of 7% are shown in Fig. 20. At a given speed raising the nip moisture decreases the occurrence of high-lows.

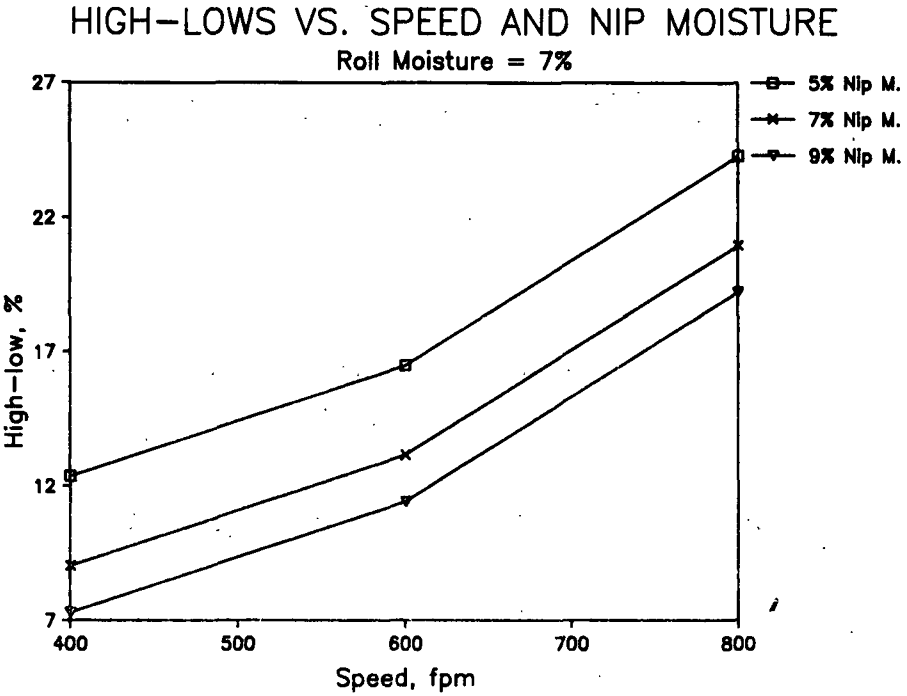


Figure 20. High-lows vs. speed and nip moisture.

In general, the temperature and moisture results indicate that the softening effects associated with higher medium temperatures and medium moistures help reduce the occurrence of high-lows.

Higher medium hot friction values increase high-lows at a given speed (see Fig. 21). The effect of friction is in the expected direction based on our runnability model. High-lows generally increase with increasing speed as discussed in past reports. The runnability model indicates that higher friction values and speeds induce higher stresses in the medium, and hence, increase high-low flute formation.

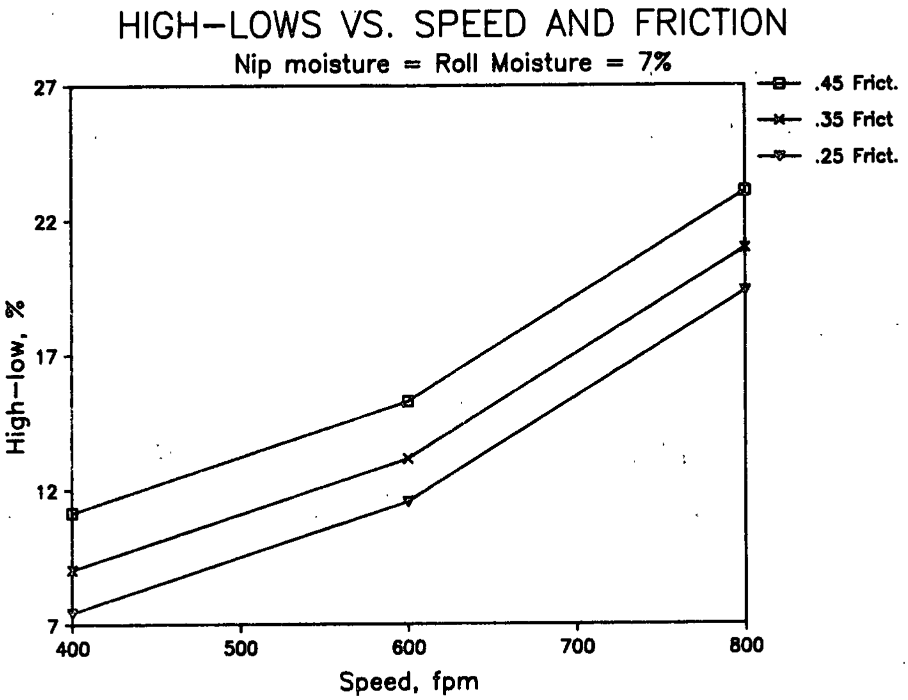


Figure 21. Higher corrugating speeds and medium friction increase high-lows.

Figure 22 shows that thicker mediums produce more high-lows at a given MD stretch value. When the MD stretch of the medium is increased, the high-lows decrease. The rate of decrease in high-low flute formation diminishes as the MD stretch value increases above about 1.2%. The effects of both factors are in the expected direction based on our runnability model.

ECT

The best fitting relationship for the composited data is shown in Table 8. The regression explained about 78% of the variation in ECT. The stepwise regression program employed identified the following medium factors as having the most influence on ECT: CD STFI compressive strength, pin adhesion, high-lows and basis weight in addition to speed. The results suggest that the effects of medium roll moisture, nip moisture and temperature affect ECT primarily through their influence on adhesion and high-lows. Poor adhesion or excessive high-lows are known to affect ECT so the results are in accord with experience. Figure 23 compares the predicted and observed ECT values and shows that a reasonably good fit was obtained to the data. Some further improvements in correlation should be obtained by allowing for the roll-to-roll variations in liner STFI strength.

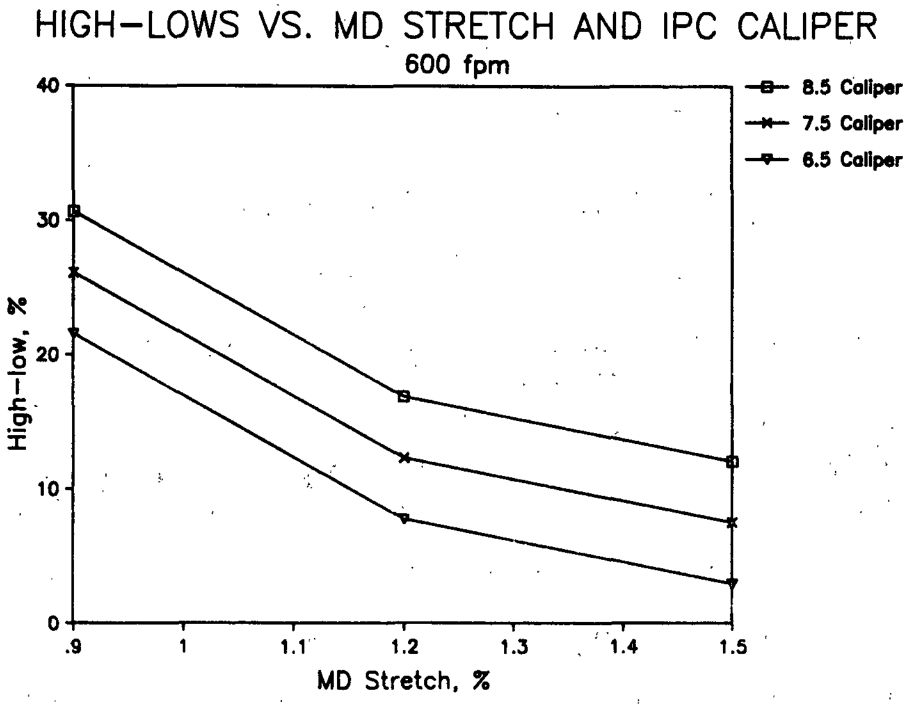


Figure 22. Lower medium caliper and higher MD stretch decrease high-lows.

Figure 24 shows that ECT strength increases as the STFI strength of the medium increases as expected. Increasing pin adhesion strength also

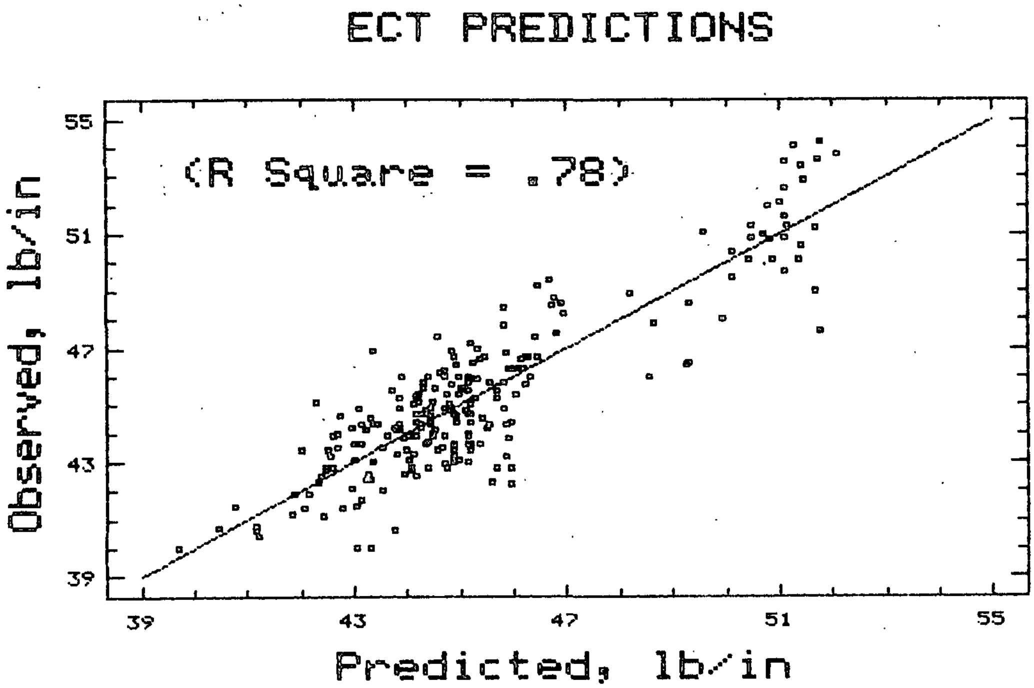


Figure 23. Comparison of observed and predicted ECT results.

Table 8. ECT relationship for composite data.

Property	Regression Coefficient	Significance
CD STFI Compression	0.40600	0.01
Pin Adhesion	0.02010	0.05
High-low >4 mil	-0.04969	0.01
Speed	-0.00088	0.10
Basis Weight	0.56100	0.01

Note: R squared = 0.78.
Number of observations = 229.

increased ECT. Low pin adhesion strength is known to reduce ECT, either because glue skips are present or some of the weaker bonds are not able to resist the stresses induced during ECT testing.

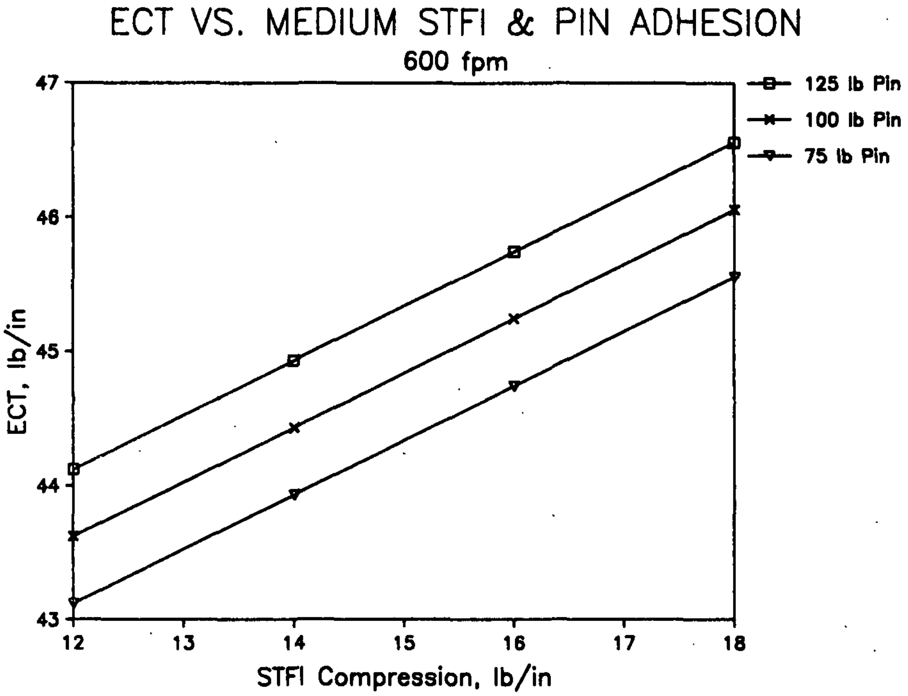


Figure 24. ECT results increase as medium STFI compression strength and pin adhesion increase.

The effects of high-lows on ECT are shown in Fig. 25. It appears that board exhibiting fairly severe high-lows (25% greater than 4 mil differences) will give ECT values about 1 lb/in. lower than would be obtained at a low level of high-lows, 5%. Flutes that are unbonded in the double-backing operation are known to weaken the ability of the board to resist compression stresses in ECT tests and in a stacking environment.

Increasing corrugating speed in our trials slightly decreased ECT over the speed range of 400 to 800 fpm (Fig. 26) at a constant pin adhesion. Because pin adhesion often decreases at higher speeds, losses in ECT would be expected if this occurs.

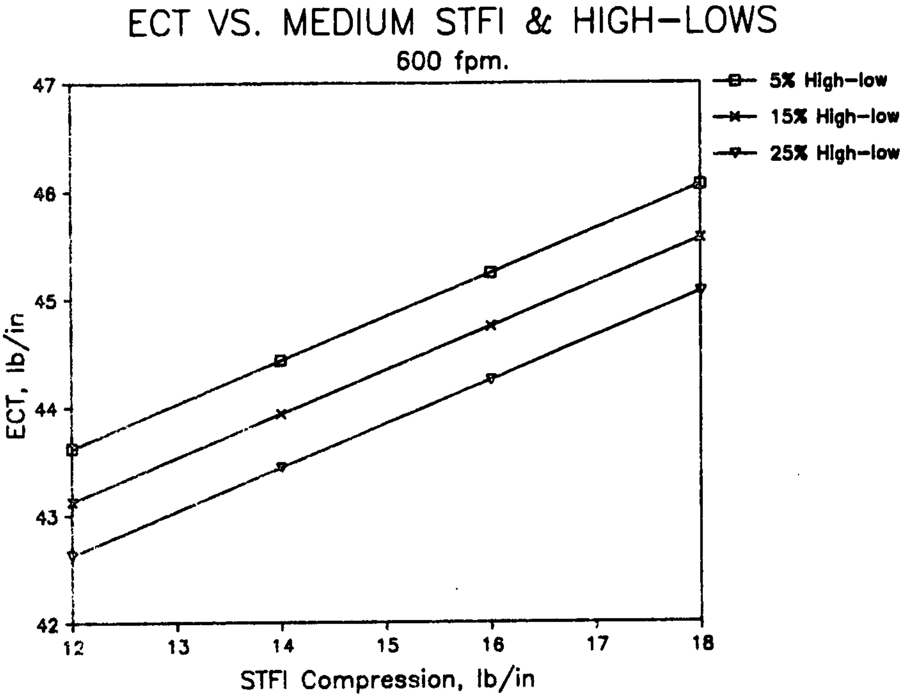


Figure 25. ECT results decrease as high-lows increase at a given medium STFI compression strength.

It should be noted that board samples with visible fractures were not tested; boards with fractured flutes or excessive high-lows are known to give low ECT values.

Briefly summarizing, the CD STFI compressive strength of the medium is a major factor affecting ECT for a given set of liners. Corrugating conditions which result in reduced pin adhesion strength and increased high-lows will reduce ECT and prevent attaining the full compression potentials of the liners and medium.

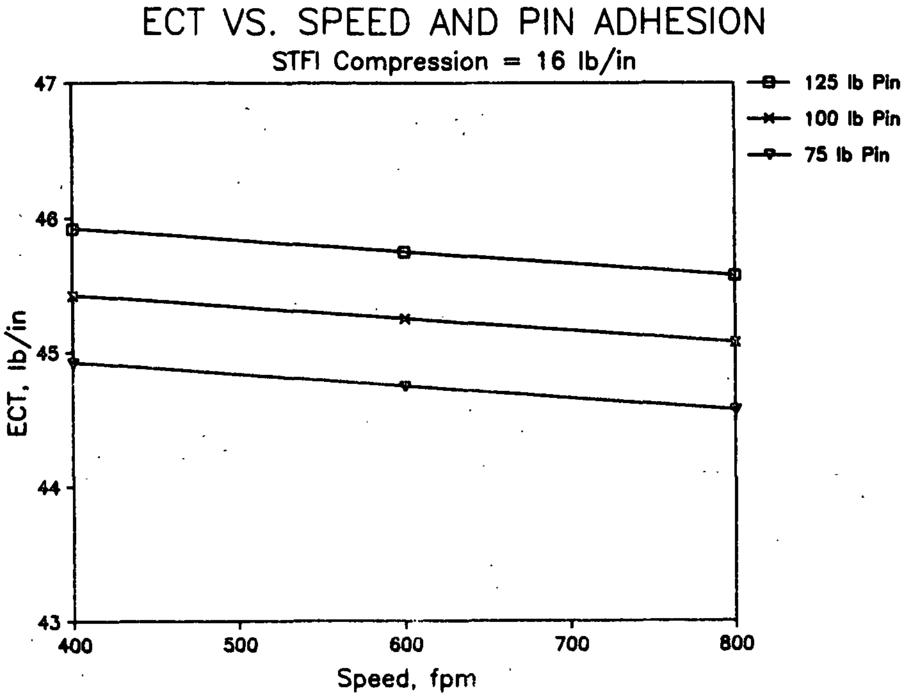


Figure 26. Increasing corrugating speed slightly decreases ECT at constant pin adhesion strength. Decreases in pin adhesion at high speed would increase the loss in ECT.

SINGLE-FACE FLUTE HEIGHT

An analysis of the single-face flute height was carried out which indicated that the main variables affecting flute height were nip moisture, nip temperature, corrugator speed, roll moisture and medium basis weight (or caliper). Regression analysis explained about 83% of the total variation, and Fig. 27 shows that good agreement was obtained between predicted and observed results.

Figure 28 shows that medium temperature had only small effects on flute height for a given level of nip moisture. The separate effects of medium roll moisture and nip moisture are shown in Fig. 29. In general, increasing roll moisture and nip moisture tended to produce modest decreases in single-face

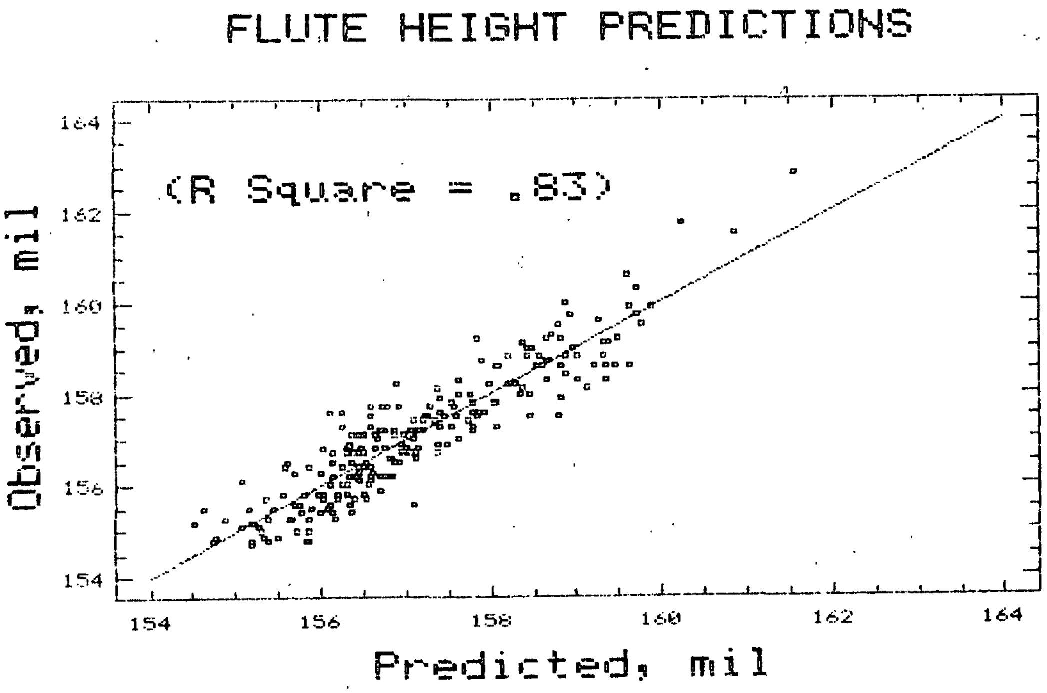


Figure 27. Comparison of predicted and observed single-face flute height results.

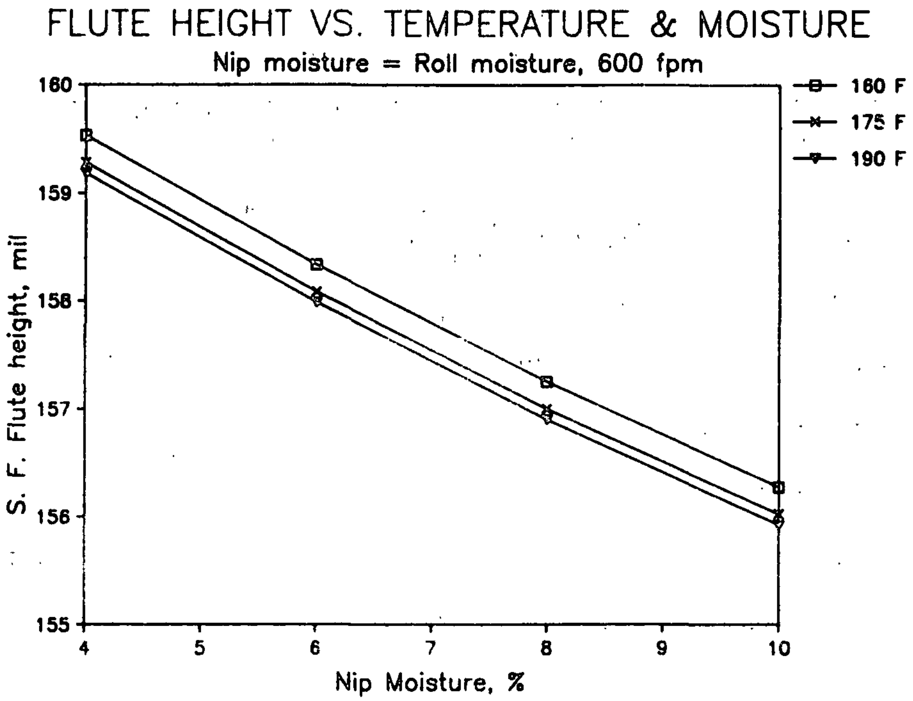


Figure 28. Single-face flute height *vs.* nip temperature and moisture.

flute height. It is speculated that the more moist mediums contract more after fluting and hence, slightly lower flute heights are obtained.

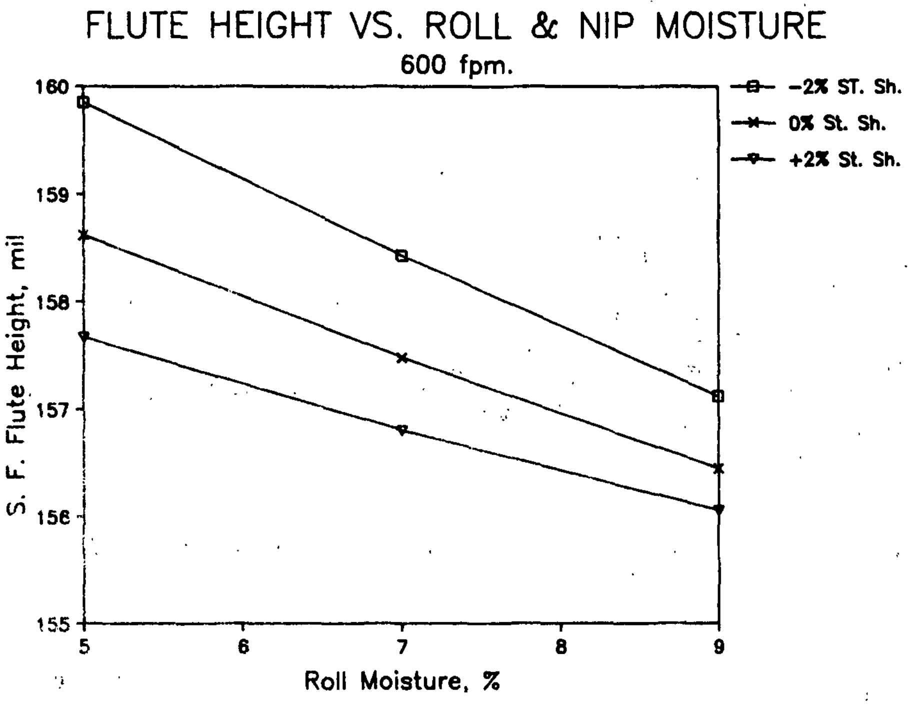


Figure 29. Increases in medium roll moisture and nip moisture tend to produce modest decreases in single-face flute height.

NIP MOISTURE/TEMPERATURE vs. OPERATING CONDITIONS

By coding the steam shower and operating conditions we were able to relate the medium moisture content and temperature before the fluting nip to roll moisture, speed, shower conditions and preheat wrap. These correlations were carried out using the results for two of the mills, mills D and I. Mill D submitted 33-lb mediums; mill I sent 26-lb mediums. Good fits to the data were obtained for both mills (see Table 9).

It was not possible to allow for nonlinear effects in this analysis, but interactions were considered. An interaction between shower conditions and speed was significant in the temperature relation.

Table 9. R squared values for nip moisture and temperature relations.

	R Squared Mill D	 Mill I
Nip moisture	0.81	0.90
Nip temperature	0.97	0.96

Figures 30 and 31 show the effects of roll moisture and steam shower condition on the nip moisture content for Mills D and I mediums, respectively. As would be expected nip moistures increased steadily as the roll moisture increased for both mills. The change from no shower to full shower increased the nip moisture content by about 1.5% for Mill D and 2+% for Mill I. While roll moisture has the most effect on nip moisture content, the steam showers can significantly raise the medium temperature.

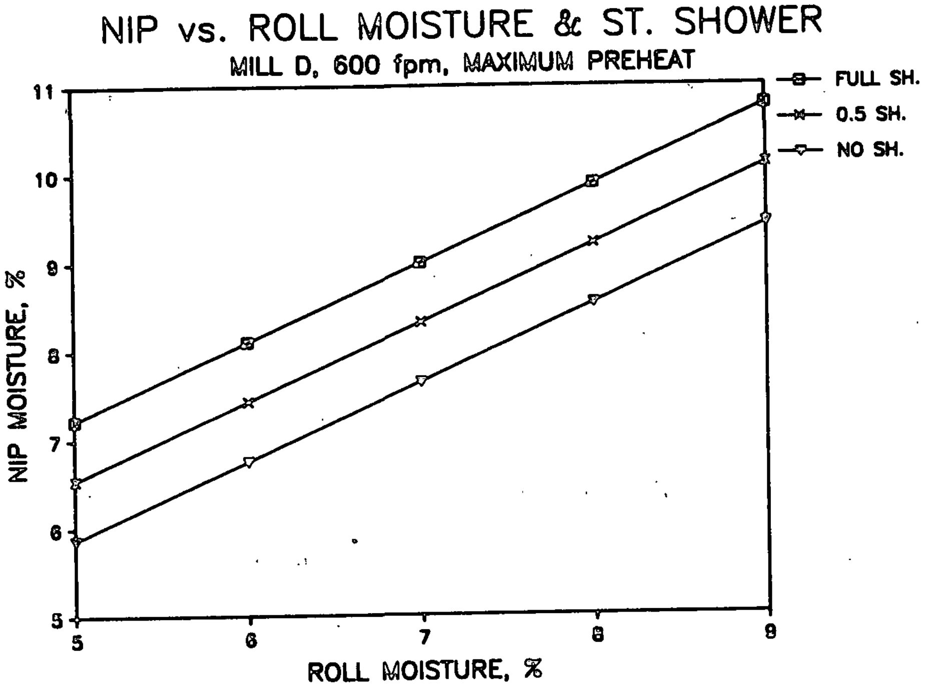


Figure 30. Nip moisture content increases as roll moisture and steam shower condition increase for mill D.

Figures 32 and 33 show that the nip temperature slightly decreases as roll moisture increases for the medium from both mills. For a 4% change in medium roll moisture content, the nip temperature decreased about 10°F for Mill D mediums and by about 20°F for Mill I mediums. Changing from no shower to full shower increased the medium temperature by 35 to 50°F. Thus, while higher roll moistures slightly decreased the nip temperature, the steam showers had a large effect on the nip temperature of the medium.

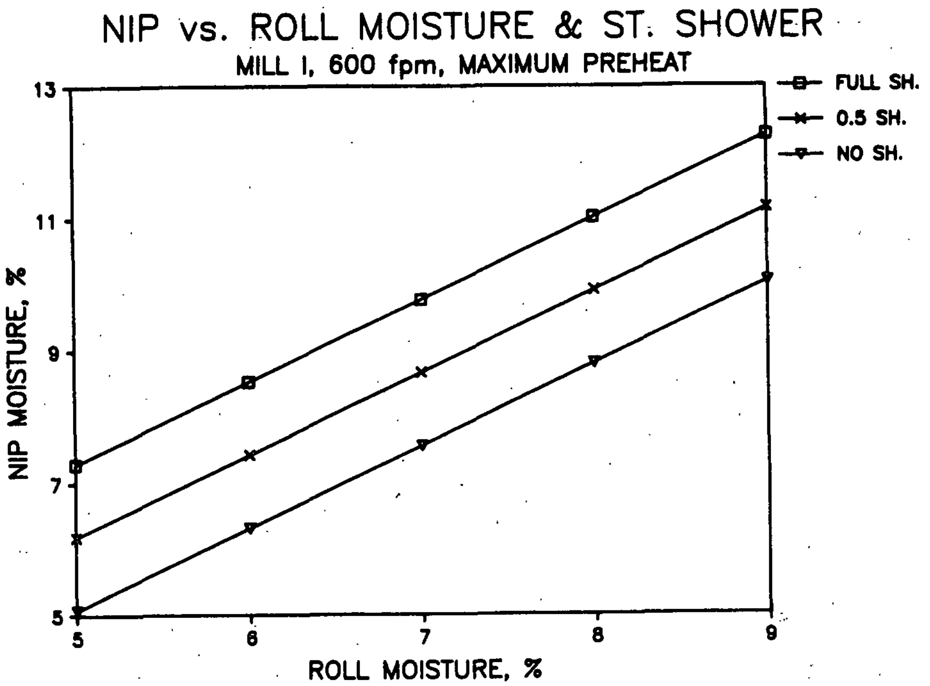


Figure 31. Nip moisture content increases as roll moisture and steam shower condition increase for Mill I.

Figures 34 and 35 show that increasing the preheater wrap from one-half to full wrap reduces the nip moisture content by about 1%. To achieve higher nip moistures at a given roll moisture content it is desirable to make maximum use of the steam showers.

Figures 36 and 37 show that the nip temperature increases about 5°F as the preheater wrap is changed from one-half to full. Increasing roll moisture

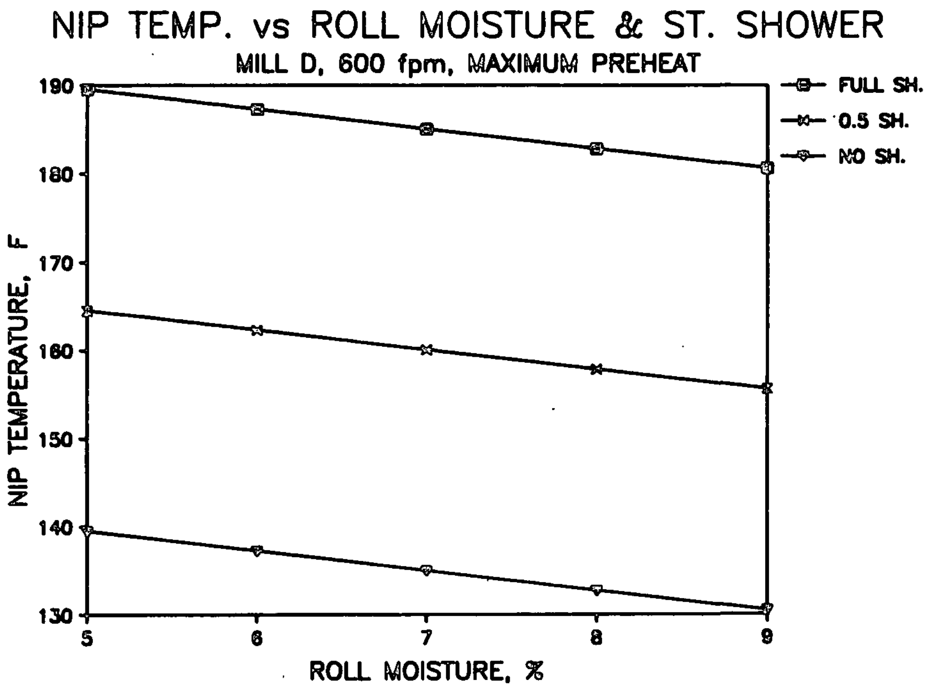


Figure 32. Nip temperature decreases slowly with increasing roll moisture content but increases greatly as the steam showers are activated.

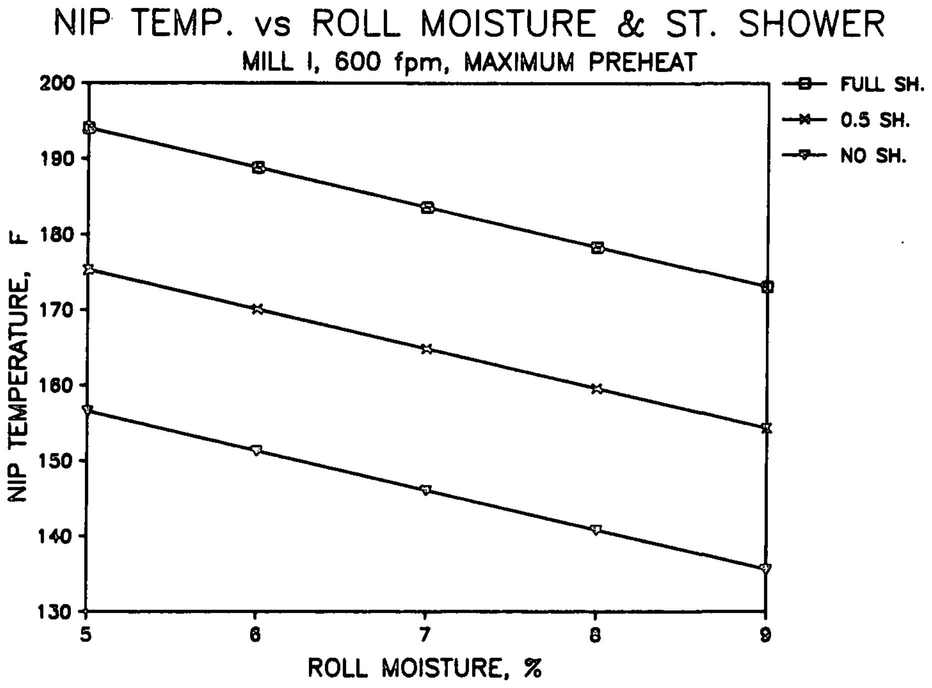


Figure 33. Nip temperature decreases as roll moisture increases but increases as the steam showers are activated.

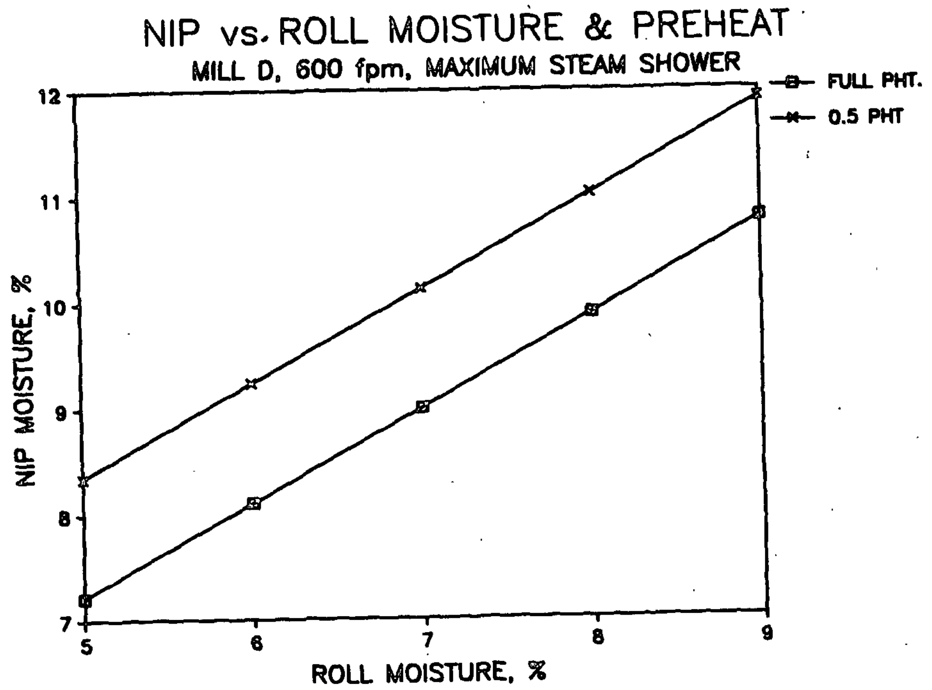


Figure 34. Nip moisture increases as roll moisture increases and preheat wrap decreases for Mill D mediums.

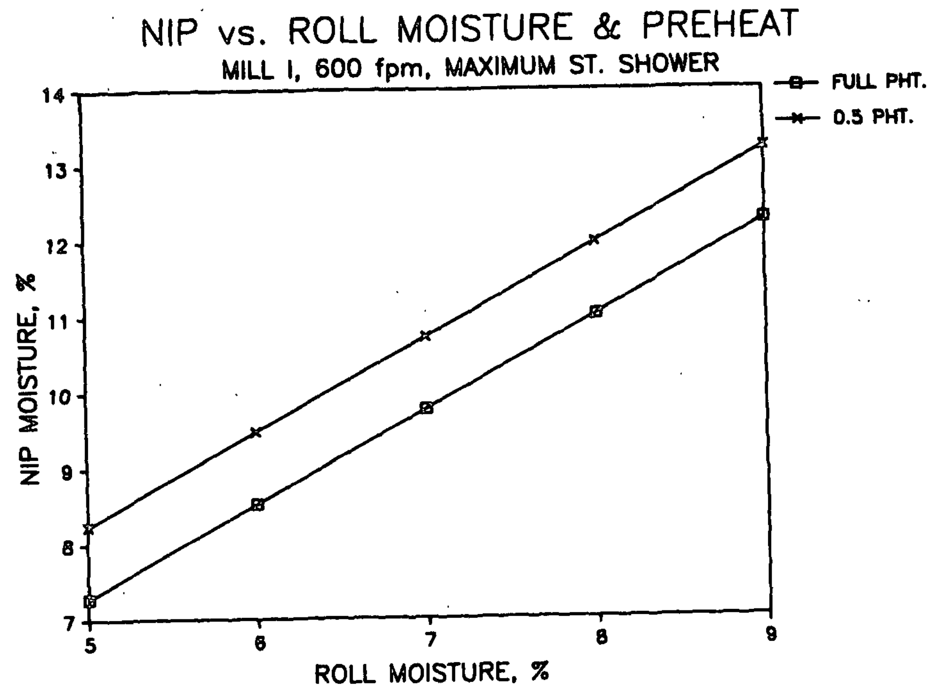
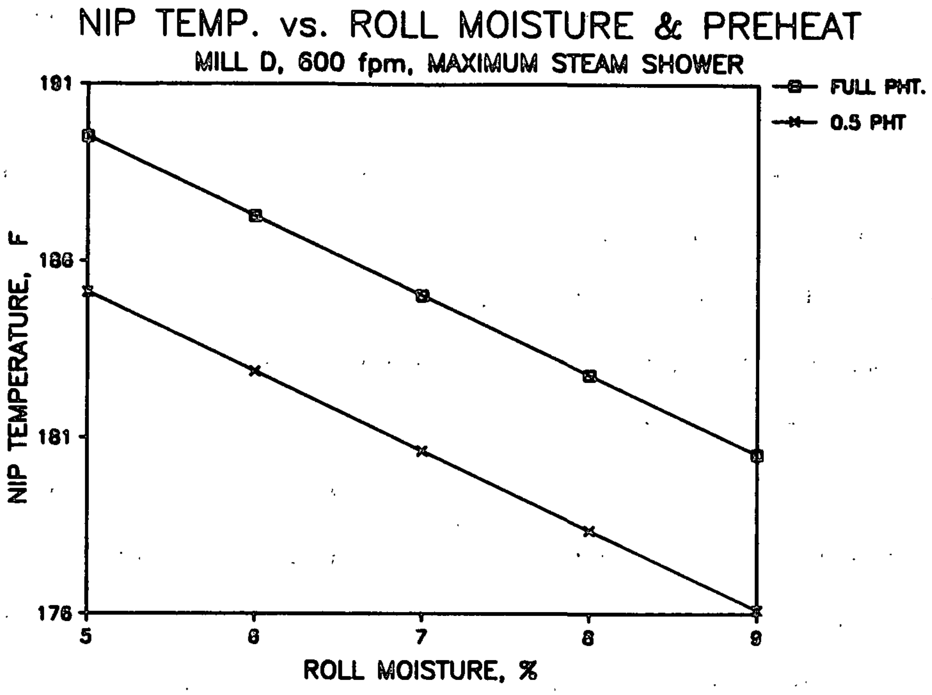
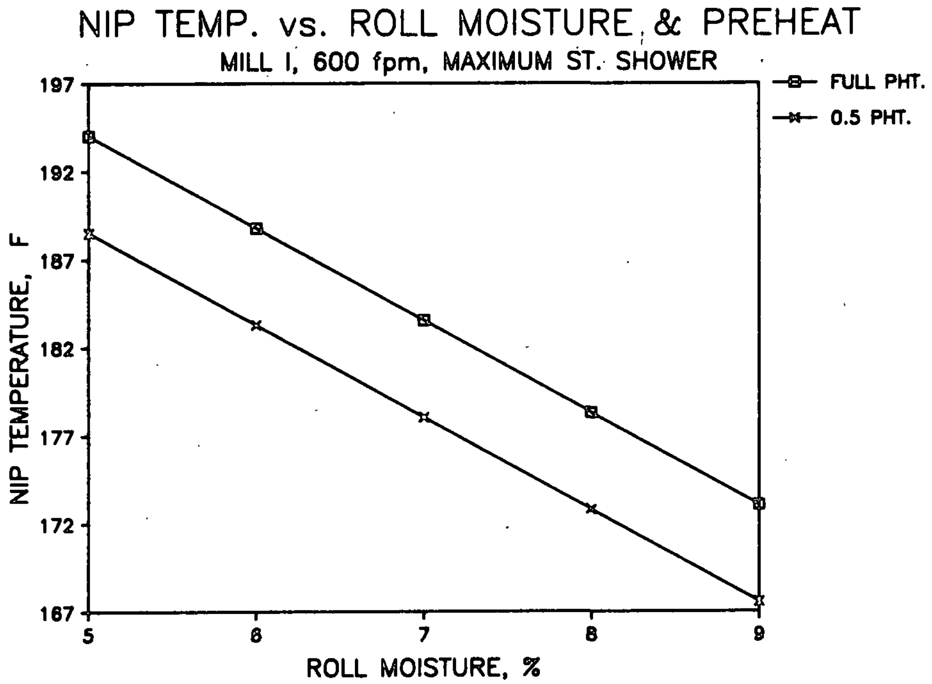


Figure 35. Nip moisture increases as roll moisture increases and preheater wrap decreases for Mill I mediums.


NIP TEMP. vs. ROLL MOISTURE & PREHEAT

MILL D, 600 fpm, MAXIMUM STEAM SHOWER

Figure 36. Nip temperatures increase about 5°F as preheater wrap was changed from one-half to full for Mill D mediums.


NIP TEMP. vs. ROLL MOISTURE & PREHEAT

MILL I, 600 fpm, MAXIMUM ST. SHOWER

Figure 37. Nip temperature increases by about 5°F as preheater wrap is changed from one-half to full for Mill I mediums.

had a larger effect on nip temperatures for the 26-lb Mill I mediums than the 33-lb Mill D mediums. This may be due to the greater density and lower thickness of the Mill I medium.

Analysis of the composited data for all mills gave trends similar to those obtained for Mill D and I. The regression coefficients for the composited data are shown in Table 10. With regard to medium properties, the nip moisture contents attained depended on the following properties: water drop, density (IPC), and porosity. Increasing medium density and water drop tended to reduce the nip moistures attained for a given roll moisture and shower/preheater condition as would be expected (Fig. 38). The more porous sheets tended to attain lower nip moistures (Fig. 39). However, the nip moisture levels did not seem to be very sensitive to small changes in these properties.

Increasing medium density tended to lower medium nip temperatures as expected (Fig. 40).

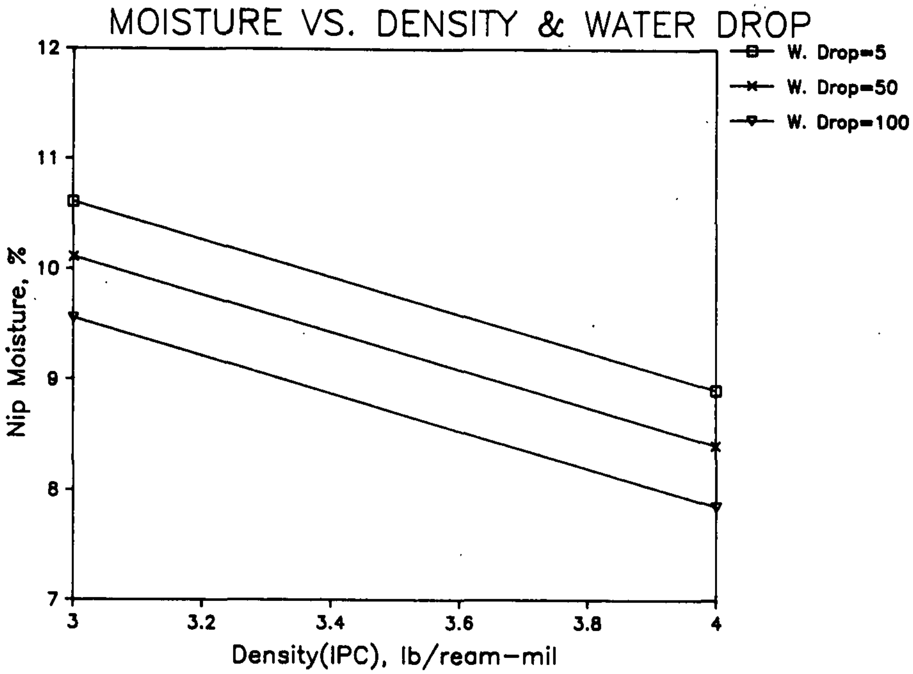


Figure 38. Increasing medium density and water drop lowered nip moisture contents, other factors constant.

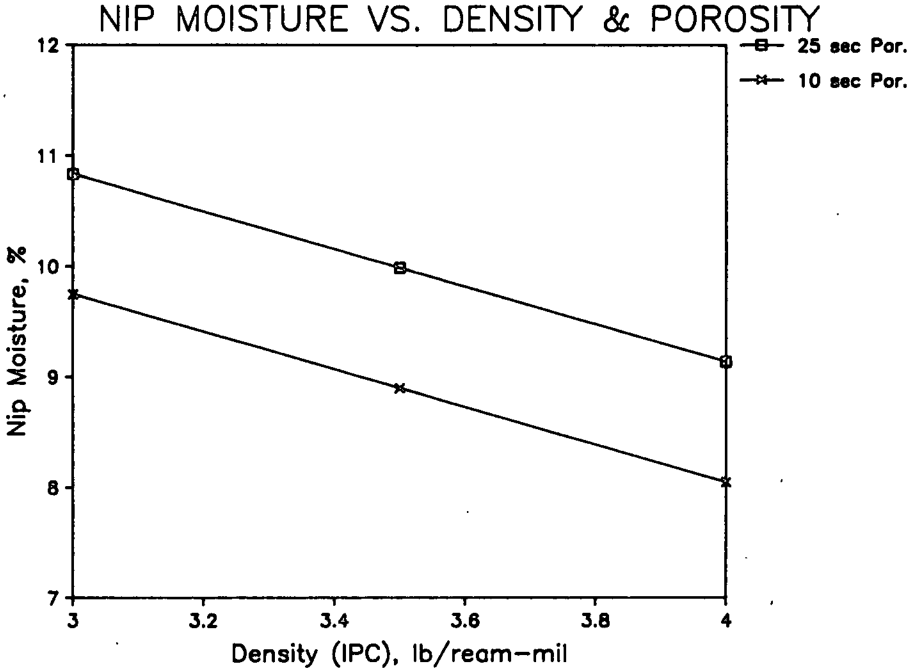


Figure 39. More porous mediums tended to attain lower nip moisture contents, other factors constant.

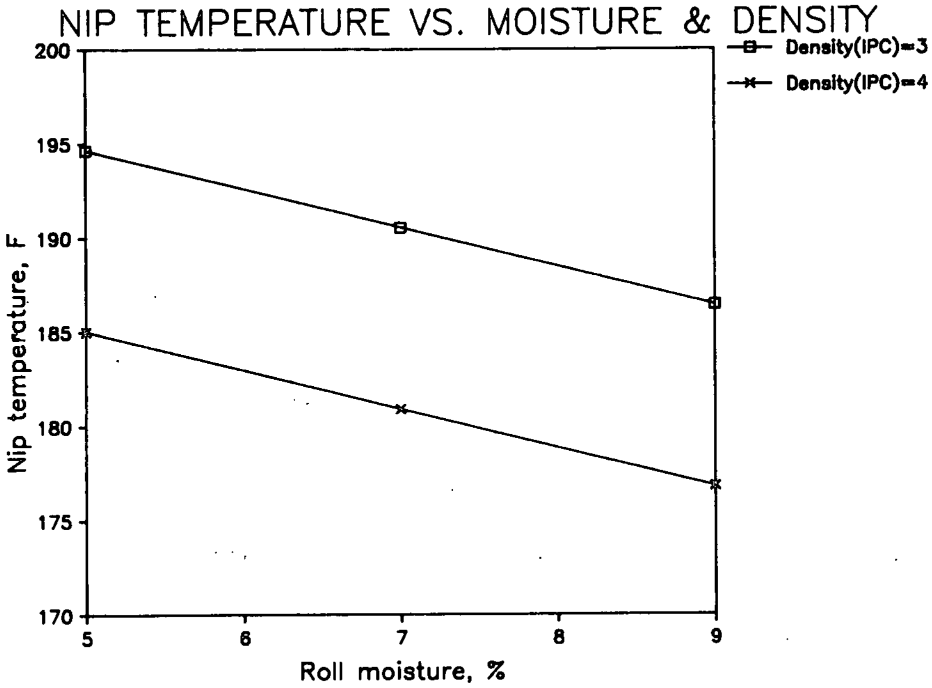


Figure 40. Higher density mediums gave lower nip temperatures, other factors constant.

Table 10. Effects of operating conditions and medium properties on medium nip moisture and temperature (composited data).

Variable	Regression Coefficient Nip Moisture	Regression Coefficient Nip Temperature
Speed	0.00311	-0.0576
Preheat Wrap	-1.23700	7.0588
Steam Shower Cond.	2.28300	5.1920
Roll Moisture	0.75400	-1.9910
St. Shower x Speed	--	0.0568
Water Absorptivity	-0.01110	--
Porosity	0.07250	--
Density (Soft Platen)	-1.70300	-9.6380
Constant	6.44000	221.9000

Notes: 1. All variables significant at the 0.01 level or higher.
2. Coded variables:
Preheater wrap: no wrap = 0; full wrap = 1.0.
Steam shower: off = 0; full on = 1.0.

DEVRON-HERCULES STEAM SHOWER

Devron-Hercules constructed a special steam shower to try out on the Institute's pilot corrugator. The Devron shower replaced the upper half of our present main shower (Fig. 41). Basically, the low pressure steam enters a large cavity and passes into another open space where the steam contacts the medium. The steam feeds into the open space through two rows of holes (orifices), one row on each end of the top unit. The hinged unit to the left is heated with steam and is intended to prevent too much loss in sheet temperature before the medium enters the labyrinth.

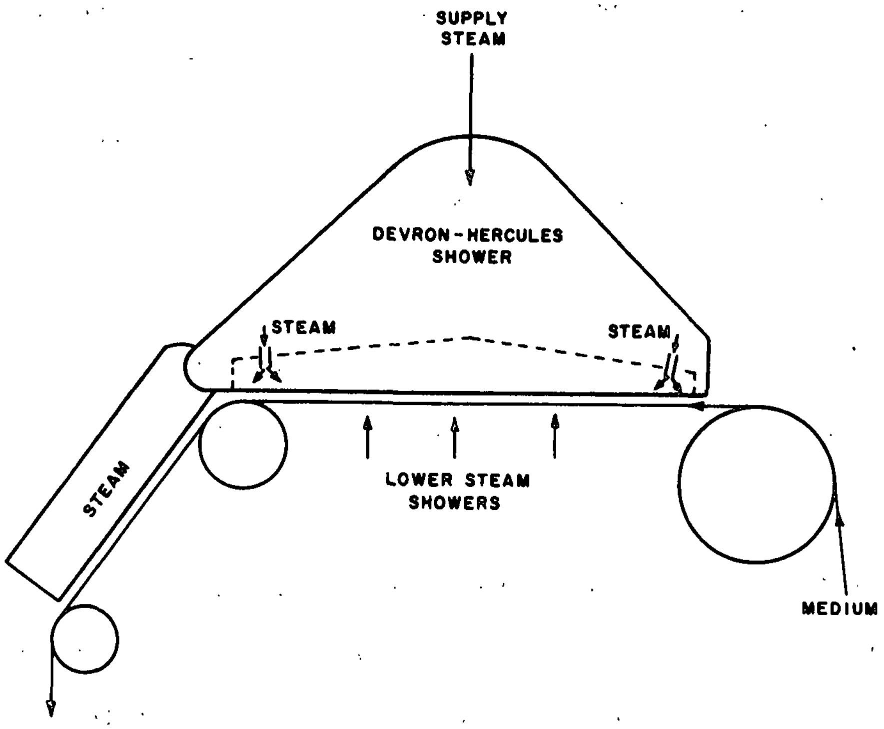


Figure 41. Schematic of Devron-Hercules steam shower.

In the initial trials we observed that much water in the form of droplets was carried along the top surface of the sheet. There were indications that so much free water was present that it began to interfere with corrugating. One of the effects was to lower the draw factor, indicating the medium was stretching more during forming and was approaching a fracture condition at lower speeds than with our standard main shower. Also, our moisture measurements became very erratic and often went off scale due to the free water droplets.

Higher medium friction is obtained as moisture increases and water droplets might accentuate this trend. For this reason a PE slip agent was applied to the medium in an effort to lower friction effects at higher moisture in all of the following runs. However, the PE agent did not appear to be very effective under these water conditions. Possibly other agents might be more effective at such high moisture levels.

In an attempt to reduce the droplet carryover, a crude scraper blade was located after the movable temperature chamber. This appeared to remove at least part of the droplets and improved the moisture measurements. However, probably a better solution would be needed.

After the initial trials, three mediums were run with the Devron showers and the results were compared to results obtained with our standard steam shower arrangement. Table 11 summarizes the data and Fig. 42-46 compare the average results.

The medium temperatures achieved with the Devron showers were about 14°F higher than obtained with our regular showers (Fig. 42). Higher moisture contents were also achieved although these results still may be influenced by water droplet carryover.

On the average the high-lows obtained with the Devron shower were slightly lower than obtained with the regular shower, and the differences became greater at 800 fpm (Fig. 43). These improvements in high-lows may be due to the higher temperature and use of a slip agent.

Single-face flat crush results obtained with the Devron shower were slightly lower than obtained with the regular showers. Lower ECT results were also obtained with the Devron shower (Fig. 44 and 45). The lower ECT results may be due to the decreases in pin adhesion which occurred with the Devron shower (Fig. 46). The previous analysis of ECT status report showed that lower pin adhesion strengths tended to decrease ECT.

In general, the Devron shower results showed no major strength or runnability advantages were achieved. The results suggest that moisture levels

Table 11. Comparison of medium shower type.

	Medium 6813		Medium 6781		Medium 6782		Average	
Showers:	Regular	Devron-Hercules	Regular	Devron-Hercules	Regular	Devron-Hercules	Regular	Devron-Hercules
Medium Temperature, °F								
200 fpm	171	192	198	213	180	198	183	201
400 fpm	175	193	198	207	184	198	186	199
600 fpm	177	195	196	205	186	198	186	199
800 fpm	176	196	193	202	183	195	184	198
av.	175	194	196	207	183	197	185	199
% diff.		11.02		5.35		7.64		7.89
Medium Moisture, %								
200 fpm	10.5	12.5	6.4	9.6	9.0	12.4	8.6	11.5
400 fpm	12.2	13.4	7.8	11.8	10.6	14.1	10.2	13.1
600 fpm	12.6	14.2	8.4	12.7	11.7	14.6	10.9	13.8
800 fpm	13.9	15.0	9.1	13.2	12.8	15.0	11.9	14.4
av.	12.3	13.8	7.9	11.8	11.0	14.0	10.4	13.2
diff.		1.48		3.90		3.00		2.79
Medium Draw								
200 fpm	1.439	1.438	1.441	1.447	1.441	1.445	1.440	1.443
400 fpm	1.438	1.438	1.445	1.447	1.436	1.446	1.440	1.444
600 fpm	1.437	1.433	1.440	1.443	1.434	1.447	1.437	1.441
800 fpm	1.435	1.432	1.435	1.445	1.428	1.437	1.433	1.438
av.	1.437	1.435	1.440	1.446	1.435	1.444	1.437	1.442
% diff.		-0.14		0.36		0.63		0.28
Hi-Los, % > 4 mils								
200 fpm	0.2	3.7	9.5	1.4	4.4	1.1	4.7	2.1
400 fpm	2.0	3.2	7.2	3.7	4.2	2.6	4.5	3.2
600 fpm	3.8	8.7	12.0	6.2	12.5	7.8	9.4	7.6
800 fpm	15.1	15.4	31.1	10.5	24.9	18.3	23.7	14.7
av.	5.3	7.8	15.0	5.5	11.5	7.5	10.6	6.9
diff.		2.48		-9.50		-4.05		-3.69
Singleface Flute Heights, mils								
200 fpm	154.9	155.9	156.7	157.2	155.2	156.7	155.6	156.6
400 fpm	155.1	156.1	157.1	157.1	155.3	158.8	155.8	157.3
600 fpm	155.3	155.7	157.2	156.8	155.2	157.9	155.9	156.8
800 fpm	155.3	155.7	157.0	157.9	154.9	156.6	155.7	156.7
av.	155.2	155.9	157.0	157.3	155.2	157.5	155.8	156.9
% diff.		0.45		0.16		1.51		0.71
Singleface Flat Crush, psi								
200 fpm	34.4	35.1	29.6	30.2	40.5	35.5	34.8	33.6
400 fpm	35.4	35.6	30.9	31.6	40.5	36.0	35.6	34.4
600 fpm	36.5	35.1	32.5	33.6	41.8	37.6	36.9	35.4
800 fpm	36.1	34.8	35.4	34.9	43.4	39.2	38.3	36.3
av.	35.6	35.2	32.1	32.6	41.6	37.1	36.4	34.9
% diff.		-1.26		1.48		-10.77		-4.07
Singleface Pin Adhesion, lbs								
200 fpm	98	93	104	81	111	79	104	84
400 fpm	118	100	104	92	105	93	109	95
600 fpm	114	102	97	87	102	83	104	91
800 fpm	116	93	90	70	95	83	100	82
av.	112	97	99	82.5	103	85	105	88
% diff.		-13.00		-16.46		-18.16		-15.79
Doublefaced ECT, lb/in.								
200 fpm	43.4	--	42.6	--	45.1	--	43.7	
400 fpm	43.9	42.3	44.1	42.8	43.8	42.4	43.9	42.5
600 fpm	43.1	43.3	42.4	41.1	42.6	40.8	42.7	41.7
800 fpm	44.3	41.7	41.4	37.6	42.5	40.8	42.7	40.0
av.	43.7	42.4	42.6	40.5	43.5	41.3	43.3	41.4
% diff.		-2.84		-4.99		-4.98		-4.26

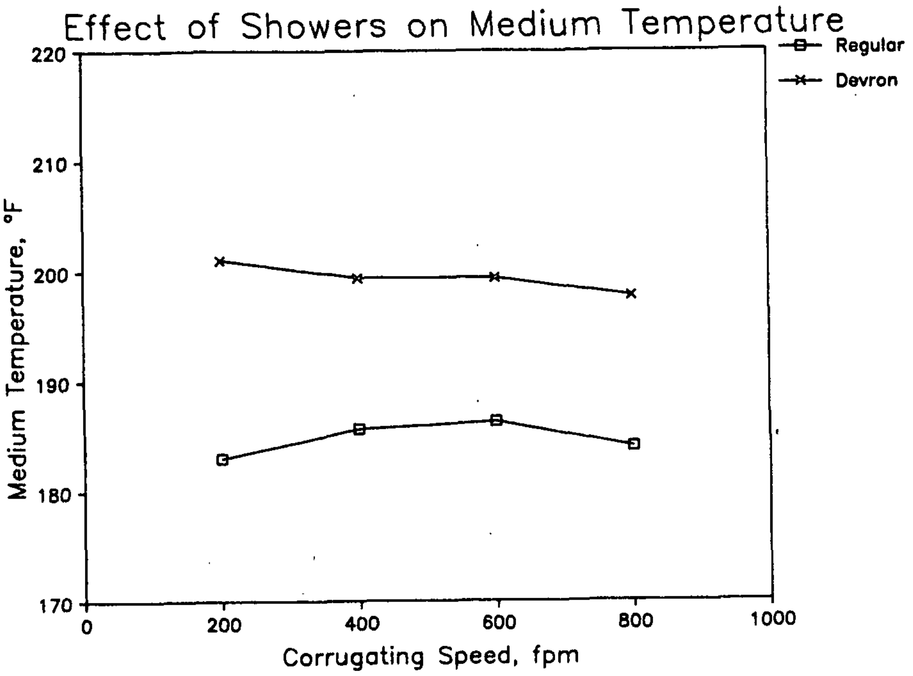


Figure 42. Effect of showers on medium temperature.

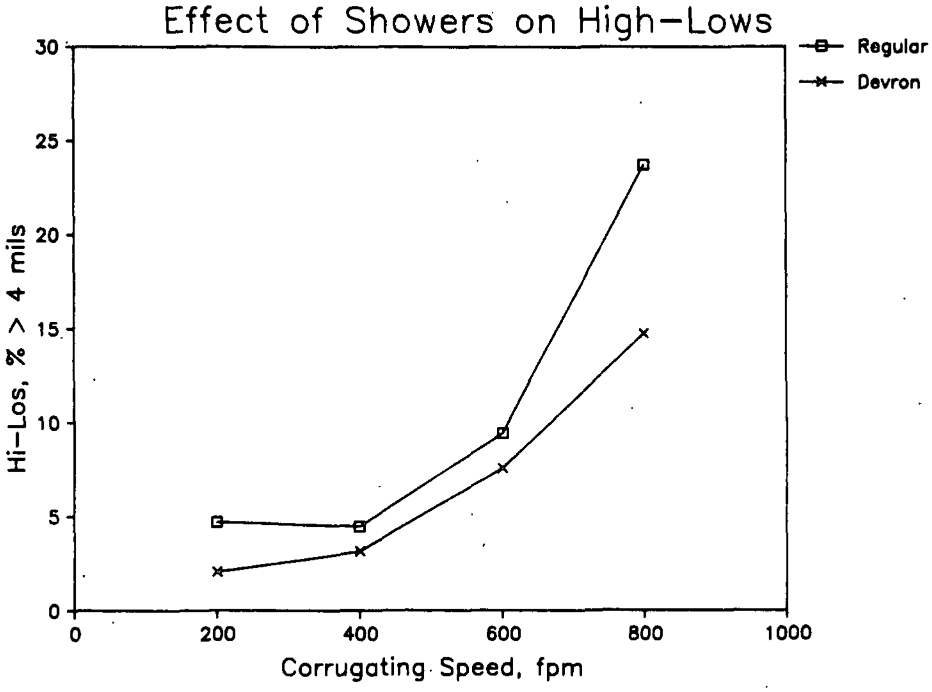


Figure 43. Effect of showers on high-lows.

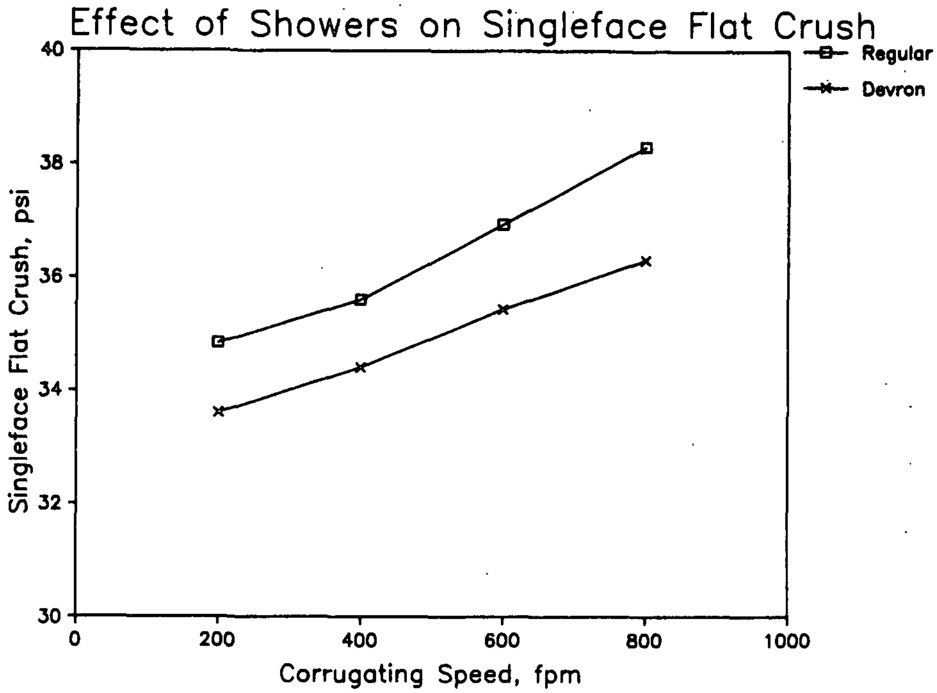


Figure 44. Effect of showers on flat crush.

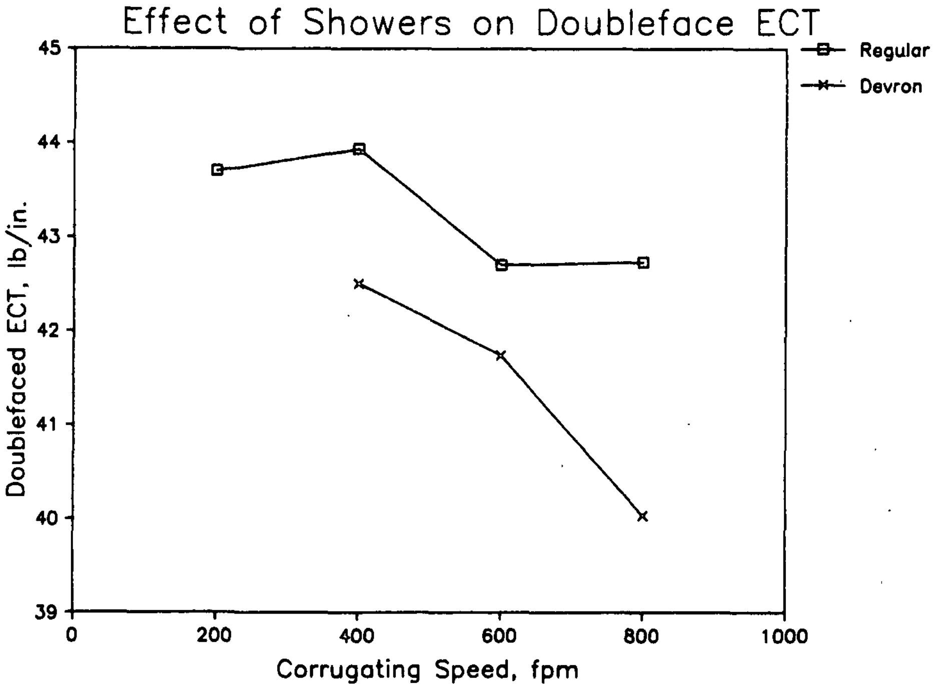


Figure 45. Effect of showers on ECT.

after the steam showers which approach 13 to 16% do not promote further improvements in corrugating operation, particularly if free water droplets are present. Some confirmation of this was obtained in limited trials with water sprays at high moisture levels.

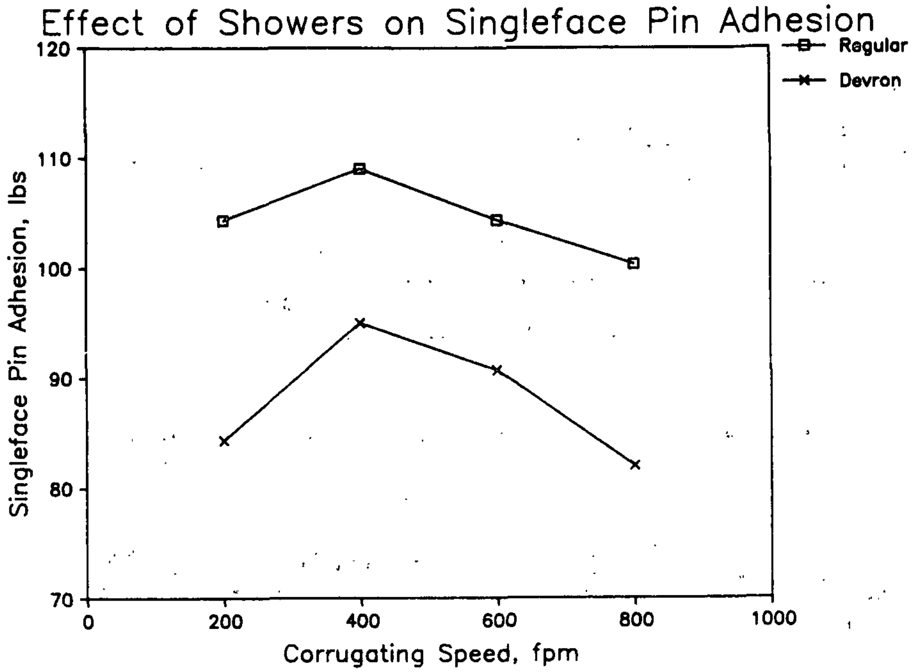


Figure 46. Effect of showers on pin adhesion.

HIGH TEMPERATURE TENSILE TESTS

During the corrugating process, mediums are subjected to high temperatures for short periods of time and can be preconditioned to a wide range of moisture contents prior to corrugating, by the showers and preheater. Also, in the flute forming process, the medium is subjected to high levels of tension over a relatively short period of time. To develop a better understanding of the medium properties during fluting, an apparatus was constructed to study the tensile load-elongation properties of mediums under typical corrugating temperature and moisture conditions. Mediums specimens, which were preconditioned to various levels of moisture content, were heated for controlled periods of time just prior to a relatively high speed tensile test.

The specimen heating apparatus was designed and built to adapt to a conventional tensile tester. The device consists of a pair of heated platens that can be pneumatically moved into position around a test specimen. The platens can be adjusted to within a few thousandths of an inch from the specimen's surface. The interval between the time that the heated platens are brought into close proximity with the specimen and subsequent loading of the specimen can be controlled to within 0.1 sec, with a time range from 0.1 sec to 10 sec. The increases in specimen temperature as a function of time are illustrated in Fig. 47. Both the surface and internal temperature of the medium are within 50°F of the platen temperature after 1.0 sec of heating.

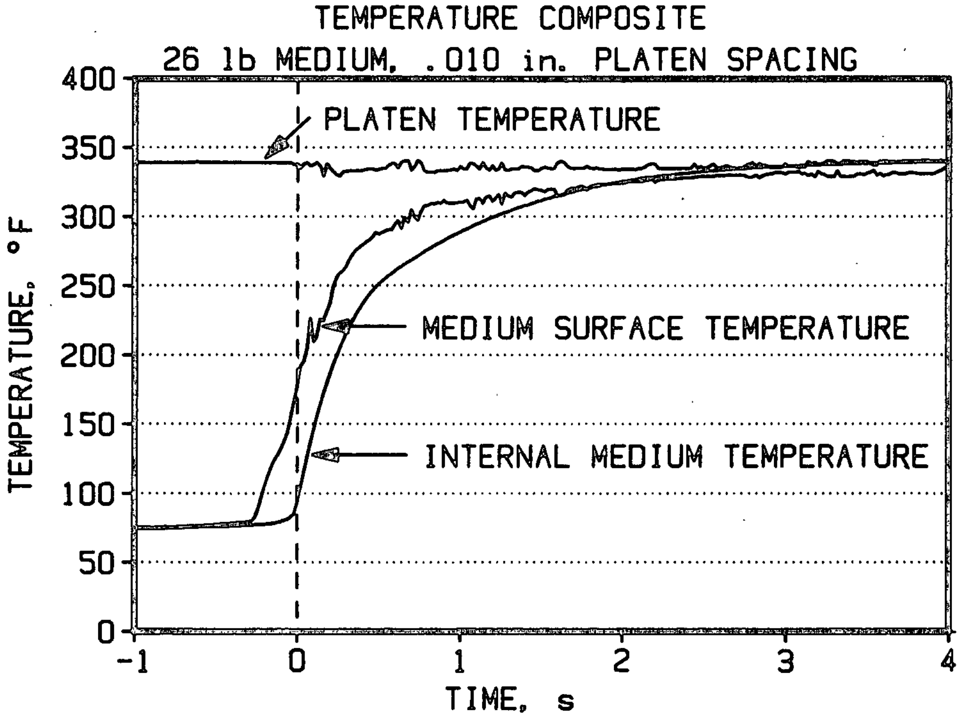


Figure 47. Heating time of the medium in the apparatus.

Specimens were foil wrapped during the heating and tensile testing to help maintain the moisture content throughout the testing period. Also, the tension tests were run at a speed of 20 in./min to minimize moisture loss as much as possible. The mediums were tested after conditioning at 50% RH, 70% RH, and 90% RH. These corresponded, on the average, to initial moisture contents of 7.0%, 9.6%, and 13.9%, respectively. The test specimens were heated in the apparatus for 1.0 sec. just prior to testing.

In addition to tension tests on the control specimens at 73°F, testing was carried out after heating the specimens with the platens at 150°F, 200°F, 250°F, 300°F and 350°F. Mediums no. 6781 (Mill AF), no. 6799 (Mill I) and no. 6811 (Mill AC) were tested. These mediums represent pulping processes of NSSC, green liquor and caustic carbonate, respectively. The test results, which include tensile strength, stretch and MD elastic modulus, are shown in Table 12. The percent changes in these properties are summarized in Table 13.

The three mediums exhibited significant differences in MD stretch behavior as temperature and initial moisture content were changed. For example, Fig. 48 shows that the NSSC and caustic carbonate mediums exhibited larger stretch increases than the green liquor medium at 250°F and an initial RH of 70% RH. Our runnability model indicates that stretch increases should increase fracture speeds and reduce high-lows (see Report One). It should be kept in mind that only one medium of each pulping type was tested. Thus, the conclusion should not be drawn that all mediums of these types will behave in exactly this way.

Table 12. High temperature medium tensile test data.

Platen Temp.	Conditioning RH	Medium 6781			Medium 6799			Medium 6811		
		Tensile (lb/in.)	Stretch (%)	MD ET (lb/in.)	Tensile (lb/in.)	Stretch (%)	MD ET (lb/in.)	Tensile (lb/in.)	Stretch (%)	MD ET lb/in.)
73	50	48.3	0.93	6794	41.7	1.15	5810	37.6	1.16	5383
150	50	35.9	1.40	3059	33.0	1.61	3073	28.3	1.59	2792
200	50	34.9	1.58	3156	29.1	1.80	2710	25.9	2.14	2515
250	50	29.0	1.62	2310	24.4	1.87	2045	21.4	2.41	1866
300	50	31.4	1.68	2871	26.4	1.81	2293	23.7	2.22	2009
350	50	29.7	1.44	2482	26.4	1.78	2193	22.4	1.91	1992
73	70	41.1	1.40	3279	35.9	1.51	2932	31.3	1.54	2773
150	70	32.0	1.70	2644	29.4	1.86	2552	23.4	2.06	2148
200	70	29.8	1.87	2419	24.4	2.15	2156	21.5	2.42	1711
250	70	24.1	1.97	2026	18.6	2.01	1574	18.7	2.70	1108
300	70	27.0	1.67	2251	20.4	1.71	2154	19.0	2.02	1737
350	70	28.2	1.59	2709	21.6	2.09	2174	18.7	2.10	1636
73	90	31.3	1.61	2638	25.9	1.67	2433	23.3	1.80	2294
150	90	26.4	1.70	2268	21.5	1.85	1887	19.1	2.14	1649
200	90	19.5	1.98	1491	16.3	2.24	1253	14.8	2.92	885
250	90	20.2	1.90	1482	16.8	2.29	1304	15.7	2.95	819
300	90	20.0	1.68	1912	13.7	1.76	1526	12.1	1.89	1162
350	90	22.4	1.47	2176	18.5	1.47	1647	15.4	1.59	1444

Note: Test speed was 20 in./min.

Table 13. Percentage change in medium tensile properties.

Platen Temp.	Conditioning RH	Medium 6781 Percent change in property			Medium 6799 Percent change in property			Medium 6811 Percent change in propert		
		Tensile	Stretch	MD ET	Tensile	Stretch	MD ET	Tensile	Stretch	MD ET
73	50	0	0	0	0	0	0	0	0	0
150	50	-26	51	-55	-21	40	-47	-25	37	-48
200	50	-28	70	-54	-30	57	-53	-31	84	-53
250	50	-40	75	-66	-42	63	-65	-43	108	-65
300	50	-35	80	-58	-37	57	-61	-37	91	-63
350	50	-39	55	-63	-37	55	-62	-40	65	-63
73	70	-15	50	-52	-14	32	-50	-17	33	-48
150	70	-34	83	-61	-29	61	-56	-38	77	-60
200	70	-38	101	-64	-41	87	-63	-43	109	-68
250	70	-50	112	-70	-55	75	-73	-50	133	-79
300	70	-44	80	-67	-51	48	-63	-50	74	-68
350	70	-42	71	-60	-48	81	-63	-50	81	-70
73	90	-35	73	-61	-38	45	-58	-38	55	-57
150	90	-45	83	-67	-48	60	-68	-49	85	-69
200	90	-60	113	-78	-61	95	-78	-61	152	-84
250	90	-58	104	-78	-60	99	-78	-58	154	-85
300	90	-59	80	-72	-67	53	-74	-68	63	-78
350	90	-54	58	-68	-56	28	-72	-59	37	-73

Note: Percentage change based on the properties at 73°F and 50% RH.

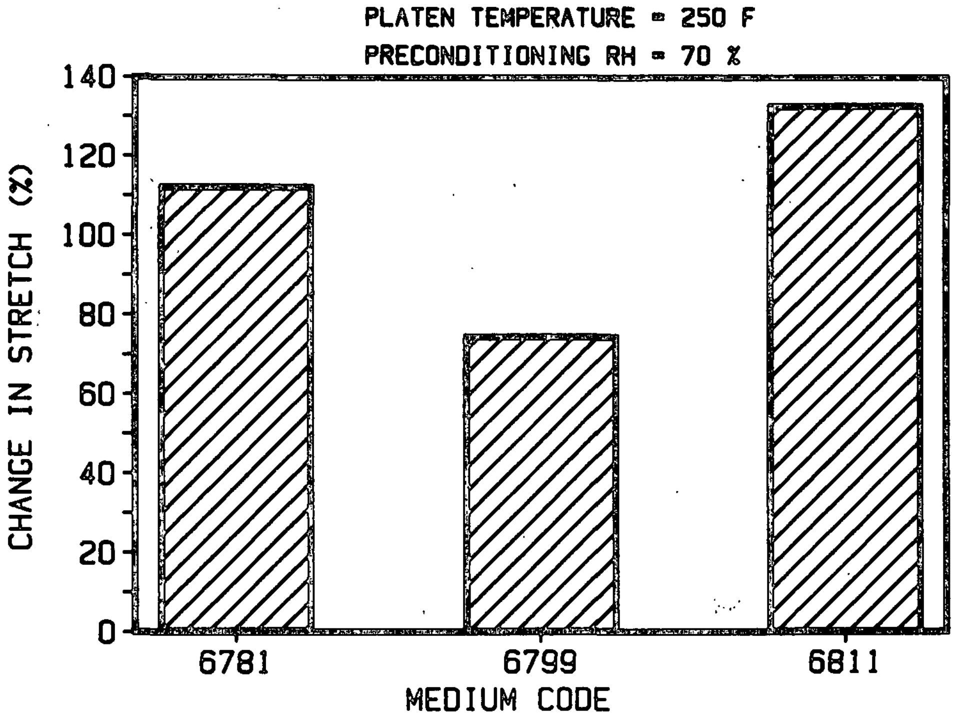


Figure 48. Significant differences in MD stretch behavior of various types of mediums were observed at high temperature. (Note: 6781 = NSSC; 6799 = green liquor; 6811 = caustic carbonate).

While the mediums exhibited large differences in the way stretch was affected by high temperature in the presence of moisture, the tests showed that MD tensile was reduced by about the same percentage amount (Fig. 49).

In the corrugating operation the lignins and hemicelluloses are believed to reach their glass transition temperature which causes them to soften and promote forming. The glass transition for these substances will depend on moisture content as well as temperature. We believe that differences in the chemical composition of various types of mediums should cause differences in the tensile properties at high temperature, and hence, affect runnability. Current work is directed to determining how chemical composition affects the high temperature properties of medium.

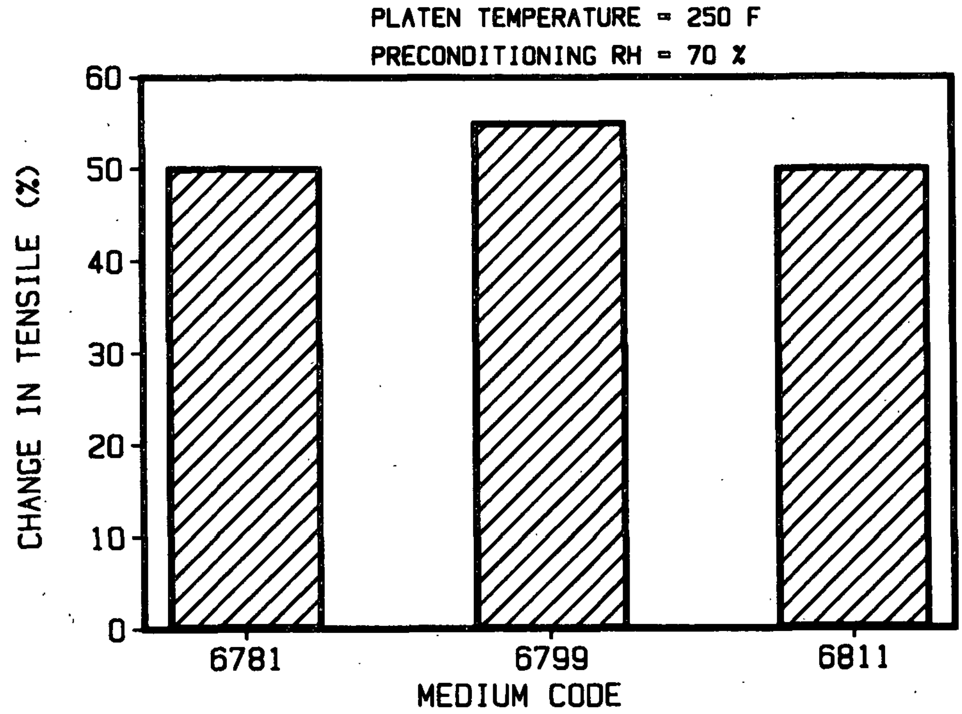


Figure 49. High temperatures caused about equal percentage losses in tensile strength of various mediums. (Note: 6781 = NSSC; 6799 = green liquor; 6811 = caustic carbonate).

The tensile strength versus platen temperature results for medium 6811 are shown in Fig. 50 to illustrate the general temperature behavior. A nearly linear decrease in tensile strength was observed, when the specimens were heated in the temperature range from 73°F and 250°F at each initial moisture level. At platen temperatures above 250°F, the tensile strength remained relatively constant. During the heating process, moisture is lost as the specimen temperature increases. Because tensile strength increases as the moisture content is lowered, it appears that at temperatures above 250°F the losses in moisture counterbalance the effect of raising the temperature. Hence, the tensile strength remains constant above 250°F in these experiments. As expected, the highest tensile strengths occurred for specimens conditioned at 50% RH and the lowest tensile strengths for specimens conditioned at 90% RH, at each platen temperature level.

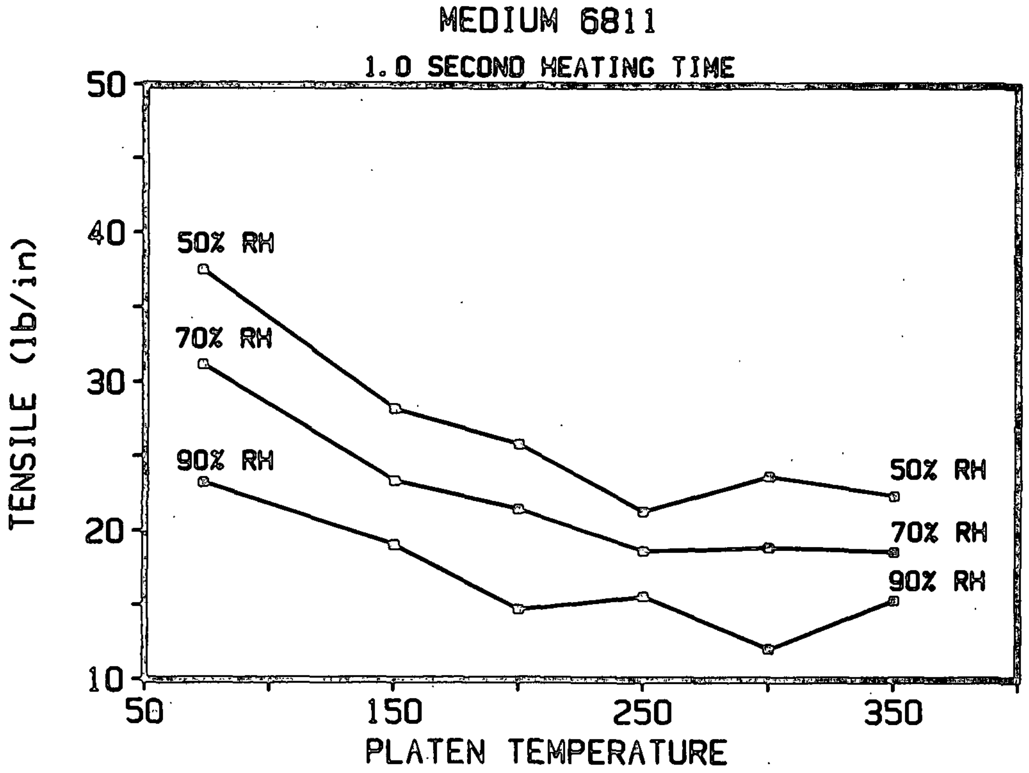


Figure 50. MD tensile strength vs. platen temperature for specimens conditioned at 50, 70, and 90% RH.

The stretch results versus the platen temperature are plotted in Fig. 51 for medium 6811. The stretch values reached a maximum in the platen temperature range between 200°F and 250°F at each initial moisture level. As the temperature increases above about 250°F, the losses in specimen moisture content more than counterbalance the effects of increased temperatures and hence, cause the stretch to decrease at the higher temperatures in these experiments. At temperatures above about 300°F, a cross-over in the stretch values occurred in which the specimens conditioned at 90% RH had lower stretch than specimens conditioned at 50% RH. It is not clear whether this effect is real; however, if verified in current work, it would help explain some corrugating effects when medium moisture content is very high.

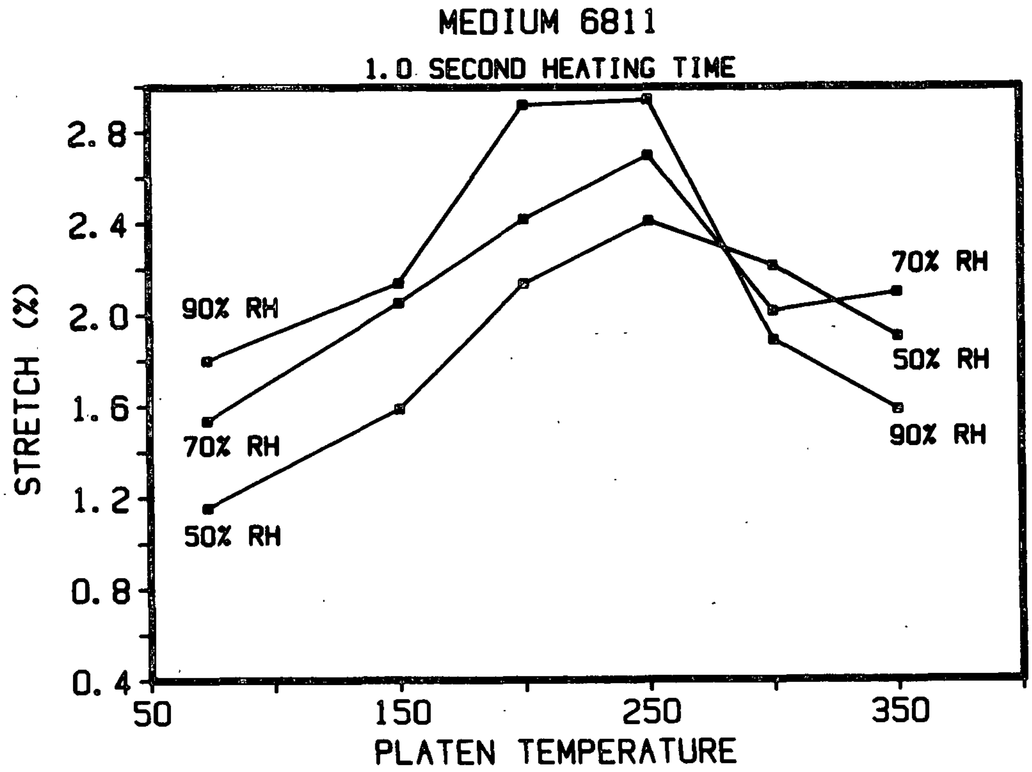


Figure 51. MD stretch vs. platen temperature for specimens conditioned at 50, 70 and 90% RH.

Comparing Fig. 50 and 51, the lowest tensile strengths for medium 6811 occur at approximately the same platen temperature as the maximum stretch. At temperatures above 250°F, the medium had a constant tensile strength but significantly decreased stretch. At temperatures below 250°F, an increase in tensile strength occurred, and a decrease in stretch took place. These results suggest that an optimum medium moisture content and temperature should exist for forming the medium. In the optimum range, the increase in the stretch values would probably more than compensate for the decreased tensile strength, based on runnability considerations.

ACKNOWLEDGMENTS

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Table 14. Trial run results for roll no. 6783 received from Mill D (33-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
D	6783	Max	Full	200	OK	1.443	192	6.0	23.3	9.1	36.5	134	51.3
				400	OK	1.443	195	6.6	20.7	6.9	38.8	136	51.6
				600	OK	1.443	195	6.8	26.3	9.7	38.9	131	51.0
				800	OK	1.436	190	6.9	46.1	28.8	40.1	118	48.6
				1000	OK	1.429	187	6.9	56.1	41.9	42.9	104	48.9
D	6783	None	Full	200	OK	1.439	174	4.8	35.3	19.6	35.3	128	50.9
				400	OK	1.437	162	5.4	40.6	25.0	35.0	123	48.0
				600	OK	1.435	135	5.3	41.8	26.6	34.9	105	46.5
				800	Delam.	1.424	126	5.5	-	-	-	-	-
				1000	-	-	-	-	-	-	-	-	-
D	6783	Max	Half	200	OK	1.441	184	7.0	20.6	8.6	38.9	131	50.9
				400	OK	1.440	189	7.6	18.6	7.5	39.5	137	49.7
				600	OK	1.440	187	7.9	31.2	15.4	42.1	132	50.1
				800	OK	1.432	184	8.0	46.1	31.2	43.5	122	46.4
				1000	Delam.	1.414	181	8.1	-	-	-	-	-

Table 15. Trial run results for roll no. 6785 received from Mill D (33-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
D	6785	Max	Full	200	OK	1.434	190	6.2	13.0	5.2	40.5	126	53.8
				400	OK	1.430	193	7.2	26.5	14.0	41.4	138	53.6
				600	OK	1.429	192	7.7	27.8	14.1	43.9	134	52.9
				800	OK	1.414	187	7.8	33.3	18.1	45.9	120	52.0
				1000	Fracture	1.395	184	8.1	-	-	-	-	-
D	6785	None	Full	200	OK	1.434	169	8.9	37.4	22.7	40.2	135	53.4
				400	OK	1.429	163	9.5	40.3	25.5	42.3	131	52.1
				600	Fracture	1.420	141	9.6	-	-	-	-	-
				800	-	-	-	-	-	-	-	-	-
				1000	-	-	-	-	-	-	-	-	-
D	6785	Max	Half	200	OK	1.435	186	7.0	32.6	17.5	43.3	137	51.2
				400	OK	1.433	190	7.8	23.2	12.3	43.7	137	54.2
				600	OK	1.427	189	8.2	30.8	18.7	45.6	138	54.1
				800	OK	1.416	186	8.2	42.6	26.3	49.2	125	51.3
				1000	Fracture	1.397	180	8.5	-	-	-	-	-

Table 16. Trial run results for roll no. 6787 received from Mill D (33-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
D	6787	Max	Full	200	OK	1.438	184	7.8	23.6	11.1	41.0	137	49.0
				400	OK	1.436	187	8.8	23.7	12.1	40.8	135	50.6
				600	OK	1.434	187	9.6	31.8	16.9	42.8	140	52.6
				800	OK	1.425	181	10.2	40.9	26.3	43.9	123	50.4
				1000	OK	1.413	178	10.6	48.9	34.6	46.3	80	47.9
D	6787	None	Full	200	OK	1.437	163	5.8	40.7	21.9	38.7	136	53.5
				400	OK	1.434	156	7.1	38.1	21.4	39.1	132	50.1
				600	OK	1.432	132	7.0	47.4	33.7	42.2	105	51.1
				800	Fracture	1.424	117	7.1	-	-	-	-	-
				1000	-	-	-	-	-	-	-	-	-
D	6787	Max	Half	200	OK	1.437	181	8.5	21.3	8.3	40.3	135	47.6
				400	OK	1.432	184	10.6	26.7	13.0	43.5	135	50.1
				600	OK	1.430	183	12.4	36.5	21.6	45.5	138	50.8
				800	OK	1.422	178	12.1	40.8	26.3	46.7	124	49.5
				1000	OK	1.405	175	12.3	53.0	37.9	46.0	82	46.0

Table 17. Trial run results for roll no. 6797 received from Mill I (26-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
I	6797	Max	Full	200	OK	1.448	196	5.2	6.3	0.7	32.4	103	46.0
				400	OK	1.451	198	5.8	4.2	1.0	33.6	109	43.4
				600	OK	1.451	196	6.1	10.9	4.2	34.1	100	43.7
				800	OK	1.449	195	6.9	16.2	6.4	33.9	99	42.8
				1000	OK	1.446	192	7.4	30.8	14.7	34.6	79	44.9
I	6797	None	Full	200	OK	1.448	189	4.0	9.7	2.0	31.8	103	46.4
				400	OK	1.451	178	5.7	5.1	0.8	31.6	95	43.5
				600	OK	1.450	169	5.9	12.9	3.6	30.7	92	44.7
				800	OK	1.447	151	5.8	39.4	22.3	31.6	69	43.5
				1000	Delam.	-	-	-	-	-	-	-	-
I	6797	Max	Half	200	OK	1.448	184	6.2	5.5	0.6	33.1	113	47.2
				400	OK	1.450	189	6.6	4.3	1.0	34.1	105	45.7
				600	OK	1.450	190	7.1	11.9	3.9	33.2	100	44.9
				800	OK	1.449	187	7.5	14.0	4.8	35.3	98	42.5
				1000	Delam.	1.447	184	8.0	-	-	-	-	-

Table 18. Trial run results for roll no. 6799 received from Mill I (26-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
I	6799	Max	Full	200	OK	1.448	189	6.8	4.3	0.2	33.8	104	45.6
				400	OK	1.448	193	7.7	5.7	1.9	35.2	104	45.4
				600	OK	1.456	193	8.3	3.4	1.0	35.6	105	46.1
				800	OK	1.458	193	8.9	6.4	0.9	36.4	102	46.0
				1000	OK	1.452	189	9.6	20.3	9.7	36.0	75	42.4
I	6799	None	Full	200	OK	1.448	175	5.4	7.8	1.3	33.0	100	46.7
				400	OK	1.451	168	6.2	6.6	1.1	32.8	101	42.9
				600	OK	1.449	153	6.1	10.8	2.6	33.0	87	44.7
				800	OK	1.445	138	6.4	38.7	22.6	34.8	53	42.3
				1000	Delam.	1.442	124	6.6	-	-	-	-	-
I	6799	Max	Half	200	OK	1.447	181	7.8	4.8	0.7	34.8	98	45.7
				400	OK	1.448	187	8.8	2.5	0.7	34.7	107	44.9
				600	OK	1.452	189	9.5	5.5	0.7	36.4	107	44.9
				800	OK	1.453	187	10.1	10.4	2.2	37.1	102	44.7
				1000	OK	1.450	186	10.0	21.3	9.8	36.3	82	43.0

Table 19. Trial run results for roll no. 6801 received from Mill I (26-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
I	6801	Max	Full	200	OK	1.446	175	9.5	7.5	1.1	36.7	97	45.5
				400	OK	1.445	180	10.8	7.1	1.7	38.8	113	46.5
				600	OK	1.445	181	11.8	11.9	3.0	41.4	105	46.9
				800	OK	1.443	181	12.0	20.4	6.9	39.6	104	44.0
				1000	OK	1.441	178	12.3	32.6	17.8	40.1	83	44.5
I	6801	None	Full	200	OK	1.448	162	5.7	7.7	1.5	33.9	110	46.6
				400	OK	1.447	153	7.5	10.3	3.3	37.2	111	44.0
				600	OK	1.446	136	8.4	16.9	6.1	38.0	91	44.3
				800	OK	1.443	126	8.3	32.2	16.9	37.4	54	42.1
				1000	Delam.	1.438	112	8.5	-	-	-	-	-
I	6801	Max	Half	200	OK	1.445	172	10.5	8.0	0.8	38.2	113	46.7
				400	OK	1.444	178	11.7	7.8	1.1	40.1	112	45.2
				600	OK	1.445	180	12.3	10.7	2.6	41.5	107	44.4
				800	OK	1.443	177	13.5	18.9	7.4	42.5	92	45.4
				1000	OK	1.434	175	14.0	32.4	19.4	41.6	69	44.2

Table 20. Trial run results for roll no. 6803 received from Mill K (26-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
K	6803	Max	Full	200	OK	1.431	178	8.2	39.8	23.5	38.3	123	44.9
				400	OK	1.423	181	9.7	30.4	18.8	37.7	121	44.6
				600	Fracture	1.413	181	10.7	-	-	-	-	-
				800	-	-	-	-	-	-	-	-	-
				1000	-	-	-	-	-	-	-	-	-
K	6803	None	Full	200	OK	1.424	154	6.0	54.2	39.4	37.3	123	45.5
				400	Fracture	1.405	145	6.9	-	-	-	-	-
				600	-	-	-	-	-	-	-	-	-
				800	-	-	-	-	-	-	-	-	-
				1000	-	-	-	-	-	-	-	-	-
K	6803	Max	Half	200	OK	1.428	174	11.3	25.3	11.5	39.5	117	46.1
				400	OK	1.422	177	12.4	22.5	9.9	39.9	122	45.7
				600	OK	1.424	178	13.8	28.9	15.4	40.0	122	43.4
				800	OK	1.414	175	14.1	36.0	22.4	38.2	115	44.3
				1000	OK	1.399	171	14.4	51.7	38.8	31.4	91	42.9

Table 21. Trial run results for roll no. 6805 received from Mill K (26-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
K	6805	Max	Full	200	OK	1.408	184	6.5	57.9	43.7	31.3	110	40.3
				400	Fracture	1.399	189	7.6	-	-	-	-	-
				600	-	-	-	-	-	-	-	-	-
				800	-	-	-	-	-	-	-	-	-
				1000	-	-	-	-	-	-	-	-	-
K	6805	None	Full	200	OK	1.433	169	4.8	50.3	35.1	35.0	107	38.4
				400	OK	1.396	165	5.7	53.4	40.4	33.7	107	41.3
				600	Fracture	<1.36	157	5.8	-	-	-	-	-
				800	-	-	-	-	-	-	-	-	-
				1000	-	-	-	-	-	-	-	-	-
K	6805	Max	Half	200	Fracture	1.404	181	7.4	-	-	-	-	-
				400	-	-	-	-	-	-	-	-	-
				600	-	-	-	-	-	-	-	-	-
				800	-	-	-	-	-	-	-	-	-
				1000	-	-	-	-	-	-	-	-	-

Table 22. Trial run results for roll no. 6807 received from Mill K (26-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
K	6807	Max	Full	200	OK	1.421	201	2.0	50.6	36.0	33.3	109	42.5
				400	OK	1.415	205	2.4	49.3	34.5	32.3	106	41.7
				600	Fracture	1.401	204	2.8	-	-	-	-	-
				800	-	-	-	-	-	-	-	-	-
				1000	-	-	-	-	-	-	-	-	-
K	6807	None	Full	200	OK	1.434	189	3.7	52.2	37.3	31.9	100	41.8
				400	Fracture	1.421	180	4.2	-	-	-	-	-
				600	-	-	-	-	-	-	-	-	-
				800	-	-	-	-	-	-	-	-	-
				1000	-	-	-	-	-	-	-	-	-
K	6807	Max	Half	200	OK	1.420	193	2.9	53.0	38.6	32.7	110	41.3
				400	OK	1.412	198	3.1	50.7	32.4	31.5	105	40.2
				600	Fracture	1.401	195	3.4	-	-	-	-	-
				800	-	-	-	-	-	-	-	-	-
				1000	-	-	-	-	-	-	-	-	-

Table 23. Trial run results for roll no. 6791 received from Mill R (26-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
R	6791	Max	Full	200	OK	1.444	181	6.9	12.4	4.3	31.0	117	46.7
				400	OK	1.444	187	7.7	14.5	5.2	32.0	124	46.6
				600	OK	1.452	186	8.6	8.8	3.8	32.9	115	46.8
				800	OK	1.448	184	9.5	22.8	10.1	35.0	108	44.4
				1000	OK	1.439	180	9.8	34.2	20.1	35.0	88	45.0
R	6791	None	Full	200	OK	1.446	169	4.0	21.4	9.2	29.1	110	44.9
				400	OK	1.447	163	4.4	22.3	10.1	30.6	113	45.5
				600	OK	1.448	147	4.8	27.5	14.2	30.3	93	44.7
				800	Delam.	1.445	124	4.8	-	-	-	-	-
				1000	-	-	-	-	-	-	-	-	-
R	6791	Max	Half	200	OK	1.445	181	6.3	12.4	3.8	30.2	118	46.7
				400	OK	1.446	187	6.6	16.3	4.5	29.5	113	42.2
				600	OK	1.448	187	7.1	14.5	4.3	30.9	108	42.8
				800	OK	1.449	184	7.5	22.9	8.5	32.8	103	43.4
				1000	OK	1.441	181	8.0	35.7	20.6	33.0	79	43.8

Table 24. Trial run results for roll no. 6793 received from Mill R (26-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
R	6793	Max	Full	200	OK	1.443	180	7.4	17.6	5.6	28.5	120	43.6
				400	OK	1.443	184	8.6	16.0	4.9	29.0	120	43.4
				600	OK	1.456	184	9.9	3.0	0.7	30.6	118	44.7
				800	OK	1.450	183	10.8	18.7	6.7	31.2	101	42.8
				1000	OK	1.417	181	11.2	30.9	19.4	30.2	84	44.1
R	6793	None	Full	200	OK	1.446	169	4.8	20.5	9.5	27.2	120	44.7
				400	OK	1.445	163	5.6	23.1	10.2	27.6	112	44.8
				600	OK	1.458	151	6.1	12.4	4.9	27.7	100	46.1
				800	OK	1.456	138	6.3	31.9	18.2	28.0	68	41.7
				1000	Delam.	-	-	-	-	-	-	-	-
R	6793	Max	Half	200	OK	1.442	177	7.6	16.2	3.7	29.6	131	45.2
				400	OK	1.441	181	8.5	19.5	8.0	29.2	125	46.0
				600	OK	1.458	183	9.1	6.2	2.9	29.6	120	43.6
				800	OK	1.458	181	10.0	14.7	3.8	31.0	110	43.9
				1000	OK	1.428	178	11.1	39.0	23.0	31.1	87	44.3

Table 25. Trial run results for roll no. 6795 received from Mill R (33-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
R	6795	Max	Full	200	OK	1.430	172	-	26.1	15.1	49.0	141	49.4
				400	OK	1.420	175	-	30.2	17.9	49.4	143	46.1
				600	OK	1.416	174	-	36.8	23.7	47.8	147	44.8
				800	OK	1.406	171	-	48.0	33.2	44.2	128	44.6
				1000	Delam.	1.398	168	-	-	-	-	-	-
R	6795	None	Full	200	OK	1.439	120	-	28.9	14.8	51.4	144	56.2
				400	OK	1.433	105	-	25.9	15.9	49.3	99	51.4
				600	OK	1.425	<100	-	34.3	21.2	45.8	35	49.0
				800	Delam.	1.413	<100	-	-	-	-	-	-
				1000	-	-	-	-	-	-	-	-	-
R	6795	Max	Half	200	OK	1.422	172	-	31.8	19.2	48.5	136	47.5
				400	OK	1.412	174	-	38.1	22.4	45.0	144	50.3
				600	OK	1.404	172	-	40.1	26.0	43.8	143	44.1
				800	OK	1.395	168	-	55.1	43.5	38.9	101	49.0
				1000	Delam.	1.390	163	-	-	-	-	-	-

Table 26. Trial run results for roll no. 6796 received from Mill R (26-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
R	6796	Max	Full	200	OK	1.447	174	9.1	4.0	0.8	38.3	126	48.2
				400	OK	1.449	178	10.4	4.7	1.6	40.3	130	47.5
				600	OK	1.452	178	11.9	8.2	2.4	40.3	125	49.2
				800	OK	1.460	178	12.4	11.4	3.8	40.7	106	47.8
				1000	OK	1.446	178	13.4	46.9	32.2	40.5	60	40.0
R	6796	None	Full	200	OK	1.450	148	7.3	9.2	2.1	36.6	127	48.6
				400	OK	1.451	139	9.4	7.0	1.8	37.8	124	49.4
				600	OK	1.466	124	10.1	6.3	3.2	37.0	95	48.4
				800	OK	1.453	111	10.2	22.1	9.1	36.2	40	44.2
				1000	Delam.	-	-	-	-	-	-	-	-
R	6796	Max	Half	200	OK	1.448	169	12.1	3.3	0.3	38.8	115	48.5
				400	OK	1.447	175	13.1	4.1	0.9	39.6	128	48.8
				600	OK	1.448	177	14.8	15.3	5.7	41.2	118	46.3
				800	OK	1.448	175	15.0	20.6	7.9	42.0	102	45.8
				1000	OK	1.446	174	16.6	45.3	29.8	42.2	76	44.2

Table 27. Trial run results for roll no. 6809 received from Mill AC (26-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
AC	6809	Max	Full	200	OK	1.442	182	7.1	4.8	0.9	36.6	109	47.4
				400	OK	1.443	187	7.5	8.2	2.8	38.4	113	45.7
				600	OK	1.442	189	7.7	18.0	5.6	38.8	114	46.3
				800	OK	1.441	187	7.9	25.6	11.3	39.7	105	45.2
				1000	OK	1.436	183	8.3	35.9	22.0	39.6	94	43.6
AC	6809	None	Full	200	OK	1.444	178	5.1	14.7	4.7	34.9	100	45.4
				400	OK	1.446	174	5.6	9.7	2.2	36.0	95	43.8
				600	OK	1.446	165	5.7	20.7	9.2	36.2	97	44.5
				800	OK	1.442	153	5.8	43.5	30.6	37.1	81	44.1
				1000	Delam.	-	-	-	-	-	-	-	-
AC	6809	Max	Half	200	OK	1.440	177	8.1	6.9	0.7	36.9	110	46.7
				400	OK	1.441	182	8.8	8.7	2.9	39.4	118	46.0
				600	OK	1.439	181	9.6	13.4	3.5	39.1	114	46.3
				800	OK	1.437	181	9.7	32.5	14.5	38.9	104	44.8
				1000	OK	1.434	178	9.5	39.0	23.0	38.9	86	45.3

Table 28. Trial run results for roll no. 6811 received from Mill AC (26-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
AC	6811	Max	Full	200	OK	1.441	176	7.8	5.5	0.7	34.7	105	42.8
				400	OK	1.442	181	8.5	6.1	1.1	35.4	97	42.3
				600	OK	1.442	183	9.1	10.8	2.4	36.9	105	44.2
				800	OK	1.439	180	9.9	24.1	8.8	36.5	99	43.0
				1000	OK	1.434	178	10.4	41.1	23.4	36.5	89	44.1
AC	6811	None	Full	200	OK	1.444	165	6.0	9.0	2.7	33.8	104	45.8
				400	OK	1.444	159	7.0	7.4	1.4	33.9	110	44.3
				600	OK	1.444	147	7.3	15.7	6.3	34.9	96	43.0
				800	OK	1.441	130	7.3	39.2	23.9	35.4	69	43.5
				1000	Delam.	1.438	117	7.8	-	-	-	-	-
AC	6811	Max	Half	200	OK	1.441	172	8.6	10.4	2.0	34.3	104	43.2
				400	OK	1.439	180	9.6	8.2	1.1	35.9	115	44.4
				600	OK	1.438	180	9.8	14.4	4.2	36.8	111	44.3
				800	OK	1.437	178	10.4	32.4	16.0	37.1	108	42.8
				1000	OK	1.434	177	10.7	41.3	26.7	36.0	89	43.9

Table 29. Trial run results for roll no. 6813 received from Mill AC (26-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
AC	6813	Max	Full	200	OK	1.439	171	10.5	2.1	0.2	34.4	98	43.4
				400	OK	1.438	175	12.2	7.5	2.0	35.4	110	43.9
				600	OK	1.437	177	12.6	15.1	3.8	36.5	114	43.1
				800	OK	1.435	176	13.9	30.9	15.1	36.1	116	44.3
				1000	OK	1.429	174	14.7	46.4	32.3	35.2	88	44.0
AC	6813	None	Full	200	OK	1.443	154	7.9	6.4	0.8	33.4	101	43.6
				400	OK	1.444	147	9.1	5.9	0.9	33.4	109	44.4
				600	OK	1.442	136	9.8	15.3	4.6	33.7	97	43.4
				800	OK	1.440	118	10.4	30.4	14.9	34.1	59	43.6
				1000	Delam.	1.440	112	10.1	-	-	-	-	-
AC	6813	Max	Half	200	OK	1.442	169	10.9	5.4	0.9	35.4	107	47.0
				400	OK	1.440	174	11.8	8.1	1.1	35.0	117	45.9
				600	OK	1.438	175	13.0	17.3	5.0	37.0	113	43.2
				800	OK	1.435	174	13.4	32.1	15.6	35.7	111	43.3
				1000	OK	1.431	171	14.6	48.4	34.9	37.3	75	45.1

Table 30. Trial run results for roll no. 6771 received from Mill AG (26-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in
AG	6771	Max	Full	200	OK	1.444	187	6.7	11.2	2.6	33.8	102	43.6
				400	OK	1.446	193	7.4	6.1	1.9	34.4	95	45.6
				600	OK	1.448	195	7.5	10.6	2.3	35.1	87	43.9
				800	OK	1.446	193	7.8	23.6	8.6	35.1	81	42.0
				1000	OK	1.442	189	8.3	33.4	19.5	36.1	69	43.9
AG	6771	None	Full	200	OK	1.443	177	5.0	12.9	4.0	32.6	89	45.1
				400	OK	1.444	172	5.7	9.8	2.0	33.9	87	44.8
				600	OK	1.444	168	6.2	12.7	4.6	33.2	80	46.0
				800	OK	1.443	157	6.2	38.2	22.9	33.9	65	43.4
				1000	OK	1.443	141	6.6	-	-	-	-	-
AG	6771	Max	Half	200	OK	1.444	180	8.1	9.0	1.4	35.0	99	45.0
				400	OK	1.445	187	8.7	5.5	1.7	35.6	91	44.6
				600	OK	1.446	189	9.3	10.5	2.8	35.8	88	44.4
				800	OK	1.446	186	9.7	21.8	9.5	36.6	73	44.3
				1000	OK	1.442	183	9.6	35.0	20.3	35.9	65	42.8

Table 31. Trial run results for roll no. 6773 received from Mill AG (26-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in
AG	6773	Max	Full	200	OK	1.448	180	9.2	5.8	0.5	33.6	112	45.9
				400	OK	1.448	184	10.9	5.5	1.6	35.6	109	43.6
				600	OK	1.457	186	11.5	3.1	0.7	35.4	98	44.1
				800	OK	1.446	184	12.0	19.0	6.9	37.1	88	44.9
				1000	OK	1.441	181	12.5	44.6	29.6	35.6	68	41.9
AG	6773	None	Full	200	OK	1.448	153	6.3	10.2	2.3	32.6	105	45.4
				400	OK	1.449	153	7.2	6.9	1.2	32.4	93	47.4
				600	OK	1.449	142	7.7	19.4	7.8	32.5	80	43.3
				800	OK	1.447	127	8.0	27.0	12.5	32.8	46	44.6
				1000	OK	1.445	117	8.1	-	-	-	-	-
AG	6773	Max	Half	200	OK	1.442	178	8.7	7.3	1.3	33.5	108	45.6
				400	OK	1.443	184	9.5	8.8	1.8	35.3	101	46.0
				600	OK	1.444	186	10.8	14.5	4.7	37.6	96	45.6
				800	OK	1.441	184	11.3	27.2	12.3	37.5	82	44.3
				1000	OK	1.440	180	11.7	40.5	22.7	37.6	64	41.1

Table 32. Trial run results for roll no. 6775 received from Mill AG (26-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
AG	6775	Max	Full	200	OK	1.442	178	9.3	9.1	0.8	35.4	115	45.0
				400	OK	1.442	184	11.0	9.5	2.0	37.8	112	44.6
				600	OK	1.443	186	12.5	16.3	5.1	38.4	106	44.4
				800	OK	1.445	184	13.4	20.8	8.6	39.7	94	44.3
				1000	OK	1.444	181	14.5	35.8	21.8	40.8	72	42.8
AG	6775	None	Full	200	OK	1.446	162	6.7	12.5	2.7	34.8	106	44.5
				400	OK	1.449	159	7.9	11.2	2.9	35.1	94	43.9
				600	OK	1.448	145	8.4	16.9	5.5	36.0	88	42.7
				800	OK	1.446	130	8.7	33.5	18.4	36.8	65	41.4
				1000	OK	1.443	121	8.9	-	-	-	-	-
AG	6775	Max	Half	200	OK	1.443	177	10.0	11.2	2.6	36.3	116	45.8
				400	OK	1.443	183	11.1	14.2	4.4	37.4	108	46.2
				600	OK	1.443	184	11.7	22.3	7.6	37.6	104	45.8
				800	OK	1.429	181	13.0	34.4	18.8	39.7	94	46.9
				1000	OK	1.442	178	13.0	46.1	31.4	39.8	67	43.4

Table 33. Trial run results for roll no. 6781 received from Mill AF (26-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
AF	6781	Max	Full	200	OK	1.441	198	6.4	21.2	9.5	29.6	104	42.6
				400	OK	1.445	198	7.8	19.7	7.2	30.9	104	44.1
				600	OK	1.444	196	8.4	26.7	12.0	32.5	97	42.4
				800	OK	1.440	193	9.1	47.1	31.1	35.4	90	41.4
				1000	OK	1.435	189	9.7	54.3	39.4	34.5	77	40.4
AF	6781	None	Full	200	OK	1.441	171	5.6	36.3	23.1	32.8	103	44.1
				400	OK	1.441	168	6.4	35.9	21.7	33.2	97	43.1
				600	OK	1.441	163	6.7	39.1	26.1	34.7	89	42.7
				800	OK	1.438	150	6.7	59.1	50.3	33.8	58	40.7
				1000	Delam.	1.439	132	6.9	-	-	-	-	-
AF	6781	Max	Half	200	OK	1.444	186	8.4	24.0	7.7	31.9	104	43.9
				400	OK	1.442	192	9.3	20.0	9.9	33.7	106	40.6
				600	OK	1.441	193	9.9	31.1	17.2	35.5	97	40.0
				800	OK	1.437	189	10.8	50.5	36.1	36.6	93	41.2
				1000	Delam.	1.433	186	11.0	-	-	-	-	-

Table 34. Trial run results for roll no. 6782 received from Mill AF (26-lb medium).

Mill	Roll No.	Steam Showers	Pre-heat	Corr. Speed, fpm	Corrugator Runnability Evaluation	Draw Factor	Medium Temp., °F	Medium Moisture, %	High-Low >3 mil, %	High-Low >4 mil, %	Flat Crush psi	Pin Adhesion lbs.	ECT lb/in.
AF	6782	Max	Full	200	OK	1.441	180	9.0	23.4	4.4	40.5	111	45.1
				400	OK	1.436	184	10.6	17.4	4.2	40.5	105	43.8
				600	OK	1.434	186	11.7	28.9	12.5	41.8	102	42.6
				800	OK	1.428	183	12.8	40.1	24.9	43.4	95	42.5
				1000	OK	1.423	181	13.2	50.2	35.5	43.7	71	40.8
AF	6782	None	Full	200	OK	1.438	156	8.2	22.4	6.6	37.2	106	43.1
				400	OK	1.438	150	10.2	20.1	7.3	37.9	115	43.4
				600	OK	1.438	139	11.0	31.4	15.1	39.1	96	41.5
				800	OK	1.434	129	11.5	52.1	37.1	39.2	66	40.6
				1000	OK	1.427	115	11.7	59.2	45.8	40.0	22	40.0
AF	6782	Max	Half	200	OK	1.443	180	8.7	25.0	8.9	41.1	103	45.2
				400	OK	1.443	184	9.7	22.0	7.7	42.2	103	45.5
				600	OK	1.442	186	10.3	41.6	23.7	43.0	94	43.2
				800	OK	1.442	183	11.5	46.3	34.6	43.5	95	41.9
				1000	OK	1.441	180	12.7	58.2	46.3	45.2	77	41.5