INSTITUTE OF PAPER CHEMISTRY
Appleton · Wisconsin

EVALUATION OF A PROTOTYPE LINERBOARD PEEL TESTER

Project 2694-14

Report Two
A Progress Report
to
FOURDRINIER KRAFT BOARD GROUP
of the
AMERICAN PAPER INSTITUTE

June 15, 1983

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SUMMARY

The objective of this project was to (1) develop a prototype mill peel tester using a single-pass (one-way) rub principle and (2) determine the appropriate design parameters based on functional operation of the prototype. The tester, as designed, has means for pressing two sheets of linerboard together while simultaneously pulling one sheet under the other. The occurrence of a peel manifests itself as a "spike" in the differential of the load vs. time curve, which can be related to the applied load at that instant. Thus, the pressure causing peel can be determined if peeling occurs.

Our experiences with the prototype tester indicate that the one-way rub principle can be used to evaluate peeling resistance. The pressures required are relatively high for many boards, as would be expected, because peels are not a frequent occurrence in service. Some boards will not peel within a reasonable load range, even at high moisture contents. To best rate linerboards in terms of peeling proclivity, the testing should be done at high moisture content, such as 80-85% RH. Tests at 50% RH may serve to detect peelers but not to quantify peeling proclivity because it appears that most linerboards will not peel within a reasonable pressure range at the lower moisture content.

The test variability is relatively high and is believed to occur because peel is triggered by local weak regions of fiber bonding rather than average bonding strength.

Modifications of the prototype tester are recommended to achieve more efficient operation. These should include provisions for a fixed distance pulling

system to reduce stretch and chatter in the detection system, a moving belt slip sheet, and automated peel detection system. In addition, the clamp on the fixed specimen should be located closer to the platens. This will also assist in minimizing the occurrence of chatter and will shorten the length of the machine.

A considerable amount of information on peel was developed in the feasibility trials preceding construction of this prototype machine. This information is appended to this report.

INTRODUCTION

In a study concerned with the scuffability of linerboard (1), a survey of the FKBG member companies revealed that peeling and dusting problems are encountered in many converting plants. Peeling can occur on the corrugator (MD) and in sheet-fed operations such as in flexo-folder-gluers. Peeling results in rejects of the finished product and lost production time. It would be desirable to detect linerboard with low peel resistance in the mill before it reaches the box plant.

The same survey indicated that the most common test for scuff is the S & S scuff tester, even though it is no longer made by the S & S Corrugated Machinery Co. S & S scuff results below about 20-25 strokes were believed to cause difficulties in the box plant. There were indications that S & S peel test results tended to be related to surface bonding strength, as might be expected. Peeling problems in the box plant usually do not involve repeated rubbing of the same surfaces; therefore, the S & S tester action does not wholly simulate box plant conditions.

Preliminary trials, carried out at the Institute, indicated that peels could be initiated on some linerboards using one-way rub conditions simulating the flexo-folder-gluer feeding operation (2). Limited tests indicated that peeling resistance increases as (1) moisture content decreases, (2) bonding strength of the VVP type increases (Note: the present work indicates this relationship is subject to considerable scatter), and (3) specimen size decreases.

Based on the foregoing, the Institute was requested by FKBG to design, construct, and evaluate a prototype mill peel tester utilizing the principle of a one-way rubbing action to simulate the flexofeeding operation. Budget limitations required selection of a single approach to the design of the machine and the peel detection system. It was anticipated that the functional examination of the prototype machine would indicate where design modifications would be required. Thus, the objective was not to develop a "finished" mill peel tester but rather to

(1) determine the feasibility of using the one-way rub principle and

(2) to determine design parameters for a peel tester of this type which would be suitable for mill use.

DESCRIPTION OF TESTER

A schematic drawing of the mechanical parts of the tester is shown in Fig. 1, and a photograph of the assembled machine is shown in Fig. 2. As the lower specimen is wound onto the pulling drum, an increasing transverse load is applied to the sandwiched specimens. At present, we monitor the load vs. time curve and the loading rate vs. time curve during the course of each test. Under normal circumstances the occurrence of a peel will manifest itself as a "spike" in the loading rate vs. time curve, which can be related to the applied load at that instant. Figure 3 shows a loading rate curve with a spike denoting peel.

The loading rate curve is used because it is much more sensitive to the small perturbation caused by the occurrence of a peel. Although the necessary electronics have not been developed, the peel perturbations in the loading rate curve could be detected electronically to provide an automatic indication of the occurrence of a peel and of the corresponding peel pressure.

Two clamps are used to hold the specimens: one fixed to the machine frame and the other to the pulling drum. Each clamp consists of a 14-inch-long-round bar attached to two 3-inch-diameter-bore pneumatic cylinders. Clamping force is approximately 1200 lb at 80 psi or 85 lb per inch of width.

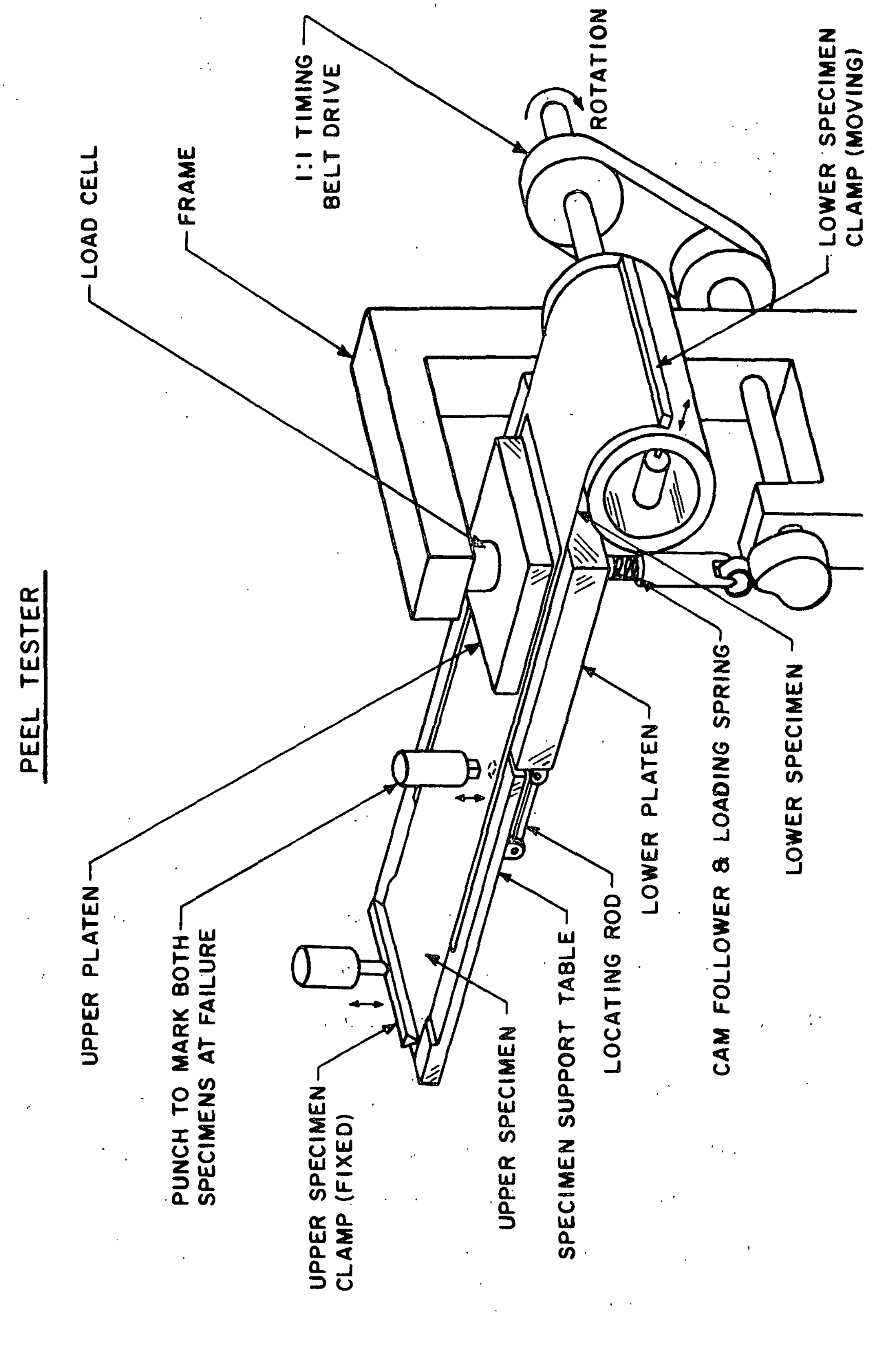

Figure 1. Schematic drawing of peel tester.

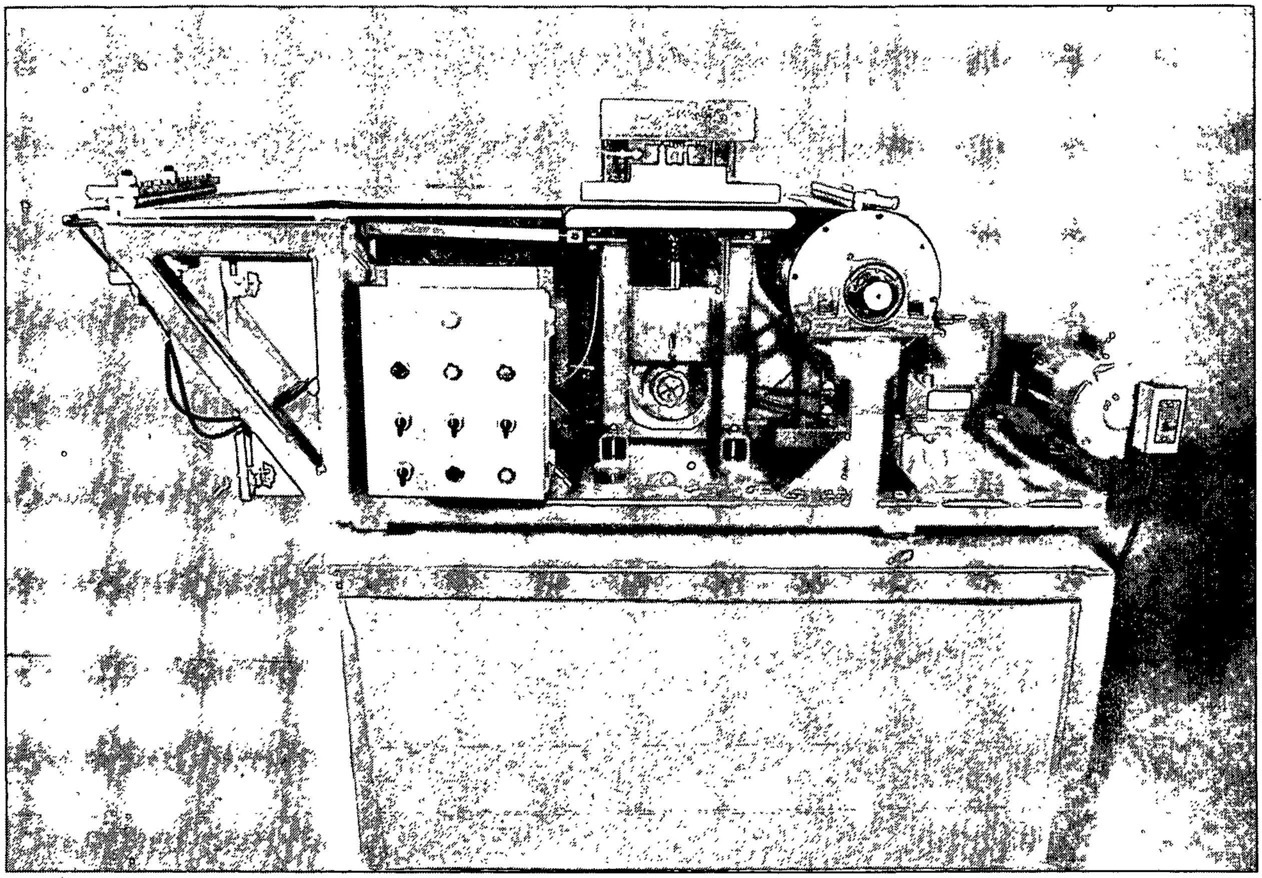

Figure 2. Peel tester.

Load is applied to the specimens by a cam that is driven from the drum shaft. The force is transferred from the cam to the lower platen via a cam follower and spring. Loading rate can be varied by changing springs. The top platen is 12 by 12 inches and made from 1-inch-thick steel. The bottom platen dimensions are 14 x 14 x 1 inch. Both platens are ground and chrome plated.

The applied load is measured with an Interface Inc. load transducer having a 1000-lb capacity and 10-volt DC output. Output is displayed on a digital voltmeter and also on a two-channel strip chart recorder as a load vs. time curve. Electronic differentiation of the load-time curve provides a loading rate vs. time curve which is also displayed on the chart.

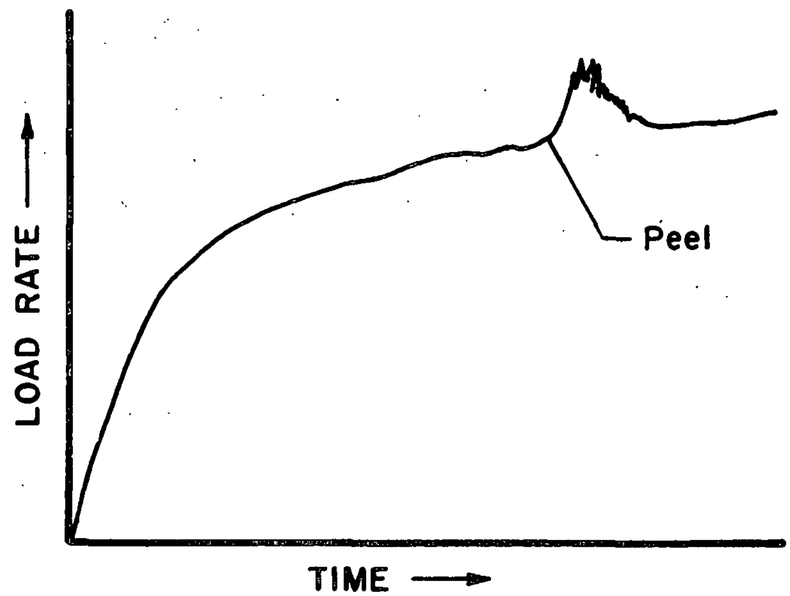

Figure 3. "Spike" in curve indicates occurrence of peel.

The above load cell allows testing up to pressures of about 3.5 psi on a 10 x 12 inch area when using the spring/cam system that appeared to give the best results. This pressure would correspond to the pressure on the bottom sheet in a stack of about 2800 sheets of 275-lb series board. Thus, the machine permits testing up to pressures beyond those encountered in commercial practice.

Drive is provided by a 1/4-horsepower, 110-volt AC motor acting through a double reduction 600:1 gear box. The output speed is 3 rpm. The gear box drives the pulling drum and cam in a 1:1 ratio by the use of timing belts and pulleys.

The bottom pulled specimen measures 12 by 42 inches, and the top stationary sheet is 10 by 42 inches. In testing, the bottom specimen, felt side up, is positioned by sliding it between the load platens and clamping one end to the rotating drum. The top specimen is placed between the platens felt side down with one end in the fixed clamp.

The drive motor and strip chart recorder are started simultaneously by manual switches. The recorder displays the load-time and load differential-time curves. The differential load recording exhibits a sharp spike in the curve when a peel occurs. When a peel occurs, the drum clamp is manually opened, releasing the bottom moving sheet. The load value at that time is held on the digital voltmeter, giving an immediate reading of the approximate load at failure. After one full rotational cycle is completed, the specimens can be removed and inspected if desired. The recorder and machine drive are turned off manually when the test cycle is completed.

OPERATIONAL PERFORMANCE AND RECOMMENDED CHANGES

Our initial tests on commercial 69-lb linerboards showed that peel occurs much more readily at high moisture contents. This has been borne out by subsequent testing. This would be expected if peel depends on the surface bonding strength.

For linerboards exhibiting a proclivity to peel, single or multiple peels can occur (Fig. 4 and 5). After the initial peel occurs, the cigarlike bundle acts like a pinch point, and the pulled sheet may tear out locally in that area due to the increasing load.

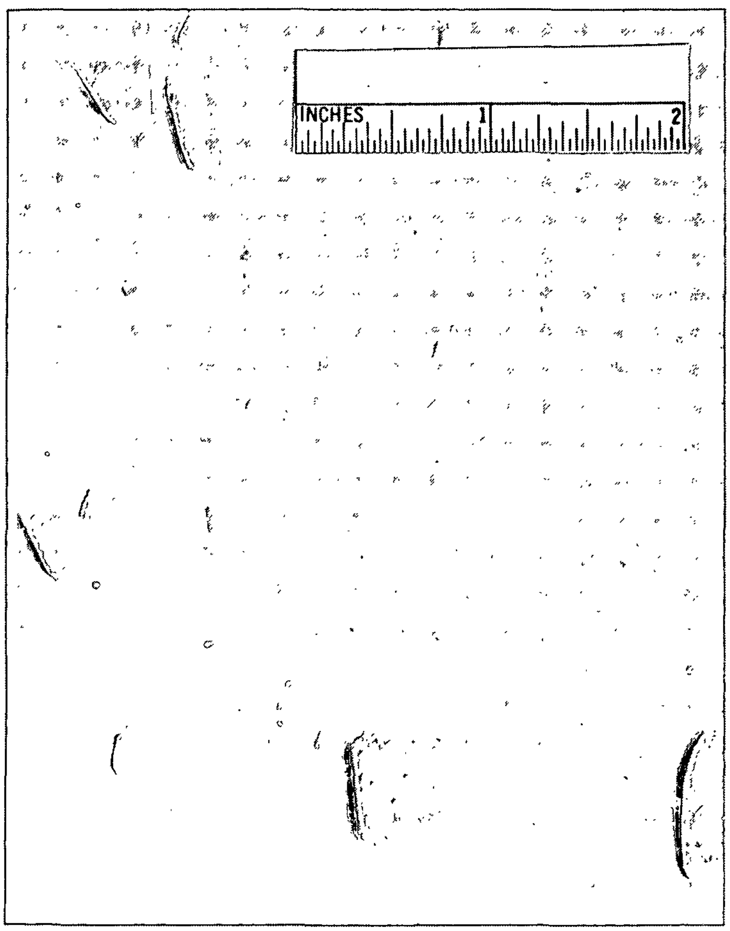

Figure 4. Multiple peel formation.

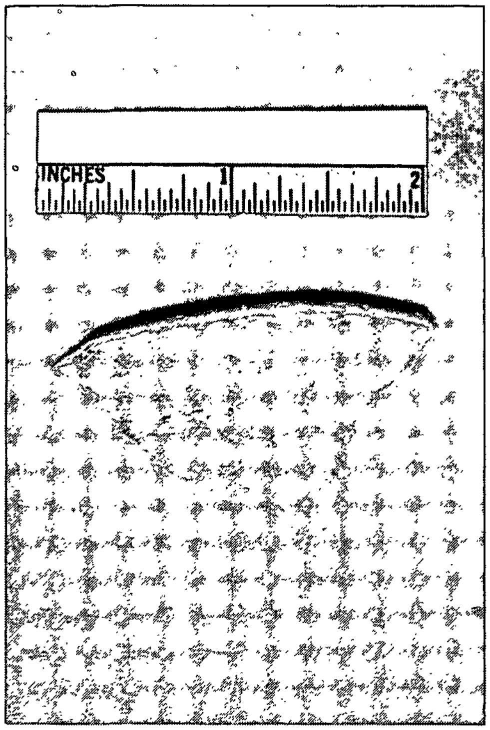

Figure 5. Example of major peel.

In our initial testing of the prototype, the occurrence of a local stress concentration, presumably due to squeezing of higher caliper areas, sometimes caused the pulled sheet to break or tear locally before we could observe peel. To delay the onset of local tearing, we have used polyethylene (PE) sheets (slip sheets) above and below the specimens. The lower polyethylene sheet is pulled together with the lower specimen to provide a moving platen. The slip sheets also introduce a certain amount of compressibility into the platen system, which may help in peel detection. The use of slip sheets is workable and could be incorporated into the design by making the lower slip sheet into a driven belt.

The design objective of providing automatic peel detection makes it necessary to use the loading rate vs. time curve, because the occurrence of a peel makes only small changes in the load vs. time curve. The amplified loading rate curve is sensitive to deviations in the cam profile, so we use a "smoothed" cam to reduce the mechanical "noise" in the system. Under some test conditions, chatter in the load system obscured the occurrence of peel (see Fig. 6). Stiffening the belt drive system did not prevent the chatter, but some improvement at 50% RH was obtained by increasing the speed of pull by a factor of about 1.7. However, chatter was still encountered at 85% RH. We traced this to stretch in the lower specimen as it wound onto the drum. By taping the lower specimen to the slip sheet and pulling them together, the stretch was reduced and the chatter disappeared, even at 85% RH. The same effect could be obtained in a new design by using a fixed distance pulling system with a short pulling span. However, the present necessity to tape the slip sheet to the lower specimen makes testing tedious and expensive. For this reason, only a limited number of tests were carried out in evaluating the commercial linerboard collected for the study.

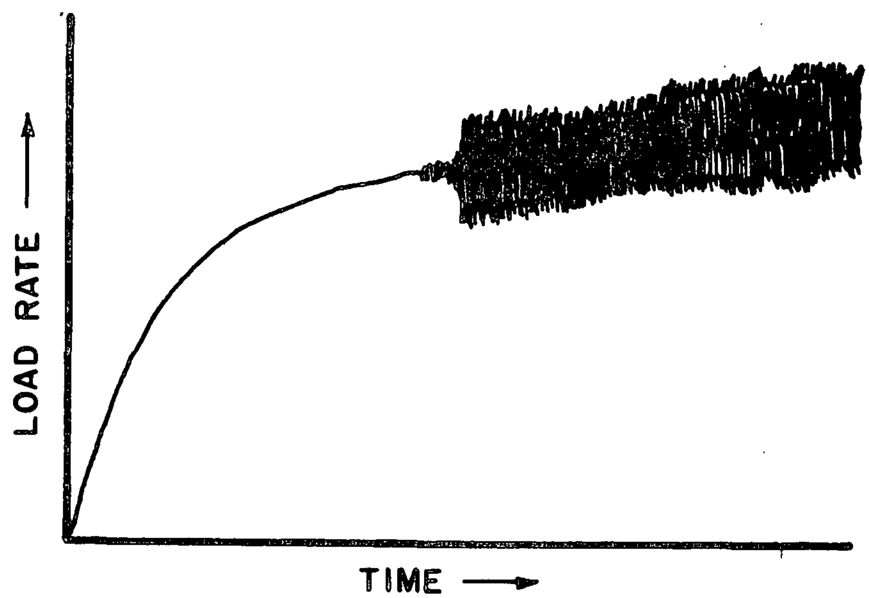

Figure 6. Occurrence of "chatter" in the loading rate curve.

Thus, to obtain better peel initiation and detection, the tester design should be modified to incorporate the fixed distance pulling system and moving belt slip sheet, as illustrated in Fig. 7. We have also considered the possibility of using smaller size samples that could reduce the machine size; limited data indicate that a narrower specimen may be feasible. In addition, the clamp on the fixed specimen should be located closer to the platens. This will also assist in minimizing the occurrence of chatter and will shorten the length of the machine.

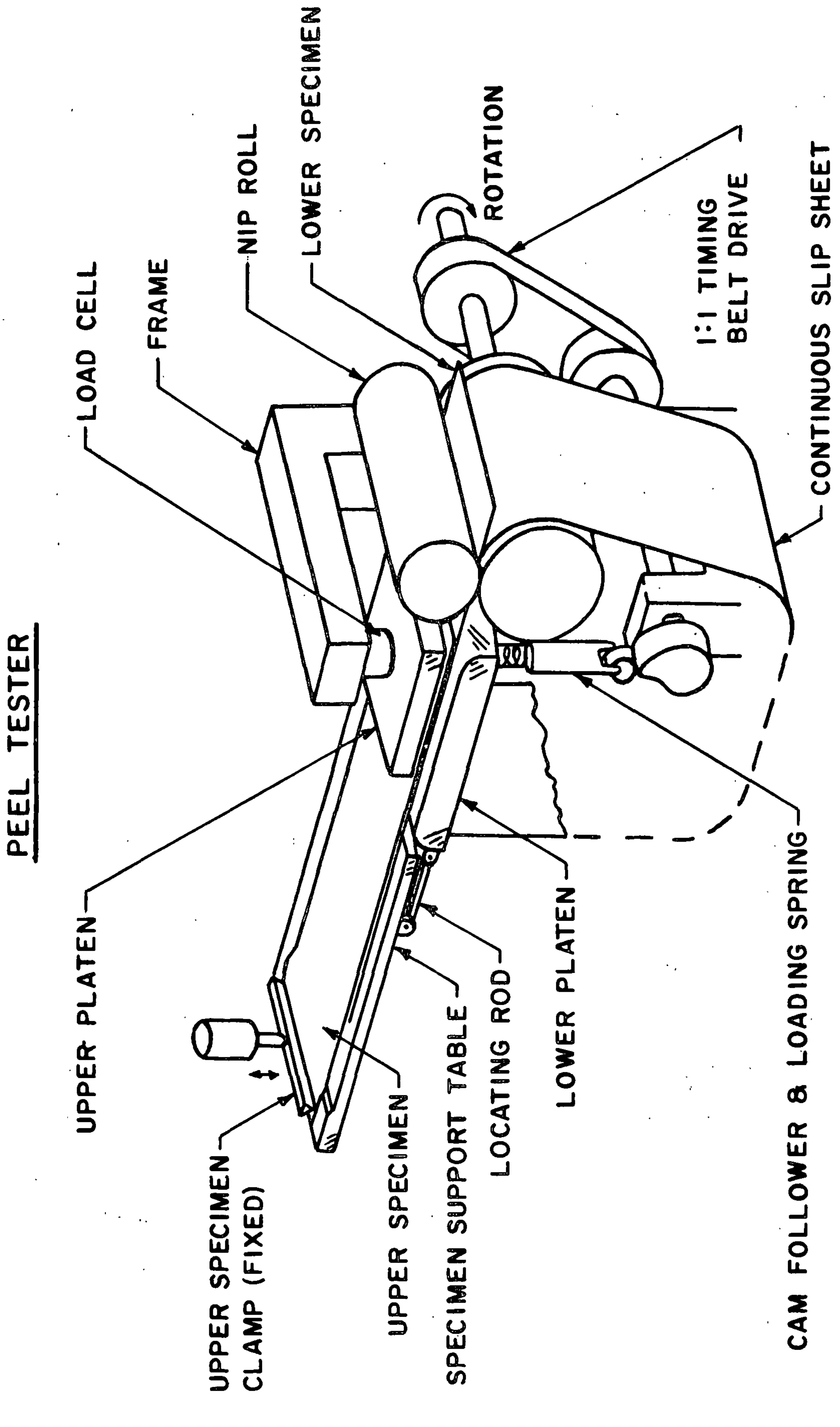

Figure 7. Schematic illustration of needed design improvements including "slip sheet" and fixed distance pulling drive.

LINERBOARD PEEL RESULTS

Cross-direction peel tests were carried out on eight 42-lb and eight 69-lb commercial linerboards. As mentioned previously, the tests were carried out by adhering the moving sheet of linerboard to the PE slip sheet to avoid chatter and allow better peel detection. In these performance comparisons, six tests were generally made on each board sample at 85% RH and on those boards tending to exhibit peels at 50% RH.

The cross-direction peel data at 50 and 85% RH are summarized in Table I. In general, these linerboards exhibited significant differences in their peeling resistance, whether viewed in terms of peeling pressure or number of specimens exhibiting peel. For the 69-lb samples, six lots exhibited some degree of peeling at 85% RH, and two lots did not exhibit peels within the load range. For the six lots which exhibited some peeling, the transverse pressures causing peel ranged from about 1 to 3 psi. The fraction of specimens that actually peeled decreased for the boards exhibiting greater resistance to peel (higher pressure). At 85%, four 42-lb lots exhibited peels, and four did not peel within the load range. The peel pressures for those 42-lb lots where peels occurred ranged from 1 to 3 psi.

Even at 85% RH, the average pressure (1 psi) to cause peel on the weakest lot is relatively high. For example, for 275-lb series combined board a stack height of about 11 feet would be required to give a pressure of 1 psi on the bottom sheet. This is an unrealistically high stack height. On the other hand, the variability in peel pressures tends to be high because peeling is probably triggered by local regions of poor fiber-to-fiber bonding, rather than average bonding strength. Thus a linerboard with low average peel resistance could give rise to sporadic peels in sheet-fed operations when weak regions are rubbed together. The

TABLE I

CROSS-DIRECTION PEEL RESULTS

Code	Description[a]	Basis Weight, lb/1000 ft^2	CD Peel - 85% RH: Peel Pressure,[b] psi	CD Peel - 85% RH: Std. Dev.,[b] %	CD Peel - 85% RH: Spec. Peeling,[c] %	CD Peel - 50% RH: Peel Pressure,[b] psi	CD Peel - 50% RH: Std. Dev.,[b] %	CD Peel - 50% RH: Spec. Peeling,[c] %	VVP Bonding Strength (CD), kp cm/sec (rupture end-pt.)
				69-lb Linerboard					
C1344	Unbl.	70.2	1.0	40	100	1.2	43	60	327
C25	Unbl.	67.1	1.7	48	100	2.4	21	83	331
C1336	Unbl.	68.3	1.9	27	100	2.9	11	100	348
C26	Unbl.	68.6	2.1	22	100	3.2	6	67	463
C14	Unbl.	68.0	2.3	22	67	- No peel[d] -		0	374
C1334	MW	--	3.0	8	50	- No peel[d] -		0	403
C1330	Unbl.	70.7	- No peel[d] -		0	- No peel[d] -		0	336
C15	Unbl.	66.8	- No peel[d] -		0	- No peel[d] -		0	415
				42-lb Linerboard					
C1337	Unbl.	41.8	1.4	68	100	2.0	41	67	208
C1342	MW	--	1.9	51	50	--	--	--	310
C1332	Unbl.	42.2	2.1	35	67	--	--	--	322
C1335	MW	44.2	3.0	13	67	- No peel[d] -		0	504
C1343	Unbl.	--	- No peel[d] -		0	- No peel[d] -		0	289
C1331	MW	43.0	- No peel[d] -		0	- No peel[d] -		0	379
C1333	Unbl.	45.3	- No peel[d] -		0	- No peel[d] -		0	499
C1329	MW	41.8	- No peel[d] -		0	- No peel[d] -		0	547

[a]MW = Mottled white; Unbl. = unbleached.
[b]Based on number of specimens exhibiting peels.
[c]Number of specimens exhibiting peels expressed as percent of total number tested.
[d]No peels on any specimen within the maximum load range of about 3.5 psi.

lower the average peel pressure, the more likely that a few sheets will be encountered with weak spots that will peel in the feeding operation, particularly if the board is "wet" or dust is present to trigger peeling.

At 50% RH the CD peeling pressures for a given lot were higher than at 85% RH, and a smaller fraction of the lots peeled within the load range. This confirms our earlier work and reflects the fact that the surface bonding strength of board increases as the moisture content decreases.

In earlier work, it appeared that VVP type bonding strength tests tended to correlate with the occurrence of peel. However, the results in Table I suggest that VVP results are not consistently related to the peel pressure as measured in this procedure. Generally, the samples with low VVP bonding had low peel resistance, but overall the two tests would rank the boards differently.

A limited number of MD peel tests were carried out on the lots that generally peeled in the cross direction (Table II). The results indicate that lots with low CD peel resistance will also peel in the machine direction at about the same pressure.

Briefly summarizing, it appears that

(1) One-way rub tests can be used to evaluate peeling resistance.

(2) The pressures required to cause peel are relatively high. Some boards will not peel within a reasonable load range even at high moisture content. This is an expected result because peeling problems are only occasionally encountered during service.

(3) To best rate linerboards in terms of peeling proclivity, the testing should be done at high RH. Tests at 50% RH may serve to detect peelers but not to quantify peeling proclivity.

(4) The test variability is high and is believed to occur because peel is triggered by local weak regions of bonding rather than average bonding strength. Smaller sample sizes would be convenient but might increase variability.

(5) Redesign of the machine, as suggested, would greatly streamline the testing operation. The recommended modifications include provisions for a fixed-distance drive system, a moving slip sheet, and automation of the detection system.

TABLE II

COMPARISON OF MD AND CD PEEL RESULTS

		CD		MD	
Code	Nominal Weight, lb/1000 ft^2	Peel Pressure,[a] psi	Spec. Peeling,[b] %	Peel Pressure,[a] psi	Spec. Peeling,[b] %
		85% RH			
C1344	69	1.0	100	---- No peel ----	
C25	69	1.7	100	1.3	100
C1336	69	1.9	100	3.2	67
C26	69	2.1	100	2.1	100
C1337	42	1.4	100	2.0	83
		50% RH			
C1344	69	1.2	60	-- No material --	
C25	69	2.4	83	2.6	83
C1336	69	2.9	100	---- No peel ----	
C26	69	3.2	67	2.6	33
C1337	42	2.0	67	2.2	17

[a]Based on number of specimens exhibiting peel.
[b]Number of specimens exhibiting peels expressed as percent of total number tested.

LITERATURE CITED

1. Investigation of methods for evaluating the scuffability of linerboard, Project 2694-14. Report One to FKBG of API, July 6, 1978.

2. Evaluation of linerboard scuffability, Project 2694-14. Status Report to Technical Division of FKBG of API, Oct. 1-2, 1980.

THE INSTITUTE OF PAPER CHEMISTRY

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APPENDIX I

PRELIMINARY TRIALS OF A SINGLE-PASS ONE-WAY RUB TEST

The construction of the prototype peel tester was preceded by a series of preliminary trials to determine what test conditions would be required to cause peeling to occur in a single-pass rub test. Among the test conditions studied were the transverse loads required to cause peel and the sensitivity of peel to test area, test rate, and moisture contents. These trials were mainly carried out using an Instron tester to apply transverse load to the two specimens being tested. In the initial trials the pulling force required to pull one specimen over the other was supplied by a second Instron tester; as the work progressed the pulling force was applied using a pair of washing machine rollers to provide a driving nip. In addition to the above variables we also gathered photographic documentation on peel initiation and the relation of peel to the internal bonding of the sheet.

The above results were mainly reported to the Technical Division of FKBG in the May and Oct., 1980 Status Reports. In the interest of completeness that information has been edited and is included herein.

The feasibility trials confirmed that peels could be initiated using a single-pass, one-way rub principle. The results indicated (1) peel occurs at lower transverse loads as moisture content increases, (2) the occurrence of peel is sensitive to loaded area, and (3) peel pressures were only mildly dependent on rubbing speed. The sensitivity of peel resistance to bonding strength, moisture content, and loaded area is of importance in the control of peel within a box plant. High moisture conditions, such as may be induced by high starch application rates or plant RH levels, high stacks of blanks, and deposits of fibrous debris underneath or between box blanks would promote peeling.

Peel Initiation

Examination of linerboard sheets which have been rubbed together under transverse load shows that the rubbing loosens many surface fibers. Some of these fibers are dislodged entirely from the sheet and twist or roll up in miniature cigarlike bundles (Fig. 8). Such bundles will manifest themselves as dust.

Many of the loosened fibers which are still bonded in the sheet will pull on the other fibers to which they are attached as the loosened fibers are rolled up by the rubbing action. The pulling action disrupts the sheet surface and may trigger peel if the local bonding strength is low. For example, Fig. 9 shows the surface after rubbing of a linerboard having relatively low average VVP bonding strength. A number of areas which could enlarge into peels are shown near the lower left, center and right-hand sides of the photograph.

Figure 10 shows a number of tightly twisted fibers which are still attached to the surface of the sheet. It appears that such fiber bundles can act to initiate peels as they pull on other fibers in the rubbing process.

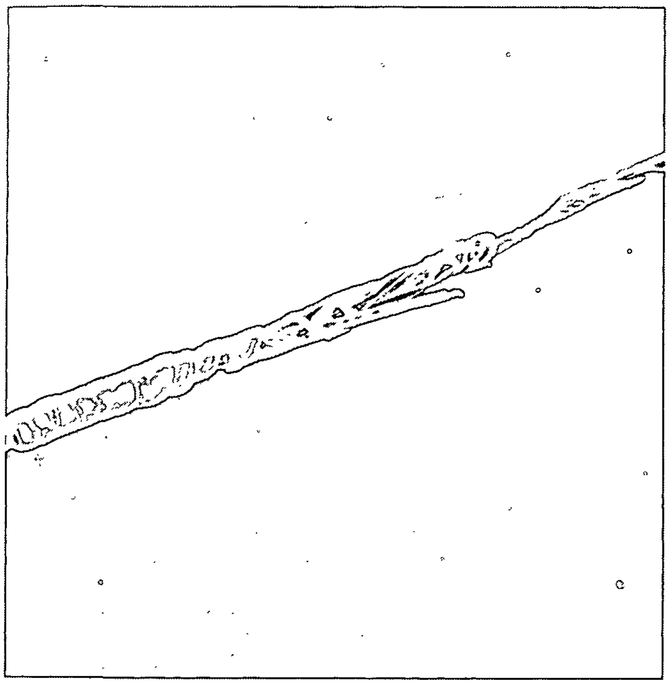
The development of a peel is shown in Fig. 11. The surface has rolled up into the familiar cigar-shaped bundle. The sheet surface under the bundle appears quite "smooth" and shows little or no disruption of the fibers. This suggests that the peel area started in a plane of local low bonding.

These photographs coupled with the peel results discussed in the following pages indicate that peel is promoted by such factors as:

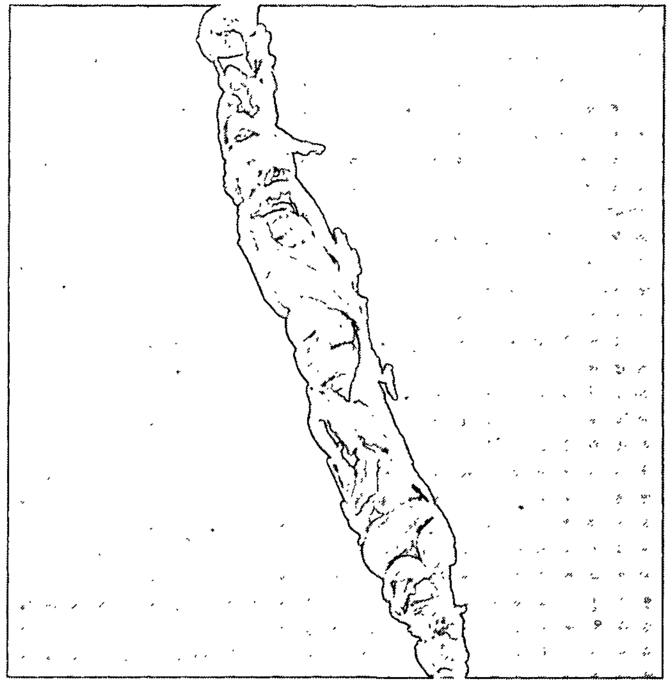
(1) weak surface bonding

(2) high moisture content (weakens bonding)

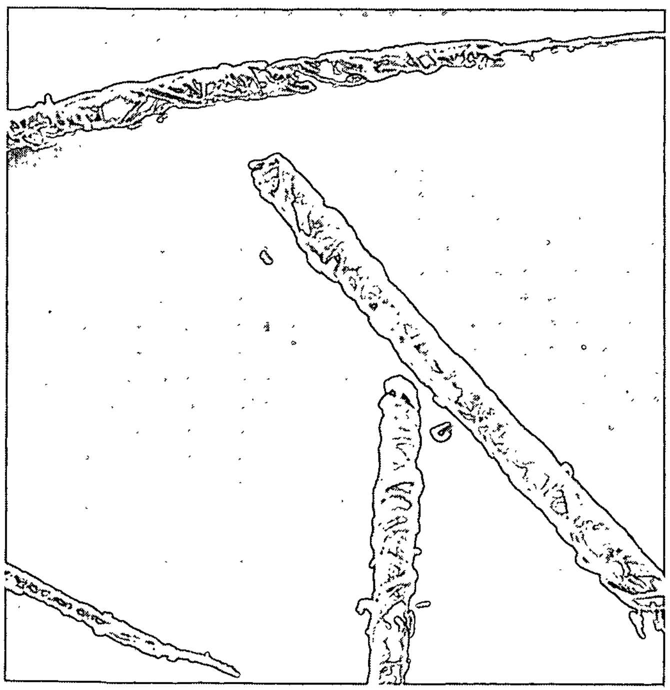
(3) high pressures which increase frictional forces



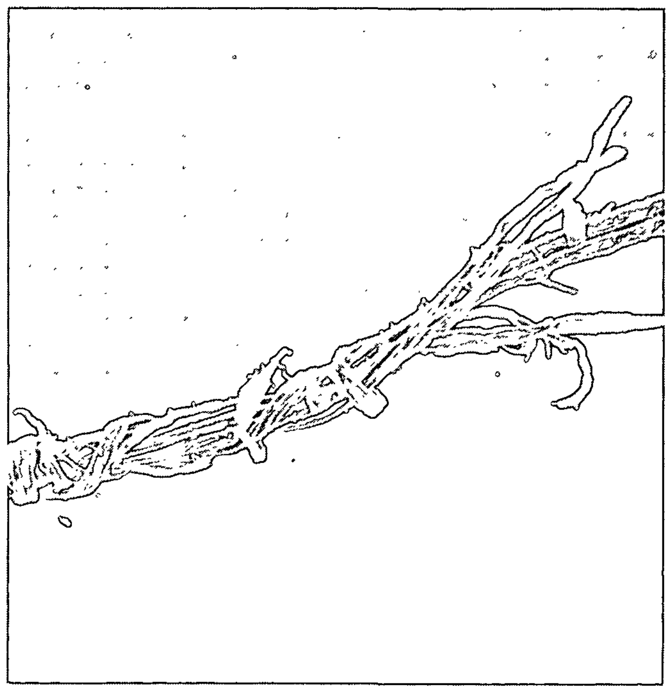
100X
0.5 psi load



125X
0.95 psi load



50X
1.37 psi load



100X
1.37 psi load

Figure 8. Loose miniature "cigar" bundles formed by rubbing.

Figure 9. Surface features after rubbing which precede peel (64 x, 1.37 psi load).

Figure 10. Cigarlike bundles on well-bonded sheet preceding peel initiation during rubbing.

Figure 11. Peel initiation on a weakly bonded linerboard (47 x, 1.37 psi load).

Peeling Under Single-Pass (One-Way) Conditions

Single-pass (one-way) rub tests were made on samples of 69-lb linerboard and combined board under conditions in which the loaded contact area and moisture content were varied. The liner samples differed in VVP bonding strength, the loaded areas ranged from 4-96 $inch^2$, and the moisture contents corresponded to those in equilibrium with relative humidities of 50, 69, and 85% at 73°F.

The results of these tests are given in Fig. 12-16 and Tables III-V. The log-log plots of the transverse pressure to cause peel vs. the loaded area, tend to be quite linear and show that the pressure to cause peel decreased markedly as the loaded area and moisture increased. The decrease in peel pressure with increase in loaded area suggests that peeling may be quite sensitive to local weak bonded areas, i.e., the larger the area, the more likely that locally weak surface bonded areas will be encountered. This suggests that peeling may be more of a problem with larger blanks if they are stacked too high. A few of the survey comments in Report One, Prog. 2694-14, 7-6-78 suggest this occurs. The decrease in peel pressure with increasing moisture is attributed chiefly to an associated decrease in bonding strength. For linerboards of low bonding strength and high moisture content, the pressure to cause peel will be quite low and approach the pressures one may expect to encounter in box plant feeding operations, e.g., approximately 0.5 psi. Thus, high moisture conditions in the box plant should promote the occurrence of peel. This is in agreement with the survey findings in Report One. High moisture levels could result from high plant RH and locally high moisture contents along glue lines. It was also observed that locally high pressures, such as may be caused by fibrous debris underneath or between sheets, may cause peel failures at pressures below the usual average for the particular board.

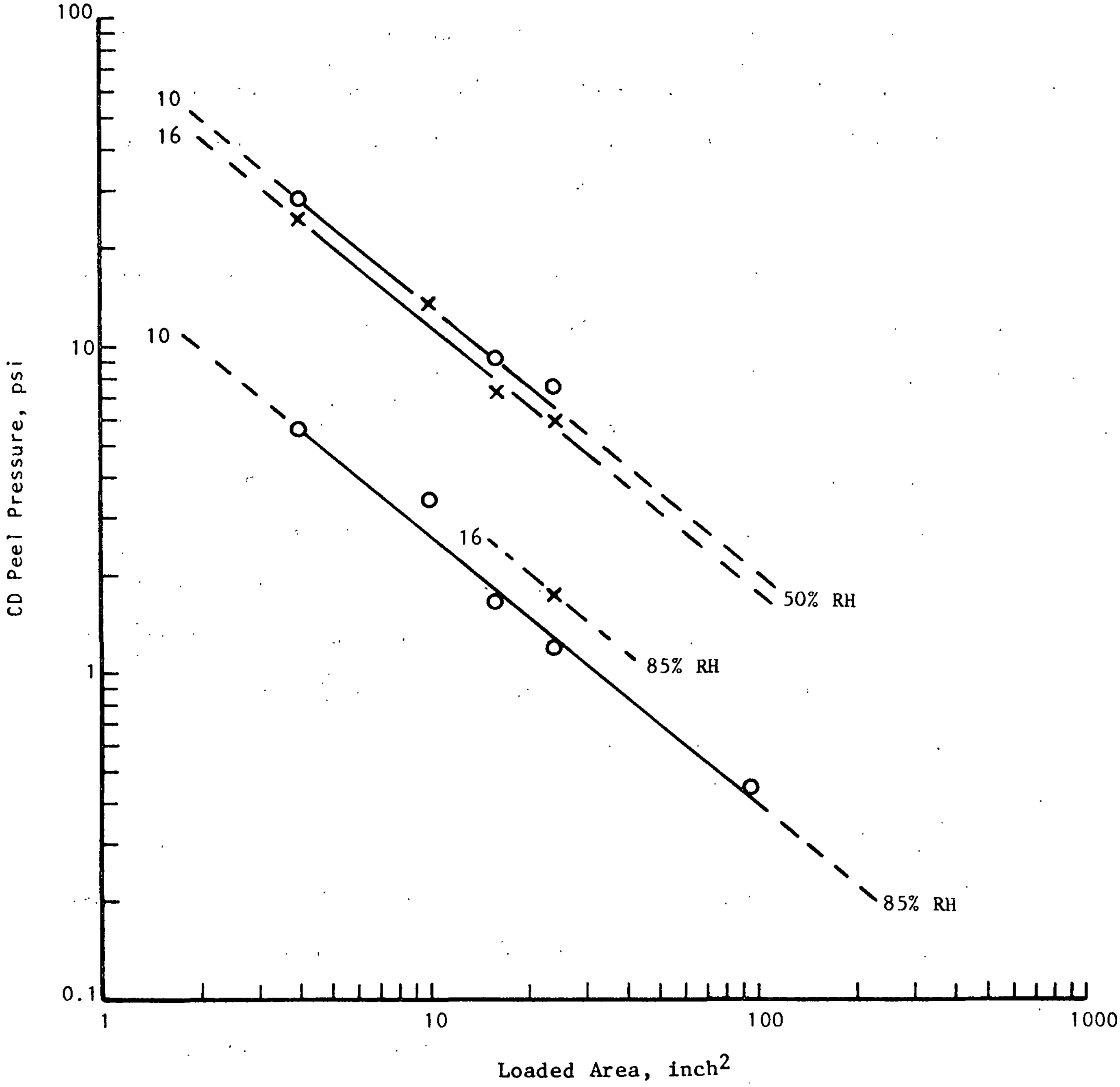


Figure 12. Effects of loaded area and relative humidity on pressure to cause CD peel of Samples 10 and 16.

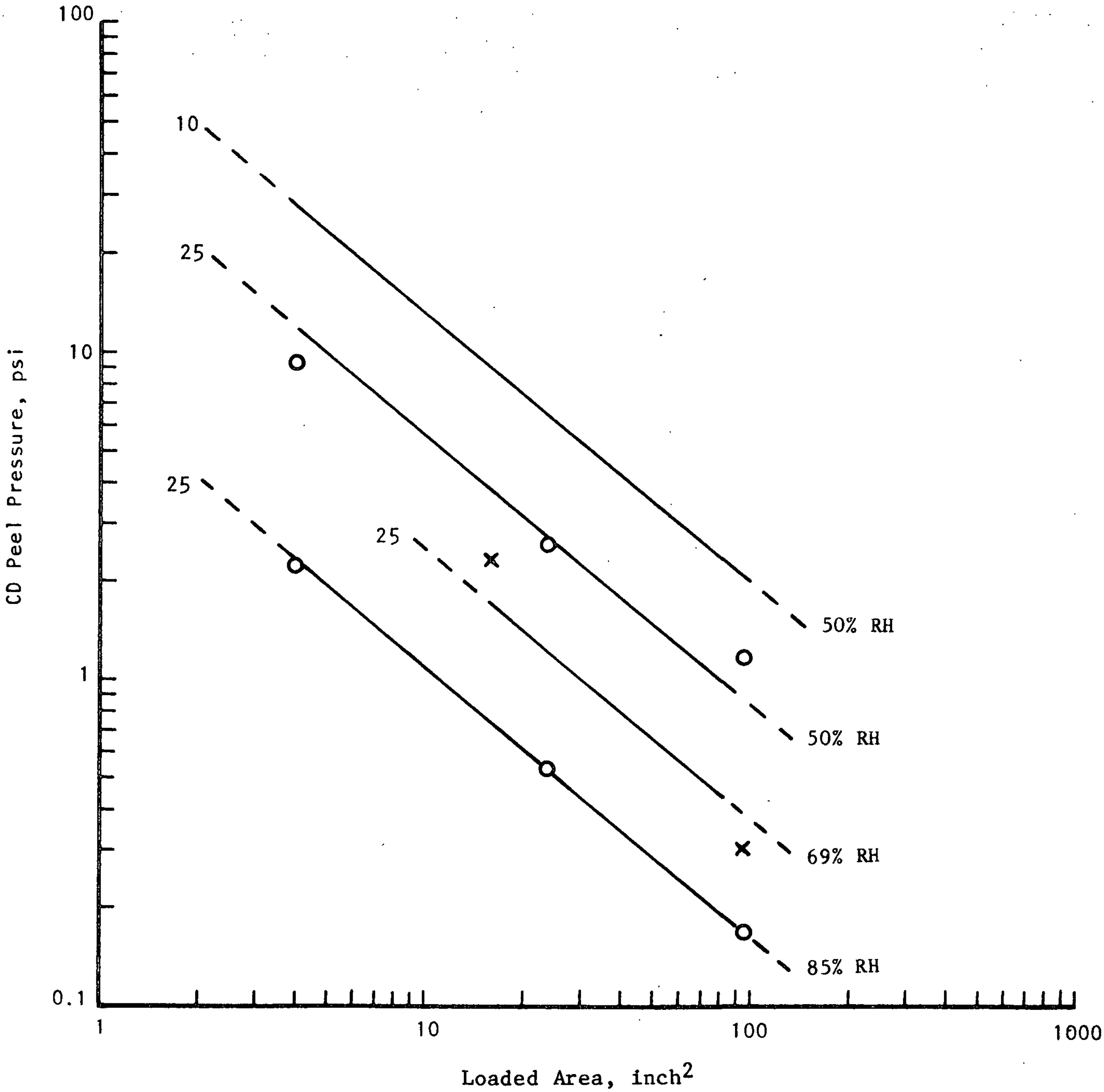


Figure 13. Effects of loaded area and relative humidity on pressure to cause CD peel of Sample 25. (50% RH results for sample 10 are shown for comparison purposes).

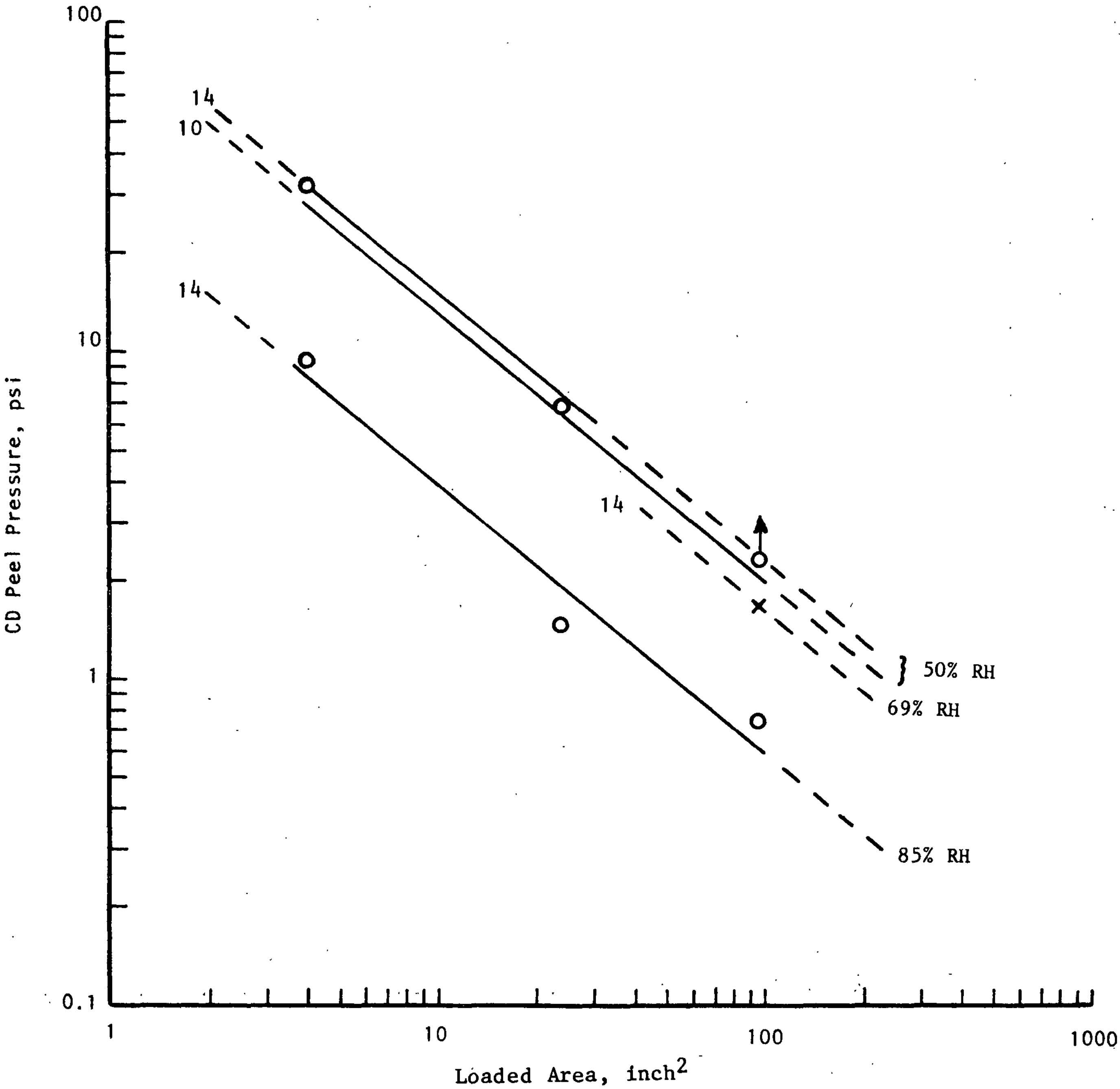


Figure 14. Effects of loaded area and relative humidity on pressure to cause CD peel of Sample 14. (50% RH results for sample 10 are shown for comparison purposes.)

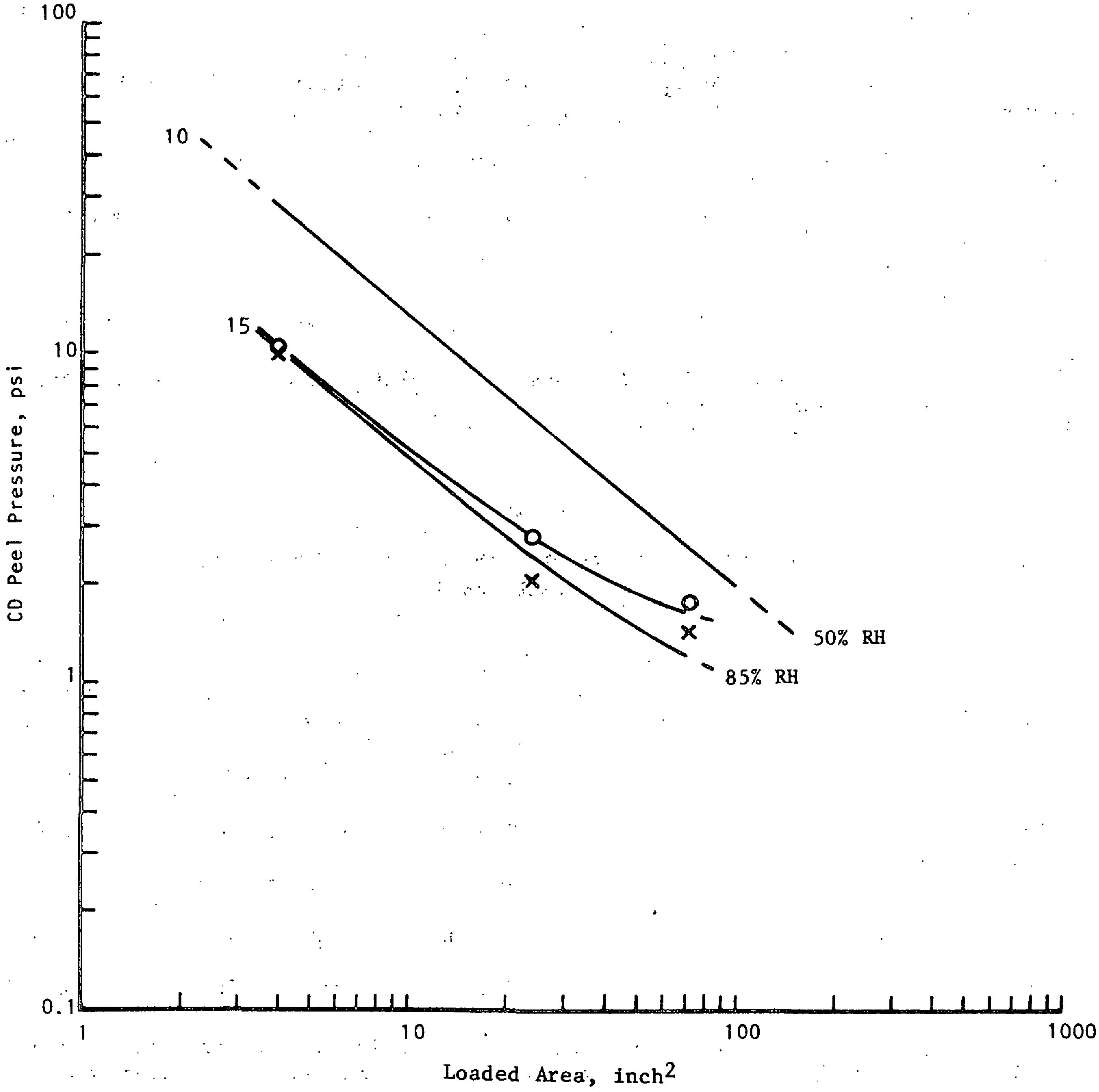


Figure 15. Effect of loaded area on pressure to cause CD peel of Sample 15 at 85% RH. The crosses represent a duplicate series of tests. (50% RH results for sample 10 are shown for comparison purposes.)

TABLE III

EFFECT OF PULLING SPEED ON CD ONE-WAY PEEL PRESSURE

Sample	RH, %	Loaded[a] Area, $inch^2$	Pulling Speed, inch/min	Peel Pressure, psi	Diff., %[b]
14	85	24	13	1.5	--
14	85	24	138	1.9	+26.6
15	85	24	13	2.8	--
15	85	24	138	3.0	+7.1

[a]The contact dimensions were 2 x 12 inches. The pulling force was in a direction parallel with the long dimension.
[b]Based on the 13 inches/min results.

TABLE IV

EFFECT OF SPECIMEN ORIENTATION AND CONTACTING SURFACES ON ONE-WAY PEEL PRESSURE

Sample	RH, %	Loaded[a] Area, $inch^2$	Direction of Pulling Force[a]	Contacting Surfaces	Peel Pressure, psi
25	69	16	CD short	felt-to-felt	2.3
25	69	16	CD long	felt-to-felt	2.4
14	85	24	CD long	felt-to-felt	1.5
14	85	24	CD long	wire-to-wire	1.9
14	85	24	MD long	felt-to-felt	4.5

[a]The contact dimensions were 2 x 8 inches and 2 x 12 inches. Short designates a pulling force in the 2-inch direction; long, a force in the 8-inch direction.

TABLE V

CD ONE-WAY PEEL PRESSURE RESULTS FOR COMBINED BOARD AT 85% RH

Sample	Contacting Faces	Peel Pressure, psi	Comments
14a[a]	Double-to-double face	>2.3	No peel failure, few miniature cigars
14a	Single-to-single face	>2.3	No peel failure, few miniature cigars
14a	Single-to-double face	>2.3	No peel failure, few miniature cigars
1289	Double-to-double face	>2.3	No peel failure, few miniature cigars
1289	Single-to-single face	1.4	Peeled
1277	Double-to-double face	>2.3	No peel failure, few miniature cigars
1277	Single-to-single face	>2.3	No peel failure, few miniature cigars
1166	Double-to-double face	1.9	Peeled
1166	Single-to-single face	2.0	Miniature peel

[a]The liners of this sample were reported to consist of the same linerboard comprising Sample 14.

The contact dimensions in the loaded area were 8 x 12 inches. The pulling force was in a direction parallel with the long dimension.

Table I shows that the transverse pressure to cause peel increases mildly with increasing rubbing speed. For a 10-fold speed increase peel resistance increased 7.1% and 26.6%, respectively, for the two samples evaluated. This may be due to an increase in bonding strength at the higher rate of stressing. It also appears that the transverse pressure to cause peel is independent of the dimensional orientation of a rectangular loaded area as indicated by the results for Sample 25, Table IV.

Relation Between One-Way Peel, VVP Bonding Strength, and S & S Scuff

Cross direction VVP bonding strength and S & S scuff tests were made at 50% RH for comparison with single-pass one-way rub test results obtained at 50% and

85% RH. The results are shown in Fig. 16-18 and Table VI. Fig. 16 shows that the pressures to cause peel at 50% and 85% RH tended to correlate with VVP bonding strength measured at 50% RH. However, our later work indicates that VVP bonding strength results are not consistently related to single-pass peel tests.

The results in Fig. 17 suggested that the S & S peel results are not linearly related to one-way peel. The relationship between S & S peel and VVP bonding strength shows a somewhat similar trend (Fig. 18).

Reducing the load on the specimen from 25 to 14 lbs in the S & S test resulted in an increase in the number of strokes required to cause peel. As shown in Table VI, the increase was disproportionately high for the two samples having the highest VVP bonding strength.

<u>VVP Bonding Strength For Front, Center, and Back Reel Positions</u>

The results on bonding strength, Table VII, suggest that linerboard obtained from different positions across a reel may exhibit difference in CD peel performance which is probably due to difference in CD shrinkage across the web and its effects on z-direction properties. Among the several samples of this study, differences in bonding strength between positions ranged from 0 up to a maximum VVP difference of 71 between the front and back positions of Sample 21. On the basis of the relationship shown in Fig. 16, this difference in bonding strength, corresponding to VVP values of 344 and 273, would correspond to transverse peel pressures ranging from about 0.25 to 0.5 psi at 85% RH and about 1.5 to 2.5 psi at 50% RH.

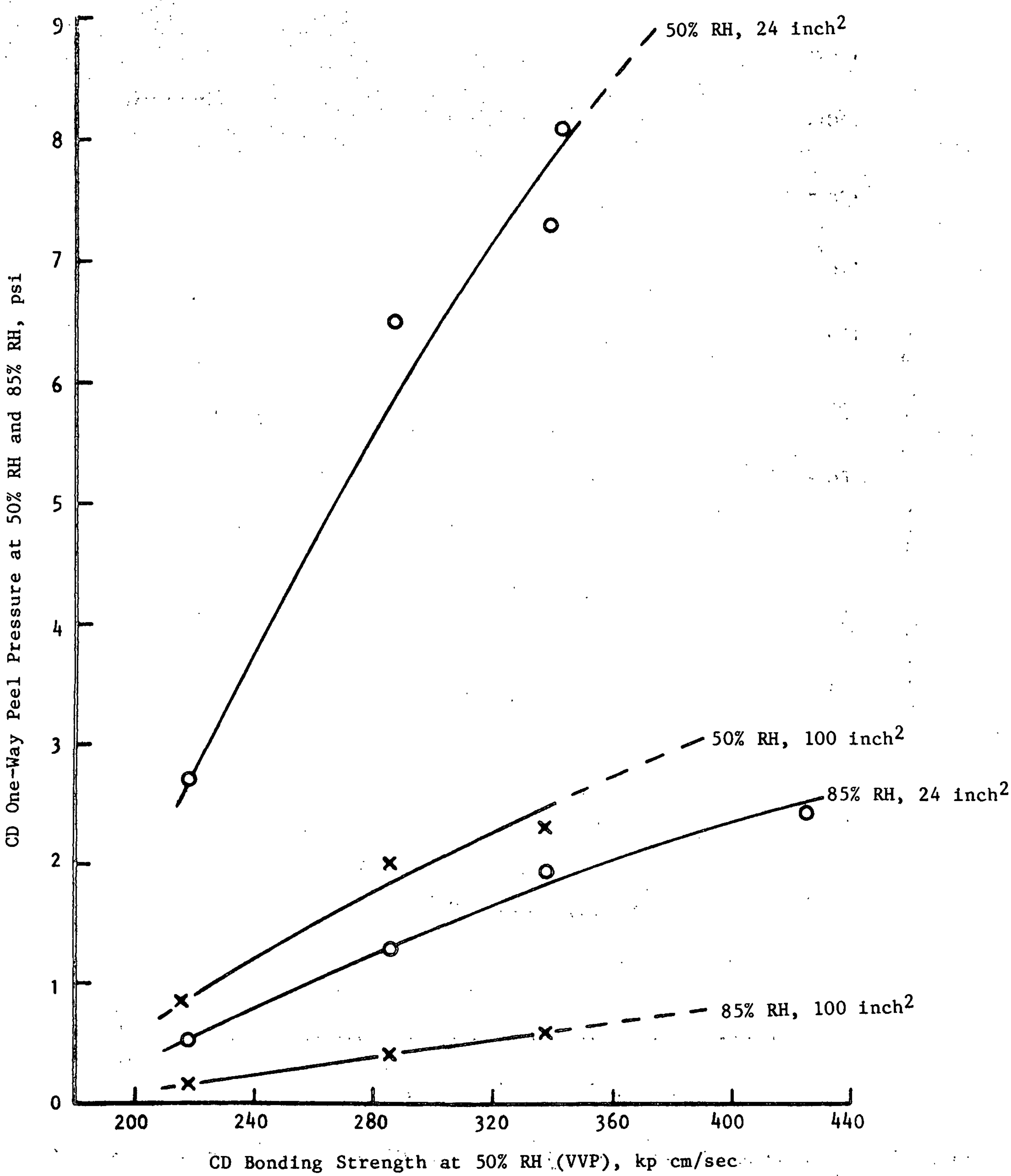


Figure 16. Relationship between CD one-way peel pressure at 50% RH and 85% RH and CD bonding strength at 50% RH, contact area = 24 $inch^2$ and 100 $inch^2$.

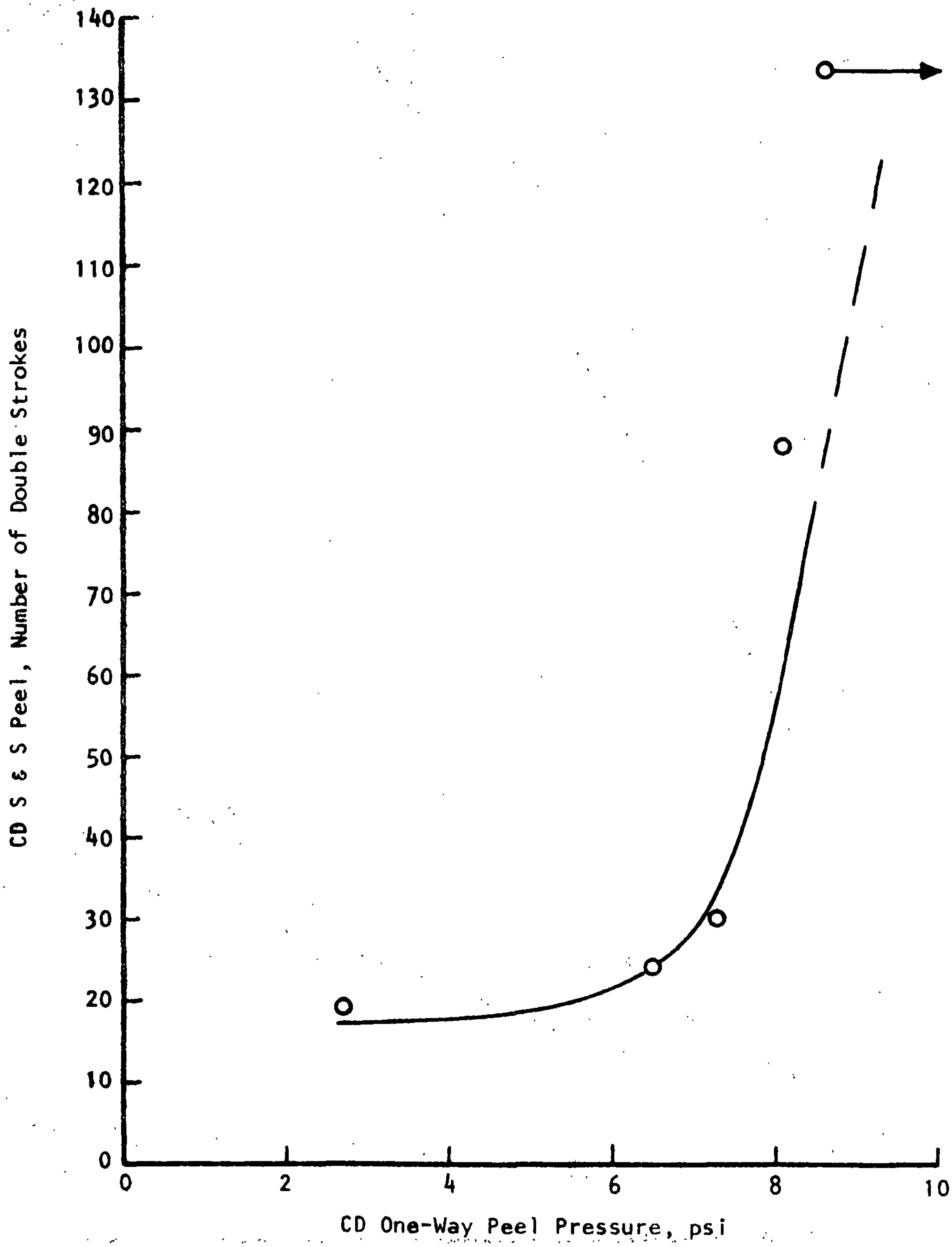


Figure 17. Relationship between CD S & S peel and CD one-way peel pressure at 50% RH, contact area = 24 inch^2.

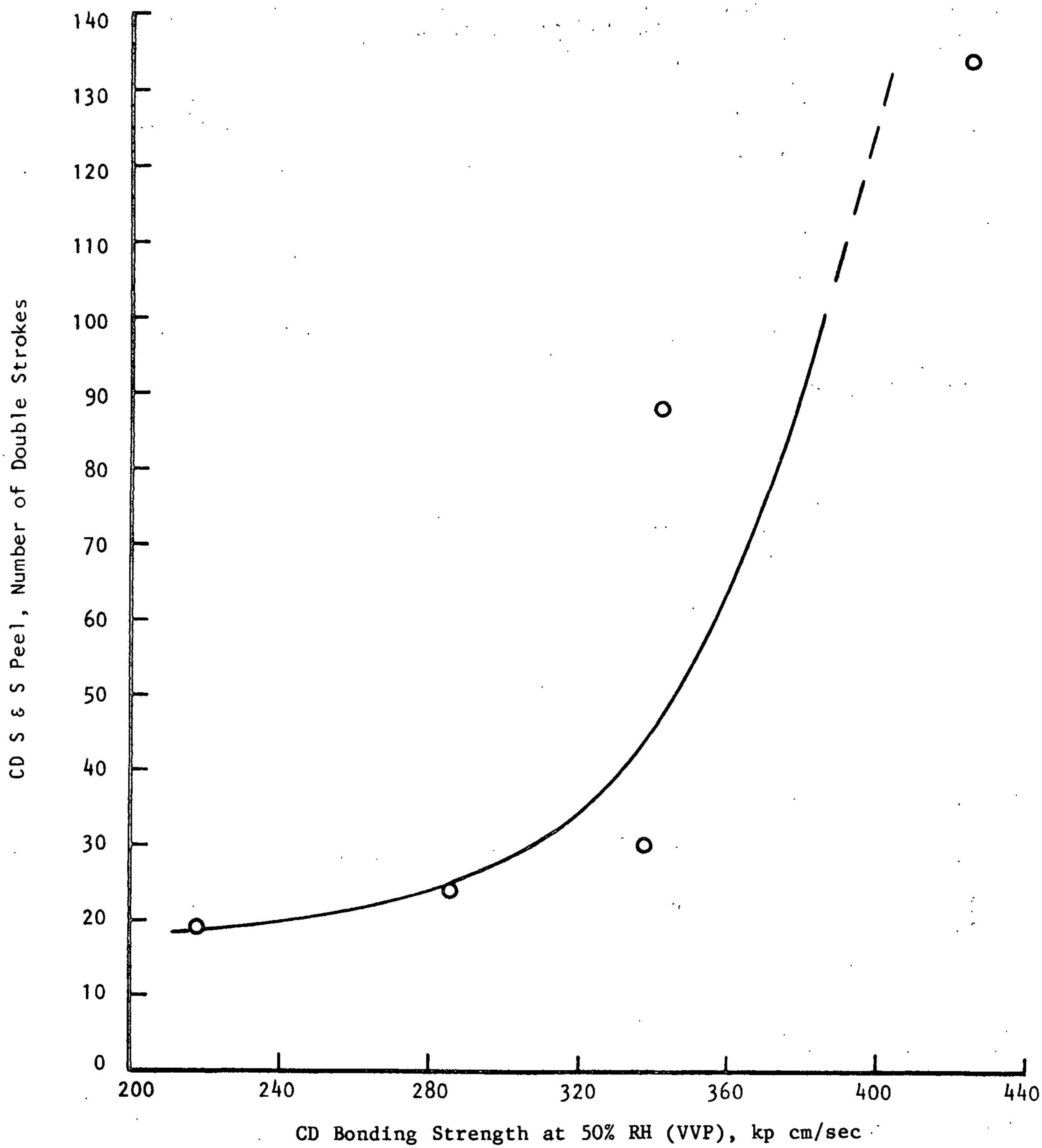


Figure 18. Relationship between CD S & S peel and CD VVP bonding strength, RH = 50%

TABLE VI

COMPARISON OF BONDING STRENGTH, S & S PEEL, AND ONE-WAY RUB RESULTS

Sample	VVP Bonding Strength, kp cm/sec	S & S Peel Load on Specimen, lb		One-way Rub Pressure to Cause Peel,[a] psi	
		25	14	50% RH	85% RH
25	218	19	19	2.7	0.53
10	286	24	30	6.5	1.28
14	338	30	38	7.3	1.93
26	342	88	148	8.1	--
15	425	134	530	>8.62	2.42

[a]24-inch^2 loaded area.

TABLE VII

BONDING STRENGTH FOR FRONT, CENTER, AND BACK REEL POSITIONS AT 50% RH

Bonding Strength, VVP, kp cm/sec

Sample	Reel Position: Front		Center		Back	
	CD	Anti-CD	CD	Anti-CD	CD	Anti-CD
10	271	300	--	--	--	--
14	316	360	281	317	--	--
15	429	421	449	417	--	--
21	321	273	344	318	331	344
22	349	335	351	349	349	306
23	336	283	293	324	291	256
25	219	218	--	--	--	--
26	341	343	--	--	--	--

CD refers to a cross-machine direction test in which the VVP progressively increased in a front-to-back direction.

Anti-CD refers to a cross-machine direction test in which the VVP progressively increased in a back-to-front direction.

The results on bonding strength, CD vs. anti-CD tests, also suggest that the direction of rub may have an effect on peel performance. Sample 14, which displayed a difference of 44 between the CD and anti-CD values, also displayed a directional effect in the single-pass one-way rub test. When the front edges of the two contacting specimens were oriented in the pulling direction, the transverse pressure to cause peel averaged 3.1 psi at 72% RH, whereas when the front edges opposed each other in direction, the pressure to cause peel tended to be higher, and two of the seven specimens tested failed to peel at the maximum available pressure (8.6 psi).