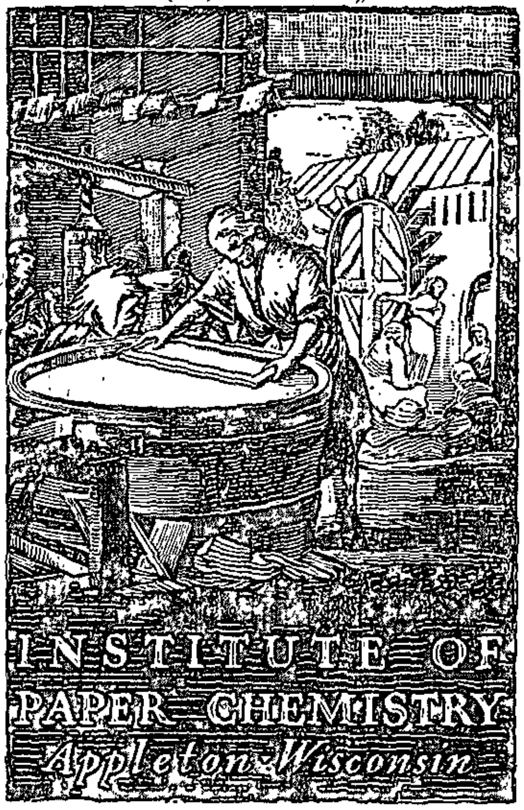

DEVELOPMENT OF RIGID-WHEN-WET CORRUGATED BOARD

✓Project 1108-27

Report Two

A Progress Report

to

RIGID-WHEN-WET COMMITTEE
FOURDRINIER KRAFT BOARD INSTITUTE, INC.

December 23, 1964

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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SUMMARY

A pilot-scale trial was carried out to determine the feasibility of making a corrugated chicken box by means of a two-step process involving initial impregnation of the components with a thermosetting resin and a subsequent treatment with thermoplastic resin. The component materials were made on an experimental paper machine and varying amounts of the thermoset resin, Durez ~~19873~~ 17983 (n.k.m.), were added at the size press. The thermoplastic resin, Piccopale-70, was impregnated in a separate and subsequent operation but prior to corrugating.

The experimental liners were fabricated with their corresponding resin content medium into A-flute corrugated board using a nonaqueous adhesive. Three degrees of component treatment were used: (1) Thermoset resin treatment only, (2) thermoset resin treatment plus thermoplastic treatment of the medium, and (3) thermoset and thermoplastic treatment of both liners and medium.

Based on combined board evaluation the following conclusions are drawn:

1. Estimates of box compression show that it is possible by the two-step impregnation process to produce a corrugated box whose compression strength after exposure to 90% R.H. or 24 hours' immersion in water is equivalent to or better than the untreated board at 50% R.H.

2. The material cost of the "impregnants" is in the neighborhood of $5.00 per thousand square feet of combined board.

3. The resin treatment embrittles the board to the extent that it is impossible to score and fold the combined board without a rupture of the double-face liner at the scoreline.

4. It is believed that the process used herein has application provided a means can be found to overcome the score "problem."

INTRODUCTION

Sometime ago The Institute of Paper Chemistry initiated a study on behalf of the Fourdrinier Kraft Board Institute, Inc., for the purpose of studying ways of developing a rigid-when-wet corrugated board and box. The results of this study were distributed to the co-operator in the form of Progress Report One to the Fourdinier Kraft Board Institute, Inc., entitled "Development of Rigid-When-Wet Corrugated Board," Project 1108-27, March 12, 1963.

The results obtained in the above investigation indicated that impregnation of the components with a small amount of thermosetting resin followed by a second stage application of thermoplastic material appeared to offer the best approach to date in the development of a reinforced corrugated box.

Late in February, 1964, The Institute of Paper Chemistry was authorized to proceed with a pilot-scale trial to develop more concrete data relative to the feasibility of the treatment, the material cost, and the performance to be expected. The Institute was advised that the pilot-scale trial should be directed to providing basic design data for a chicken box. The maximum material cost goal established by the co-operator was $5.00 per thousand square feet of combined board upcharge for the treatment.

The pilot-scale trial involved: (a) the manufacture of linerboard and corrugating medium on an experimental paper machine in which varying percentages of thermosetting resins were added at the size press, and (b) the subsequent impregnation of the trial-produced components with thermoplastic materials and their ultimate fabrication into corrugated combined board with a nonaqueous adhesive.

MANUFACTURE OF LINER AND MEDIUM IMPREGNATED WITH THERMOSET RESIN

The experimental liners and mediums were made on the experimental paper machine at the School of Paper Technology, Western Michigan University, Kalamazoo, Michigan. The machine in question is a scaled-down replica of a conventional fourdrinier machine equipped with a vertical size press with means for applying treatment to one or both sides of the sheet. The trim width is approximately 24 inches. As a result of the scaled-down wire length, number and size of driers, etc., the machine is limited to much slower speeds on given grades than its commercial counterpart. The stock preparation equipment is limited to one Valley beater and one plug refiner.

LINERBOARD

Four different experimental linerboards were made – each at a different level of thermoset resin. Initially five had been planned; however, it was decided to abandon the highest impregnation level (15%) because of (a) inability to hold to a given fiber substance weight and (b) the sheet at the next lower level was extremely brittle. The four different liners were made from a furnish of unbleached kraft pulp obtained as wet lap pulp with a permanganate number of 26-30. The pulp was refined at 4% consistency in the Valley beater to a freeness of 585 cc. (C.S.). When the above freeness level was attained, the beater roll was raised and 1% dry rosin size added and then 3% dry alum. After thorough mixing, the stock was pumped to a beater chest where it was diluted to 2% consistency. From the beater chest the stock was pumped through the refiner to the machine chest.

The fiber substance of the linerboards was set at 42-lb./M ft.^{2}; however, it was not possible to hold this level even within a given linerboard sample because of deficiencies in the machine drive and the stock pumping system. The

Institute had been advised that previously a similar grade of board had been made at 50 f.p.m. without difficulty; however, in the trials described herein, the machine speed had to be reduced to 30 f.p.m.

The thermoset resin used was Durez ~~19875~~ 17983 (m.k.m.) made by the Durez Division, Hooker Chemical Corporation. The resin was applied to each side of the sheet at the size press. As mentioned previously, the initial plans called for five levels of thermoset resin impregnation: 0, 5, 7.5, 10, and 15%; however, due to unforeseen difficulties only four levels of application were used. The design levels were 0, 5, 7.5, and 10%. As will be shown later, the actual pickups were less than the design levels. These levels of treatment were obtained by diluting the resin with water to give a concentration about twice the pickup desired in the board and adjusting the moisture level of the sheet at the size press. No difficulty was encountered with resin dilution except at the 5% level wherein it was necessary to use deionized water because of the extreme hardness of the tap water in the Kalamazoo area. The pickup at the size press on a given sheet is primarily a function of the dwell time or machine speed, the viscosity of the resin, and the moisture content of the sheet entering the size press — the pickup appeared to go through a maximum as the moisture content of the sheet entering the size press increased. As previously mentioned, due to unavoidable variations in basis weight, the amount of pickup varied far more than desired. The liner sample with no thermoset resin was run first and then in sequence the increasing resin contents.

Quantitative determinations of the resin pickup was determined for each sample by two methods: (1) digestion with sodium chlorite, and (2) pyrolysis. The results obtained are tabulated in Table I.

TABLE I

CHARACTERISTICS OF COMPONENT MATERIAL
(50% R.H.)

Roll No.	Resin Addition, % Design Level	Resin Addition, % Actual Pickup	Basis Weight, lb./M sq. ft.	Caliper, pt.	Mod. Ring Compression C.D., lb./in.	Concora Flat Crush, p.s.i.	Bursting Strength, p.s.i.
				Liner			
4667	0	0	43.4	13.0	15.0	--	68
4673	5	0.5	43.2	12.7	14.4	--	76
4669	7-1/2	2.4	44.4	13.0	18.5	--	87
4671	10	8.9	44.8	12.8	23.4	--	93
				Medium			
4675	0	0	26.6	9.5	13.9	32.4	--
4683	5	3.8	27.9	9.3	17.0	49.0	--
4681	7-1/2	6.0	28.8	10.3	19.0	59.0	--
4679	10	7.3	28.1	9.5	17.8	58.0	--
4677	15	12.0	29.1	10.3	19.7	66.0	--

CORRUGATING MEDIUM

The corrugating medium was made from a furnish consisting of 85% waste semichemical corrugating medium and 15% of the unbleached kraft wet lap pulp obtained for the linerboard trials. The kraft pulp was fed to the beater first and then the waste semichemical medium. The mixed furnish was refined to a freeness of 385 cc. (C.S.). No size or alum was used in the medium furnish as the size appeared to inhibit resin pickup on the liner. The fiber substance was 26-lb./M $ft.^2$ and the machine speed was held at 50 f.p.m. There was some fluctuation in basis weight; however, it was considerably less than in the case of the linerboard samples. The trim width was 24 inches. The sequence of running was to make the sample without resin first, then the 15% resin sample, and then the balance of the samples in the order of decreasing resin content.

The characteristics of the samples and the applied resin levels are given in Table I.

COMBINED BOARD FABRICATION

The experimental linerboard and corrugating medium samples made on Western Michigan University's paper machine with varying amounts of thermosetting resin were in the form of 24-inch width rolls. These were forwarded to The Institute of Paper Chemistry where they were subsequently slit and rewound into 11-1/2-inch width rolls.

The four experimental liners were fabricated with their "corresponding" resin content medium into A-flute combined board on the Institute's corrugator using a nonaqueous adhesive. The latter consisted of 50% by weight of Elvax 150 and 50% by weight of Super Beckacite 2000 (1). The liner sample with 10%

thermosetting resin (design level) was also combined with the corrugating medium made with 15% thermosetting resin (design level). These material combinations were fabricated (1) without further treatment, (2) impregnation of the mediums with thermoplastic resin, and (3) impregnation of both liner and medium with thermoplastic resin to give the combinations shown in Table II. The thermosetting resin used herein was Piccopale-70 made by the Pennsylvania Industrial Chemical Company. The corrugator speed was held at 100 f.p.m.

TABLE II

FABRICATION COMBINATIONS

Trial No.	Medium Thermosetting Resin, %	Medium Thermoplastic Resin, %	Liner Thermosetting Resin, %	Liner Thermoplastic Resin, %
B-1	0	0	0	0
B-2	3.8	0	0.5	0
B-3	6.0	0	2.4	0
B-4	7.3	0	8.9	0
B-5	12.0	0	8.9	0
C-2	3.8	22.6	0.5	0
C-3	6.0	14.9	2.4	0
C-4	7.3	18.9	8.9	0
C-5	12.0	22.3	8.9	0
D-2	3.8	22.6	0.5	7.1
D-3	6.0	14.9	2.4	12.1
D-4	7.3	18.9	8.9	11.4
D-5	12.0	22.3	8.9	11.4

The purpose of the thermoplastic resin was twofold - specifically, (1) to facilitate corrugating by temporarily flexibilizing the medium which was embrittled by initial impregnation with the thermosetting resin and (2) to bolster t strength of the board when exposed to moisture. The basic concept of a two-step process (1) involved applying the thermosetting resin at the size press and the th plastic in line on the corrugator. Because of the expense involved in equipping t

Institute's corrugator with the proper impregnating equipment suitable for this type of two-side application, it was decided to carry out the thermoplastic impregnation as a separate operation. For this purpose, the liners and the mediums were impregnated using a one-side resin application and making two passes through the impregnator in order to obtain resin on both sides. A great deal of difficulty was encountered in applying the desired amount of thermoplastic resin and getting it to migrate into the sheet in contrast to having it on the surface. It is believed that considerable attention needs to be devoted to developing a method of application which will permit the uniform application of the desired amount of thermoplastic resin. Impregnating this way resulted in a much lower temperature of the medium entering the corrugating nip than would have been obtained if the medium had been impregnated in line on the corrugator. To offset the lack of flexibility due to it being colder, atomized water was applied to the thermoplastic impregnated medium just prior to the corrugating rolls. The atomized water was not necessary with the medium impregnated with only the thermosetting resin - Series B. Under the conditions described all the mediums corrugated without fracturing.

The single-faced boards fabricated from the material combinations shown in Table II were manually double-faced using the same type liner for the double-face as on the single-face side. The nonaqueous adhesive was also used for bonding the double-face liners.

The component materials and double-faced board resulting from the above-described combinations were evaluated for weight, caliper, torsion tear, and edgewise compression after conditioning: (1) at 50% R.H., (2) 72 hours at 90% R.H., and (3) after 24-hour immersion in water.

DISCUSSION OF RESULTS

The combined board results obtained on the various experimental samples made for this study are tabulated in Table III. The combined board tests used herein were selected because of their relation to box performance. Previous studies (2) have shown that top-load box compression may be accurately described by two basic combined board properties – i.e., edgewise compression and flexural stiffness – and the load perimeter, a configurational factor. Top-load box compression has the following relationship to the above combined board and box factors:

$$P = 2.028\, P_m^{0.746}\, (\sqrt{D_x D_y})^{0.254}\, Z^{0.492} \qquad (1)$$

where

P = top-load box compression

P_m = combined board edgewise compression

D_x, D_y = combined board flexural stiffness in the machine- and cross-machine direction, respectively.

The above equation has been further simplified (2,3) by an empirical relationship so that box compression may be expressed as a function of combined board edgewise compression and caliper, and box perimeter in accordance with the following relationship:

$$P = 5.874\, P_m\, h^{0.508}\, Z^{0.492} \qquad (2)$$

wherein h is combined board caliper and P_m and Z are as defined for Equation (1). Thus, box compression may be estimated from the edgewise compression and caliper of the combined board for a box of given load perimeter.

TABLE III

COMBINED BOARD RESULTS

Trial No.	Medium Treatment, %		Liner Treatment, %		C.D. Edgewise Compression, lb./in.			Caliper			Torsion Tear, in.-oz.					
											50% R.H.		90% R.H.		24-hr.-water	
	Durez	Piccopale-70	Durez	Piccopale-70	50% R.H.	90% R.H.	24-hr.-water	50% R.H.	90% R.H.	24-hr.-water	In	Cross	In	Cross	In	Cross
B-1	0	0	0	0	41.7	--	--	222.8	--	--	308	239	--	--	--	--
B-2	3.8	0	0.5	0	50.8	22.5	3.8	218.1	224.8	238.4	299	204	378	273	108	58
B-3	6.0	0	2.4	0	43.2	18.1	3.5	218.9	222.5	234.1	278	212	360	257	199	68
B-4	7.3	0	8.9	0	57.3	21.6	5.6	223.2	225.0	238.9	359	222	492	302	452	100
B-5	12.0	0	8.9	0	63.9	20.4	5.8	222.1	226.8	242.7	271	235	435	299	372	92
C-2	3.8	22.6	0.5	0	62.3	40.6	19.2	219.1	221.5	238.8	267	233	381	292	236	114
C-3	6.0	14.9	2.4	0	48.7	36.7	23.8	225.1	227.2	256.9	275	225	366	271	188	156
C-4	7.3	18.9	8.9	0	63.0	39.0	19.1	220.8	226.3	247.2	274	209	413	315	197	135
C-5	12.0	22.3	8.9	0	67.9	38.4	23.4	220.4	225.0	248.1	220	226	371	324	202	158
D-2	3.8	22.6	0.5	7.1	65.4	45.2	30.0	220.8	--	225.4	214	164	366	243	243	230
D-3	6.0	14.9	2.4	12.1	56.6	46.2	26.8	226.5	--	232.5	336	217	349	339	339	207
D-4	7.3	18.9	8.9	11.4	68.3	49.5	35.0	225.0	--	230.1	163	149	190	368	368	175
D-5	12.0	22.3	8.9	11.4	72.5	59.1	42.6	230.4	--	233.1	171	184	255	263	263	231

Other studies (4) have shown that with normal board combinations - i.e., untreated board - the rough handling characteristics, such as measured by drum and drop tests, are well correlated to the torsion tear strength of the combined board in the flap scoreline area. Thus, the torsion tear test was used to evaluat the rough-handling characteristics.

As may be seen from the data tabulated in Table III, tests were made under three environmental conditions - conditioned at 50% relative humidity, conditioned at 90% relative humidity for 72 hours, and immersed in water for 24 hours The results for Sample B-1 at 50% relative humidity are used as the reference in this study because it is felt that the level of strength exhibited by conventional corrugated board would be adequate at the two moisture conditions. When edgewise compression is considered, it may be noted that at 50% relative humidity, all the treated board samples exceeded the untreated board. At 90% relative humidity none of the samples impregnated only with the thermosetting resin, Durez, exhibited edgewise compression characteristics equal to the corresponding value for the untreated sample at 50% relative humidity. Similarly, none of the samples fabricate with mediums impregnated with both thermosetting resin and thermoplastic resin (Piccopale) and liners impregnated with Durez exhibited edgewise compression value at 90% relative humidity equivalent to the untreated at 50% relative humidity. Hc ever, it may be noted that the results for Samples C-2 and C-4 were only slightly lower. When the medium and liners were impregnated with both Durez and Piccopale resins, the edgewise compression results at 90% relative humidity were considerab] higher than the untreated at 50% relative humidity. The higher the Durez resin content, the higher the edgewise compression. When the edgewise compression resu] after 24-hour water immersion are considered, it may be observed that only one sa Sample D-5, exhibited compression strength greater than the untreated at 50% rela humidity.

Combined board caliper did not appear to increase until both Durez and Piccopale resins were used. In general, the samples so made exhibited higher caliper results which should be conducive to better top-load box compression. As would be expected, the results at 90% relative humidity were significantly higher than the corresponding results at 50% relative humidity. In turn, the results after 24-hour immersion were markedly higher than the results at 90% relative humidity.

When the torsion tear results are considered, it may be noted that, with few exceptions, the machine-direction results at 90% relative humidity were equal to or higher than the corresponding results at 50% relative humidity. The same trend may be noted for the cross-machine direction results. In general, the results after 24-hour water immersion were considerably lower than the results at 50% relative humidity. It should be emphasized that the results reported herein for combined board torsion tear were for unscored board. On the basis of these results, it would appear that boxes made from board impregnated with both Durez and Piccopale resins should have reasonable rough handling provided the board can be scored and folded without a high loss in strength.

Inasmuch as the fabrication of the experimental samples carried out on the Institute's experimental corrugator was limited to 12-inch wide components, this width was not sufficient to make boxes; therefore, box compression was estimated from a consideration of the combined board edgewise compression and caliper in accordance with Equation (2). A RSC box of size 20 by 14 by 10 was selected. The results are tabulated in Table IV. It may be observed that as expected all treated samples exhibited higher estimated top-load box compression at 50% relative humidity than the untreated sample, B-1. The higher the resin content, the higher the estimated box compression generally. At 90% relative humidity, only the samples

TABLE IV

ESTIMATED BOX COMPRESSION

Trial	Medium Treatment, %		Liner Treatment, %		Estimated Box Compression, lb.[a]					
No.	Durez	Piccopale-70	Durez	Piccopale-70	50% R.H.	Diff., %[b]	90% R.H.	Diff., %[b]	24-hr.-water	Diff., %[b]
B-1	0	0	0	0	913	--	--	--	--	--
B-2	3.8	0	0.5	0	1100	+20.5	495	-45.8	86	-90.6
B-3	6.0	0	2.4	0	937	+ 2.7	396	-56.6	79	-91.4
B-4	7.3	0	8.9	0	1256	+37.5	475	-47.9	127	-86.1
B-5	12.0	0	8.9	0	1397	+53.0	451	-50.6	131	-85.6
C-2	3.8	22.6	0.5	0	1352	+48.1	886	- 2.9	453	-52.3
C-3	6.0	14.9	2.4	0	1072	+17.4	811	-11.1	559	-38.8
C-4	7.3	18.9	8.9	0	1373	+50.4	862	- 5.6	441	-51.7
C-5	12.0	22.3	8.9	0	1478	+61.9	844	- 7.6	542	-40.6
D-2	3.8	22.6	0.5	7.1	1425	+56.1	996	+ 9.1	664	-27.3
D-3	6.0	14.9	2.4	12.1	1250	+36.9	947	+ 3.7	600	-34.3
D-4	7.3	18.9	8.9	11.4	1503	+64.6	1089	+19.3	775	-15.1
D-5	12.0	22.3	8.9	11.4	1614	+76.8	1324	+45.0	954	+ 4.5

[a] Based on RSC size, 20 x 14 x 10, and abridged box formula, $\underline{P} = 5.875\ \underline{P}_{\underline{m}}\ \underline{h}^{0.508}\ \underline{Z}^{0.492}$.
[b] Based on B-1 as reference.

impregnated with both Durez and Piccopale equalled or exceeded the results obtained on the untreated at 50% relative humidity. Further, when immersed in water for 24 hours, only one of the samples, (D-5), exhibited estimated box compression equal to the untreated at 50% relative humidity; however, a few samples were within 15-25%. Thus, it appears that it should be possible to make reinforced corrugated by the method practiced herein which will be equivalent in box compression to the untreated board at 50% relative humidity.

As previously mentioned, the initial cost goal was a material cost not to exceed $5.00 per thousand square feet. For purpose of comparison, the material cost calculated on a 1000 square foot combined board basis is given in Table V. It may be noted that the material cost for Sample D-5, the only sample to exhibit equal or better estimated box compression at 90% relative humidity and after 24-hour water immersion than the untreated (Sample B-1) at 50% relative humidity, exceeded the cost goal by about 30%. Sample D-4, which after water immersion was nearly equivalent to the untreated at 50% relative humidity, exceeded the goal by 15%. Samples D-2 and D-3, although less strong, were considerably under the cost goal. In this connection, it is believed that a significant reduction could be made in the cost of the nonaqueous adhesive through substitution of adhesive materials and determination of the most appropriate film thickness and application conditions.

The foregoing analysis of combined board quality and their subsequent projection to box compression indicate that it should be possible to make corrugated board by the "two-step impregnation process" used herein which will give box compression performance equivalent to the untreated at 50% relative humidity. It may be recalled that the torsion tear results indicated favorable levels provided the board could be scored and folded without an excessive loss in strength. To check

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TABLE V

QUALITY AND ESTIMATED COST

Trial	Medium Treatment, %		Liner Treatment, %		Estimated Box Compression, lb.			Torsion Tear, in.-oz.						Material Cost/M ft.^{2} Combined Board, $[a]			
								50% R.H.		90% R.H.		24-hr.-water					
No.	Durez	Piccopale-70	Durez	Piccopale-70	50% R.H.	90% R.H.	24-hr.-water	In	Cross	In	Cross	In	Cross	Durez	Piccopale-70	Adhesive	Total
B-1	0	0	0	0	913			308	239	--	--	--	--				
B-2	3.8	0	0.5	0	1100	495	86	299	204	378	273	108	58	0.49	0	1.20	1.69
B-3	6.0	0	2.4	0	937	396	79	278	212	360	257	199	68	1.11	0	1.20	2.31
B-4	7.3	0	8.9	0	1256	475	127	359	222	492	302	452	100	2.60	0	1.20	3.80
B-5	12.0	0	8.9	0	1397	451	131	271	235	435	299	372	92	3.07	0	1.20	4.27
C-2	3.8	22.6	0.5	0	1352	886	435	267	233	381	292	236	114	0.49	1.08	1.20	2.77
C-3	6.0	14.9	2.4	0	1072	811	559	275	225	366	271	188	156	1.11	0.72	1.20	3.03
C-4	7.3	18.9	8.9	0	1373	862	441	274	209	413	315	197	135	2.60	0.91	1.20	4.71
C-5	12.0	22.3	8.9	0	1478	844	542	220	226	371	324	202	158	3.07	1.07	1.20	5.34
D-2	3.8	22.6	0.5	7.1	1425	996	664	214	164	366	217	243	230	0.49	1.80	1.20	3.49
D-3	6.0	14.9	2.4	12.1	1250	947	600	336	217	349	277	339	207	1.11	1.94	1.20	4.25
D-4	7.3	18.9	8.9	11.4	1503	1089	775	163	149	190	176	368	175	2.60	2.06	1.20	5.86
D-5	12.0	22.3	8.9	11.4	1614	1324	954	171	184	255	236	263	231	3.07	2.22	1.20	6.49

[a] Based on 42-26-42 material combination and no allowance for differential between regular and nonaqueous adhesive costs.

this point, samples of treated board were subjected to conventional panel scoring and folding technique. All samples exhibited cracking of the double-face liner when folded through 180°. In the case of the D-series samples, the single-faced liners were "cut" during the scoring operation. In an attempt to circumvent the problem other types of scores were used. These involved the following:

1. Bar scores, conventional fold at normal and high humidities.
2. Bar scores, back fold, at normal and high humidities.
3. Hot bar scores followed by folding after cooling.
4. Hot bar scores followed by immediate folding.
5. Cut scores (single-faced liner cut to relieve strain in double-faced liner by removal of the compression "anvil").

Under the above conditions of scoring and folding, all the treated samples exhibited unsatisfactory scores when folded. The scores were of such a quality as to be unsatisfactory for commercial use. This condition would appear to be the greatest obstacle to the use of this process for the manufacture of reinforced corrugated board. There are a number of possible approaches which have not been investigated because the budget has been depleted. Among these are the use of plastic coating or plastic tape at the scoreline or the use of an elastomeric coating on the outside of the double-face liner in place of the thermoplastic resin or possibly only in the area of the scoreline.

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