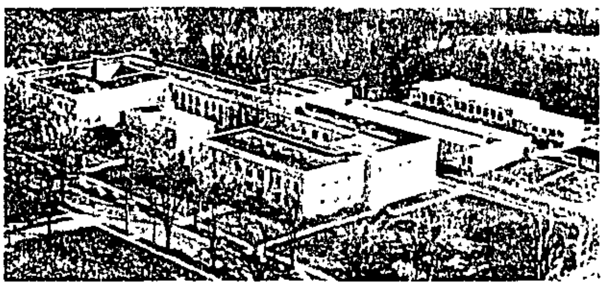
[redacted]



THE INSTITUTE OF PAPER CHEMISTRY, APPLETON, WISCONSIN

COMPARATIVE PERFORMANCE STUDY

Project 2392

Report to Directors

of

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

July 16, 1969

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

COMPARATIVE PERFORMANCE STUDY

Project 2392

Report to Directors

of

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

July 16, 1969

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

COMPARATIVE PERFORMANCE STUDY

Project 2392

Report to Directors

of

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

July 16, 1969

TABLE OF CONTENTS

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

SUMMARY

The results of a study of the comparative performance of combined board and boxes made with two sources of European and one source of domestic linerboard at four grade weight levels show the following trends:

1. The European linerboards used in this study were made from a furnish of softwood unbleached kraft (90% Scotch pine and 10% Norway spruce), refined to a lower freeness and shorter average fiber length and presumably made at a slower machine speed than domestic unbleached kraft linerboard.

2. The two sources of European linerboard averaged 5.5 and 8.3% lower in basis weight and approximately 30% higher in bursting strength than the corresponding domestic linerboard.

3. The comparative top-load box compression performance of boxes made with European linerboard increased with increase in grade weight. Boxes made with 25.6 lb. European linerboard were approximately 5% lower, those with 30.7 lb. and 35.8 lb. linerboards equal to slightly higher, those with 41.0 lb. linerboard slightly higher than boxes made with corresponding domestic linerboards.

4. The comparative end-load box compression performance of boxes made with European linerboard was quite similar to boxes made with the corresponding domestic linerboard. Boxes made with 25.6 lb. European linerboard were about equal, those with 30.7 lb. and 35.8 lb. linerboards equal to slightly lower, and those with 41.0 lb. linerboard equal to slightly higher than boxes made with corresponding domestic linerboards.

5. The comparative rough handling performance in terms of corner drop varied somewhat with grade weight and source of linerboard, however, the general performance may

be characterized as equal to slightly lower. For example, boxes made with 25.6, 35.8 and 41.0 lb. European linerboards were equal to slightly lower, and those made with 30.7 lb. linerboard equal to slightly higher in corner drop performance than boxes made with the corresponding domestic linerboards.

6. In general, the drum performance of boxes made with European linerboard were equal to slightly lower than boxes made with domestic linerboard.

7. When box performance was compared on the basis of equivalent weight of material, the comparative performance of boxes made with European linerboard improved considerably relative to boxes made with domestic linerboard. Top-load box compression ranged from approximately 5 to 11% higher at the 30.7, 35.8 and 41.0 lb. linerboard weight levels; however, the performance at the 25.6 lb. linerboard weight level was still slightly lower than boxes made with domestic linerboard.

   End-load box compression was comparable to boxes made with domestic linerboard at the three lowest linerboard weight levels, but higher at the 41.0 lb. linerboard weight level.

   Rough handling performance of boxes made with European linerboard tended to be equal to slightly higher in most cases than boxes made with domestic linerboard when compared on an equivalent weight basis.

8. The comparative performance of boxes fabricated with European linerboard is such that the competitive potentials of European linerboard should not be disregarded.

9. The superiority of European linerboard in bursting strength is not reflected in a correspondingly high box performance relative to domestic linerboard.

10. The rough handling performance of boxes made with European linerboard was considerably better than would normally be anticipated from the tearing strength characteristics of the linerboard and corresponding combined board. In terms of rough handling, the lower tearing strength was compensated for, in part at least,

by substantially higher tensile energy absorption characteristics compared to domestic linerboard.

11. The combined board made with European linerboard generally exhibited the following relative to combined board made with domestic linerboard:

    a. Lower (2 - 6%) basis weight
    b. Lower caliper
    c. Lower puncture
    d. Lower scoreline torsion tear strength
    e. Lower pin adhesion
    f. Approximately equal flat crush
    g. Higher (13.5 - 56.8%) bursting strength
    h. Higher flexural stiffness

12. The lower pin adhesion strength of the combined board made with European linerboard is believed to be due to the generally less porous structure of the European linerboard and, hence, it would be expected that greater difficulty would be encountered with adhesion on the corrugator with European linerboard, especially at the higher speeds.

13. The European linerboards made by Enso Gutseit and Svenska Cellulosa exhibited the following performance compared to domestic linerboard:

    a. Lower (8 - 10%) caliper
    b. Lower (12 - 20%) tearing strength
    c. Higher (approximately 30%) bursting strength
    d. Higher (33 - 45%) tensile strength
    e. Higher modulus of elasticity
    f. Higher tensile energy absorption, T.E.A.
    g. More dense in terms of porosity
    h. Less smooth

14. In general, the domestic linerboards were more uniform than their European counterparts in bursting strength, edgewise compression, flexural stiffness, and tearing strength.

INTRODUCTION

In the free world today there are two primary producing areas of virgin kraft containerboard -- namely, the North American and the Scandinavian countries. These "producers" compete to a greater or lesser degree in practically all world containerboard markets; however, the largest joint market is Western Europe. These two containerboard producing areas practice different manufacturing philosophies, each undoubtedly oriented toward the most economical manufacture and distribution of its product. The two philosophies differ mainly in respect to the importance of weight and bursting strength of the components to box quality.

The Scandinavian countries because of advantageous wood species, manufacturing economies specific to their area, and less restrictive regulatory specifications in certain Western European countries, notably West Germany, manufacture unbleached kraft containerboard at a lower weight and higher bursting strength than is practiced with corresponding board made in this country. In effect, the Scandinavian philosophy advocates a lighter weight container in contrast to United States practice and implies that the container weight can be reduced with impunity provided the lower weight is compensated for by an increase in bursting strength. In contrast, the philosophy practiced by U.S. manufacturers suggests that a quality box requires a certain minimum weight of fiber; if more substance (fiber) is used, the bursting strength of the linerboard need not be as high as that associated with the lighter weight Scandinavian linerboard.

The manufacturing philosphy practiced by the Scandinavian containerboard manufacturers places a burden on U.S. exportation of linerboard to those countries where weight is not considered a factor in containerboard quality. United States linerboard manufacturers can make linerboard to the same specifications as

Scandinavian linerboard; however, this would require modifying current manufacturing practices--e.g., more refining, slower speeds, etc.--which would adversely influence costs.

In order to determine the comparative performance of combined board and boxes made with European and domestic kraft linerboards, a study was initiated at The Institute of Paper Chemistry by the Fourdrinier Kraft Board Institute, Inc. The study involved the fabrication of two Scandinavian and one domestic linerboard at each of four nominal grade weight levels with 23-lb. European and 26-lb. domestic semichemical corrugating medium into A- and B-flute combined board and boxes under normal but controlled conditions of fabrication using starch as the adhesive. The four nominal grade weights of European linerboards--i.e., 25.6, 30.7, 35.8 and 41.0-lb.--were made by Enso Gutseit (Finland) and Svenska Cellulosa (Sweden). The 23-lb. semichemical medium was made by Fiskeby. Also, a few trials were made in which a 26-lb. European semichemical corrugating medium (Finnkarton) was fabricated with domestic linerboards into combined board and boxes. The domestic linerboards--i.e., 26, 33, 38, and 42-lb.--were obtained from a member company of Fourdrinier Kraft Board Institute, Inc., and the manufacturing specifications relative to quality were those corresponding to the current industry average quality level for each grade weight. [See Figure 1 for constructions used.]

The combined boards and boxes resulting from the fifty-two experimental material combinations used in this study, together with samples of the components used in each run, were evaluated for performance at 50 ± 2% relative humidity and 73 ± 3.5°F. (standard conditions in United States), and 65% relative humidity at 68°F. (standard conditions in Europe). It should be borne in mind in interpreting the results that the comparative performance is based on the results obtained on two samples of European linerboard and one sample of domestic linerboard at each of the four grade weight levels. The results, therefore, represent comparative performance only to the extent that the linerboards are representative at each grade

Run No.	Nominal Grade Liner Weight	Nominal Grade Medium Weight	
1	25.6 lb. Enso Gutseit	26-lb. U. S.	A and B Flute
2	26.0-lb. U. S.	26-lb. U. S.	A and B Flute
3	25.6-lb. Svenska Cellulosa	26-lb. U. S.	A and B Flute
4	30.7-lb. " "	26-lb. U. S.	A and B Flute
5	33.0-lb. U. S.	26-lb. U. S.	A and B Flute
6	30.7-lb. Enso Gutseit	26-lb. U. S.	A and B Flute
7	35.8-lb. " "	26-lb. U. S.	A and B Flute
8	38.0-lb. U. S.	26-lb. U. S.	A and B Flute
9	35.8-lb. Svenska Cellulosa	26-lb. U. S.	A and B Flute
10	41.0-lb. " "	26-lb. U. S.	A and B Flute
11	42.0-lb. U. S.	26-lb. U. S.	A and B Flute
12	41.0-lb. Enso Gutseit	26-lb. U. S.	A and B Flute
13	25.6-lb. Enso Gutseit	23-lb. European	A and B Flute
14	26.0-lb. U. S.	23-lb. European	A and B Flute
15	25.6-lb. Svenska Cellulosa	23-lb. European	A and B Flute
16	30.7-lb. " "	23-lb. European	A and B Flute
17	33.0 lb. U. S.	23-lb. European	A and B Flute
18	30.7-lb. Enso Gutseit	23-lb. European	A and B Flute
19	35.8-lb. " "	23-lb. European	A and B Flute
20	38.0-lb. U. S.	23-lb. European	A and B Flute
21	35.8-lb. Svenska Cellulosa	23-lb. European	A and B Flute
22	41.0-lb. " "	23-lb. European	A and B Flute
23	42.0 lb. U. S.	23-lb. European	A and B Flute
24	41.0-lb. Enso Gutseit	23-lb. European	A and B Flute
25	26.0-lb. U. S.	26-lb. European	A Flute
26	33.0-lb. " "	26-lb. European	A Flute
27	38.0-lb. " "	26-lb. European	A Flute
28	42.0-lb. " "	26-lb. European	A Flute

Figure 1. Material Combinations

weight level.

In order to obtain a quick review of the relative performance of boxes and combined board made with domestic and European components, a series of tables have been prepared of the composite average percentage difference in performance of each board construction. Only the results at 50% R.H. are presented as the results obtained at 65% R.H. show about the same trend as the 50% R.H. results. These are presented in the following section together with an interpretation of the trends indicated by the data.

DISCUSSION OF RESULTS

I. Comparative Performance of Boxes Fabricated with Domestic and European Kraft Linerboard.

A. Comparative Performance on a Box Basis

The average comparative performance of the boxes made with domestic and European components are summarized in Table I without regard to the differences in combined board weight. In all cases the results obtained on boxes fabricated with domestic linerboards are used as the reference.

TABLE I

COMPARISON OF BOX PERFORMANCE
(50% R.H.)

Comparison Linerboard	Difference[a] in Box Performance, % Top-Load Compression	End-Load Compression	Corner Drop	Drum Performance
25.6 - 26.0-lb. Level				
Enso Gutseit	-5.3(s)	-4.1(ns)	+ 3.0(ns)	- 9.5(ns)
Svenska Cellulosa	-5.1(s)	-0.7(ns)	-23.9(s)	-12.7(ns)
30.7 - 33.0-lb. Level				
Enso Gutseit	-1.6(s)	-5.3(s)	0.0(ns)	-19.8(s)
Svenska Cellulosa	0.0(ns)	-2.8(ns)	+16.9(s)	+ 8.6(ns)
35.8 - 38.0-lb. Level				
Enso Gutseit	+7.4(s)	+2.2(ns)	-14.3(s)	-18.3(s)
Svenska Cellulosa	+1.0(ns)	-8.9(s)	- 6.7(ns)	+ 1.8(ns)
41.0 - 42.0-lb. Level				
Enso Gutseit	+8.7(s)	+7.1(s)	+ 4.9(ns)	- 3.7(ns)
Svenska Cellulosa	+2.7(s)	+3.8(ns)	+ 1.9(ns)	+ 2.8(ns)

[a] Boxes made with domestic linerboards used as reference.

The results tabulated in Table I show the following trends:

1. At the 25.6 - 26.0-lb. grade weight level, the boxes made with European linerboards gave approximately 5% lower top-load compression, about equal end-load compression and equal to lower drop and drum performance.

2. At the 30.7 - 33.0-lb. grade weight level, the boxes made with European linerboards gave about equal top-load compression and equal to slightly lower end-load compression. The boxes made with Enso Gutseit linerboard exhibited equal to lower rough handling in terms of drop and drum performance; however, the corresponding boxes made with Svenska Cellulosa linerboard exhibited equal to slightly higher rough handling performance.

3. The boxes made with 35.8-lb. grade weight European linerboards gave equal to slightly higher top-load compression, but equal to slightly lower end-load compression. The rough handling performance of the boxes made with Enso Gutseit linerboard exhibited significantly lower rough handling performance from those made with 38.0-lb. grade weight domestic linerboard.

4. The boxes made with 41.0-lb. grade weight European linerboard gave slightly higher top-load compression performance and equal to slightly higher end-load compression performance. The drop and drum results were not significantly different from the results exhibited by the boxes made with 42.0-lb. grade weight domestic linerboard.

B. Comparative Performance at Equivalent Combined Board Weight

European kraft linerboard is made at a lower grade weight and a higher bursting strength than the corresponding domestic linerboard. A comparison of the nominal grade weights and the actual weights of linerboard used in this study is given in Table II. It may be observed that the nominal grade weights of the European linerboard averaged 4.2% lower than the corresponding average for the domestic linerboard. The weight difference was even greater in the linerboards used in this study as the Enso Gutseit and Svenska Cellulosa linerboards average 5.6 and 7.8% lower, respectively, than the domestic linerboards. The lower weight of the European linerboards resulted in lower combined board weight and, hence, lower box weight. This is of economic importance in that the square footage and, hence, number of boxes per ton of linerboard is greater with European linerboard. In order to determine the comparative performance on an equivalent weight basis, the box results were computed to a given combined board weight. The comparative performance based on an equivalent weight may be seen from the results tabulated in Table III.

TABLE II

NOMINAL AND ACTUAL LINERBOARD WEIGHTS

Nominal			Actual				
Domestic	European	Diff., %	Domestic	EG	Diff., %	SC	Diff., %
26.0	25.6	-1.5	28.0	26.5	-5.4	26.7	- 4.6
33.0	30.7	-7.0	35.0	31.8	-9.1	31.0	-11.4
38.0	35.8	-5.8	39.4	37.4	-5.1	36.4	- 7.6
42.0	41.0	-2.4	42.8	41.6	-2.8	39.6	- 7.5
Av.		-4.2			-5.6		- 7.8

[a]Domestic linerboard used as reference.

TABLE III

COMPARISON OF BOX PERFORMANCE
(Equivalent Weight Basis)

Comparison Linerboard	Comparative Difference in Box Performance[a], %			
	Top-Load Compression	End-Load Compression	Corner Drop	Drum Performance
	25.6 - 26.0-lb. Level			
Enso Gutseit	- 3.2	-1.9	+ 4.3	- 7.6
Svenska Cellulosa	- 1.7	+1.9	-21.4	-10.6
	30.7 - 33.0-lb. Level			
Enso Gutseit	+ 7.5	+0.3	+ 5.7	-14.9
Svenska Cellulosa	+ 6.8	+4.1	+24.3	+14.9
	35.8 - 38.0-lb. Level			
Enso Gutseit	+11.1	+5.8	-11.2	-15.2
Svenska Cellulosa	+ 5.5	-5.0	+11.2	+ 6.5
	41.0 - 42.0-lb. Level			
Enso Gutseit	+11.3	+9.7	+ 7.2	0.0
Svenska Cellulosa	+ 9.6	+9.0	+ 6.0	+ 8.3

[a]Boxes made with domestic linerboard used as reference.

The differences in test results tabulated in Table III show the following trends when performance is compared on an equivalent weight basis:

1. At the 25.6 - 26.0-lb. level the boxes made with European linerboard exhibited about equal top- and end-load compression performance when compared to boxes made with domestic linerboards. In general, the corresponding rough handling performance was equal or slightly lower for the boxes made with European linerboard at this level.
2. The boxes made with European linerboard at the 30.7 - 33.0-lb. level exhibited above a 7% higher top-load compression and equal to slightly

higher end-load compression than boxes made with domestic linerboard. Boxes made with Enso Gutseit linerboard displayed equal or slightly lower rough handling performance; however, the corresponding boxes made with Svenska Cellulosa linerboard gave slightly higher rough handling performance compared to boxes made with domestic linerboard.

3. At the 35.8 - 38.0-lb. level the European linerboard resulted in boxes of approximately 6 to 11% higher top-load compression. In terms of end-load, the boxes made with Enso Gutseit linerboard were approximately 6% higher and those with Svenska Cellulosa linerboard 5% lower than the corresponding results for domestic linerboard. In general, the rough handling performance was equal to slightly lower for boxes made with Enso Gutseit linerboard and equal to slightly higher for boxes made with Svenska Cellulosa linerboard.

4. The boxes made with European linerboard at the 41.0 - 42.0-lb. level exhibited 9 to 11% higher top- and end-load compression and about equal rough handling compared to the corresponding boxes made with domestic linerboard.

II. Comparative Performance of Combined Board Made with Domestic and European Linerboard.

As previously mentioned, European linerboard is manufactured to a lower basis weight but higher bursting strength than domestic linerboard. The effect of the type of linerboard -- domestic vs. European -- on the combined board properties may be seen from the results tabulated in Table IV. The following trends may be observed for the combined boards:

1. Basis Weight.

The combined boards made with European linerboard ranged from 2 to 6% lower in basis weight. As would be expected, the largest difference

TABLE IV

COMBINED BOARD RESULTS
(50% R.H.)

Liner-board	Difference Combined Board Performance[a], %									
	Weight	Caliper	Bursting Strength	Edgewise Compression M.D.	Edgewise Compression C.D.	Flexural Stiffness[b]	Puncture	Scoreline Torsion Tear	Flat Crush	Pin Adhesion
					25.6 - 26.0 lb. Level					
E.G.	- 2.1	- 2.0	+ 35.7	-10.2	-3.1	+ 7.6	- 4.2	- 7.5	- 7.6	- 19.0
S.C.	- 3.1	- 1.3	+ 56.8	+ 0.7	-4.7	+ 7.1	- 16.7	- 21.4	- 3.2	- 15.5
					30.7 - 33.0 lb. Level					
E.G.	- 5.6	- 2.0	+ 20.7	- 10.2	-6.7	+ 9.0	- 5.3	- 7.3	+ 0.2	- 22.8
S.C.	- 6.4	- 1.3	+ 13.5	- 4.2	-7.4	- 3.6	- 5.3	- 2.6	+ 0.2	- 5.3
					35.6 - 38.0 lb. Level					
E.G.	- 3.4	- 1.9	+ 34.4	+ 0.4	+2.6	+ 38.3	- 5.9	- 8.6	+ 1.2	- 12.5
S.C.	- 4.2	- 1.3	+ 28.8	- 6.6	+2.4	+ 14.8	- 3.0	- 2.9	- 0.7	- 6.3
					41.0 - 42.0 lb. Level					
E.G.	- 2.4	0.0	+ 23.4	+ 19.8	+4.4	+ 36.6	- 0.9	- 2.8	- 0.5	- 5.7
S.C.	- 4.8	+ 1.3	+ 25.1	+ 8.3	-0.2	+ 16.2	- 1.4	- 9.6	- 1.2	0.0

[a]Combined board made with domestic linerboard used as reference.

[b]Geometric mean of flexural stiffnesses, $\sqrt{D_x D_y}$

occurred at the 30.7-lb. level which reflects the largest difference in nominal weights.

2. Caliper.

In general, the caliper of the combined boards made with European linerboard was slightly lower than the board made with domestic linerboard. The one exception was at the 41.0-lb. level where the caliper was equal or slightly higher.

3. Bursting Strength.

The bursting strength of the combined boards made with European linerboard was significantly higher than board made with domestic linerboard. The differences ranged from 13.5 to 56.8%. The greatest disparity being at the 25.6 - 26.0-lb. level and the least at the 31.7 - 33.0-lb. level.

4. Edgewise Compression.

a. The machine-direction edgewise compression, which is considered to be one of the fundamental combined board properties governing end-load compression, was equal to slightly lower at the 25.6, 30.7 and 35.8-lb. linerboard levels, but higher than the corresponding board made with domestic linerboard at the 42.0-lb. level. In general, the end-load box performance shown in Table I followed the same trend.

b. The cross-direction edgewise compression, which is one of the two fundamental combined board properties governing top-load compression, was generally slightly lower at the 25.6 and 30.7-lb. levels, but slightly higher at the 35.8 and 41.0-lb. levels than the corresponding combined boards made with domestic linerboard. The top-load box compression results (see Table I) exhibited about the same trend.

5. Flexural Stiffness.

The geometric mean of the machine- and cross-machine direction flexural stiffness, although of secondary importance compared to the edgewise compression, is the other fundamental property of combined board which governs box compression. It may be noted from Table IV that the geometric mean is generally higher, particularly at the two higher linerboard grade weights -- i.e., 35.8 and 41.0-lb. As mentioned in connection with the edgewise compression results, the top-load box compression generally was higher at these two levels of linerboard weight compared to boxes made with domestic linerboards.

6. Puncture.

At all levels of linerboard grade weights, the combined boards made with European linerboard exhibited lower puncture strength than board made with domestic linerboard. The disparity was least at the 41.0-lb. level.

7. Scoreline Torsion Tear.

The scoreline torsion tear tester measures the resistance of the combined board in the area of the flap scoreline to the propagation of a tear and has been found to be highly correlated with the rough handling performance of boxes made with domestic linerboard. It may be noted in Table IV that the scoreline torsion tear resistance was slightly lower for all combined boards made with European linerboard.

8. Flat Crush.

Inasmuch as the flat crush results are independent of the linerboard properties and the same corrugating mediums were fabricated with domestic and European linerboards, it is not surprising that there is little if any significant difference in the flat crush results associated with the type of linerboard.

9. Pin Adhesion.

Under the conditions used in this study, the pin adhesion results are a measure of converting efficiency. It may be noted that in practically all cases the pin adhesion results were lower for the combined boards made with European linerboard than for the boards made with domestic linerboard. This is believed due in part at least to the European linerboard being less porous and rougher than domestic board.

III. Comparison of the Properties of Domestic and European Linerboard.

There are a number of inherent differences in the character of domestic and European kraft linerboards. First of all there is a difference in fiber characteristics due to difference in wood species native to the two geographic areas. European kraft linerboard is made with approximately 100% softwood (90% Scotch pine and 10% Norway spruce) unbleached kraft and a trace of hardwood kraft (birch). In contrast, the domestic kraft linerboards used in this study consisted of 85% softwood (southern pine) unbleached kraft and 15% hardwood (mainly gum with a trace of oak, beech, maple, and yellow poplar) kraft. As a result of species and manufacturing philosophy, the European linerboard is made at a lower freeness and average fiber length than domestic linerboard in order to attain the higher bursting strength at a lower weight. The European linerboard is also made at a lower machine speed because of the slower drainage and drying due to the lower freeness stock.

It is hoped that the above background information may be helpful in interpreting the comparative performance of domestic and European linerboards in terms of percentage differences in test properties as given in Table V in

TABLE V

LINERBOARD RESULTS
(50% R.H.)

	Difference[a] in Linerboard Properties, %									
	25.6 lb.		30.7 lb.		35.8 lb.		41.0 lb.		Average	
	EG	SC	EG	SC	EG	SC	EG	SC	EG	SC
Weight	- 5.4	- 4.6	- 9.1	-11.4	- 5.1	- 7.6	- 2.8	- 7.5	- 5.6	- 8.3
Caliper	-18.8	-18.8	-10.2	- 1.0	-10.7	-11.6	- 4.1	- 0.8	-11.0	- 8.1
Apparent Density	+13.3	+13.3	0.0	-11.1	+ 5.6	+ 2.8	0.0	-11.1	+ 4.7	- 1.5
Bursting Strength										
p.s.i.g	+38.9	+47.2	+18.1	+ 6.7	+38.8	+38.8	+27.0	+19.1	+30.7	+28.0
factor	+46.7	+54.4	+30.0	+20.3	+46.2	+50.2	+30.5	+28.6	+38.4	+38.4
Elmendorf Tear, M.D.										
g/sheet	-17.8	-29.2	-17.9	-11.7	-10.5	-10.5	- 1.0	- 9.6	-11.8	-15.3
factor	-13.2	-25.7	- 9.8	- 0.3	- 5.7	- 3.2	+ 1.9	- 2.2	- 6.7	- 7.9
Elmendorf Tear, C.D.										
g/sheet	-18.4	-25.6	-18.2	-22.7	-11.3	-15.4	- 3.0	-14.0	-12.7	-19.4
factor	-13.8	-21.9	-10.0	-12.7	- 6.5	- 8.5	- 0 1	- 7.1	- 7.6	-12.6
Edgewise Compression, M.D.										
lb./in.	+ 0.6	+ 8.8	- 8.1	-14.5	+ 2.5	- 4.2	+17.1	+ 7.8	+ 3.0	- 0.5
factor	+ 7.0	+14.0	+ 1.5	- 3.0	+ 8.2	+ 3.3	+20.0	+17.8	+ 9.2	+ 8.0
Edgewise Compression, C.D.										
lb./in.	- 0.9	+ 2.6	- 5.0	-11.2	+14.1	+ 5.8	+ 7.8	+ 3.9	+ 4.0	+ 2.8
factor	+ 4.9	+ 7.3	+ 4.3	0.0	+20.0	+12.5	+11.1	+11.1	+10.1	+ 7.7
Taber Stiffness, M.D.	-23.1	-15.4	- 7.5	+ 5.0	0.0	- 9.4	+14.7	+23.5	- 4.0	+ 0.9
Taber Stiffness, C.D.	-20.0	-20.0	- 7.1	0.0	+31.2	+12.5	+30.4	+17.4	+ 8.6	+ 2.5

TABLE V (Cont'd)

LINERBOARD RESULTS
(50% R.H.)

	Difference[a] in Linerboard Properties, %									
	25.6 lb.		30.7 lb.		35.8 lb.		41.0 lb.		Average	
	EG	SC	EG	SC	EG	SC	EG	SC	EG	SC
Tensile Strength, M.D.										
lb./in.	+39.6	+57.5	+23.6	+13.2	+35.8	+29.1	+31.7	+32.8	+32.7	+33.2
factor	+47.1	+64.7	+36.0	+27.9	+43.1	+39.9	+35.6	+43.7	+40.5	+44.1
Tensile Strength, C.D.										
lb./in.	+37.8	+18.9	+25.2	+29.8	+63.3	+58.5	+54.1	+41.0	+45.1	+37.1
factor	+45.6	+25.3	+38.4	+46.5	+72.6	+72.6	+58.4	+51.9	+53.8	+49.1
Stretch, M.D.	+ 5.6	+22.2	- 9.1	-13.6	-10.0	+15.0	-18.2	- 9.1	- 7.9	+ 3.6
Stretch, C.D.	+45.2	+58.1	+19.4	+41.7	-22.7	+22.7	-10.5	+23.7	+ 7.9	+36.6
Modulus of Elasticity, M.D.	+52.9	+60.7	+33.8	+ 3.1	+42.5	+22.8	+37.5	+22.3	+41.7	+27.2
Modulus of Elasticity, C.D.	+35.1	+18.8	+20.9	- 2.3	+68.5	+35.5	+51.3	+10.3	+44.0	+15.6
T.E.A., M.D.	+33.8	+71.8	+ 8.1	- 4.8	+19.3	+44.7	+11.0	+14.0	+18.1	+31.2
T.E.A., C.D.	+88.7	+84.9	+40.0	+68.2	+15.0	+78.0	+28.4	+67.4	+43.0	+74.6
IPC Bond Strength, M.D.	-23.5	+13.1	- 7.3	+51.6	+24.7	+70.1	- 9.9	+23.1	+ 4.3	+39.4
IPC Bond Strength, C.D.	-24.9	-19.8	+ 2.7	+39.8	+34.5	+57.1	+ 5.3	+13.7	+ 4.4	+22.7
Porosity, sec./100 cc.	+84.6	+207.7	+257.9	-31.6	+369.0	+120.7	+289.3	+135.7	+250.2	+108.1
Smoothness, ml./min.	-22.5	-13.1	+97.6	+66.7	+49.0	-19.2	+36.6	+49.0	+40.2	+20.8
Cobb Size, g./M^2	- 3.4	- 2.9	+21.6	+ 7.6	- 1.9	+ 0.3	- 2.4	+11.4	+ 3.4	+ 4.1

[a] Domestic linerboard used as reference.

which domestic linerboard is used as the reference.

1. Basis Weight.

The linerboard made by Enso Gutseit and Svenska Cellulosa averaged 5.6 and 8.3% lower than the corresponding domestic linerboard. The greatest disparity in basis weight was at the 30.7 - 33.0-lb. nominal grade weight level. In practically all cases the difference in weight between domestic and European linerboard was greater than the difference in nominal weight.

2. Caliper.

In general, the caliper of the European linerboard was 8 to 10% lower than domestic board.

3. Bursting Strength.

The bursting strength of the European linerboards ranged from 6.7 to 47.2% higher than domestic linerboard. The average was approximately 30%. The European linerboards were approximately 38% more efficient in terms of the bursting strength developed per pound of ream weight.

4. Elmendorf Tearing Strength.

The results show rather clearly that the development of bursting strength was at the expense of lower tearing strength as the European linerboards were 12 to 20% lower in tearing strength. It would be expected that this significantly lower tearing strength would adversely affect the rough handling performance of the box. The loss in tear is offset to a degree, as will be shown later, by the much greater cross-direction tensile strength, stretch, modulus of elasticity and T.E.A.

5. Tensile Strength.

As may be seen in Table V, the machine- and cross-machine tensile results of the European linerboards were 33 to 45% higher than the domestic linerboards. Similarly, the European linerboards developed far more tensile per pound of ream weight than did the domestic linerboards.

6. Stretch.

As may be seen the difference in machine-direction stretch of domestic and European linerboard varied with the grade weight. In general, Enso Gutseit linerboard was approximately 8% lower and Svenska Cellulosa approximately 4% higher than the corresponding domestic linerboards. In the case of cross-machine stretch, the linerboard made by Enso Gutseit exhibited significantly higher values at the 25.6 and 30.7-lb. grade weight levels, but lower values at the 35.8 and 41.0-lb. levels. In contrast, the Svenska Cellulosa linerboard exhibited significantly higher results at all grade weights -- the average difference being approximately 37%.

7. Modulus of Elasticity.

The modulus of elasticity is defined as the ratio of stress to strain. It is an important factor in flexural stiffness which is functionally related to EI where E is the modulus of elasticity and I the moment of inertia. The modulus of elasticity of linerboard plays an important role because of its relationship to flexural stiffness and edgewise compression of combined board.

The European linerboards exhibited significantly higher moduli than the domestic linerboard, the respective average differences for Enso Gutseit and Svenska Cellulosa linerboards being approximately 42 and 27% for machine-direction and 44 and 16% for cross-direction.

8. T.E.A.

The tensile energy absorption, T.E.A., is a measure of the energy absorption capacity of linerboard. It is the energy corresponding to the area under the tensile load-deformation curve; thus, T.E.A. is a function of both tensile and stretch characteristics.

It may be recalled that the tensile strengths of European linerboards were higher than the corresponding domestic linerboards; however, the stretch characteristics of the former varied from higher to lower depending on the grade weight and source. It may be noted from the results in Table V that the machine-direction T.E.A. values were higher, except for one case, than the values for the corresponding domestic linerboards, the respective average differences for Enso Gutseit and Svenska Cellulosa linerboards were approximately 18 and 31%. The cross-machine results displayed the same trend, the respective average differences being approximately 43 and 75%. It is believed that the comparatively good rough handling performance of boxes made with European linerboard is due in large part to the significantly higher cross-machine energy absorption, T.E.A., of the linerboards. The higher T.E.A. apparently offsets the disadvantage of the lower tearing strength of the European linerboards.

9. Bond Strength.

The bond strength is a measure of the degree of transverse bonding of the fibers and consequently it is related to the various mechanical properties of the linerboard. It may be observed that only at the 35.8-lb. level was the machine-direction bond strength of the Enso Gutseit higher than the corresponding domestic linerboard. In contrast, the Svenska Cellulosa linerboard displayed higher bond values at all grade weights -- the average difference being approximately 39%. The same general trend was exhibited by the cross-machine results, although in this case the average difference for the Svenska Cellulosa linerboard was approximately 23%.

10. Porosity.

The porosity of linerboard plays an important role in printing, in adhesion on the corrugator, in case sealing, etc., and is functionally related to density. The porosity is determined in terms of the time for a given volume of air to pass through the test specimen, therefore the higher the time the less porous the linerboard. It may be noted that the European linerboards required significantly greater time and, hence, were less porous (more dense) than the corresponding domestic linerboard. The respective average differences for Enso Gutseit and Svenska Cellulosa linerboards were approximately 250 and 108% higher than the corresponding domestic linerboard.

11. Smoothness.

Smoothness also plays an important role in printing, adhesion, and case sealing. The Bendtsen smoothness tester used in this study measures smoothness in terms of the volume of air which passes between the surface of the linerboard and the test plate in a given time, thus the higher the volume the rougher the surface of the linerboard. Except at the 25.6-lb. grade weight level, the European linerboards generally were rougher than the domestic boards.

12. Cobb Size.

The Cobb test measures the degree of sizing in terms of the weight of water absorbed by a given area of linerboard surface. Thus, the higher the size number, the greater the water pick-up and, hence, lower the degree of size. Except for the 30.7-lb. Enso Gutseit and the 41.0-lb. Svenska Cellulosa linerboards, there appeared to be no significant difference in the degree of sizing as measured by the Cobb test.

13. The coefficient of variation determined for a number of test properties indicated that domestic linerboard is more uniform in bursting strength, tearing strength, edgewise compression, and Taber stiffness than European linerboard. The Enso Gutseit linerboard was more uniform than the Svenska Cellulosa linerboard.

IV. Comparative Performance of Boxes Fabricated with Domestic and European Semichemical Corrugating Mediums.

It may be recalled that each grade weight of domestic and European linerboard was fabricated with a 26-lb. domestic and a 23-lb. European semichemical corrugating medium. The latter is understood to be the conventional weight used in Western Europe. In addition, the domestic linerboards also were fabricated with a 26-lb. European semichemical corrugating medium.

A. Comparative Performance of Boxes Made with 26-lb. Domestic and 23-lb. European Semichemical Medium.

The comparative performance of boxes fabricated from combined board corrugated with both domestic and European linerboards and (a) 26-lb. domestic corrugating medium, and (b) 23-lb. European corrugating medium may be seen from the percentage difference in box performance tabulated in Table VI. The percentage differences in box performance tabulated in Table VI show the following trends:

TABLE VI

EFFECT OF TYPE OF MEDIUM ON BOX PERFORMANCE
(50% R.H.)

Linerboard Grade Weight, lb.	Difference[a] in Box Performance, %							
	Top-Load Compression		End-Load Compression		Corner Drop		Drum Performance	
	A-Flute	B-Flute	A-Flute	B-Flute	A-Flute	B-Flute	A-Flute	B-Flute
25.6 - 26.0	+3.5(s)	-0.7(ns)	-3.9(ns)	-4.4(s)	-25.3(s)	-20.7(s)	-24.1(s)	-27.8(s)
30.7 - 33.0	-0.7(ns)	0.0	+0.6(ns)	-5.9(s)	-10.0(ns)	-12.5(ns)	-22.9(s)	-32.4(s)
35.8 - 38.0	0.0	+1.4(ns)	+1.3(ns)	-7.4(s)	-14.6(s)	-17.2(s)	-24.8(s)	-22.6(s)
41.0 - 42.0	+2.7(ns)	-1.4(ns)	-0.2(ns)	-1.4(ns)	-18.3(s)	-13.9(s)	-23.4(s)	-17.6(s)

[a]Difference between results for 26-lb. domestic and 23-lb. European mediums using 26-lb. domestic results as reference

1. With one exception there was no significant difference in top-load box compression between boxes made with 26-lb. domestic and 23-lb. European mediums. The one exception was the A-flute box made with 23-lb. European semichemical medium which exhibited a 3.5% higher top-load compression; however, this difference was not observed with the corresponding B-flute.

2. There was no significant difference in the end-load performance of A-flute boxes fabricated with 26-lb. domestic and 23-lb. European semichemical corrugating medium. In contrast, all the B-flute boxes made with 23-lb. European medium exhibited lower end-load compression results than the corresponding results made with 26-lb. domestic corrugating medium. All of these latter differences were statistically significant except for the boxes fabricated at the 41.0 - 42.0-lb. linerboard grade weight level.

3. The boxes fabricated from combined board corrugated with 23-lb. European corrugating medium exhibited a lower rough handling performance in terms of corner drop than the boxes containing the domestic 26-lb. corrugating medium. In general, the noted differences were significant.

B. Comparative Performance of Combined Board Made with 26-lb. Domestic and 23-lb. European Corrugating Medium.

The following trends may be noted from the average percentage differences in the properties of combined board fabricated with 26-lb. domestic and 23-lb. European corrugating medium tabulated in Table VII in which the results with the domestic medium are used as reference:

1. Combined board with European medium 3 to 4% lower in basis weight.

TABLE VII

EFFECT OF TYPE OF MEDIUM ON COMBINED BOARD PROPERTIES
(50 % R.H.)

Combined Board Property	Difference in Performance[a], %			
	25.6 – 26.0	30.7 – 33.0	35.8 – 38.0	41.0 – 46.0
Basis Weight	- 4.6	- 4.5	- 4.7	- 3.2
Caliper	- 0.6	- 1.1	- 1.6	- 2.3
Bursting Strength	- 3.8	+ 7.8	+ 4.6	+ 10.5
Puncture	- 8.3	- 7.3	- 6.2	- 7.1
Scoreline Torsion Tear	- 15.5	- 13.0	- 11.0	- 9.6
Edgewise Compression, M.D.	- 10.4	- 5.8	- 1.4	- 0.2
Edgewise Compression, C.D.	+ 7.1	+ 5.8	+ 4.7	+ 7.3
Flat Crush	- 11.7	- 13.4	- 10.3	- 8.3
Flexural Stiffness[b]	+ 4.1	+ 3.5	+ 5.7	+ 2.3
Pin Adhesion	- 8.1	- 6.5	- 1.1	- 2.8

[a]Based on combined board made with 26-lb. domestic medium as reference. A- and B-flute differences averaged.

[b]Geometric mean of M.D. and C.D.

2. Caliper of combined board made with European medium ranged from approximately 0.5 to 2.5% lower.

3. Bursting strength on combined board made with 23-lb. European medium 5 to 10% higher except at the 25.6 - 26.0-lb. linerboard level wherein it averaged approximately 4% lower.

4. The puncture and scoreline torsion tear strengths were significantly lower on the combined board made with 23-lb. European medium and is probably the reason for the lower rough handling results noted previously for the boxes made with 23-lb. European medium.

5. The machine-direction edgewise compression results for the combined board made with 23-lb. European medium were generally slightly lower. On the other hand, the cross-machine edgewise compression results were approximately 5 to 7% higher.

6. The 23-lb. European medium produced combined board which exhibited approximately 8 to 13% lower flat crush.

7. The geometric mean of the machine- and cross-machine flexural stiffness, which plays an important role in box compression, was slightly higher for the combined board made with the 23-lb. European corrugating medium.

8. In general, the pin adhesion was slightly lower on the combined board made with 23-lb. European corrugating medium.

C. Comparative Performance of Boxes Made with 26-lb. Domestic and 26-lb. European Corrugating Medium.

The average percentage difference in box performance of boxes made with 26-lb. European and domestic corrugating mediums are tabulated in Table VIII using the results for the 26-lb. domestic medium as reference.

TABLE VIII

COMPARATIVE PERFORMANCE OF BOXES MADE WITH 26-LB.
DOMESTIC AND EUROPEAN CORRUGATING MEDIUMS
(50% R.H.)

Linerboard Grade Weight Level	Difference[a] in Box Performance, %			
	Top-Load Compression	End-Load Compression	Corner Drop	Drum Performance
Domestic 26.0-lb.	+ 2.8	- 7.4	- 27.5	- 3.6
Domestic 33.0-lb.	+ 10.1	+ 7.2	- 14.9	+ 16.3
Domestic 38.0-lb.	+ 1.6	- 2.5	- 18.0	- 39.0
Domestic 42.0-lb.	0.0	+ 6.6	- 14.3	- 4.2
Composite	+ 3.5	+ 1.6	- 17.9	- 10.6

[a]Based on results on 26-lb. domestic medium as reference.

The following trends may be noted:

1. In general, the boxes made with 26-lb. European medium exhibited higher top-load compression.

2. The end-load performance of boxes made with 26-lb. domestic and European mediums varied with the combined board series; however, on an overall composite average basis there was no significant difference in end-load box compression.

3. With one exception the rough handling performance of boxes measured in terms of corner drop and drum was lower for the boxes made with 26-lb. European corrugating medium.
