STUDY OF PAPER BOARD QUALITY

AS RELATED TO

FIBER BOX PERFORMANCE

REPORT NUMBER I

Baseline Studies 1. The Evaluation of Current Kraft Liners and Corrugating Mediums

PART II. COMBINED BOARDS AND BOXES

INSTITUTE OF PAPER CHEMISTRY
Appleton Wisconsin

REPORT TO

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

STUDY OF PAPER BOARD QUALITY

AS RELATED TO

FIBER BOX PERFORMANCE

REPORT NUMBER I

Baseline Studies 1. The Evaluation of Current Kraft Liners and Corrugating Mediums

PART II. COMBINED BOARDS AND BOXES

REPORT TO

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

Appleton, Wisconsin

THE INSTITUTE OF PAPER CHEMISTRY

OCTOBER, 1946

TABLE OF CONTENTS

A STUDY OF PAPERBOARD QUALITY AS RELATED TO BOX PERFORMANCE

Baseline Studies 1. The Evaluation of Current Kraft Liners and Corrugating Mediums

Part 2. Combined Boards and Boxes

INTRODUCTION

In 1944 the Fourdrinier Kraft Board Institute, Inc. initiated a long-range program of co-operative research and development at The Institute of Paper Chemistry. This program has as its broad objective the development of basic information needed for improving the measurement and control of the quality of paperboard boxes and their components.

In any long-range research enterprise in which the trend of the quality of materials or commodities is to be followed, it is important to first establish a baseline. This baseline can then be used as a reference point throughout the study.

In this particular project, it was decided that the baseline should be established by determining an index of the quality of the current paperboard production of the co-operating mills.

The first phase of the baseline study (Part I) was concerned with the problem of sampling, in a truly impartial cross-sectional manner, the current routine production of the co-operating mills and evaluating these samples as completely as possible by means of existing board-testing methods. This phase of the study has been covered in detail in the report entitled "Baseline studies 1. The evaluation of current kraft liners and corrugating mediums," issued in October, 1945.

The second phase of the baseline study (Part II), the subject of this report, is concerned with (1) the selection of the most representative roll or rolls of each mill's sampled production, (2) the fabrication of these representative rolls into corrugated combined boards and conversion of these combined boards into boxes, and (3) laboratory evaluation of these boxes and their components by means of conventional board and box-testing methods. The corrugating operation and the conversion into boxes was carried out by The Institute of Paper Chemistry in co-operation with an impartial boxmaker under carefully controlled, but normal, conditions of manufacture.

The objectives of this phase of the baseline study were threefold. First, the study was to provide additional data required for the establishment of the current quality index, or baseline—namely, data on combined board and boxes. Second, the study was to provide information concerning the deviation in test values which may be expected when paperboards are converted under closely controlled conditions of corrugating and boxmaking. Third, the additional data on combined boards and boxes were intended to provide each mill with a further means of comparing the quality of its product with that of the other mills co-operating in this study.

SUMMARY

The B-flute combined boards resulting from the various combinations of liners and corrugating mediums selected in this study were fabricated consecutively on the same corrugator and by the same operating crew. The various combinations of liners and corrugating mediums are designated as "run combinations" throughout this report. Combined board for testing and blanks for conversion into boxes were made with the corrugator operating at a speed of 300 to 325 lineal feet per minute. In so far as possible, the same machine settings and adjustments were used on all the run combinations. Following the fabrication operation, the box blanks were printed, scored, and slotted on the same printer-slotter. The printed, scored, and slotted blanks were made up into RSC 24 No. 2½ can-size boxes with stitched joints.

Samples of component materials, combined board, and boxes were taken from each run. All samples were preconditioned at 35% relative humidity prior to being conditioned and tested in an atmosphere maintained at 50 ± 2% relative humidity and a temperature of 73 ± 3.5° F.

The physical tests carried out on the components were basis weight, moisture content, bursting strength, G. E. puncture, Elmendorf tear, ring compression (Riehle), and Amthor tensile and stretch. The combined board samples were tested for basis weight, moisture content, bursting strength, G. E. puncture, G. E. stiffness, pin adhesion, and flat crush. Top- and end-load compression, drum, and 12-inch corner drop test values were determined on the boxes.

Run Combinations 1–8

The results of the physical tests on the *boxes* resulting from Run Combinations 1 through 8—standard liners fabricated with each mill's average corrugating medium—show that the average test characteristics were as follows:

Top-load compression, lb. (in deflection range 0–0.75 in.)	477
End-load compression, lb. (in deflection range 0–0.50 in.)	563
Drum, falls to box failure	44
Drop, drops to box failure	7.9

There was considerable variation in the test results obtained for the boxes in this series. For example, the

drum, drop, and compression results for the boxes made from Run Combinations 6 and 8 were above the average and the corresponding test results for Run Combinations 5 and 7 were consistently below the average for the group.

The results of the physical tests on the *combined board* samples taken from the boxes made in this series show that the average characteristics were as follows:

Basis weight, lb./1000 sq. ft.	121
Moisture, % at 50% relative humidity	8.3
Bursting strength, points	234
G. E. puncture, units	208
G. E. stiffness, units	86
Pin adhesion, lb.	68
Flat crush, lb./sq. in.	26.8

The bursting strength results for all the combined board samples in this series were in excess of 200 points. There was more variation in the G. E. puncture values than in the bursting strength values. For example, the difference between the maximum and minimum sample averages of the bursting strength amounted to only 20 points. On the other hand, the difference between the maximum and minimum sample averages for the G. E. puncture was 57 units. The combined board samples from Run Combinations 5 and 7 had the lowest G. E. puncture values and the boxes made from these combined boards also had the lowest drum, drop, and compression values.

Run Combinations 9–18

The data obtained on *boxes* made from Run Combinations 9 through 18—standard corrugating medium fabricated with a set of each mill's average liner—indicate that the average quality of the boxes in this series was as follows:

Top-load compression, lb. (in deflection range 0–0.75 in.)	476
End-load compression, lb. (in deflection range 0–0.50 in.)	580
Drum, falls to box failure	53
Drop, drops to box failure	9.2

The results of the physical tests on the boxes made from Run Combinations 10, 11, and 12 were substantially above the group average and those from Run Combinations 13, 17, and 18 were consistently lower than the group average. The drum test results on the boxes in this series ranked the boxes in approximately the same order as the drop test results. The same behavior was noted in the results of the drum and drop tests on boxes made from Run Combinations 1 through 8.

The data on *combined board* samples taken from boxes made from Run Combinations 9 through 18 show that the average physical characteristics of the combined board were as follows:

Basis weight, lb./1000 sq. ft.	122
Moisture, % at 50% relative humidity	8.0
Bursting strength, points	230
G. E. puncture, units	217
G. E. stiffness, units	87
Pin adhesion, lb.	74
Flat crush, lb./sq. in.	26.2

The bursting strength data show that the combined board from all the run combinations in this series had a bursting strength in excess of 200 points, except Run Combination 13 which averaged 185 points. All the G. E. puncture values were above 200 units, except for Run Combinations 13 and 18 which had G. E. puncture values of 191 and 176 units, respectively.

Run Combinations 19–22

The results of the physical tests on the *boxes* made from the combined boards fabricated in Run Combinations 19 through 22—various combinations of high- and low-test liners and corrugating mediums—indicate that the physical characteristics of the liners had a greater influence on the drum and drop results than did the physical characteristics of the corrugating medium. On the other hand, the quality of the corrugating medium appeared to influence the results of the compression tests to a greater extent than did the quality of the liners.

The *combined board* test data obtained for this series indicate that the bursting strength test was more dependent on the strength of the liners than on the strength of the corrugating medium. On the other hand, the G.E. puncture test appears to be influenced more by the physical characteristics of the corrugating medium than by the physical characteristics of the liners.

Correlation Coefficients

In order to determine the relationships between the results of (1) combined board and box tests and (2) components and box tests, the data obtained for the twenty-two run combinations were subjected to statistical analysis.The relationships have been expressed in terms of correlation coefficients.

The following observations were noted from the results of the correlation of combined board and box tests:

1. The drum and drop test results indicate a high degree of correlation. On the basis of the boxes tested, a box with a high drum value would have, in general, a correspondingly high drop test value.

2. The top- and end-load compression values—in the deflection range 0–0.75 and 0–0.50 inch, respectively—show fairly good correlation.

3. The correlation coefficients obtained for the drum or drop and the top- or end-load compression tests show that neither the drum nor the drop test correlates very highly with either the top- or end-load compression test. In other words, they indicate that the magnitude of the top- or end-load compression value—in deflection ranges 0–0.75 and 0–0.50 inch, respectively—is a poor criterion of box performance as measured by the drum or 12-inch corner drop test.

4. The correlation coefficients obtained for the test data on the combined boards used in this study show that the bursting strength has very poor correlation with any of the other combined board tests. The same may be said about the pin adhesion test.

5. G. E. puncture correlates well with G. E. stiffness and fairly well with flat crush.

6. The correlation coefficient for the bursting

strength and G. E. puncture results was +0.48. This indicates that the bursting strength and G. E. puncture tests do not measure exactly the same physical characteristics of the combined board. Therefore, predictions of combined board quality based on one of these tests would not necessarily parallel those based on the other test.

7. The correlation coefficients for combined board and box test results indicate that, on the basis of the samples tested, the G. E. puncture test, as a single test for combined board, is probably a better criterion of the top- or end-load compression, drum, or drop tests than is the bursting strength, pin adhesion, G. E. stiffness, or flat crush test.

8. By means of a statistical technique known as multiple regression, the bursting strength, G. E. puncture, and pin adhesion results obtained on the combined boards have been used to predict the probable drum and drop tests on the boxes made from these combined boards. The (multiple) correlation coefficient for the predicted and observed drum test was +0.86 and for the drop test was +0.91.

9. When based solely on the G. E. puncture test results, the predicted and observed top- and end-load compression values had correlation coefficients of +0.90 and +0.91, respectively.

The following conclusions may be drawn from the results of the correlation of the components and box tests:

1. *Inspection of the relationships* (a) between the results of the different component tests and (b) between component and box tests indicates that average Elmendorf tear (average of the machine and across-machine direction results), Amthor stretch in the across-machine direction, bursting strength, and G. E. puncture tests measured many of the physical characteristics of the component materials which had an important influence on the laboratory performance of the boxes considered in this study.

2. Average Elmendorf tear and Amthor stretch values in the across-machine direction for the three components—single-face liner, corrugating medium, and double-face liner—when properly weighted (by multiple regression) gave predicted drum and drop test values which correlated well with the observed values for the boxes. The correlation coefficients for the predicted and observed values for each of the two compression tests were lower than those for the drum or drop test. The multiple correlation coefficients obtained for these relationships were:

Drum	+0.93
Drop	+0.94
Top-Load Compression	+0.87
End-Load Compression	+0.86

3. A comparison of the weight factors used in determining the correlation coefficients indicates that the Elmendorf tear and *Amthor stretch characteristics* of the single-face liner have a greater influence on the drum and drop test results than the corresponding characteristics of either the corrugating medium or the double-face liner.

4. The Elmendorf tear and Amthor stretch in the across-machine direction characteristics of the corrugating medium were probably more important in predicting compression results than were the corresponding characteristics of the liners.

5. The Elmendorf tear characteristics of the single-face liner appeared to have a greater influence on drum and drop results than did the corresponding characteristics for the double-face liner. In other words, the results indicate that, for the best drum or drop results, the liner with the highest tear should be on the inside of the box.

6. When the predicted box test values were based on the bursting strength and G. E. puncture relationship, the correlation of predicted and observed values was poorer for all the box tests than when the predictions were based on the average Elmendorf tear and Amthor stretch (in the across-machine direction) relationship.

The correlation coefficients determined in this study are based on the results obtained on twenty-two different lots of components, combined boards, and boxes. The foregoing conclusions may or may not apply to components, combined boards, and boxes made from different materials and under different conditions of manufacture and conversion. The correlation coefficients, however, are indicative of the probable relationship between the conventional tests currently being used to evaluate Fourdrinier kraft board and boxes.

SELECTION OF ROLLS FOR FABRICATION

The first step in the second phase of the baseline study was the selection, from the large number of rolls of liners and corrugating medium sampled and tested in Part I of Baseline Studies 1, of the particular rolls required for the fabrication run—the second step in this phase.

Before making this selection, it was necessary to outline the procedure for the fabrication run in order to determine the types of rolls and the number of each type required. Such an outline was made (see Figure 1). From this outline, it is apparent that at least one roll of corrugating medium and two rolls of liner were required from each of the mills. The rolls selected were to represent as nearly as possible the average quality of the rolls sampled for each mill. It was also apparent that certain other rolls were required, representing the average quality of the liners and corrugating mediums produced by all the mills. In addition, a few other rolls were to be selected for specific comparison on the basis of their high or low average strength characteristics.

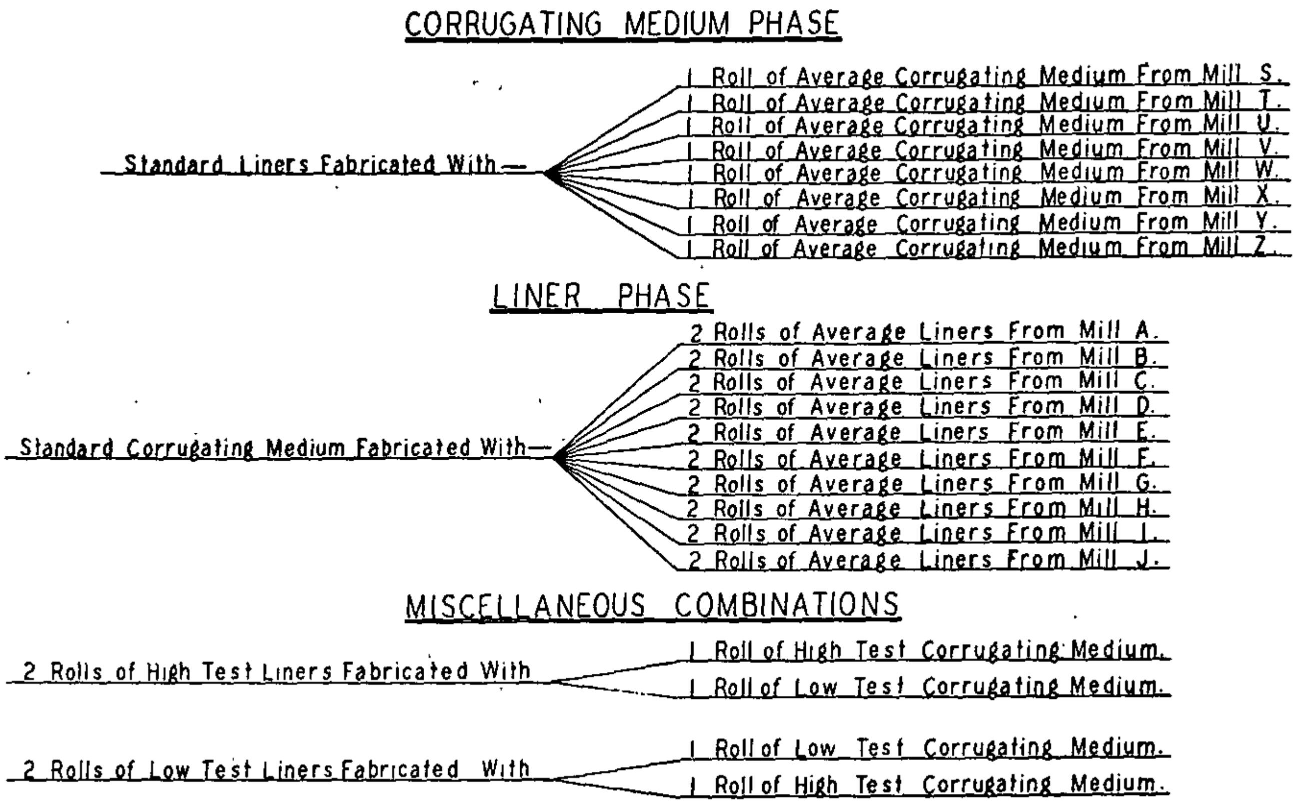

FIGURE 1. Predetermined Fabrication Schedule.

The data obtained by testing all the sample rolls examined under phase one of the baseline study have been presented in the report entitled, "Baseline studies 1. The evaluation of current kraft liners and corrugating mediums." These data were used as a basis for selecting the rolls for fabrication. The physical tests used for the purpose of selecting these rolls were: bursting strength, Amthor tensile and stretch, Elmendorf tear, and ring compression (Riehle). Basis weight and caliper were not considered in this selection as these characteristics are fairly well defined by the grade specifications and the variations from standard values were not large enough to be of primary significance in determining relative over-all quality. Although G. E. puncture tests were performed on all the samples, the data obtained were not used in the selection of the rolls for fabrication because of the newness of the test and a general lack of understanding and agreement regarding its significance. However, inclusion of the G. E. puncture data in these reports provides an interesting illustration of the relationship of this test to the other physical tests performed on these particular samples.

In order to determine which roll was most representative of each mill's sampled production, all the strength data were tabulated for every roll of a given grade tested for a particular mill From these data, it was possible to obtain the average value for each strength characteristic for that mill. For each roll, the deviation of each test value from the average value for *that mill* was then calculated on a percentage basis. These percentage deviations were summed for all the tests on each of the rolls. For each grade of stock, the rolls made by an individual mill were then ranked according to the absolute value of the sum of the percentage deviations. Those rolls having the minimum total percentage deviations were then selected as most representative of the quality of that mill and, therefore, were the rolls required for subsequent fabrication according to the plan illustrated in Figure 1. In the case of corrugating medium, one roll was then selected from each mill and, in the case of liners, two rolls were selected from each mill.

Similarly, in order to select the rolls most representative of the quality produced by all the mills, percentage deviations were calculated for each roll of a given grade on the basis of the group average rather than on the basis of the mill average. The summation of the squares of the percentage deviations was then carried out for each roll and the rolls were ranked accordingly. The rolls of each grade which had the lowest summation of the squares of the percentage deviation values were then selected to represent the over-all or group average quality for all the mills in the fabrication run.

The miscellaneous high- and low-test liners and corrugating mediums required for the fabrication schedule shown in Figure 1 were selected readily on the basis of the data for the individual rolls.

Liners and Corrugating Medium

Because of the shortage of raw material at the time this study was made, there were a few instances in which it was necessary for the converter to use the rolls which had been set aside and tested in the first part of these studies. In those cases where the rolls selected on the basis of the above method had been unavoidably used, the next roll in line in terms of minimum percentage deviation was selected. The test results obtained for the 42-pound DFBS Fourdrinier kraft liner [the designation DFBS is to be understood in future references to Fourdrinier kraft liner in this report] and .009/26-pound corrugating medium selected for fabrication (see Figure 2) are given in Tables I, II, III, and IV. As described in Part I of this study the test results were obtained on samples taken from near the outside of each roll. Thus, they are representative of the quality of the rolls in question only to the extent that the samples taken from a roll were representative of the entire roll. These test results were used only in the selection of the rolls for fabrication. One of the corrugating mediums included in this study was a bogus medium [Mill V (see *Baseline Studies 1, Part I*)]. The rolls of standard corrugating medium were selected on the basis of the group averages for the .009/26-pound kraft corrugating mediums only.

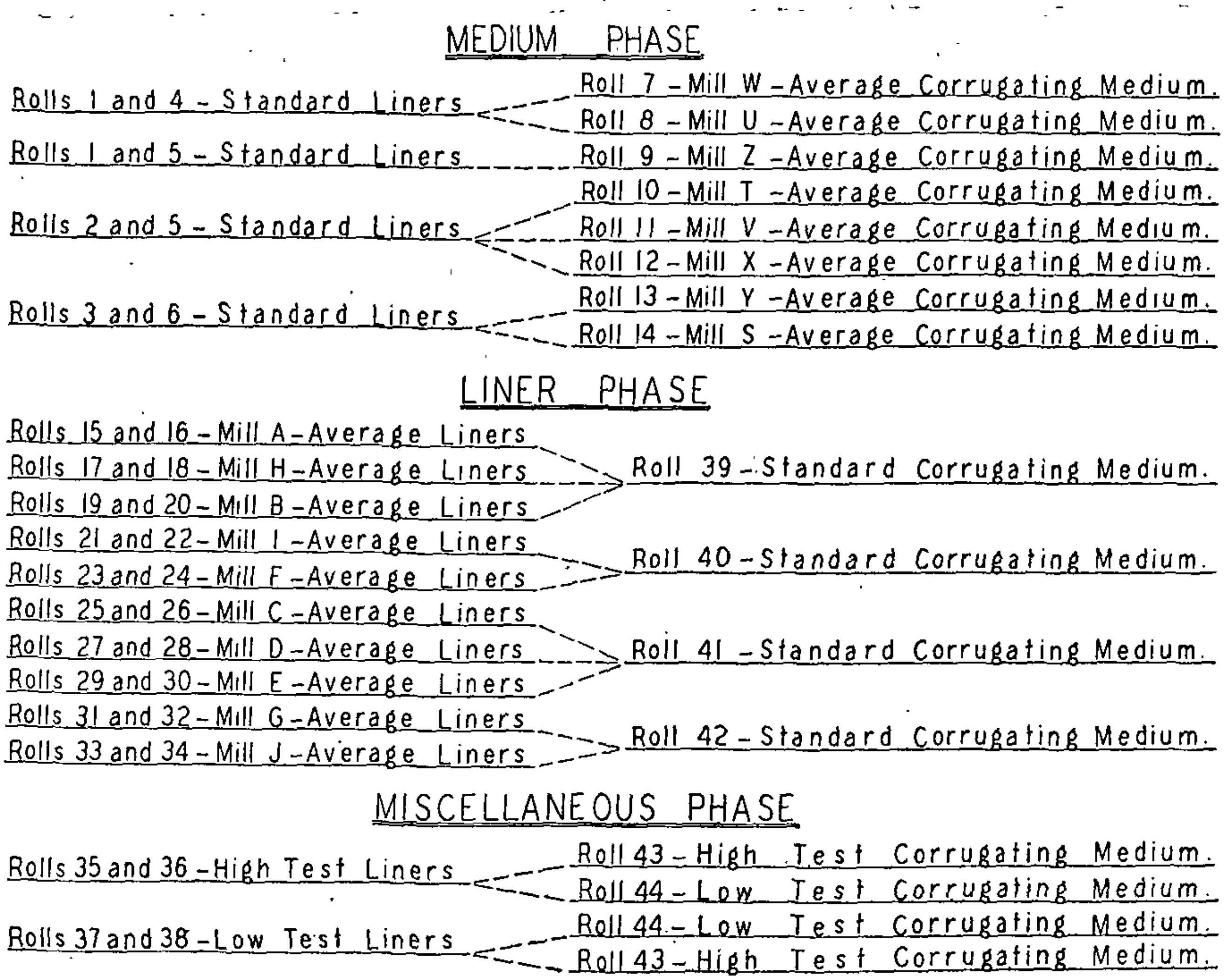

FIGURE 2. Fabrication Sequence.

Starch

The starch adhesive used in this fabrication run was a commercial grade of Bondcor C obtained from Stein, Hall & Company, Inc. Samples of the raw starch used in this study were tested by standard analytical methods at The Institute of Paper Chemistry. The results of these analytical determinations are given in Table V. Bacteriological examination of the starch indicated that it had a relatively low bacterial count. The total bacterial count, as represented by the colonies which

TABLE I

PHYSICAL CHARACTERISTICS OF 42-LB. FOURDRINIER KRAFT LINERS

Two Selected Rolls and Average of All Rolls for Each Mill

Mill Code	I.P.C. Roll No.	Date of Manuf.	Basis Weight (12 x 12/1000), lb.	Caliper, points	Apparent Density, lb./cu. ft.	Moisture, %	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb.		Elmendorf Tear, g./sheet		Amthor Tensile, lb.		Amthor Stretch, %	
									In	Across	In	Across	In	Across	In	Across
Av. (XV)*			41.1	14.8	33.2	9.1	99	35	28.5	22.1	343	391	78.5	36.2	2.2	3.4
A-7	15	11/15/44	40.1	14.5	33.2	11.7	103	34	29.0	22.1	351	396	78.1	37.6	2.5	3.4
A-22	16	3/14/45	42.7	14.9	34.3	9.9	100	36	27.6	22.3	321	370	77.1	35.2	2.1	3.3
Av. (XVII)*			42.9	15.4	33.4	8.7	101	37	30.6	23.7	353	397	84.1	38.1	2.2	3.8
B-13	19	9/25/44	42.8	15.6	32.9	11.1	103	38	32.3	23.8	352	407	85.7	38.7	2.4	3.5
B-1	20	1/29/45	42.2	15.7	32.2	9.0	101	34	29.7	22.6	337	412	83.6	35.4	2.4	3.6
Av. (XIX)*			42.7	14.5	35.3	7.1	100	39	29.8	22.2	364	405	85.9	38.9	1.9	4.1
C-10	25	4/ 4/45	42.3	14.7	34.5	5.8	103	40	28.9	22.0	366	401	85.2	36.7	1.8	4.4
C-9	26	4/ 4/45	42.1	15.0	33.7	5.5	99	40	29.9	21.1	376	411	92.0	35.7	1.9	4.2
Av. (XXI)*			41.7	14.8	33.8	7.4	98	36	28.1	22.5	360	378	70.4	39.5	2.0	3.5
D-20	27	11/ 3/44	41.0	15.1	32.6	5.5	93	36	27.8	22.4	358	372	70.4	39.3	2.3	4.1
D-5	28	12/30/44	43.9	16.7	31.5	7.7	100	44	27.4	21.6	391	415	69.7	39.8	1.9	3.2
Av. (XXIII)*			43.4	15.7	33.2	7.5	91	35	27.5	20.6	324	365	77.1	34.3	1.8	3.6
E-5	29	3/21/45	43.0	16.0	32.2	6.9	92	35	30.4	20.9	303	362	82.3	33.3	1.7	3.6
E-3	30	—	42.5	14.0	36.4	8.5	92	31	25.0	18.7	314	349	75.7	34.5	1.6	3.7
Av. (XXV)*			39.7	13.4	35.6	10.0	85	33	23.3	18.7	302	343	66.7	33.0	1.9	3.1
F-5	23	5/ 5/45	39.3	13.0	36.3	10.3	83	29	23.7	19.8	279	325	63.6	32.8	2.0	3.0
F-6	24	5/ 5/45	39.4	13.4	35.3	7.8	78	31	23.2	19.7	292	320	61.1	33.8	2.0	3.1
Av. (XXVII)*			41.9	15.6	32.2	7.0	91	38	27.4	23.7	380	405	72.3	41.8	1.7	3.6
G-12	31	4/ 2/45	40.2	15.3	31.5	5.8	91	39	28.1	23.7	364	407	70.8	38.6	1.6	3.6
G-1	32	4/ 2/45	42.6	15.5	33.0	7.3	93	37	27.4	23.6	373	429	76.0	41.4	1.7	3.1
Av. (XXIX)*			42.6	15.9	32.2	8.0	108	37	30.7	24.5	386	407	75.8	42.7	2.2	4.1
H-11	17	4/13/45	42.9	15.9	32.4	8.5	108	38	30.5	23.7	391	409	80.0	41.0	2.3	4.1
H-8	18	4/13/45	42.0	16.1	31.3	6.3	110	36	28.6	23.9	373	389	80.5	40.9	2.3	3.9
Av. (XXXI)*			43.5	15.3	34.2	8.4	109	41	30.9	21.8	408	465	85.4	36.8	2.3	4.5
I-10	21	1/31/45	43.2	15.5	33.4	8.9	109	40	29.8	20.4	405	463	83.9	36.5	2.2	4.5
I-12	22	1/30/45	43.8	15.7	33.5	9.6	109	40	30.0	22.3	422	470	80.5	37.0	2.3	4.4
Av. (XXXIII)*			41.7	14.7	34.2	7.7	93	32	30.4	23.7	301	355	74.8	35.9	2.0	3.2
J-11	33	2/25/45	41.9	15.2	33.1	7.7	96	34	30.6	22.7	290	370	75.7	34.3	2.0	3.0
J-3	34	3/15/45	41.9	15.4	32.6	7.6	97	34	28.9	23.8	319	378	76.5	38.2	2.0	2.8

* Mill averages: data from tables on pages 30 to 41 of Baseline Studies 1, Part I.

TABLE II

PHYSICAL CHARACTERISTICS OF .009/26-LB. CORRUGATING MEDIUM

One Selected Roll and Average of All Rolls for Each Mill

Mill Code	I.P.C. Roll No.	Date of Manuf.	Basis Weight (12 x 12/1000), lb.	Caliper, points	Apparent Density, lb./cu. ft.	Moisture, %	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb.		Elmendorf Tear, g./sheet		Amthor Tensile, lb.		Amthor Stretch, %	
									In	Across	In	Across	In	Across	In	Across
Av. (XLV)*			27.3	10.1	32.4	8.5	68	20	19.5	15.5	268	276	52.3	30.4	1.6	4.7
S-6	14	2/ 6/45	27.1	10.1	32.2	9.8	71	21	18.5	15.9	265	286	51.6	30.7	1.6	4.8
Av. (XLVII)*			27.0	10.0	32.5	11.8	57	20	15.9	12.8	237	261	45.1	24.2	1.8	3.7
T-9	10	5/ 2/45	25.9	9.7	32.0	10.9	58	20	15.9	12.9	214	246	48.0	24.1	1.9	3.8
Av. (XLIX)*			26.9	10.7	30.2	8.4	65	20	19.7	13.5	238	266	53.0	25.7	2.0	4.8
U-8	8	12/11/44	26.0	10.1	30.9	8.8	65	19	19.3	13.2	223	246	55.4	24.1	2.1	5.1
Av. (LI)*			25.8	10.1	30.7	9.2	32	11	12.9	10.3	121	134	31.0	17.2	1.4	2.4
V-7	11		26.1	10.3	30.4	8.5	31	13	12.4	10.3	115	129	31.4	18.0	1.2	2.4
Av. (LIII)*			26.8	10.1	31.8	11.1	69	19	17.7	11.5	228	300	56.6	21.8	2.1	3.8
W-8	7	2/27/45	25.7	9.1	33.9	10.0	69	18	17.3	10.7	226	310	55.5	22.6	2.5	3.7
Av. (LV)*			27.4	9.8	33.7	8.7	68	21	17.1	13.1	250	281	52.1	25.3	2.1	4.3
X-2	12	3/14/45	27.1	9.5	34.2	6.7	67	19	18.1	12.9	236	261	51.9	23.0	1.9	4.2
Av. (LVII)*			26.0	9.3	33.9	9.7	58	15	17.3	12.3	189	219	50.7	22.1	2.0	3.6
Y-9	13	3/12/45	26.1	9.2	34.0	11.1	51	13	16.0	11.9	180	219	49.0	22.1	1.9	3.3
Av. (LIX)*			26.8	9.3	34.7	9.1	75	20	19.9	15.8	251	262	53.8	33.0	2.0	4.7
Z-8	9	2/26/45	26.4	9.0	35.2	9.9	75	19	20.1	15.0	231	254	55.9	33.6	2.0	5.4

* Mill averages: data from tables on pages 59 to 67 of Baseline Studies 1, Part I.

TABLE III

PHYSICAL CHARACTERISTICS OF 42-LB. FOURDRINIER KRAFT LINERS

Mill Code	I.P.C. Roll No.	Date of Manuf.	Basis Weight (12 x 12/1000), lb.	Caliper, points	Apparent Density, lb./cu. ft.	Moisture, %	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb. In	Amthor Tensile, lb. Across	Amthor Stretch, % In	Amthor Stretch, % Across
Standard 42-lb. Liners																
Av. (III)*			42.1	15.0	33.7	8.1	98	36	29.0	22.5	354	394	77.8	37.8	2.1	3.7
A-18	1	2/ 8/45	41.9	15.3	32.8	9.1	104	34	29.8	24.4	339	404	80.5	36.9	2.0	3.7
H-6	2	3/20/45	41.6	15.9	31.4	7.7	105	36	31.3	22.8	339	391	79.5	39.1	2.1	4.0
B-3	3	1/29/45	44.1	15.5	34.1	8.9	105	36	28.7	22.6	356	395	77.6	36.1	2.4	3.9
A-24	4	3/15/45	43.3	15.1	34.4	10.1	98	37	27.7	22.6	331	404	74.7	36.1	2.2	3.4
A-27	5	11/15/44	40.5	14.8	32.8	7.6	95	33	28.2	21.4	325	373	74.9	37.4	2.1	3.3
A-28	6	11/15/44	40.0	14.6	32.8	6.0	99	33	27.5	21.5	320	385	77.3	37.5	2.0	3.4
High-Test Liners																
C-3	35	1/29/45	44.0	14.0	37.7	7.7	109	38	31.2	24.5	389	389	86.4	45.0	2.2	4.7
H-14	36	4/13/45	42.3	15.6	32.5	7.4	114	36	31.1	25.4	406	420	73.7	40.3	2.3	4.2
Low-Test Liners																
E-1	37	2/13/45	44.9	17.3	31.1	9.0	52	28	22.0	17.5	274	278	54.0	29.9	1.2	2.7
E-2	38	2/13/45	44.6	17.8	30.1	5.2	58	28	24.3	18.6	271	282	60.5	29.6	1.3	2.9

* Group average: data from Table III of Baseline Studies 1, Part I.

TABLE IV

PHYSICAL CHARACTERISTICS OF .009/26-LB. CORRUGATING MEDIUM

Mill Code	I.P.C. Roll No.	Date of Manuf.	Basis Weight (12 x 12/1000), lb.	Caliper, points	Apparent Density, lb./cu. ft.	Moisture, %	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb. In	Amthor Tensile, lb. Across	Amthor Stretch, % In	Amthor Stretch, % Across
Standard Corrugating Mediums																
Av. (XXXV)*			26.9	10.0	32.5	9.5	66	19	18.3	13.4	238	268	52.2	25.9	2.0	4.3
U-15	39	11/ 1/45	28.1	11.0	30.7	5.8	67	21	19.1	13.2	244	271	56.5	26.6	2.0	4.1
X-1	40	3/14/45	26.3	9.3	33.9	5.5	64	18	17.8	13.8	231	253	51.8	23.6	2.0	4.2
U-20	41	10/ 4/44	27.5	11.6	28.4	7.7	68	20	17.8	11.9	236	280	55.2	23.9	2.0	4.4
Y-6	42	3/10/45	27.0	9.8	33.1	10.5	65	18	16.8	13.1	238	270	54.0	26.6	2.1	3.7
High-Test Corrugating Mediums																
U-11	43	10/16/44	27.6	11.2	29.6	8.3	70	19	20.9	14.9	238	255	54.4	26.3	2.2	4.9
Low-Test Corrugating Mediums																
Y-10	44	3/12/45	24.9	9.5	31.6	10.1	48	13	14.3	10.0	182	214	45.9	20.2	1.8	3.0

* Group average: data from Table XXXV of Baseline Studies 1, Part I.

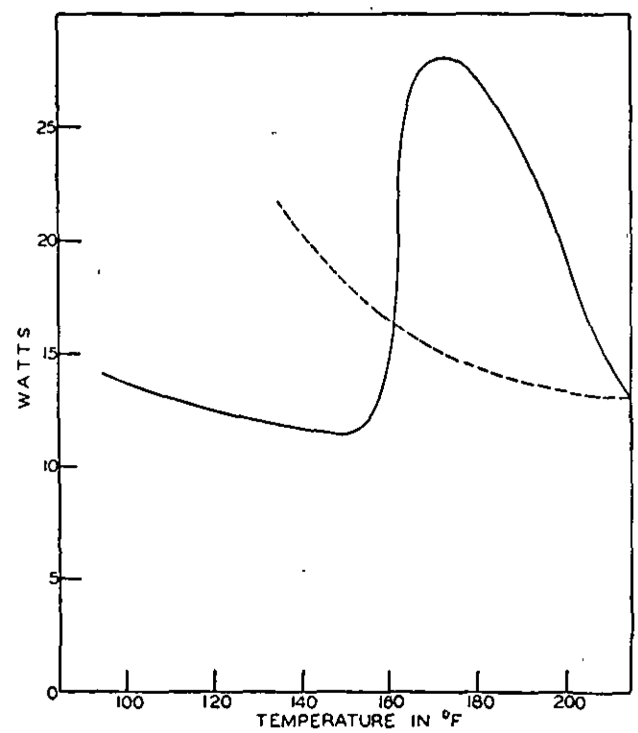

FIGURE 3. Consistometer Curve of Raw Starch Suspension.
———Heating --------Cooling

TABLE V

ANALYTICAL DATA FOR BONDCOR C ADHESIVE

Moisture*	9.54%
Cold water extractives**	0.23%
Ether extractives**	0.15%
Methanol-water (80-20) extractives**	0.67%
Potentiometric titration to pH 6.9*	4.1 ml. of 0.0195 N NaOH = 0.032% acid as SO_2
Potentiometric titration of whole starch with iodine**	25.5% amylose

* As received.
** Ovendry.

developed in Difco Nutrient Agar incubated at 37° C. for 48 hours, was 660 colonies per gram of dry starch. The estimated number of starch-hydrolyzing colonies was 430 per gram of dry starch.

A consistometer (viscosity) curve (determined on both a heating and cooling cycle) for a sample of Bondcor C starch suspension, as determined on the Institute's consistometer, is shown in Figure 3. In this curve, the power input is plotted as a function of the temperature of the raw starch suspension. The power input is the number of watts required to maintain a constant speed of rotation in the consistometer. As the temperature of the suspension increases and approaches the gel point of the starch, the viscosity of the suspension increases and, consequently, requires a corresponding increase in power input to maintain a constant speed of rotation. Thus, the power input serves as a measure of the viscosity of the suspension.

A single batch of starch adhesive was prepared and used for the entire fabrication run. Representatives of Stein, Hall & Company, Inc. and The Institute of Paper Chemistry collaborated in the preparation of the starch paste.

The carrier portion of the batch was made in a Francis mixer (666-gallon capacity) by suspending 150 pounds of Bondcor C starch in 1334 pounds of water previously heated to 110° F. Twenty-five pounds of sodium hydroxide were dissolved in 60 pounds of water and the solution was added to the starch suspension. This carrier portion was heated with direct steam to 165° F. and held at that temperature for 15 minutes.

In the meantime, the secondary mixer was charged with the following ingredients and agitated until thoroughly mixed:

2800 lb. of water at 80° F.,
24 lb. of bentonite (mixed 3 min.),
33 lb. of borax,
1020 lb. of Bondcor C starch, and
6 lb. of formaldehyde.

The carrier portion was mixed with the above charge in the secondary mixer until a homogeneous suspension resulted. The viscosity of the homogeneous suspension was 32.0 seconds (at 102° F.) as measured by The Institute of Paper Chemistry's viscometer (water—15 seconds at 72° F.).

General Procedure

The accomplishment of the objectives of this study required that the corrugating operation and the conversion into boxes be carried out by an impartial box maker under carefully-controlled, but normal, conditions of manufacture and according to the predetermined schedule of component combinations shown in Figure 1. All the combinations outlined were to be made at a machine speed of not less than 300 or more than 325 feet per minute. The same adhesive, operating crew, machine, and machine settings, within the limits of practicability were to be used. Thus, every effort was made to eliminate differences in machine or operational variables from combination to combination in order that the ultimate comparison of the combined board and boxes could be made on the basis of the characteristics of the liner and corrugating materials.

It is apparent that, in order to satisfy the conditions of fabrication set forth above, it was necessary that the fabrication and box-making procedure be carried out with extreme care. Otherwise, all the precautions taken to assure valid component sampling would be fruitless. In this regard, The Institute of Paper Chemistry was very fortunate in enlisting the services and co-operation of the Downing Box Company, 3832 Third Street, Milwaukee, Wisconsin, as the impartial box maker. It should be mentioned that, throughout the entire fabrication (July 21, 1945) and box-making program, the entire personnel of the Downing Box Company were extremely co-operative, even at times at the sacrifice of their own work.

Following the selection of the 42-pound Fourdrinier kraft liners and the 26-pound corrugating mediums for fabrication, the converters in whose warehouses the selected rolls happened to be stored were asked to ship them to the Downing Box Company for fabrication.

Initially, the component sampling program was to include only rolls 46 to 48 inches in width because the rolls selected for fabrication were to be made ultimately into 24 No. 2½ can size boxes; this width roll would permit running such box blanks "two out" on the corrugator. The scarcity of material resulting from wartime restrictions and emergency conditions made it necessary to sample rolls from 46 to 73 inches in width. Although a few of the selected rolls were in the width range of 46 to 48 inches, the majority were of greater width, and it was necessary, as an operational aid, to slit and rewind these rolls. The slitting and rewinding were done by the Hummel and Downing Company, 1514 East Thomas Avenue, Milwaukee, Wisconsin. The rolls which were slit and rewound are tabulated in Table VI. It should be mentioned that, whenever a roll is rewound, the outside lap of the original roll becomes the innermost lap of the new roll. Therefore, for all rolls which were slit and rewound, the outer end of the roll originally sampled and tested became the innermost part of the roll adjacent to the core after rewinding.

In order to facilitate the handling and arranging of the rolls in regard to sequence of running, each roll selected for conversion was assigned a new roll number. These roll numbers have been used throughout this report under the heading "I.P.C. roll numbers." These numbers (1 through 44) were stencilled on the ends of each roll. The numbers were approximately six inches in height and could easily be noted from some distance. At the time the rolls were renumbered, they were arranged in the warehouse in the exact order in which they were to be run on the corrugator. The sequence of fabrication, together with the I.P.C. roll numbers and the corresponding coded mill roll numbers, are given in Table VII and Figure 2. The coded mill roll numbers refer to the roll numbers as reported in Part I of Baseline Studies 1.

The fabrication run was made on a conventional 78-inch Langston duplex corrugator equipped with A- and B-flute rolls. However, only the B-flute rolls were used in this study. The corrugator was also equipped with a duplex slitting and scoring attachment, together with a double (continuous traveling) cut-off. The hot-plate section consisted of twenty-nine 18-inch plates, having an over-all length of approximately 45 feet and was equipped with the Velocity Steam System. Steam for the preheaters, rolls, and hot plates was furnished to the machine through a header at 125 to 130 pounds per square inch. The "cold" or pull section was approximately 46 feet in length.

The cutting schedule called for each roll combination to be made up into approximately 600 B-flute RSC 24 No. 2½ can size boxes. Since the selected rolls were slit and rewound to approximately 46-inch width rolls, this necessitated running the box blanks two-out on the corrugator. In addition, approximately 300 full-width unscored sheets were to be taken from each run for test purposes.

The sequence of running the stock on the corrugator was as follows: In order to make the necessary adjustments and settings, a set of unidentified 42-pound kraft liners and .009/26-pound kraft corrugating medium was run over the corrugator. This not only enabled the operator to make the necessary adjustments, but it also permitted the circulation of the starch adhesive which had been prepared for this fabrication run. All adjustments were made during the time the unidenti-

TABLE VI

ROLLS SLIT AND REWOUND

42-lb. Fourdrinier Kraft Liner Rolls

I.P.C. Roll No.	Mill Coded Roll No.	Original Width, in.	Lineal Feet	Weight, lb.	Trimmed Width, in.	New Weight, lb.
1	A-18	54	10,991	1998	48	1730
2	H-6	73	11,576	2802	48	—
5	A-27	52	12,648	2132	48	1940
6	A-28	52	12,486	2168	46	1915
15	A-7	50	12,471	2070	46	1900
16	A-22	49	8,135	1370	46	1290
17	H-11	49	11,867	1940	46	1815
18	H-8	49	11,928	1936	46	1800
21	I-10	58	7,400	1484	46	1190
22	I-12	58	7,500	1520	46	1180
23	F-5	54	13,300	2330	46	1935
24	F-6	54	13,400	2344	46	1950
25	C-10	50	—	1765	46	1610
26	C-9	50	—	1700	46	1600
27	D-20	56	7,928	1435	46	1185
28	D-5	54	10,660	2080	46	1800
29	E-5	60.5	—	2430	46	1735
30	E-3	52	—	1376	46	1165
31	G-12	54	9,030	1591	46	1350
32	G-1	56	11,880	2313	46	1885
33	J-11	50	—	1324	46	1200
35	C-3	50	—	2440	46	2220
36	H-14	49	11,918	1920	46	1765
37	E-1	66	—	1598	46	1110
38	E-2	52	—	1184	46	1030

.009/26-lb. Corrugating Medium Rolls

I.P.C. Roll No.	Mill Coded Roll No.	Original Width, in.	Lineal Feet	Weight, lb.	Trimmed Width, in.	New Weight, lb.
8	U-8	68	18,811	2570	48	1830
10	T-9	54	18,500	2094	46	1710
11	V-7	51	12,500	1490	46	1180
12	X-2	58	8,795	1100	46	885
13	Y-9	55.5	13,800	1666	46	1355
14	S-6	61	11,740	1541	46	1125
39	U-15	62	16,621	2226	46	1610
40	X-1	58	9,124	1130	46	895
41	U-20	63	15,771	2260	46	1635
42	Y-6	57	13,000	1592	46	1220
43	U-11	72	17,091	2752	46	1730
44	Y-10	57	13,000	1536	46	1200

TABLE VII

FABRICATION SEQUENCE

Run Sequence	Run Combination Number	Single-Face Liner		Corrugating Medium		Double-Face Liner	
		I.P.C. Roll Number	Mill Coded Roll Number	I.P.C. Roll Number	Mill Coded Roll Number	I.P.C. Roll Number	Mill Coded Roll Number
1	1	4	A-24	7	W-8	1	A-18
2	2	4	A-24	8	U-8	1	A-18
3	3	5	A-27	9	Z-8	1	A-18
4	4	5	A-27	10	T-9	2	H-6
5	5	5	A-27	11	V-7	2	H-6
6	6	5	A-27	12	X-2	2	H-6
7	7	6	A-28	13	Y-9	3	B-3
8	8	6	A-28	14	S-6	3	B-3
9	9	15	A-7	39	U-15	16	A-22
10	10	17	H-11	39	U-15	18	H-8
11	11	19	B-13	39	U-15	20	B-1
12	12	21	I-10	40	X-1	22	I-12
13	13	23	F-5	40	X-1	24	F-6
14	14	25	C-10	41	U-20	26	C-9
15	15	27	D-20	41	U-20	28	D-5
16	16	29	E-5	41	U-20	30	E-3
17	17	31	G-12	42	Y-6	32	G-1
18	18	33	J-11	42	Y6	34	J-3
19	19	35	C-3	43	U-11	36	H-14
20	20	35	C-3	44	Y-10	36	H-14
21	21	37	E-1	44	Y-10	38	E-2
22	22	37	E-1	43	U-11	38	E-2

fied rolls were running. Once the final adjustments were made, they were not changed materially throughout the entire fabrication of the selected rolls.

At the start of the preliminary run, using the unidentified rolls, the clearance between the glue pick-up roll and the glue transfer roll of the single facer was set at 0.012, 0.012, and 0.012 inch for front, center, and back, respectively. However, because of the condition of the corrugating rolls, it was necessary to increase this clearance to 0.013, 0.013, and 0.013 inch. After the pressure roll on the single facer was set, this setting was determined by means of a torque wrench, so that the same pressure could be maintained for each roll com-

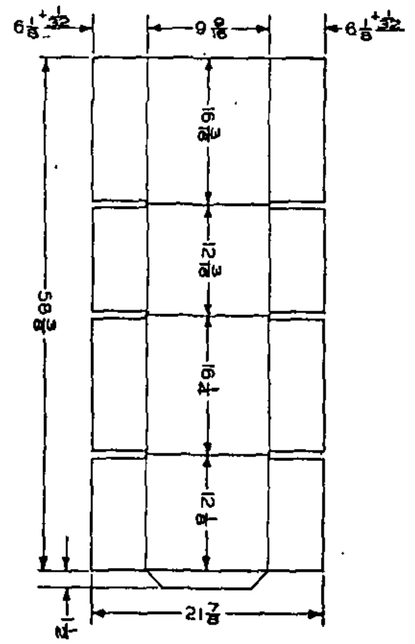

FIGURE 4. Scoring and Slotting Specifications.

bination. The finger settings were also checked for alignment and clearance.

The clearance between the glue pick-up roll and the glue transfer roll of the double facer was set at 0.012, 0.012, and 0.012 inch for front, center, and back, respectively. The clearance between the glue transfer roll and the top riding roll was set at 0.104 inch minimum.

The settings and final adjustments of the cut-off knives, slitters, and the conventional three-point creasing wheels, for putting in the horizontal (flap) scores, were made during the running of the unidentified rolls to give a blank size 58$\frac{3}{8}$"×21$\frac{7}{8}$", the flap scoring being 6$\frac{5}{32}$"×9$\frac{9}{16}$"×6$\frac{5}{32}$".

After the necessary adjustments had been made and the corrugator was producing satisfactory B-flute corrugated board at 300 lineal feet per minute, the unidentified rolls were replaced with the rolls selected for Run Combination 1. As soon as both the single facer and double facer were operating at a speed of at least 300 lineal feet per minute, the operator placed a mark on the single-face liner and at the same time notified the checker that the machine was up to the required speed. When the above mark reached the cut-off, the scored box blanks were saved. As soon as the required number of box blanks was obtained, the double-facer section of the corrugator was stopped, the sheet cut, and the slitter assembly rotated into a horizontal position so that a full-width unscored sheet could be obtained. The cut-off length remained unchanged. The double-facer section was started as soon as the slitter assembly was in the clear (this change required not over two minutes) and the required number of full-width untrimmed and unscored sheets was saved after the corrugator was up to and operating at a speed of at least 300 lineal feet per minute. When the required number of full-width sheets had been secured, the corrugator was stopped, and the rolls for Run Combination 2 were spliced on. The same procedure was followed in the fabrication of Run Combination 2, with the exception that the full-width untrimmed sheets were made first, since the slitter assembly was already set up for full-width sheets from Run Combination 1. In other words, in all the odd numbered run combinations the scored box blanks were made first and in all the even numbered run combinations the full-width untrimmed and unscored sheets were made first.

In each run combination, the front and back blanks were piled on different skids. In order to avoid any chance of crushing, each skid was loaded with stock from only one run combination.

Following the corrugating operation, each skid load of board was conditioned immediately by drawing air through the corrugations for 10 minutes by placing the skid load of board alongside a suction grill through which air was drawn by a 6500-cubic feet per minute exhaust fan.

Following fabrication and conditioning, the scored blanks were allowed to season overnight at atmospheric conditions before going to the printer-slotter. The printing, slotting, and panel scoring of all box blanks were carried out on a 32 by 70-inch Langston printer-slotter equipped with spring tension feed rolls and an automatic feeder. The printing and slotting were done the day following the fabrication run. The various combinations were printed and slotted in the same sequence as that used in the fabrication—i.e., *Run Combination 1* first and Run Combination 22 last.

The printing consisted of the box maker's certificate, run combination or lot number, and the letter F or B. The letter F identified the blank as having been made on the front side of the corrugator. Similarly, the letter B denoted a back-side blank. The scoring and slotting specifications are given in Figure 4.

As soon as the stock came from the printer-slotter, it was taken directly to the stitching department where it was stitched (6 stitches per box) on five Model No. 385 Bliss semi-automatic stitchers manufactured by the Dexter Folder Company. The stitching wire was 0.020 inch thick and 0.104 inch wide. The staple clinching legs were each 0.375 inch and the reach was 0.50 inch. Following the stitching the finished boxes were packed in A-flute RSC cartons. Approximately 45 knock-down boxes were packed per carton.

FABRICATION DATA AND SAMPLING

One of the major specifications for the fabrication run was that it should be made under carefully controlled but normal conditions of manufacture. To provide this control and to demonstrate that the operating conditions were normal, rather extensive operational data were taken.

The actual operation of the corrugator was carried out by the regular operating crew of the Downing Box Company. Representatives of The Institute of Paper Chemistry were assigned the tasks of collecting and recording pertinent operational information, and of sampling the components and combined board periodically throughout the entire fabrication operation.

Before each roll was shafted and at the end of each run combination, a sample the full width of the roll and at least 15 feet in length was obtained from each component roll. At the middle of each run combination (during the slitter change), "cut-out" samples approximately 12 inches wide and 10 feet long were obtained for each roll. For those rolls (standard liners and corrugating medium) which were used in more than one run combination, full width samples were taken only at the time the rolls were shafted and when the rolls were taken out of the machine. All other samples taken from these rolls were "cut-outs," since a full-width sample would have necessitated breaking down the sheet.

Each sample strip was marked as to front or back side, roll number, run combination, radius of roll, where sampled, and the time. For moisture determination, three one-square foot samples (one each from front, center, and back) were cut from each full-width strip. Where only "cut-out" samples were taken, it was possible to secure only two moisture samples, one from the front and one from the back side. The moisture samples were weighed immediately to obtain their airdry weight, and then calipered. The samples were forwarded to The Institute of Paper Chemistry where they were oven dried to constant weight in an oven equipped with forced circulation and maintained at a temperature of 103–105° C. All weighings were made on a balance which was graduated to 0.01 gram. The remainder of the sample not used for moisture determination was also forwarded to the Institute for test purposes. The results of the moisture determination on the component materials are shown in Table VIII.

A complete tabulation of the quantity of the corrugated board, together with the corrugator speed at which it was produced, is given in Tables IX and X. All the corrugated board made at a speed of less than 300 feet per minute was discarded; however, the total lineal footage was recorded in order to compute the adhesive consumption per thousand square feet of combined board. When the corrugator was making satisfactory board at a speed of at least 300 feet per minute, samples for that particular run combination were collected. At the beginning and end of each sampling period, two front and two back side scored blanks were taken for moisture and caliper determinations. Two one-square foot samples were cut from each scored blank, coded, calipered, and weighed. After a one-hour interval, the same samples were reweighed and forwarded to the Institute for determining the ovendry weight. The results of the moisture determinations made on samples of combined board immediately after fabrication and also after seasoning for one hour at room atmosphere are given in Table XI.

TABLE VIII

MOISTURE CONTENT OF COMPONENT MATERIALS AT TIME OF FABRICATION

Run Combination	Single-Face Liner	Corrugating Medium	Double-Face Liner
	Moisture (ovendry basis), %		
1	9.3	9.7	9.4
2	9.9	9.5	9.3
3	8.9	10.5	9.7
4	9.9	9.9	6.8
5	10.4	9.9	10.4
6	10.0	9.4	10.0
7	9.3	10.1	9.4
8	10.4	9.6	9.8
9	9.4	8.9	8.2
10	8.4	10.0	8.3
11	8.4	9.5	8.6
12	8.5	8.1	8.4
13	8.9	10.2	8.6
14	8.0	9.1	8.6
15	8.4	10.2	8.4
16	8.8	10.0	9.5
17	8.3	8.5	8.4
18	8.8	9.6	8.7
19	8.1	8.8	8.5
20	8.3	8.9	8.4
21	7.6	9.6	7.5
22	9.1	9.5	9.2

In addition to the men recording the fabrication data, checking roll sequence and alignment, roll settings and clearances, etc., three men were assigned the responsibility of recording all pertinent temperature data. One of these men was assigned the checking and recording of the temperatures at the single facer, a second man the double facer, and the third man the temperatures of the hot plates. All temperatures were taken by means of Alnor pyrometers which were previously checked for accuracy. Temperature check diagrams were used by these observers to assist them in recording the temperature data as to location, time, and run combination.

The temperature check diagram used at the single

TABLE IX
SCORED SHEETS PRODUCED

Run Combination	Sheet Blank Size, Inches	No. Out	Counter Reading: Start Run	Start Sampling: Time	Start Sampling: Reading	End Sampling: Time	End Sampling: Reading	End Run	Experimental Sheets: Front	Experimental Sheets: Back	Untrimmed Width, in.	Totals: Sheets Run	Totals: Sq. Ft.	Machine Speed, Lineal Feet per Minute*
1	58⅜ x 21⅞	2	0	8:29	124		448	467	324	324	48	467	9087.0	320
2	58⅜ x 21⅞	2	0	8:47	109		300	309	191	191	48	309	6012.6	315
3	58⅜ x 21⅞	2	0	9:15	102		300	307	198	198	48	307	5973.7	325
4	58⅜ x 21⅞	2	0	9:29	155		408	418	253	253	46	418	7794.7	320
5	58⅜ x 21⅞	2	0	9:57	93	10:00	333	342	240	240	46	342	6377.5	325
6	58⅜ x 21⅞	2	0	10:07	112	10:10	268	283	156	156	46	283	5277.3	325
7	58⅜ x 21⅞	2	0	10:35	125	10:40	424	431	299	299	46	431	8037.1	325
8	58⅜ x 21⅞	2	0	10:47	121	10:54	420	432	299	299	46	432	8055.8	320
9	58⅜ x 21⅞	2	0	11:19	110	11:24	415	419	305	305	46	419	7813.3	315
10	58⅜ x 21⅞	2	0	11:35	198	11:40	499	513	301	301	46	513	9566.2	325
11	58⅜ x 21⅞	2	0	1:06	83	1:11	378	384	295	295	46	384	7160.7	315
12	58⅜ x 21⅞	2	0	1:21	164	1:26	461	474	297	297	46	474	8839.0	320
13	58⅜ x 21⅞	2	0	1:44	110	1:48	335	345	225	225	46	345	6433.4	315
14	58⅜ x 21⅞	2	0	2:00	163	2:05	458	470	295	295	46	470	8764.4	320
15	58⅜ x 21⅞	2	0	2:26	115	2:31	415	424	300	300	46	424	7906.6	310
16	58⅜ x 21⅞	2	0	2:57	132	3:02	429	440	297	297	46	440	8204.9	325
17	58⅜ x 21⅞	2	0	3:30	159	3:35	454	462	295	295	46	462	8615.2	310
18	58⅜ x 21⅞	2	0	3:47	198	3:52	439	449	241	241	46	449	8372.8	315
19	58⅜ x 21⅞	2	0	4:19	78	4:25	375	384	297	297	46	384	7160.7	320
20	58⅜ x 21⅞	2	0	4:30	136	4:35	436	445	300	300	46	445	8298.2	315
21	58⅜ x 21⅞	2	0	4:54	89	4:57	289	298	200	200	46	298	5557.0	320
22	58⅜ x 21⅞	2	0	5:02	119	5:06	319	330	300	300	46	330	6153.7	325

* The corrugator speeds were automatically recorded on the chart of a "Tetco" recorder, Type R300, produced by The Tachometer Corporation.

TABLE X
UNSCORED SHEETS PRODUCED

Run Combination	Blank Size, in.	No. Out	Counter Reading: Start Run	Start Sampling: Time	Start Sampling: Reading	End Sampling: Time	End Sampling: Reading	End Run	Experimental Blanks Saved: Width, in.	Experimental Blanks Saved: No.	Untrimmed Blanks Run	Blanks, Square Ft.	Machine Speed, Lineal Feet Per Minute*
1	58⅜ x 48	1	0			8:25 A.M.	220	225	48	220	225	4,378.1	310
2	58⅜ x 48	1	0		90	8:55 A.M.	242	242	48	152	242	4,708.9	325
3	58⅜ x 48	1	0		401	9:11 A.M.	551	565	48	150	565	10,993.9	320
4	58⅜ x 46	1	0		132	9:41 A.M.	276	288	46	144	288	5,370.5	325
5	58⅜ x 46	1	0		142	9:52 A.M.	300	313	46	158	313	5,836.7	325
6	58⅜ x 46	1	0		88	10:15 A.M.	189	193	46	101	193	3,599.0	340
7	58⅜ x 46	1	0		123	10:29 A.M.	277	289	46	154	289	5,389.2	320
8	58⅜ x 46	1	0		145	11:00 A.M.	346	354	46	201	354	6,601.3	310
9	58⅜ x 46	1	0		163	11:15 A.M.	321	334	46	158	334	6,228.3	320
10	58⅜ x 46	1	0		171	11:52 A.M.	320	400	46	149	400	7,459.0	320
11	58⅜ x 46	1	0		167	1:03 P.M.	317	336	46	150	336	6,265.6	320
12	58⅜ x 46	1	0		115	1:33 P.M.	261	269	46	146	269	5,016.2	320
13	58⅜ x 46	1	0		167	1:41 P.M.	330	343	46	163	343	6,396.1	325
14	58⅜ x 46	1	0		134	2:10 P.M.	283	291	46	149	291	5,426.5	310
15	58⅜ x 46	1	0		117	2:22 P.M.	315	328	46	198	328	6,116.4	320
16	58⅜ x 46	1	0		124	3:10 P.M.	395	459	46	271	459	8,559.2	315
17	58⅜ x 46	1	0		469	3:25 P.M.	569	580	46	100	580	10,815.6	310
18	58⅜ x 46	1	0		140	4:01 P.M.	435	441	46	295	441	8,223.6	305
19	58⅜ x 46	1	0		154	4:14 P.M.	352	365	46	198	365	6,806.4	310
20	58⅜ x 46	1	0		80	4:41 P.M.	280	288	46	200	288	5,370.5	320
21	58⅜ x 46	1	0		138	4:51 P.M.	240	253	46	102	253	4,717.8	310
22	58⅜ x 46	1	0		143	5:21 P.M.	380	380	46	237	380	7,086.1	320

* See Note Table IX.

facer may be seen in Figure 5. The temperature checks on the single-face liner preheaters, corrugating medium preheater, pressure roll, and corrugating rolls were taken at approximately hourly intervals. The temperature checks at the various points on the single-face liner and corrugating medium were taken on every run combination at the time the samples for that particular run were being collected. The temperature data taken at the single facer are shown in Table XII. The temperatures throughout the entire run were, from a practical standpoint, quite uniform.

In addition to the men who were responsible for recording the temperature data, one man was assigned the responsibility of checking and recording all pertinent starch data. A complete record of the starch suspension characteristics, together with periodic pH and specific gravity values, was maintained during the entire run. The recorded data are given in Table XIV.

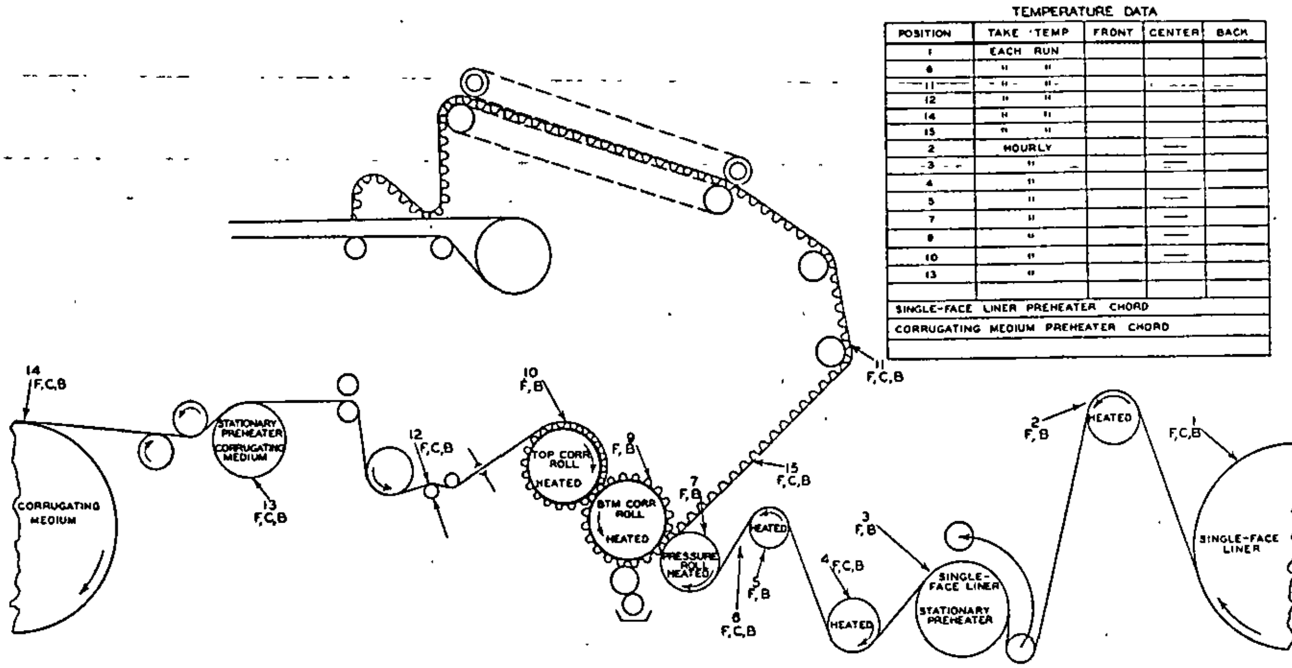

FIGURE 5. Temperature Check Diagram—Single Facer.

The temperature check diagram used at the double facer is shown in Figure 6. The temperature checks on the preheaters were taken at approximately hourly intervals. The temperature checks on the double-face liner and single-faced board were taken on every run combination at the time samples for that particular run were being collected. The temperature data recorded at the double facer are given in Table XIII. It may be noted that, with few exceptions, the temperature at any given point was practically the same throughout the entire fabrication phase.

Once during each run combination the temperatures on the front and back sides of each hotplate were measured and recorded. These temperature readings were taken during the time that board samples were being collected—i.e., the corrugator was operating at a speed of at least 300 lineal feet per minute.

In addition to the hotplate temperatures, the surface temperature of the double-face liner was continuously measured and recorded by means of a thermocouple and a Minneapolis-Honeywell continuous recorder. The thermocuple was so arranged that it contacted the double-face liner as it emerged from the hotplate section. The temperature data taken at the end of the hotplate section are shown in Table XIII.

The pH, gel point, viscosity, temperature, and specific gravity of the starch adhesive did not change significantly during the fabrication run.

Consistometer tests were made on samples of the

TABLE XI

MOISTURE CONTENT OF COMBINED BOARD

ROOM ATMOSPHERE

Run Combination	Immediately from Machine, %	After One Hour, %
1	8.7	10.1
2	8.0	—
3	9.2	—
4	8.5	—
5	8.3	—
6	8.0	—
7	8.4	—
8	8.9	—
9	8.4	—
10	7.2	—
11	7.7	7.7
12	6.2	7.0
13	7.3	7.6
14	7.8	8.1
15	8.2	8.5
16	8.4	8.6
17	7.3	7.6
18	9.0	9.1
19	7.6	7.9
20	7.6	7.9
21	8.0	8.1
22	7.9	8.1

TABLE XII

TEMPERATURE DATA AT SINGLE FACER

All data in °F.

Run Combination	Time Reading Front–Back	Pressure Header Line to Single Facer	#1** Temperature Liner Roll			#11 Single-Faced Stock—Liner Side at Base of Incline Conveyor			#12 Corrugating Medium—Top Side After Dancer Roll			#14 Corrugating Medium Roll			#2 Temperature First Heated Roll for Single-Face Liner			#3 Stationary Preheater Single-Face Liner	
			Front	Center	Back	Front	Center	Back	Front	Center	Back	Front	Center	Back	Front	Center	Back	Front	Back
Prelim. Run	8:00– 8:10	135	80	75	75	250	240	240	100	100	100	80		85	345		345	335	335
1	8:19– 8:29	125	50	60	60	240	240	240	215	240		90	90	80				348	
2	8:40– 8:50	130	80	80	82	225	225	225	200	191	190	80	80	80	345		345	345	345
3	9:05– 9:15	130	80	75	80	250	248	250	150	160	150	82	85	82					
4	9:28– 9:32	130	75	75	75	265	260	265	160	160	160	75	75	75	355	350	350	340	345
5	9:48– 9:52	130	70	70	70	255	250	250	145	150	150	80	80	80				348	348
6	10:07–10:11	130	75	75	75	260	260	260	155	155	150	80	80	80					
7	10:30–10:36	130	78	78	78	265	260	270	160	155	150	80	80	80	360	360	360	348	345
8	10:49–10:55	130	80	78	78	255	255	255	160	155	155	75	78	80	360		360	342	342
9	11:12–11:15	130	72	72	72	260	260	260	160	160	160	88	88	88	355	355	355	345	340
10	11:32–11:40	130	80	80	80	265	265	265	145	145	145	85	85	85				345	345
11	1:00– 1:07	128	80	80	80	260	260	260	150	150	140	90	90	90	340	340	340	345	345
12	1:18– 1:23	128	85	85	85	255	260	255	145	145	145	80	80	80					
13	1:36– 1:47	128	75	75	75	270	270	265	160	160	160	80	80	80	345	345	345	345	348
14	1:58– 2:01	130	75	75	75	245	245	245	155	155	153	85	85	85					
15	2:18– 2:30	128	80	80	80	245	245	245	140	140	140	85	85	85	340	340	340	340	340
16	2:55– 3:00	130	85	85	85	250	248	250	140	140	140	88	88	88					
17	3:15– 3:28	130	80	80	80	250	250	250	145	145	145	85	85	85	345	345	345	340	340
18	3:43	125	80	80	80	250	250	250	150	150	150	85	85	85					
19	4:09– 4:20	130	80	80	80	250	248	250	145	145	148	85	85	85	345	345	345	340	340
20	4:29– 4:32	128	75	75	75	245	245	245	145	145	145	85	82	82					
21	4:47– 4:55	130	82	82	82	245	245	245	145	145	145	83	83	83	340		345	342	343
22	4:59– 5:03	128	80	80	80	242	242	245	140	140	140	83	82	83					

* The preheater liner chord was measured as the minimum chord which could be drawn between the points where the liner contacted the circular preheater; thus, it is an indirect measure of the contact surface.

** Number at top of column corresponds to like number in temperature check diagram.

TABLE XIII

TEMPERATURE DATA AT DOUBLE FACER

All data in °F.

Run Combination	Time Read	#16 Double-Face Liner Before Preheaters			#21 Single-Faced Stock Entering Glue Station Corrugated			#22 Single-Faced Stock Liner Surface Before Entering Hot Plates			#23 Single-Faced Stock from Bridge Liner Surface		#24 Single-Faced Stock from Bridge Corrugated Surface		
		Front	Center	Back	Front	Center	Back	Front	Center	Back	Front	Back	Front	Center	Back
1	8:10– 8:25	85	90	90	95	110	100	130		155	100	105	100	110	100
2	8:30– 8:45	80	85	80	110	125	105	95	100	150	100	100	180	175	150
3	9:05– 9:15	80	80	80	110	110	85	95	100	105	95	100	155	130	140
4	9:30– 9:45	80	80	80		90	90		105	110		100		95	90
5	9:50– 9:55	70		80	100	100	90	135	140	140	90	100	105	105	110
6	10:05–10:15	75	60	85	120	110	100	145	150	140	95	105	100	90	105
7	10:25–10:35	50	55	85	95	95	105	135	140	140	100	95	100	95	110
8	10:45–10:55	75	80	75	100	95	110	130	130	130	95	90	95	95	95
9	11:10–11:20	80	85	50	100	105	95	135	140	140	95	100	95	100	95
10	11:35–11:50	70	70	80	115	110	90	135	140	135	95	95	120	110	95
11	1:00– 1:05	90	85	60	95	90	105	135	140	130	115	105	105	110	90
12	1:15– 1:25	60	70	80	105	105	105	130	135	135	95	95	110	110	95
13	1:35– 1:40	80	85	80	101	100	90	135	140	135	105	90	90	95	95
14	1:55– 2:05	95	95	85	105	105	100	140	145	135	100	80	110	105	90
15	2:20– 2:25	90	90	95	95	90	85	130	140	145	110	85	90	95	100
16	2:55– 3:05	90	90	100	100	100	115	130	140	135	120	90	110	110	95
17	3:15– 3:25	90	90	80	105	105	115	140	145	135	110	90	90	85	90
18	3:45– 4:00	60	60	80	100	100	100	140	145	150	100	95	110	110	95
19	4:10– 4:20	85	85	75	115	115	100	135	145	140	100	85	95	95	85
20	4:30– 4:40	80	80	60	110	110	105	140	145	145	85	85	75	75	80
21	4:45– 4:50	70	75	80	105	100	100	135	140	140	105	100	100	95	100
22	5:00– 5:15	75	75	80	105	100	100	140	145	140	100	100	95	95	95

* See Note Table XII.

TABLE XII

TEMPERATURE DATA AT SINGLE FACER

All data in °F.

#4 First Heater Roll After Stationary Single-Face Liner Preheater			#5 Second Heated Roll After Stationary Preheater for Single-Face Liner		#9 Bottom Corrugating Roll		#10 Top Corrugating Roll		#7 Pressure Roll		Shower Steam Pressure for Medium		#6 S. F. Liner Before Pressure Roll			* Single-Facer Pre-heater Liner Chord	#13 Medium Preheater			Run Combination
Front	Center	Back	Front	Back	Front	Back	Front	Back	Front	Back	Top	Bottom	Front	Center	Back		Front	Center	Back	
340	340	340	340	340	335	335					10	7	230	225	225	15⅜"	340		340	Prelim. Run
			350		340						10	10	240	250	240	15⅜"				1
345	345	348	348	345	325				345		25	10	225	225	230	15⅜"	348		348	2
											10	10				15⅜"				3
345	345	345			350	350	340	335		355	10	10				15⅜"	345	345	348	4
348	345	348			340	342			348	345	10	10				15⅜"				5
							310	315			10	10				15½"	340	340	340	6
348	348	348	348	348	325	325	322	320	348	348	10	10				15½"	345	345	345	7
					330	330	330	330	355	355	2	10				15½"	340	340	340	8
350	350	350									23	10				15½				9
350	348	348	348	348	330	325	325	325	340	340	25	10				15⅜"	345	345	345	10
345	340	345	345	345	325	325	325	320	345	345	25	10				15½"	345	345	345	11
											25	10				15½"				12
348	345	345	348	350	330	325	330	328	348	350	25	10				15½"	345	345	345	13
											10	10				15½"				14
345	345	345	345	345	330	325	325	325	345	345	10	10				15½"	345	345	345	15
											10	10				15½"				16
345	345	345	345	345	330	330	325	325	345	350	20	12				15½"	345	345	345	17
											20	10				15½"				18
342	343	343	345	345	330	330	330	330	345	345	10	10				15½"	345	345	345	19
											20	10				15½"				20
350	345	343	348	348	330	330	325	325	348	345	15	10				15½"	345	345	345	21
											10	10				15½"				22

TABLE XIII

TEMPERATURE DATA AT DOUBLE FACER

All data in °F.

#25 Double-Face Liner Before Entering Hot Plates Bottom Side			#17 Bottom-Liner Preheater Stationary		#18 Revolving Roll-Bottom Line Preheater		#20 Preheater Single-Faced Stock		Pre-heater Arc-Chord	Temperature Double-Face Liner (°F.) Discharge End of Hot Plate	Run Combination
Front	Center	Back	Front	Back	Front	Back	Front	Back			
145		165	310	305		325	350	345	12⅛	300	1
145	145	135							14¼	300	2
105	105	110							13¼	300	3
	150	150	350	345	375	360	355	355	14¼	300	4
145	150	140							14¼	300	5
140	140	150	340	345	355	360	360	355	14½	300	6
145	150	145							14½	305	7
150	*150*	*130*							*14½*	*310*	8
145	150	145	340	340	365	375	355	335	14½	305	9
140	145	155							14¼	300	10
145	150	155	340	360	355	370	350	375	14¼	305	11
140	150	155							14¼	297	12
140	150	150							13⅞	295	13
140	150	140	350	350	355	350	355	365	13⅞	310	14
145	150	150							13⅞	308	15
135	145	150	350	350	365	370	360	355	13½	305	16
155	165	155							13½	305	17
140	150	150							13¼	305	18
155	155	150	350	350	360	365	355	365	13¼	300	19
145	150	150							13¼	300	20
150	155		350	355	355	360	360	360	13¼	305	21
150	155	150							13¼	305	22

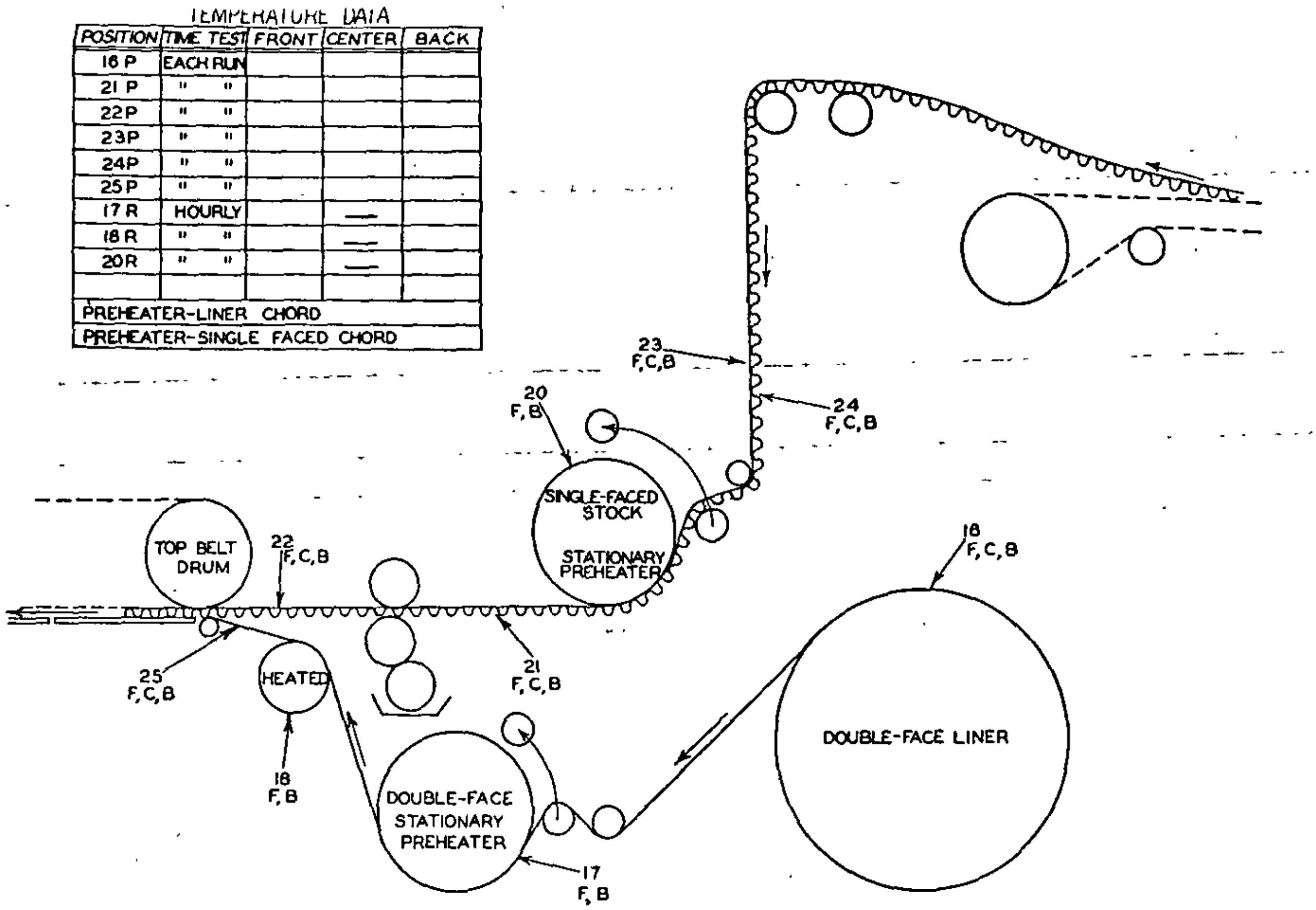

FIGURE 6. Temperature Check Diagram—Double Facer.

Bondcor C suspension taken from the storage tank at the beginning and end of the fabrication run and are given in Figures 7 and 8, respectively. The curves show a satisfactory gel point for corn starch and indicate that the starch had not been degraded. These curves also show that the viscosity characteristics of the starch suspension at the beginning and end of the run were practically identical and that the gel point did not shift during the run.

TABLE XIV
DATA ON THE CORRUGATING ADHESIVE DURING FABRICATION RUN

	pH Units	Gel Point in Pan, °C.	Temperature, °F. Storage Tank	Temperature, °F. Starch Pan	Viscosity, sec.* Storage Tank	Viscosity, sec.* Starch Pan	Specific Gravity in Storage Tank
7:30 a.m.**	10.95	67	102	102	32	33	1.075
8:30					32.0		
8:45	10.95		100		32.0	32.0	
9:10			100	102	33.0	32.0	
9:40	10.97	67.5	100	102	32.5	30.6	
10:10			100	101	32.5	32.5	
10:40			100	103	31.5	30.5	1.075
11:10			101	104	32.5	31.5	
11:40			100	104	32.2	30.0	
12:40 p.m.			100	104	32.0	31.0	
1:00	10.92	66.5	100	104	32.1	31.0	1.075
1:30			101	104	33.0	31.2	
2:00			100	105	33.0	29.3	
2:35			100	103	32.5	31.3	
3:00	10.91		100	104	33.5	31.2	1.075
3:30			101	104	33.5	31.5	
4:00		67.0	101	105	33.5	30.7	
4:30			102	105	31.9	30.0	
5:00			103	106	31.3	31.0	1.075

* Institute of Paper Chemistry viscometer (water = 15 seconds at 72° F.)
** Fabrication run started at 8:00 a.m. and was completed at approximately 5:00 p.m

TESTING PROCEDURE

The testing program carried out on the samples obtained from the fabrication of the various run combinations may be divided into three parts. First, physical tests were run on the samples of the component materials from which the combined board was fabricated. Second, physical tests were carried out on the combined board. Third, the boxes made during this run were subjected to laboratory tests to determine their comparative laboratory performance.

Component Tests

A component sample may be defined as a sample of either the liner or corrugating medium taken from the front, center, or back of the respective roll at any specific sampling period (beginning, middle, or end) of any of the twenty-two run combinations. These samples were conditioned and tested for basis weight, caliper, bursting strength, G. E. puncture, Elmendorf tear, Amthor tensile and stretch, and ring compression.

The samples were conditioned and tested by the procedure described in detail in Part I of Baseline Studies 1. In general, the number of specimens per sample and the number of tests per specimen were as outlined in the previous report. However, in some instances, the "cut-out" samples, taken at the middle of the run combination, were not of sufficient size to permit running all the tests. The detailed results for the physical characteristics of the components used in Run Combinations 1 through 22 are given in Table XLVII of Appendix A.

Combined Board Tests

Following the fabrication of the selected rolls into B-flute corrugated boards and their subsequent conversion into boxes, the "knock-down" boxes were packed in cartons and delivered by truck to The Institute of Paper Chemistry. As soon as the boxes were received, each specimen within each run combination or sample lot was stamped with a number corresponding to the code number under which the identity of that particular sample lot was filed. Following the coding, the specimens in each sample lot were thoroughly shuffled. Ten "knock-down" boxes made from the front-side blanks and ten boxes from the back-side blanks were withdrawn for the combined board tests (detailed test results are given in Tables XLV and XLVI of Appendix A). Within each sample lot, the combined board samples taken from the two lots of boxes were tested separately. However, the results shown in the body of the report are the average of the results thus obtained.

The combined board tests were carried out on the panels and flaps of the boxes selected for testing from each sample lot.

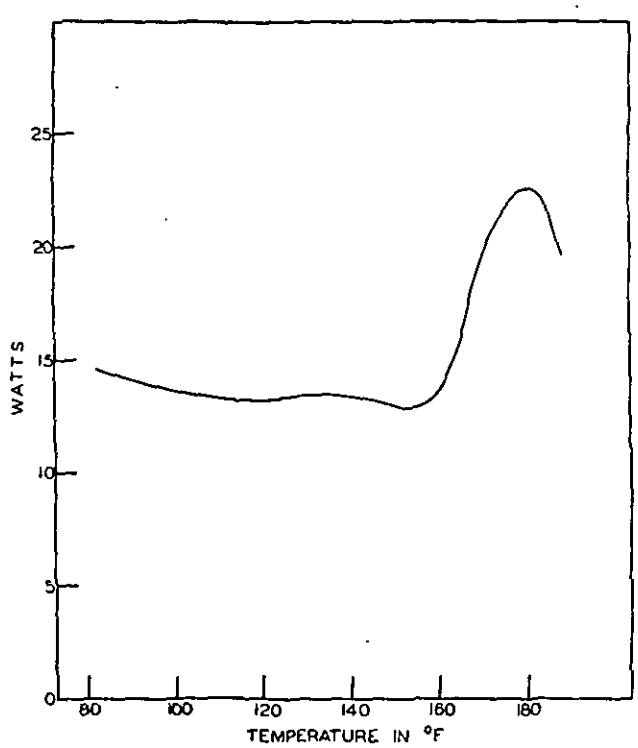

Figure 7. Consistometer Curve for Starch Adhesive at Beginning of Fabrication Run.

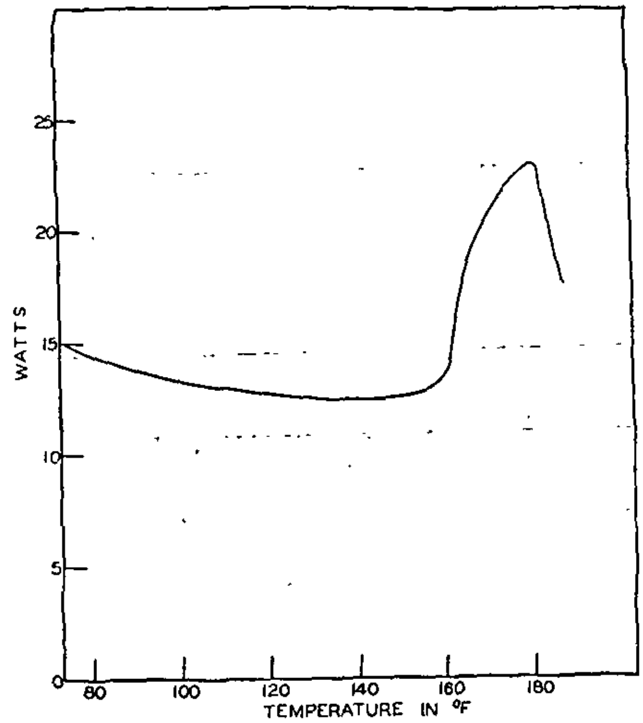

Figure 8. Consistometer Curve for Starch Adhesive at End of Fabrication Run.

The boxes withdrawn for combined board tests were preconditioned for at least 24 hours at a relative humidity of $35 \pm 2\%$ and at a temperature of $73 \pm 3.5°$ F. Following the preconditioning, the samples were conditioned for at least 48 hours and tested in an atmosphere at $50 \pm 2\%$ relative humidity and a temperature of $73 \pm 3.5°$ F.

The following combined board tests were carried out.

Basis Weight

The basis weight, expressed as the weight in pounds per thousand square feet of combined board, was determined by weighing one 9 by 12-inch specimen free from score lines from each of five test boxes. The five specimens were weighed at one time on a balance on which the smallest scale division was 0.01 gram. The results were then converted to pounds per thousand square feet.

Bursting Strength

Bursting strength tests were performed with a motor-driven "Jumbo" Mullen tester equipped with a 300-pound gage and also with a special attachment for controlling the clamping pressure on the specimen.

Two test readings were obtained on each of 10 specimens per sample. On each specimen, one test was obtained with the diaphragm pressure applied to the single-face liner and one test with the pressure applied to the double-face liner. The clamping pressure was set at approximately 15 pounds per square inch.

FIGURE 9. Small Revolving Drum Tester.

G. E. Puncture

The G. E. puncture tests were carried out with the new model G. E. puncture tester. TAPPI Standard T 803 m-44 was followed. Two punctures, one in each direction, were made on each of the 10 specimens per sample.

G. E. Stiffness

G. E. stiffness tests were carried out on the G. E. puncture tester by slitting the combined board along the lines corresponding to the edges of the puncture head and testing the aligned samples on the puncture tester (TAPPI Standard T 803 m-44). Two stiffness tests, one in each direction, were made on each of the 10 specimens per sample.

Adhesion

The normal adhesion test (pin adhesion test) was run on 10 specimens per sample. Five samples were run with the single-face liner down and five with the double-face liner down. Institute Tentative Method 581 was used for this work. Briefly, the method consists of inserting steel pins in the flutes of a corrugated board sample and forcing the liners apart uniformly by means of two racks (each of which engages alternate pins) in a small compression machine until rupture occurs. The rupture may be in the liner, in the glue line, or in the corrugations. The load at which rupture occurs and the nature of the rupture are recorded.

Hinde and Dauch Flat Crush

The flat crush resistance of corrugated board is the *maximum compressive force in pounds per square inch* that the corrugations will sustain before failure by collapse when the force is applied perpendicular to the surface of the board. Institute Tentative Method 575 was used for these tests. Tests were made on ten specimens per sample.

Moisture

The moisture content of the corrugated board was determined after conditioning in an atmosphere at $50 \pm 2\%$ relative humidity and a temperature of $73 \pm 3.5°$ F. Specimens from each sample lot were weighed in a tared weighing bottle and then dried for approximately 18 hours in a forced air circulation oven maintained at 105° C. When constant weight was attained, the loss in weight from the initial sample weight at 50% relative humidity was considered moisture and was calculated as such on the ovendry basis.

BOX TESTS

The specimens in each sample lot were coded and thoroughly shuffled so as to obtain random selection of each test specimen. In order to compensate for any possible difference between the boxes made on the front side of the corrugator from those made on the back side, equal numbers of boxes from each side were tested (for detailed test results, see Table XLIV of Appendix A) and the results are given as the average of the two tests.

Prior to testing, all boxes were preconditioned for 24 hours in an atmosphere at a relative humidity of not over 35%. The samples were then placed in an atmosphere having a relative humidity of $50 \pm 2\%$ and a temperature of $73 \pm 3.5°$ F. After 48 hours' conditioning in the atmosphere maintained at 50% relative humidity, the bottom flaps were flexed and sealed with silicate of soda.

Each container specimen for the drop and the drum test was loaded with 24 No. $2\frac{1}{2}$ size cans filled with water so that the gross weight of the cans was $50 \pm \frac{1}{2}$ pounds. The cans used were 1.25 hot-dipped tin-coated, plain tin inside and out.

After being sealed, all specimens were conditioned for a minimum of 48 hours in the testing atmosphere prior to testing.

Small Revolving Drum Test

The drum tests were performed in a 7-foot revolving drum tester (Figure 9). The drum had six faces with the usual standardized hazards and baffle boards for each fall.* Adjacent faces formed angles of about 120° with one another. The faces were mounted between two large steel annular rings which provided the driving surface for the drum. The drum revolved at a rate of $1\frac{5}{8}$ revolutions per minute, subjecting the specimen

* Newlin, J. A., and Wilson, T. R. C. The development of a box testing machine and some results of tests. Proc. Am. Soc. Testing Materials 16: 320–342 (1916). For drum specifications, see TAPPI Standard T 800 sm-44.

to 11 falls per minute, one fall being the passage of the specimen over one face of the drum.

Eight specimens of each type of box were tested in each sample lot. Each specimen was placed in the same position in the tester at the start of the test. As the drum revolved, observations were made of the number of falls at which various degrees of box damage developed. These included: (1) the first can cut, (2) the first six-inch tear, and (3) the final box failure.

Figure 10. 12-Inch Corner Drop Tester.

A *can cut* is defined as an opening in a score of the container produced by the impact or pressure of a can.

A *six-inch tear* is defined as the tear in a container measuring six inches in length, regardless of the position of such a tear.

A *final box failure* is indicated by the spilling of the contents and/or by a tear joining any two parallel faces of the container.

Twelve-Inch Corner Drop Test

Drop tests to failure were made from a height of 12 inches by means of the apparatus shown in Figure 10. The containers were dropped on successive corners (as illustrated in Figure 11) onto the level, machined, cast-iron base of the apparatus.

Eight front and eight back specimens were tested in each sample lot. Each specimen was positioned in a canvas sling which was suspended from a quick release

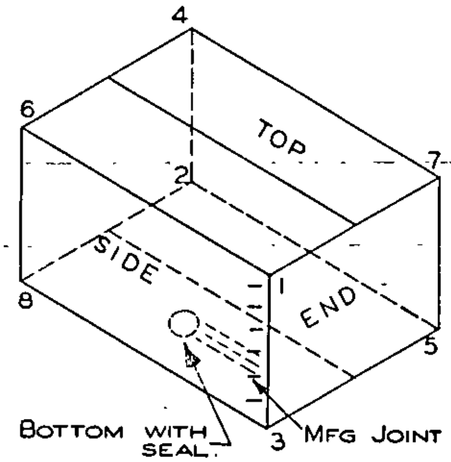

Figure 11. 12-Inch Drop Sequence.

hook which, in turn, was held by a block and tackle mechanism fastened to the top frame of the drop tester. Before each drop, the specimen was so aligned that a diagonal passing through opposite corners and the center of gravity of the box was perpendicular to the cast-iron base of the drop tester. The specimen was inspected after each drop. The number of drops required to develop each degree of box damage was reported on the same basis as for the small revolving

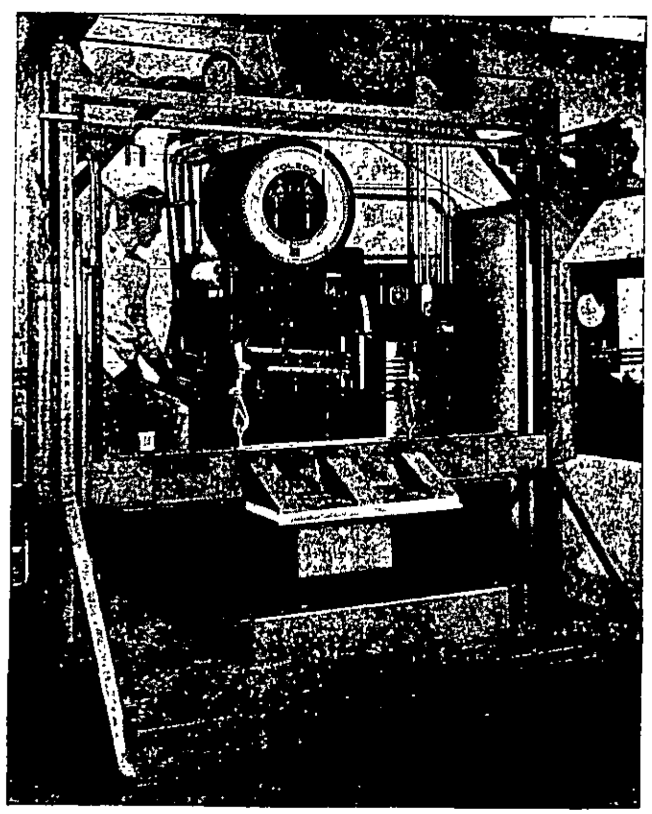

Figure 12. Compression Tester.

... i.e., first can cut, first 6-inch tear, and final *box failure.*

Compression Tests

Compression tests were made on empty, sealed containers according to TAPPI Standard T 804 m-45 (A.S.T.M. Designation D 642–43). The apparatus is shown in Figure 12. The upper platen of the compression tester was lowered mechanically at a uniform rate of $\frac{1}{2}$ inch per minute throughout each test. The upper platen was parallel to the platform of a scale which acted as the lower platen. Autographic stress-strain curves were obtained over the entire testing period. In this way, the stress value at any given strain value was obtained.

In this study, the deflection at an initial load of 50 pounds was considered as zero deflection. Thus, all the deflection values reported herein were measured with the zero deflection at 50-pound load as the zero reference point.

Eight front and eight back specimens were tested in each sample lot for top-load and end-load compression. The values obtained from the stress-strain diagram were:

1. The maximum load sustained
2. The deflection at maximum load
3. The loads sustained in the deflection ranges 0 to 0.25, 0 to 0.50, and 0 to 0.75 inches.

As indicated in Figure 2, the fabrication phase of the baseline study was divided into three sections. The first section consisted of Run Combinations 1 through 8 and was a comparison of the relative quality of the combined board and boxes which were produced by fabricating a roll of each participating mill's average quality corrugating medium with standard liners. The standard liners were representative of the over-all average quality of all the 42-lb. Fourdrinier kraft liner rolls tested in Part I of Baseline Studies 1.

The second section included Run Combinations 9 through 18 and was a comparison of the relative quality of the combined boards and boxes resulting from the fabrication of a set of each participating mill's average quality 42-lb. Fourdrinier kraft liners with a

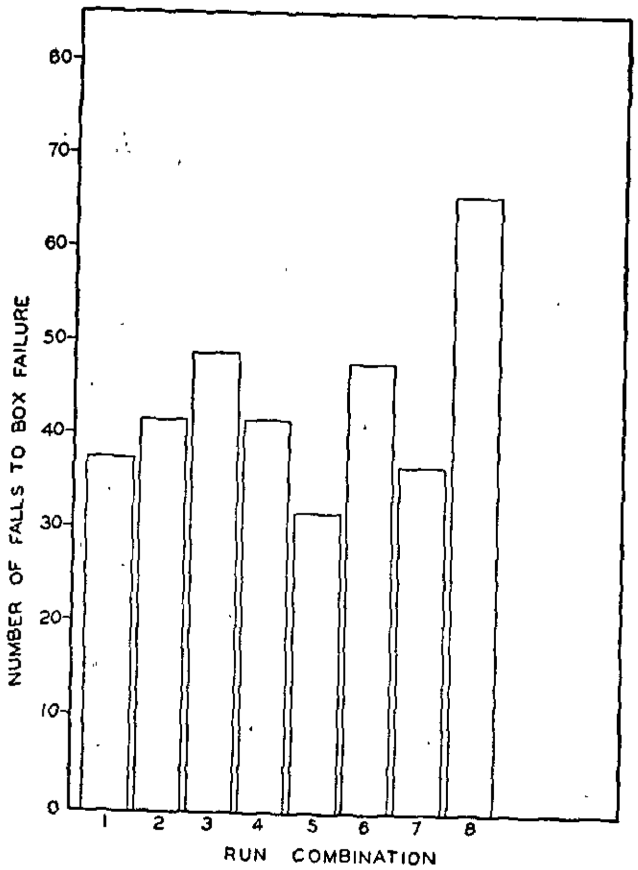

Figure 13. Comparison of Drum Tests—Run Combinations 1–8.

standard corrugating medium. The standard corrugating medium was representative of the over-all quality of all the 26-lb. Fourdrinier kraft corrugating rolls tested in Part I of Baseline Studies 1.

The third section included Run Combinations 19 through 22 and was a study of the quality of the combined board and subsequent boxes which were produced by the fabrication of various combinations of low- and high-test liners and corrugating mediums. It

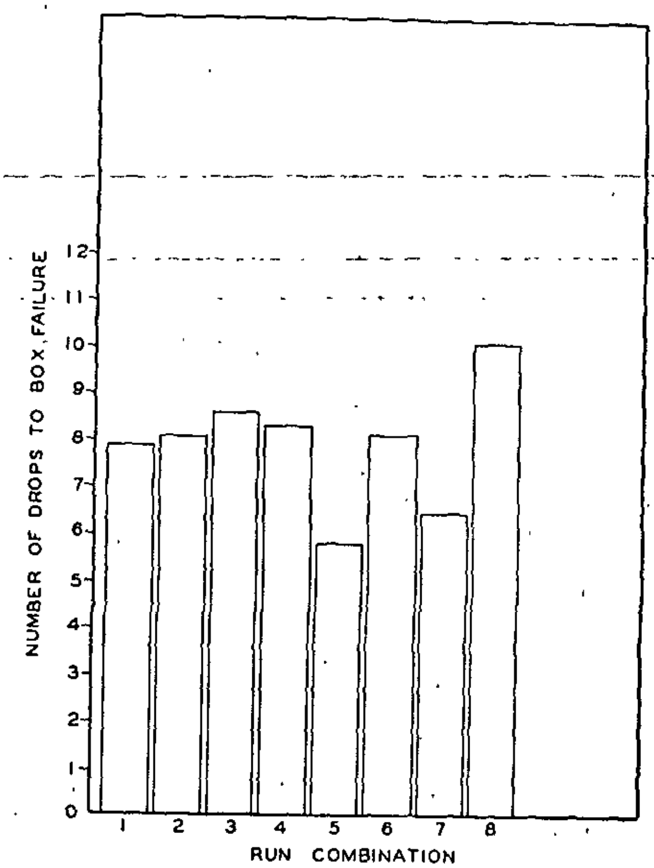

Figure 14. Comparison of 12-Inch Corner Drop Tests—Run Combinations 1–8.

is to be emphasized that the terms "high" and "low" strength as used in this particular study ***do not*** refer merely to low and high bursting strength but are indicative of the over-all physical strength comparison of those particular rolls as determined by bursting strength, Amthor tensile, stretch, Elmendorf tear, and ring compression.

Effect of Varying the Corrugating Medium (Run Combinations 1–8)

Boxes

The results of the physical tests on the boxes made from Run Combinations 1 through 8 may be seen in Table XV (see also Table XLI of Appendix A) and Figures 13–15. The average number of falls to box failure in the small revolving drum was 44 for the boxes in this group. When specimens from the same sample lots were subjected to the twelve-inch corner drop test, the group average number of drops to box failure was 7.9. Similarly, the group average top-compression load sustained within the deflection range 0–0.75 inch and the group average end-compression load sustained in the deflection range 0–0.50 inch were 477 and 563 pounds, respectively.

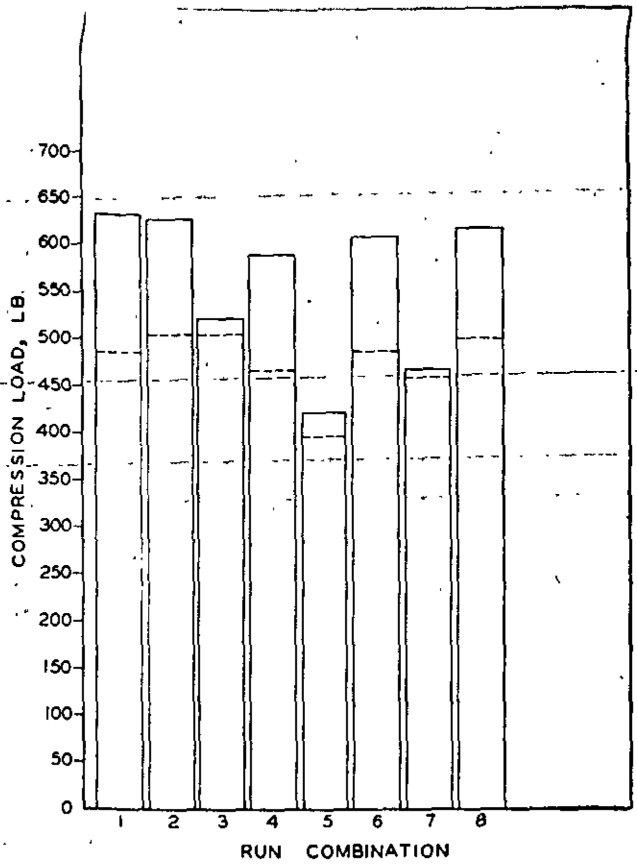

FIGURE 15. Comparison of Compression Tests—Run Combinations 1–8.
——— End Load (0–0.50 inch)
------------ Top Load (0–0.75 inch)

There was considerable variation among the boxes made in this series with corrugating mediums representative of the sampled production of the various mills. From the standpoint of compressive strength, Samples 1, 2, 6, and 8 were above the average. Samples 3 and 4 had compression values which were approximately the same as the group average. On the other hand, Samples 5 and 7 were substantially below the average for the group.

When the performance of the eight different samples was based on the results of the drop and drum tests, Samples 3, 6, and 8 were above the average, Samples 1, 2, and 4 compared favorably with the average for the group, and Samples 5 and 7 were below average.

The drum, drop, and compression results for Samples 6 and 8 were above the average for the group, and the same test results for Samples 5 and 7 were consistently below the average for the group.

A comparison of the results of the drum and drop tests showed that the drum test ranked the samples in approximately the same order as the drop test. However, the compression results did not necessarily align the samples in the same order as the drum or drop tests. This behavior indicated that the drum, drop, and compression tests do not necessarily measure the same characteristics of a box. Consequently, no one of the above tests alone should be used as an over-all index of quality as defined by laboratory box performance.

Combined Boards

The results of the combined board tests on samples taken from the boxes made from Run Combinations 1 through 8 are given in Table XVI (see also Table XLI of Appendix A) and Figures 16 and 17. It may be noted that the bursting strength results for all the run combinations were in excess of 200 points. The average bursting strength for the group was 234 points. The difference in bursting strength between the maximum (240) and minimum (220) sample averages amounted to only 20 points.

The group average for the G. E. puncture value was 208 units but, unlike the bursting strength, the difference between the maximum (226) and the minimum (169) sample average amounted to 57 units. Furthermore, the bursting strength value was always higher in magnitude than the corresponding G. E. puncture value. Samples 5 and 7, which had the lowest drum, drop, and compression values for the boxes, had the lowest G. E. puncture values on the combined board.

The group average for the G. E. stiffness value was 86 units. In general, the G. E. stiffness values showed about the same trend as the G. E. puncture values.

The average pin adhesion strength for the group was 68 pounds. Most of the samples were fairly consistent in respect to pin adhesion strength, the only exceptions being Samples 3 and 7.

It may be noted that the average flat crush value for

TABLE XV

PHYSICAL CHARACTERISTICS OF BOXES—RUN COMBINATIONS 1–8

Run Combination	I.P.C. Roll No.	Mill Code	Weight per 1000 Boxes, lb.	Drum: Falls to Box Failure	Drum: S. E.	Drum: S. E., %	12-Inch Corner Drop: Drops to Box Failure	12-Inch Corner Drop: S. E.	12-Inch Corner Drop: S. E., %	Top-Load Compression in Deflection, Range 0–0.75 in.: Load, lb.	Top-Load: S. E.	Top-Load: S. E., %	End-Load Compression in Deflection, Range 0–0.50 in.: Load, lb.	End-Load: S. E.	End-Load: S. E., %
1	7	W-8	1047	38	3.2	8	7.9	.50	6	487	7.1	1	634	16.8	3
2	8	U-8	1047	42	2.9	7	8.1	.32	4	506	8.3	2	628	10.9	2
3	9	Z-8	1031	49	3.1	6	8.6	.41	5	505	6.0	1	523	24.3	5
4	10	T-9	1038	42	3.4	8	8.3	.38	5	469	9.5	2	592	16.1	3
5	11	V-7	1038	32	2.8	9	5.8	.17	3	397	6.8	2	423	16.4	4
6	12	X-2	1038	48	3.3	7	8.1	.46	6	489	8.7	2	611	23.6	4
7	13	Y-9	1044	37	3.5	9	6.5	.38	6	460	7.2	2	469	12.6	3
8	14	S-6	1053	66	5.5	8	10.1	.50	5	502	6.2	1	620	17.9	3
Average			1042	44	3.5	8	7.9	.39	5	477	7.5	1.6	563	17.3	3.4

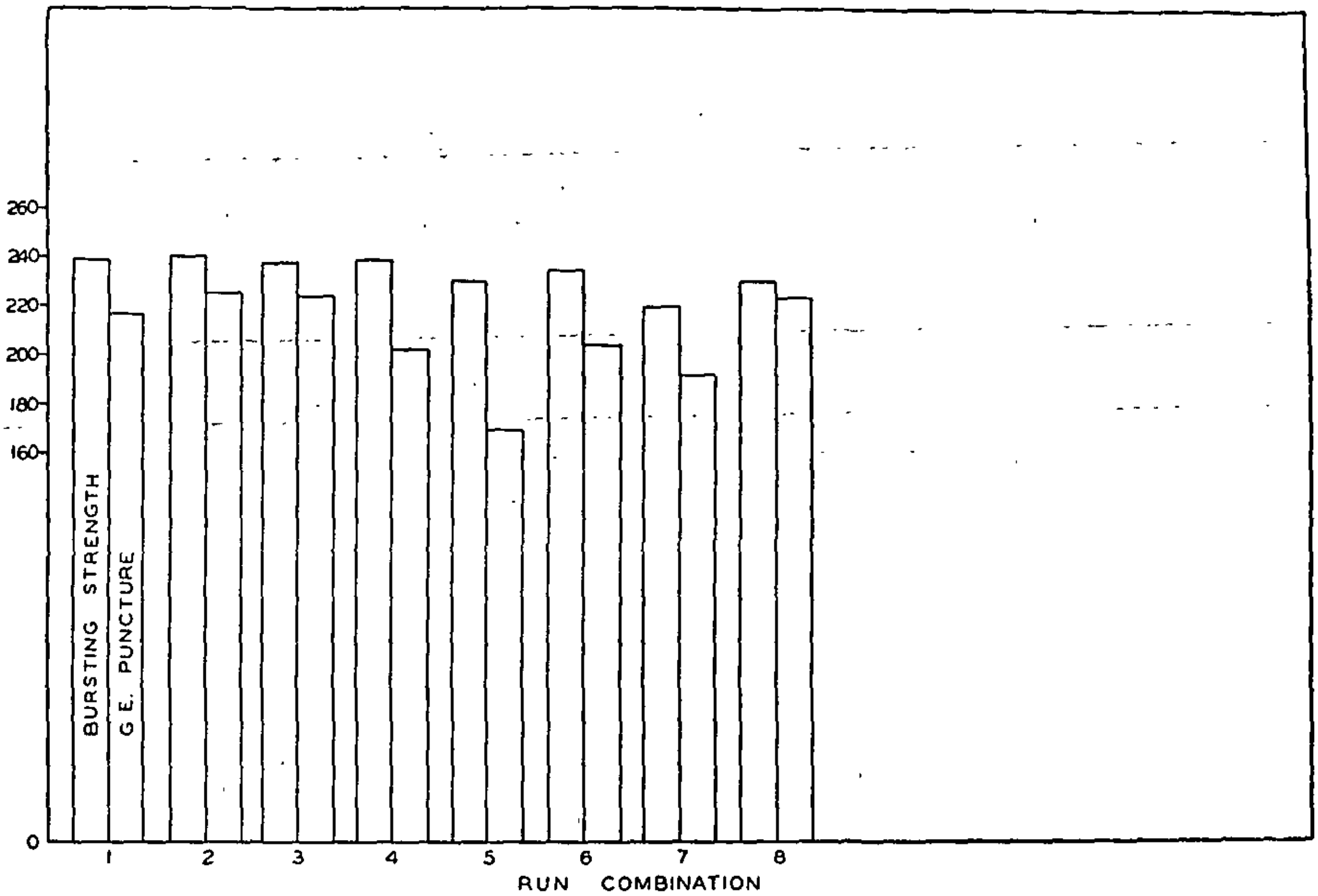

FIGURE 16. Comparison of Bursting Strength and G. E. Puncture Tests—Run Combinations 1-8.

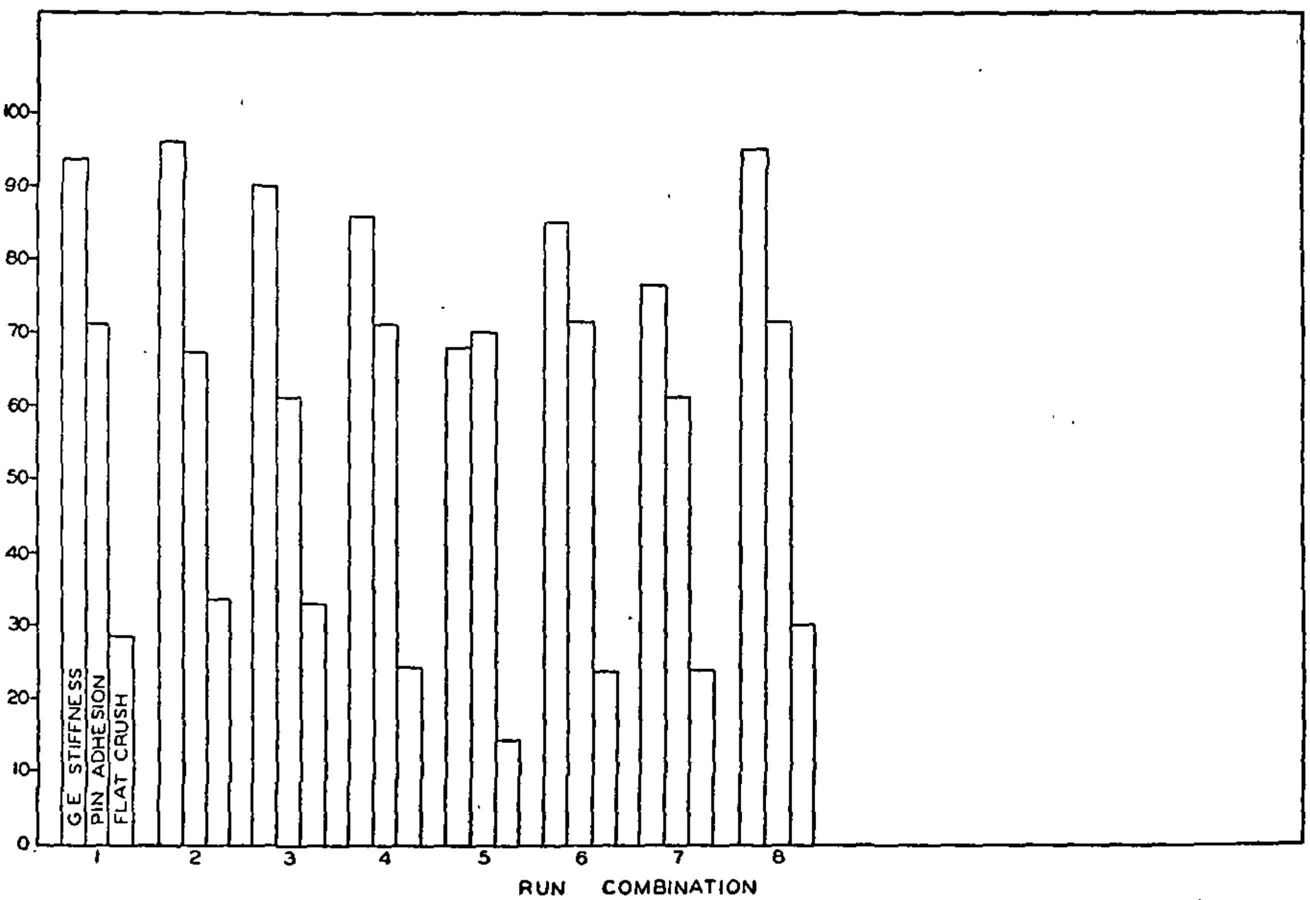

FIGURE 17. Comparison of G. E. Stiffness, Pin Adhesion, and Flat Crush Tests—Run Combinations 1-8.

TABLE XVI
PHYSICAL CHARACTERISTICS OF COMBINED BOARD—RUN COMBINATIONS 1–8

Run Combination	I.P.C. Roll No.	Mill Code	Moisture at 50% R. H., %	Basis Weight (12 x 12 x 1000), lb.	Bursting Strength			G. E. Puncture			G. E. Stiffness			Pin Adhesion			H. and D. Flat Crush		
					Points	S. E.	S. E., %	Units	S. E.	S. E., %	Units	S. E.	S. E., %	lb.	S. E.	S. E., %	lb./sq. in.	S. E.	S. E., %
1	7	W-8	8.3	121	239	2.5	1	217	1.5	1	93	1.3	1	71	1.2	2	28.1	0.7	2
2	8	U-8	7.9	122	240	3.3	1	226	1.4	1	96	1.1	1	67	1.1	2	34.2	0.4	1
3	9	Z-8	8.6	120	238	3.3	1	225	1.6	1	90	1.2	1	61	1.9	3	33.8	1.0	3
4	10	T-9	8.1	120	239	3.3	1	203	1.6	1	86	0.9	1	71	1.1	2	25.5	0.6	3
5	11	V-7	8.1	120	232	2.9	1	169	1.2	1	68	1.2	2	70	1.6	2	14.5	0.4	3
6	12	X-2	8.4	120	234	4.1	2	207	1.3	1	85	1.3	2	72	0.6	1	24.0	0.7	3
7	13	Y-9	8.4	120	220	3.1	1	194	1.9	1	77	1.4	2	62	2.2	4	23.8	1.2	5
8	14	S-6	8.6	122	230	2.9	1	224	1.3	1	94	1.7	2	72	0.9	1	30.1	1.9	6
Average			8.3	121	234	3.2	1	208	1.5	1	86	1.3	2	68	1.3	2	26.8	0.9	3

the group (26.8 p.s.i.) was considerably lower than the flat crush normally encountered on B-flute board. Samples 2, 3, and 8 were the only ones which had flat crush values of 30 p.s.i. or above. Sample 5 had an exceedingly low flat crush value—namely, 14.5 p.s.i. The sample with the lowest flat crush results also gave the lowest drum, drop, and compression results on the boxes. The flat crush, G. E. stiffness, and G. E. puncture tests ranked the samples in the same general order.

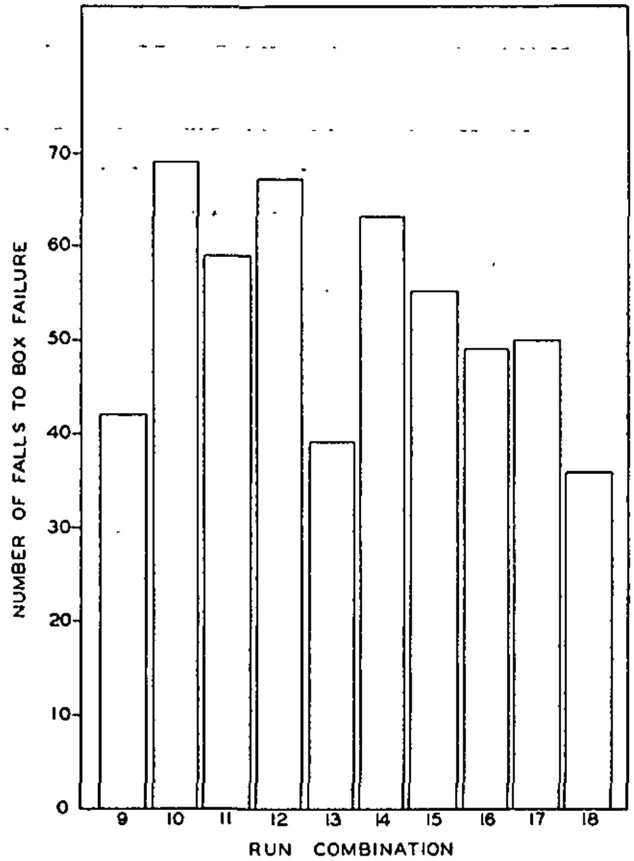

FIGURE 18. Comparison of Drum Tests—Run Combinations 9–18.

Components

A tabulation of the physical characteristics of the materials used in Run Combinations 1 through 8 is given in Table XVII (see also Table XLI of Appendix A). A comparison of the over-all test results indicated that, in general, the physical characteristics of the single-face liners used in Run Combinations 1–8 were fairly uniform. The same may be said regarding the double-face liners. On the other hand, the corrugating mediums used in Run Combinations 5 and 7 had lower bursting strength, G. E. puncture, and tear values than those used in the other run combinations.

Effect of Varying the Liner (Run Combinations 9–18)

Boxes

The second phase of this study involved the fabrication of rolls of "standard" corrugating medium with sets of liners representative of the average for each participating mill. The results of the tests on the boxes

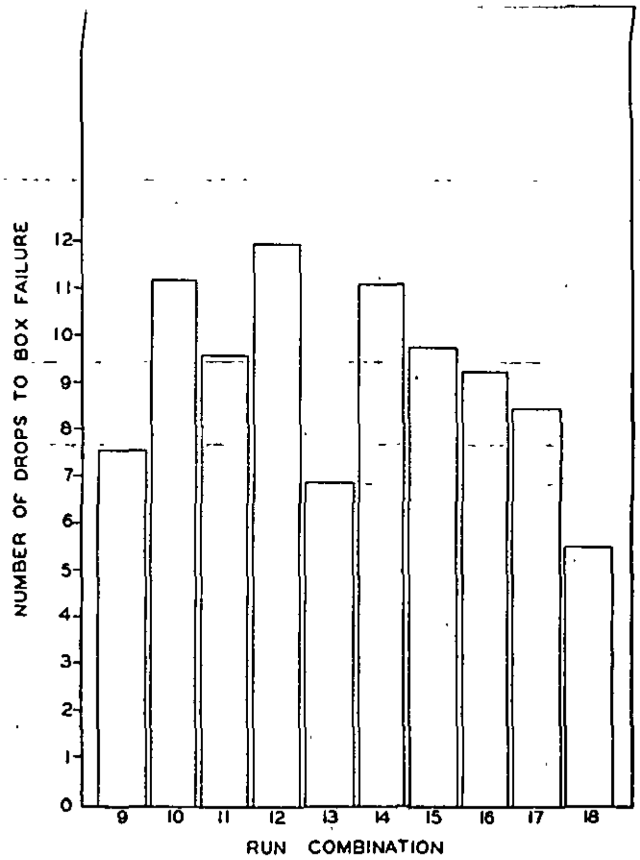

FIGURE 19. Comparison of 12-Inch Drop Tests—Run Combinations 9–18.

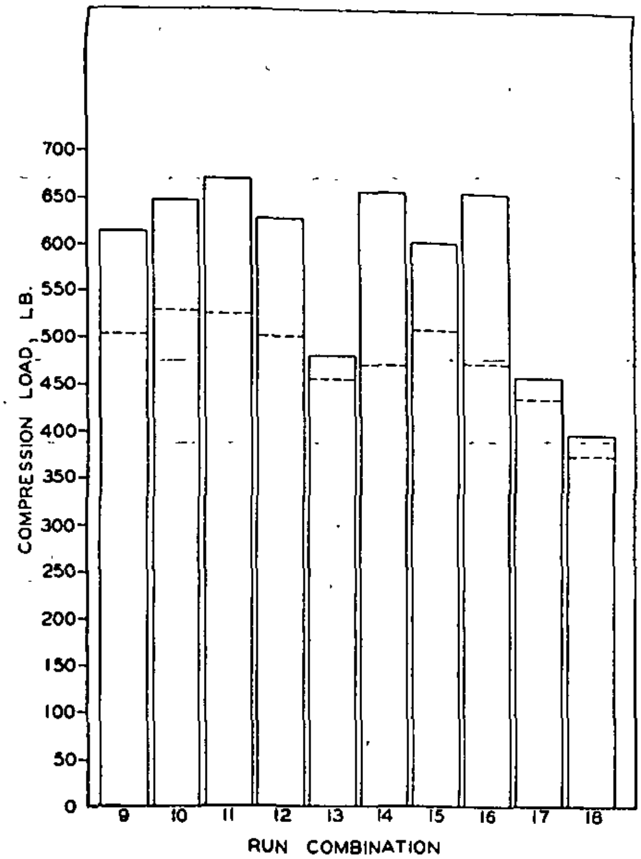

FIGURE 20. Comparison of Compression Tests—Run Combinations 9–18.
——— End Load (0–0.50 inch)
- - - - - Top Load (0–0.75 inch)

TABLE XVII

PHYSICAL CHARACTERISTICS OF COMPONENTS—RUN COMBINATIONS 1 THROUGH 8

Run Combination	I.P.C. Roll No.	Basis Weight (12 x 12 / 1000), lb.	Caliper, points	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb./in. In	Amthor Tensile, lb./in. Across	Amthor Stretch, % In	Amthor Stretch, % Across
						Corrugating Medium							
1	7	26.0	9.2	61	19	17.9	11.9	195	268	56.6	21.6	1.7	3.1
2	8	25.9	10.1	61	18	18.2	13.1	198	238	53.2	24.3	1.8	4.2
3	9	26.4	8.9	75	20	19.4	15.8	216	241	56.8	32.8	2.0	4.7
4	10	26.1	10.0	57	20	16.9	13.2	211	235	47.1	23.8	1.5	3.2
5	11	26.2	10.5	31	9	13.0	10.2	109	121	30.1	17.8	1.0	2.1
6	12	27.1	9.5	58	19	19.5	14.4	239	259	51.3	25.1	2.0	4.1
7	13	26.0	8.8	50	15	18.7	13.3	165	196	48.0	22.2	1.9	3.3
8	14	26.5	9.9	53	21	19.1	15.7	259	254	48.4	31.3	1.5	4.7
						Single Face Liner							
1	4	42.9	15.1	87	39	26.5	22.0	331	389	76 0	36.6	1.8	2.8
2	4	41.9	15.2	88	37	27.4	21.9	322	386	75.4	37.5	1.7	2.7
3	5	39.8	14.4	89	35	31.1	24.1	324	386	76.5	37.3	2.0	2.9
4	5	40.1	14.4	93	—	29.4	22.5	315	381	74.7	37.1	2.2	3.0
5	5	40.6	14.5	94	—	29.2	22.9	323	364	75.2	37 2	2.1	2.9
6	5	40.7	14.5	96	34	30.3	23.6	329	377	75.2	36.3	2.1	3.0
7	6	39.9	14.4	89	36	29.3	23.1	335	388	75 1	37 8	2.1	3.1
8	6	39.9	14.4	89	35	26.4	22.3	329	374	76.8	37.9	2.0	3.0
						Double Face Liner							
1	1	41.4	15.4	90	36	30.7	23.8	336	394	84.5	36 9	2 0	3.4
2	1	41.7	15.2	98	—	31.1	23.3	359	397	81.1	38.5	1.8	3.5
3	1	42.3	15.3	98	39	31.5	23.4	350	407	86.2	37.2	2.0	3.2
4	2	41.6	15.9	107	38	31.0	24.1	334	377	82.6	40 9	2.2	3.3
5	2	41.9	16.2	104	—	35.6	26.1	348	394	82.0	38.2	2.5	3.2
6	2	41.9	16.1	101	38	34.0	25.7	346	396	83.1	39 0	2.3	3.5
7	3	43.4	16.3	87	38	28.7	20.8	350	399	82.7	36.3	2 0	3.2
8	3	43.4	16.0	93	38	30.7	22.3	331	376	81.0	36.3	2.2	3.2

in *Table XVIII (see also Table XLII of Appendix A)* and Figures 18 to 20.

The drum test results (Figure 18) showed that the boxes of Run Combination 10 gave the highest average with 69 falls to box failure; boxes from Run Combinations 12 and 14 averaged above 60 falls. The remaining run combinations, arranged in the order of decreasing drum values, were 11, 15, 17, 16, 9, 13, and 18. The drum test results obtained on the boxes of Run Combinations 9 through 18 showed that the variation between boxes made with liners from different mills was of considerable magnitude. The average for a given run combination varied from a maximum of 69 falls to a minimum of 36 falls to box failure.

The drop test results given in Table XVIII and Figure 19 show that the average number of drops to box failure for the group was 9.2. Boxes of Run Combination 12 had an average of 12.0 drops to box failure. The boxes of Run Combination 18 had the lowest drop test—namely, 5.6 drops. A comparison of the test results indicated that a variation of considerable magnitude existed between the boxes of the different run combinations. The drop test results arranged the boxes of Run Combinations 9 through 18 in approximately the same order as did the drum test results.

The results of the compression tests are shown in Table XVIII and are illustrated in Figure 20. The *sion results were 476 and 580 pounds, respectively.* In the deflection range 0–0.75 inch, boxes of Run Combinations 9, 10, 11, and 15 had top-compression values above 500 pounds. On the other hand, boxes of Run Combination 18 had a top-compression test of only 374 pounds. Similarly, in the deflection range 0–0.50 inch, boxes of Run Combinations 11, 14, and 16 had end-compression values in excess of 650 pounds. The lowest end-compression value was obtained for boxes of Run Combination 18.

TABLE XVIII

PHYSICAL CHARACTERISTICS OF BOXES—RUN COMBINATIONS 9–18

Run Combination	I.P.C. Roll No.	Mill Code	Weight per 1000 Boxes, lb.	Drum: Falls to Box Failure	Drum: S. E.	Drum: S. E., %	12-Inch Corner Drop: Drops to Box Failure	12-Inch Corner Drop: S. E.	12-Inch Corner Drop: S. E., %	Top-Load Compression in Deflection Range 0–0.75 in.: Load, lb.	Top-Load: S. E.	Top-Load: S. E., %	End-Load Compression in Deflection Range 0–0.50 in.: Load, lb.	End-Load: S. E.	End-Load: S. E., %
9	15 16	A-7 A-22	1056	42	2.8	7	7.6	.35	5	501	9.5	2	614	15.1	2
10	17 18	H-11 H-8	1085	69	6.0	9	11.2	.58	5	528	6.9	1	646	13.9	2
11	19 20	B-13 B-1	1076	59	5.9	10	9.6	.46	5	525	7.6	1	668	12.4	2
12	21 22	I-10 I-12	1075	67	3.5	5	12.0	.47	4	500	7.8	2	624	15.4	2
13	23 24	F-5 F-6	1019	39	3.5	9	6.9	.39	6	458	6.1	1	478	15.2	3
14	25 26	C-10 C-9	1079	63	4.1	7	11.1	.52	5	468	7.4	2	656	15.1	2
15	27 28	D-20 D-5	1076	55	3.6	7	9.8	.52	5	506	9.1	2	602	14.4	2
16	29 30	E-5 E-3	1072	49	2.9	6	9.3	.30	3	470	6.3	1	653	14.6	2
17	31 32	G-12 G-1	1044	50	2.9	6	8.5	.34	4	434	7.0	2	459	14.3	3
18	33 34	J-11 J-3	1041	36	3.5	10	5.6	.34	6	374	7.4	2	399	15.0	4
Average			1062	53	3.9	8	9.2	.43	5	476	7.5	2	580	14.5	2

The data in Table XVIII indicated that there was considerable variation in the relative performance characteristics of the boxes made from combined boards produced by the fabrication of a set of each participating mill's average quality 42-lb. kraft liner with a "standard" corrugating medium.

Combined Boards

The results of the combined board tests on Run Combinations 9 through 18 are shown in Table XIX *(see also Table XLII of Appendix A) and Figures 21* and 22. The results of the bursting strength test indicated that all the run combinations had bursting strengths above 200 points, except Run Combination 13 which averaged 185 points. The average bursting strength for the group was 230 points.

All the G. E. puncture values were above 200 units, except for Run Combinations 13 and 18, which had

TABLE XIX
PHYSICAL CHARACTERISTICS OF COMBINED BOARD—RUN COMBINATIONS 9–18

Run Combination	I.P.C. Roll No.	Mill Code	Moisture, %	Basis Weight (12 x 12 x 1000), lb.	Bursting Strength			G. E. Puncture			G. E. Stiffness			Pin Adhesion			H. & D. Flat Crush		
					Points	S. E.	S. E., %	Units	S. E.	S. E., %	Units	S. E.	S. E., %	lb.	S. E.	S. E., %	lb./sq. in.	S. E.	S. E., %
9	15 16	A-7 A-22	8.4	121	235	2.7	1	221	1.1	1	89	1.3	2	73	1.0	1	26.3	0.6	2
10	17 18	H-11 H-8	8.0	123	247	4.1	2	226	1.5	1	92	1.4	2	78	0.9	1	25.4	0.7	3
11	19 20	B-13 B-1	8.3	124	236	2.7	1	228	1.5	1	97	1.4	2	75	1.0	1	25.8	0.6	2
12	21 22	I-10 I-12	7.8	124	248	3.5	1	233	1.7	1	87	1.2	1	77	1.0	1	28.4	0.7	2
13	23 24	F-5 F-6	7.6	117	185	2.6	1	191	1.2	1	78	1.6	2	71	0.8	1	26.2	0.7	3
14	25 26	C-10 C-9	7.8	125	243	3.3	1	233	1.3	1	92	1.1	1	78	0.8	1	30.8	0.9	3
15	27 28	D-20 D-5	8.2	124	235	2.6	1	236	1.5	1	95	1.2	1	69	1.0	2	32.7	0.6	2
16	29 30	E-5 E-3	8.3	123	243	3.7	2	221	1.2	1	96	1.3	1	71	0.6	1	31.0	0.7	2
17	31 32	G-12 G-1	7.9	120	214	3.3	2	204	1.7	1	73	1.3	2	71	1.4	2	19.2	0.8	4
18	33 34	J-11 J-3	8.1	120	217	2.8	1	176	1.5	1	70	0.9	1	75	1.1	2	16.2	0.3	2
Average			8.0	122	230	3.1	1	217	1.4	1	87	1.3	2	74	1.0	1	26.2	0.7	3

puncture values of 191 and 176 units, respectively. The average G. E. puncture value for the group was 217 units.

The group average for the pin adhesion strength was 74 pounds. The group averages for G. E. stiffness and flat crush were 87 units and 26.2 p.s.i., respectively. The flat crush results were lower in general than those normally obtained on B-flute board.

Components

Although the four rolls selected as standard corrugating medium were comparable in terms of the over-all average of the laboratory test results, their running characteristics were not the same. The corrugating medium used in Run Combinations 14, 15, and 16 ran very well on the corrugator. On the other hand, considerable difficulty was encountered on the corrugator with the corrugating medium used in Run Combinations 17 and 18. Differences were also noted in the G. E. stiffness and flat crush test results obtained for the run combinations in question. It is apparent that the over-all average quality of the corrugating medium, as determined by the laboratory tests to which these samples were subjected, did not adequately predict the G. E. stiffness or flat crush results obtained on the resulting combined boards. The results of the tests on the standard corrugating medium and the various sets of mill average liners are given in Table XX.

The test results in Table XX (see also Table XLII of Appendix A) show that, in general, the liners used in Run Combination 13 had the lowest values. When only bursting strength, G. E. puncture, tear, and tensile are considered, the liners used in Run Combination 12 had the highest over-all test values with 10, 14, and 15 next in order of decreasing magnitude.

Miscellaneous Combinations of Liners and Corrugating Mediums (Run Combination 19–22)

Boxes

The results of the physical tests on the boxes resulting from the fabrication of various low- and high-test liners and corrugating mediums are presented in Table XXI (see also Table XLIII of Appendix A) and are shown graphically in Figures 23, 24, and 25. The terms "low" and "high" strength do not refer merely to bursting strength but include an over-all comparison with the average rolls on the basis of the following tests: bursting strength, Amthor tensile and stretch, Elmendorf tear, and ring compression. In Run Combination 19, two high-strength liners were fabricated with a high-strength corrugating medium; in Run Combination 20 the two liners used in Run Combination 19 were fabricated with a low-strength corrugating medium. In Run Combination 21, two low-strength liners were combined with the low-strength corrugating medium used in Run Combination 20. In Run Combination 22, the low-strength liners used in Run Combination 21 were fabricated with the high-strength corrugating medium used in Run Combination 19.

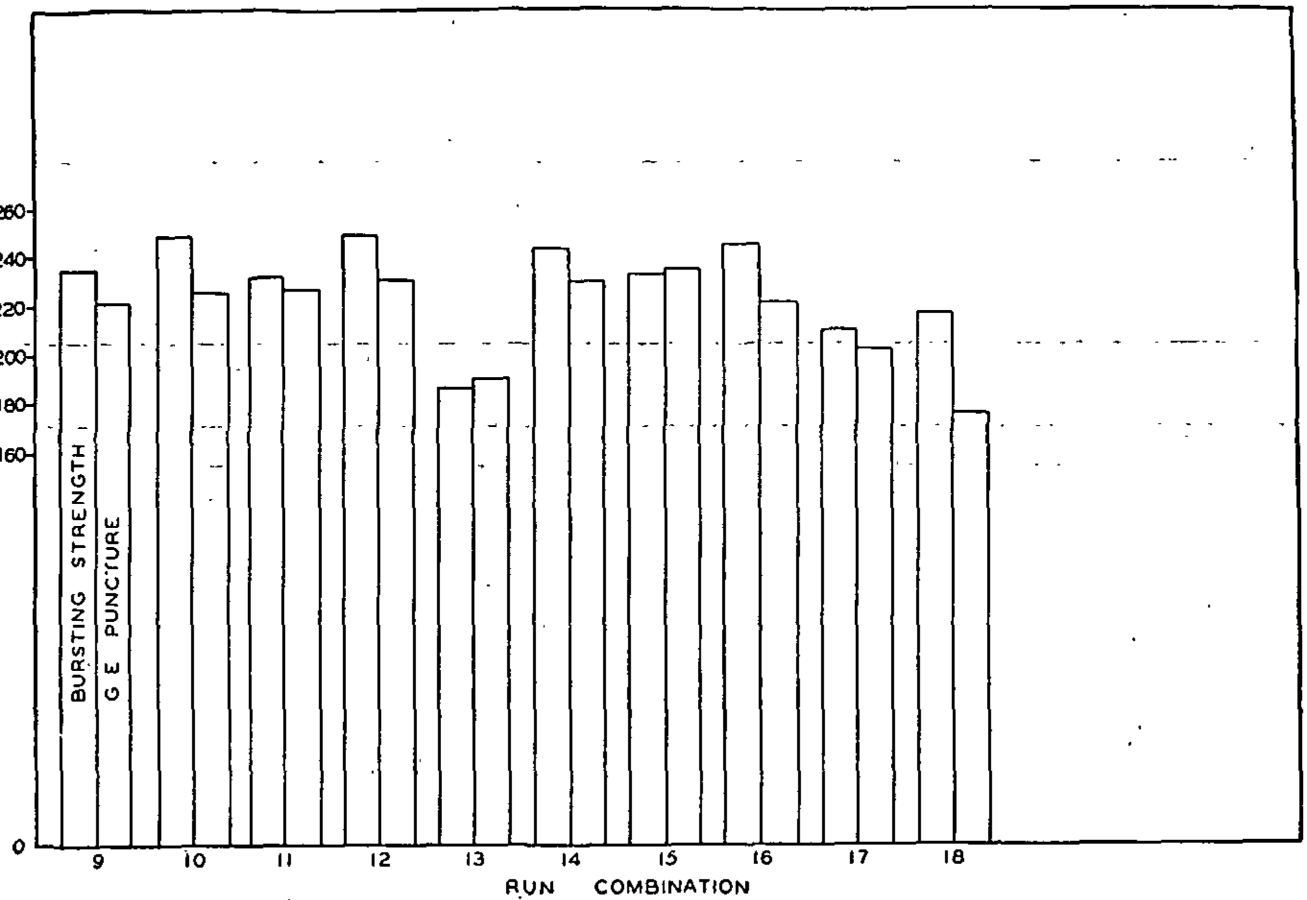

FIGURE 21. Comparison of Bursting Strength and G. E. Puncture Tests—Run Combinations 9–18.

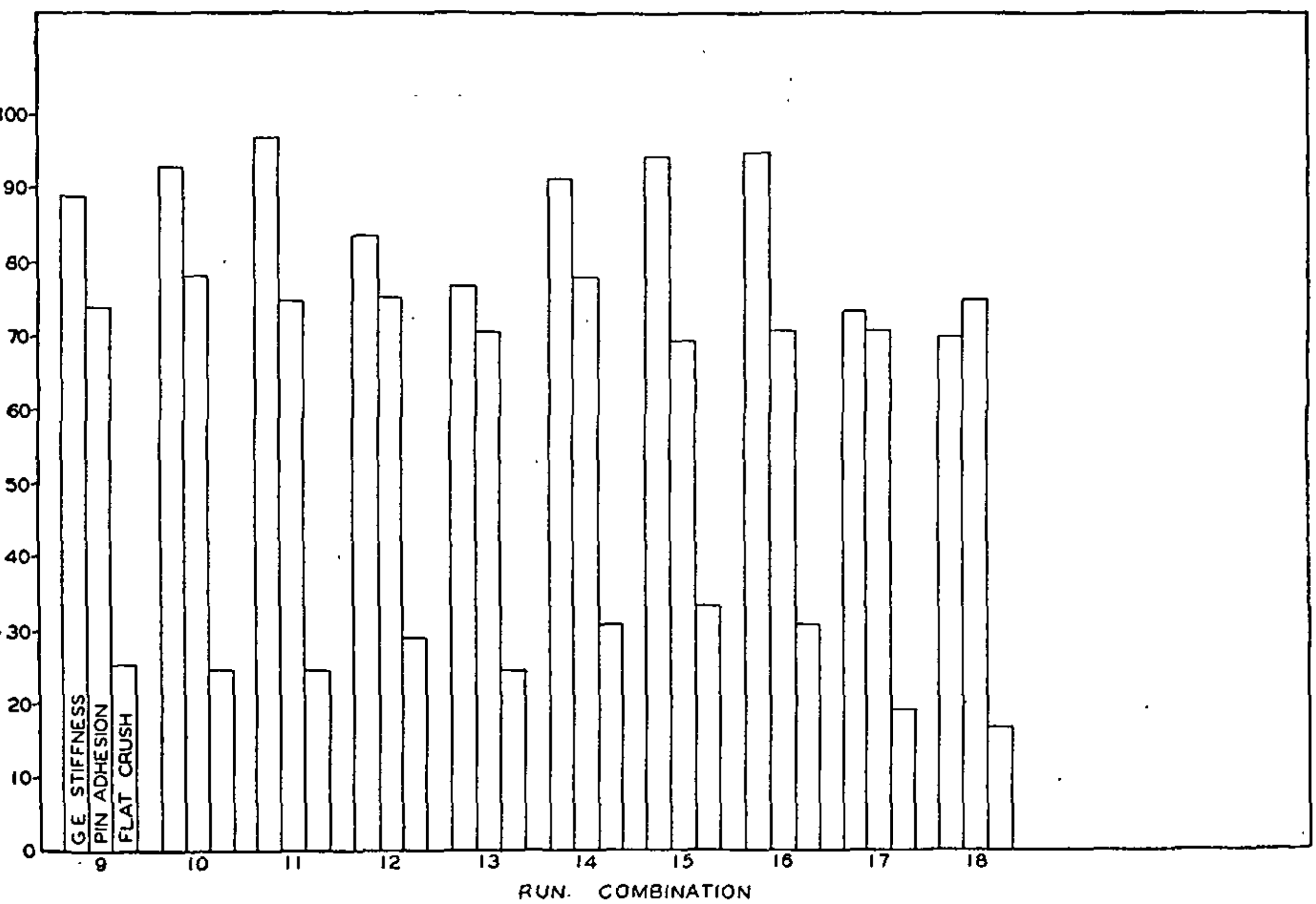

FIGURE 22. Comparison of G. E. Stiffness, Pin Adhesion, and Flat Crush Tests—Run Combinations 9–18.

TABLE XX

PHYSICAL CHARACTERISTICS OF COMPONENTS—RUN COMBINATIONS 9–18

Run Combination	I.P.C. Roll No.	Basis Weight (12 x 12 x 1000), lb.	Caliper, points	Bursting Strength, points	G. E. Puncture, unit	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb./in. In	Amthor Tensile, lb./in. Across	Amthor Stretch, % In	Amthor Stretch, % Across
Corrugating Medium													
9	39	28.0	11.1	59	21	19.4	14.6	243	282	55.8	25.7	1.7	3.3
10	39	27.8	11.0	64	—	20.3	15.0	244	281	56.6	26.8	1.6	3.3
11	39	27.8	10.9	62	21	18.9	15.1	244	283	56.7	26.8	1.9	3.4
12	40	26.8	9.2	63	19	18.2	13.0	214	252	53.6	23.1	2.1	3.9
13	40	26.2	9.2	63	17	21.0	14.4	226	250	50.6	23.4	1.9	4.1
14	41	27.1	11.3	62	17	21.2	13.5	226	268	57.0	23.3	2.2	4.0
15	41	27.0	11.4	67	—	18.8	14.0	221	275	54.9	23.3	2.2	4.3
16	41	27.2	11.4	63	19	18.2	13.1	229	278	52.4	23.4	2.0	4.3
17	42	26.0	9.3	62	16	19.2	14.1	208	249	52.4	24.3	1.8	2.9
18	42	26.1	9.3	64	16	21.4	15.8	198	249	52.8	24.6	1.9	2.9
Single-Face Liner													
9	15	40.3	13.8	92	35	29.9	24.4	318	367	76.2	38.8	2.0	3.1
10	17	42.2	15.6	99	38	29.4	24.0	382	422	75.4	40.2	2.0	3.5
11	19	43.3	15.7	96	38	30.6	24.7	361	431	86.6	40.4	2.0	3.0
12	21	43.1	14.9	104	42	28.4	21.2	371	452	85.1	36.4	2.3	4.3
13	23	40.3	12.9	81	36	25.1	21.9	305	334	68.4	35.5	1.7	2.9
14	25	42.0	14.5	94	38	31.0	19.4	340	420	86.5	36.8	1.4	3.7
15	27	41.0	14.8	90	37	28.0	22.4	372	380	71.1	42.8	2.1	3.9
16	29	42.6	16.0	84	35	28.6	20.1	320	391	83.0	33.5	1.6	3.4
17	31	41.0	15.5	80	38	26.2	20.2	362	381	68.0	38.2	1.4	3.3
18	33	41.3	15.0	87	34	30.6	23.8	304	371	76.8	36.3	1.7	2.6
Double-Face Liner													
9	16	40.6	14.9	85	35	27.8	22.4	301	361	74.5	35.9	1.8	2.6
10	18	42.3	15.2	96	38	28.8	24.1	370	415	80.7	41.2	2.2	3.6
11	20	41.8	16.1	89	36	28.3	22.8	341	400	82.9	35.9	1.9	3.1
12	22	43.8	15.2	96	50	28.9	24.1	408	439	79.8	37.6	2.0	4.4
13	24	39.6	12.6	78	28	25.0	20.8	273	313	63.7	33.1	1.8	2.7
14	26	42.0	14.7	94	40	29.4	20.3	332	416	84.8	36.3	1.8	3.9
15	28	44.2	16.3	91	42	26.1	20.8	397	449	71.0	41.4	1.7	2.8
16	30	41.9	14.1	85	34	25.4	19.2	306	355	77.8	34.6	1.6	3.6
17	32	42.6	15.0	86	39	27.2	21.6	361	402	75.4	42.0	1.6	2.9
18	34	41.9	15.2	90	31	31.4	25.1	310	364	76.6	38.7	1.5	2.3

TABLE XXI

PHYSICAL CHARACTERISTICS OF BOXES—RUN COMBINATIONS 19–22

Run Combination	Strength Combination			Weight per 1000 Boxes, lb.	Drum			Drop			Maximum Top-Load Compression in Deflection Range 0–0.75 in.			Maximum End-Load Compression in Deflection Range 0–0.50 in.		
	S. F.	Corr.	D. F.		Falls to Box Failure	S. E.	S. E., %	Drops to Box Failure	S. E.	S. E., %	Load, lb.	S. E.	S. E., %	Load, lb.	S. E.	S. E., %
19	High	High	High	1085	73	4.8	7	11.4	0.52	5	568	7.7	1	682	11.3	2
20	High	Low	High	1056	51	5.5	11	7.8	0.37	5	393	8.1	2	411	14.0	3
21	Low	Low	Low	1076	20	1.1	5	4.8	0.17	4	333	4.8	1	361	13.2	4
22	Low	High	Low	1119	33	2.8	9	6.3	0.25	4	439	8.5	2	608	9.2	2

The results of the drum test indicate the role played by the liners in resisting the rough handling action of the drum. The boxes of Run Combination 19, as might be expected, had a higher drum test value than those of Run Combination 20. Similarly, the drum test results for Run Combination 22 were higher than for those for Run Combination 21. As seen in Table XXII, the substitution of the low-test corrugating medium for the high-test corrugating medium resulted in approximately 30 to 40% reduction in the drum test results. On the other hand, the substitution of the low-test liners for the high-test liners resulted in approximately a 55 to 60% reduction in the drum test results. These results indicate that, in these four combinations, the liners had a greater effect on drum strength than did the corrugating medium.

The four miscellaneous run combinations (19 to 22)

TABLE XXII

COMPARISON OF THE EFFECT OF COMPONENT STRENGTH ON DRUM, DROP, AND COMPRESSION TEST RESULTS

Run Combination	Corrugating Medium	Drum	Drop	Top-Load Compression	End-Load Compression
19	High	7.3	11.4	568	682
20	Low	5.1	7.8	393	411
Difference		30%	32%	31%	40%
22	High	33	6.3	439	608
21	Low	20	4.8	333	361
Difference		39%	24%	24%	41%

Run Combination	Liner	Drum	Drop	Top-Load Compression	End-Load Compression
19	High	73	11.4	568	682
22	Low	33	6.3	439	608
Difference		55%	45%	23%	11%
20	High	51	7.8	393	411
21	Low	20	4.8	333	361
Difference		62%	38%	15%	12%

were ranked in the same order by the drop test results as by the drum test results. Also, the relative percentage difference between the drop test results was approximately the same as for the drum test results. Therefore, it is indicated that, in this particular study, the drum and the 12-inch corner drop test tend to measure the same physical characteristics of a box.

The results of the compression test on the four miscellaneous run combinations are tabulated in Table XXI and shown graphically in Figure 25. The results show that the combination of the high-test liners and the high-test corrugating medium (Run Combination 19) had the highest top-load and end-load compression values. The combination of the low-test liners and the high-test corrugating medium (Run Combination 22)

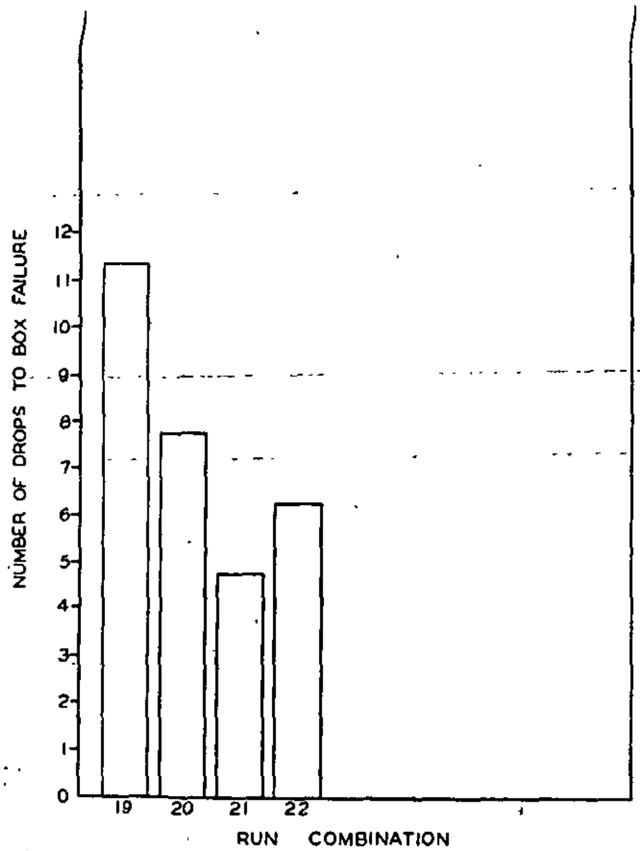

FIGURE 23. Comparison of Drum Tests—Run Combinations 19–22.

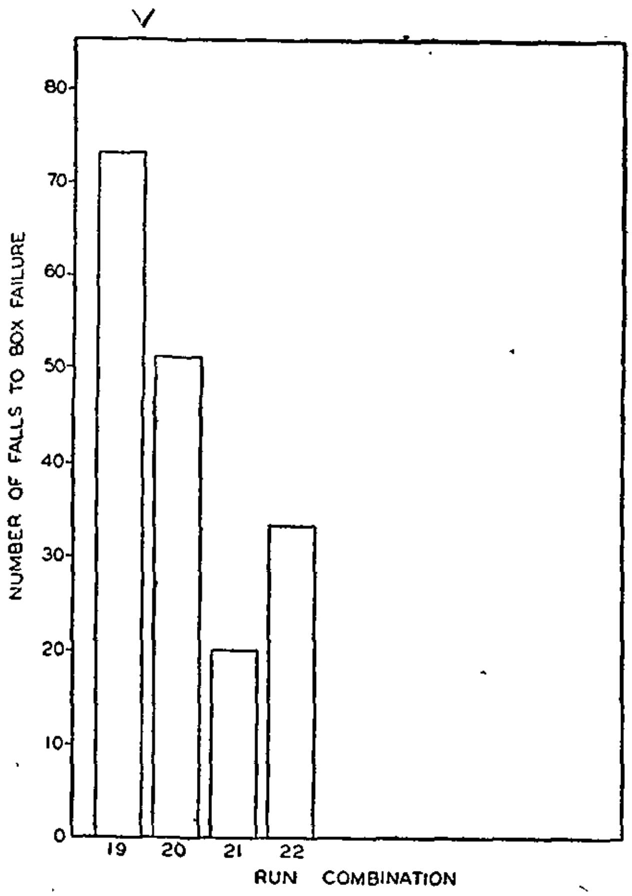

FIGURE 24. Comparison of 12-Inch Corner Drop Tests—Run Combinations 19–22.

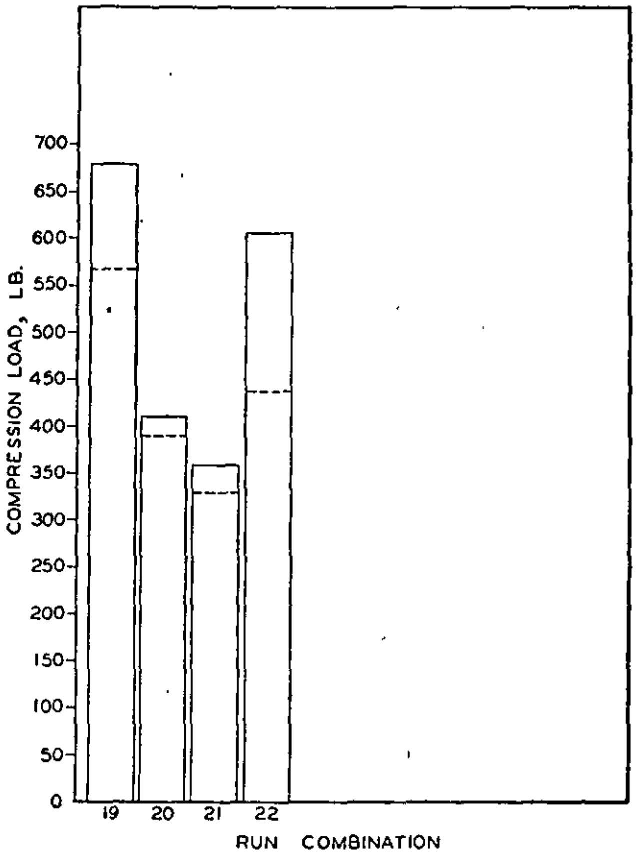

FIGURE 25. Comparison of Compression Tests—Run Combinations 19–22.
———— End Load (0–0.50 inch)
------------ Top Load (0–0.75 inch)

had higher compression values than Run Combination 20, which was made up of high-test liners and low-test corrugating medium. The results also show that the substitution of a low-test for a high-test corrugating medium resulted in a decrease of approximately 25 to 30% in top-to-bottom compression and approximately 40% in end-to-end compression strength. On the other hand, the substitution of the low-test for the high-test liners resulted in a decrease of approximately 15 to 23% in top-load compression and 11 to 12% in end-load compression. This indicates that, in these four combinations, the corrugating medium had a greater effect on compressive strength than did the liners.

A comparison of the results of the drum, drop, and compression tests indicates that, for the four run combinations in question, the physical characteristics of the liners had a greater influence on the results of the drum and drop tests than did the physical characteristics of the corrugating medium. On the other hand, the quality of the corrugating medium influenced the results of the compression test to a greater extent than did the quality of the liners. Obviously, a quality box must have adequate strength in both the liners and corrugating medium. However, within limits, the results indicate that, to obtain more compressive strength, a strong corrugating medium should be used and, to increase drum and drop test values, stronger liners should be used.

TABLE XXIII

PHYSICAL CHARACTERISTICS OF COMBINED BOARD—RUN COMBINATIONS 19–22

Run Combination	Strength Combination			Moisture, %	Basis Weight (12 x 12 x 1000), lb.	Bursting Strength			G. E. Puncture			G. E. Stiffness			Pin Adhesion			H. & D. Flat Crush		
	S. F.	Corr.	D. F.			Points	S. E.	S. E., %	Units	S. E.	S. E., %	Units	S. E.	S. E., %	lb.	S. E.	S. E., %	lb./sq. in.	S. E.	S. E., %
19	High	High	High	8.1	125	246	4.0	2	238	1.2	1	105	1.2	1	74	1.4	2	33.0	0.9	3
20	High	Low	High	7.8	122	240	3.5	2	177	1.5	1	67	1.2	2	70	1.7	3	17.0	0.5	3
21	Low	Low	Low	8.0	124	194	7.0	4	149	1.3	1	65	1.4	2	64	1.1	2	15.7	0.6	4
22	Low	High	Low	8.3	130	168	1.9	1	215	1.1	1	96	1.0	1	67	0.8	1	35.7	0.4	1

Combined Boards

The results of the combined board strength tests for Run Combinations 19 and 20 are given briefly in Table XXIII (see also Table XLIII of Appendix A). It is interesting that, although the bursting strength values rank the Run Combinations 19, 20, 21, and 22 in order of decreasing value, the puncture tests rank them in the order 19, 22, 20, and 21 which, furthermore, is the same order obtained for the compression results. Since Run Combinations 19 and 20 each have high-strength liners and 21 and 22 have low-strength liners, the indications are that the bursting strength test is influenced more by the strength of the liner than by the strength of the corrugating medium. Also, the indications are that the puncture test is influenced more by the strength of the corrugating medium than by the strength of the liner. This point may be illustrated by considering the bursting strength data (see Table XXIII) when high-strength corrugating medium was used; the difference between the bursting strengths of samples made with high- and low-test liners (Run Combinations 19 and 22) amounted to 78 points. When low-strength corrugating medium was used, the difference between the bursting strength on samples made with high- and low-test liners (Run Combinations 20 and 21) amounted to 46 points. On the other hand, when high-strength liners were used, a change from high to low-strength corrugating medium (Run Combinations 19 and 20) resulted in only a 6-pound decrease in bursting strength. When low-strength liners were used, a change from high to low-strength corrugating medium (Run Combinations 21 and 22) resulted in a 26-pound decrease in bursting strength. The same type of illustration with the G. E. puncture test shows decreases of 23 and 28 units for the respective changes in liners, but decreases of 61 and 66 units when the corrugating media were changed.

The G. E. stiffness test results appear to rank the miscellaneous run combinations in about the same way as the G. E. puncture test results. This means that it also is influenced somewhat more by the corrugating medium than by the liner.

The pin adhesion test results did not rank the run combinations in the same order as the puncture or the bursting strength test results. Furthermore, the spread of the pin adhesion test values was very narrow.

The flat crush test results definitely distinguish between those run combinations fabricated from the high-strength corrugating medium and those fabricated from the low-strength corrugating medium. The data indicate that the liners had very little effect on the flat crush test results. The samples made with low-strength corrugating medium had approximately half the flat crush test value shown by those having high-strength corrugating medium.

Components

The results of the tests on the components used in Run Combinations 19 through 22 are given in Table XXIV (see also Table XLIII of Appendix A). The normal conditions of operation, offer an ideal opportunity for investigating these relationships.

The relationship or correlation between any two tests can be judged roughly by merely observing the numerical data. However, this method leaves much to be desired in that only the more obvious correlations are apparent. The second method of observing the correlation between tests is to plot the values obtained by one test against those obtained by another. Absolute correlation exists if, when the plotted values are connected, a straight line results and all plotted points are on the straight line. When the plotted points do not fall on the line, the correlation is not absolute. In fact, the more the plotted points are scattered about the line, the less the correlation. A third method of determining the correlation is the statistical method, in which correlation coefficients are calculated for the group of test results in question.

TABLE XXIV

PHYSICAL CHARACTERISTICS OF COMPONENTS—RUN COMBINATIONS 19–22

Run Combination	I.P.C. Roll No.	Basis Weight (12 x 12 x 1000), lb.	Caliper, points	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb.		Elmendorf Tear, g./sheet		Amthor Tensile, lb./in.		Amthor Stretch, %	
						In	Across	In	Across	In	Across	In	Across
						Corrugating Medium							
19	43	27.5	11.1	70	17	21.5	16.0	227	254	53.3	26.4	2.0	4.3
20	44	24.9	9.1	52	15	17.2	11.9	177	208	44.5	22.2	1.8	2.8
21	44	24.8	9.1	50	13	19.0	12.4	176	202	45.7	21.4	1.8	2.8
22	43	27.6	11.1	70	18	21.7	15.7	228	254	54.1	26.6	1.8	4.3
						Single-Face Liner							
19	35	43.9	14.0	98	35	32.4	25.9	381	387	78.2	44.1	1.8	4.0
20	35	44.3	14.0	97	36	32.7	26.9	383	388	84.3	44.3	2.0	4.5
21	37	44.3	16.8	57	29	21.6	16.8	272	280	53.5	29.2	1.1	2.5
22	37	44.9	16.5	58	31	21.5	16.9	265	282	55.1	29.8	1.2	2.5
						Double-Face Liner							
19	36	41.6	15.4	100	34	29.6	23.3	345	393	77.1	40.6	2.1	3.5
20	36	42.1	15.5	100	36	29.9	23.2	369	402	77.6	42.5	2.1	3.7
21	38	43.9	17.2	59	30	22.8	16.7	279	282	54.6	30.0	1.0	2.3
22	38	44.6	17.4	56	30	22.6	16.1	274	288	54.7	28.4	1.3	2.7

values of the test results were considerably greater for the high-test than for the low-test corrugating medium. Also, the respective test values were, in general, uniform for the two combinations in which each type of medium was used.

The test values obtained for the high-test liners were considerably higher than those obtained for the low-test liners. This condition existed in spite of the fact that the lower test liners had higher basis weights. This difference in test values is especially apparent in the case of the bursting strength.

RELATIONSHIPS BETWEEN VARIOUS COMBINED BOARD AND BOX TESTS

In order to determine the relationships between the results of (1) different combined board tests, (2) different box tests, and (3) combined board and box tests, the results obtained for the twenty-two run combinations have been treated as one collective group of data. These results, which were obtained on combined board and boxes fabricated under carefully controlled but

The combined board and box results obtained in this study have been subjected to statistical analysis in order to obtain a more comprehensive and reliable insight into the relationship between the various tests. This analysis is a determination of simple correlation involving the interrelationship between two different tests. The relationship between two characteristics may be obtained by plotting the respective test results and then determining the line of least variance by the method of the sum of the least squares. The tightness of the swarm (degree of scattering of the plotted points) about the line of the least square is a measure of the correlation between the two characteristics in question. However, it is possible by algebraic means, to calculate the correlation coefficient and thus eliminate the necessity for plotting the points and determining the line by the sum of the least squares.

In simple correlation,* the correlation coefficient is

* Correlation is defined as

$$r = [n\Sigma xy - (\Sigma x)(\Sigma y)]/\sqrt{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]},$$

where x and y are the two quantities or characteristics, n is the number of items under consideration, and r is the correlation coefficient.

tics are related—*i.e.*, it is a measurement of the intimacy of two quantities or characteristics. For example, a correlation coefficient of unity (1.00) indicates perfect correlation. Similarly, a correlation coefficient of zero (0.00) indicates absence of any correlation. The sign (positive or negative) preceding the coefficient designates whether the correlation is direct or inverse—*i.e.*, a positive sign indicates direct correlation and a negative sign designates inverse correlation.

Boxes

The four main physical box tests considered were (1) the maximum top-load compression sustained in the deflection range 0–0.75 inch, (2) the maximum end-load compression sustained in the deflection range 0–0.50 inch, (3) the drum test based on the number of falls to box failure, and (4) the 12-inch corner drop test based on the number of drops to box failure. The correlation between these four physical tests on boxes is presented graphically. It has also been studied in terms of numerical coefficients. In addition to the above, the correlation coefficients have been calculated for (1) the maximum top-load compression sustained in the deflection range 0–0.25 inch and (2) the maximum end-load compression sustained in the deflection range 0–0.25 inch.

The results of the box tests for the twenty-two run combinations are given in Table XXV and the correlation coefficients in Table XXVI. The correlation between the top-load (deflection range 0–0.75 inch) and end-load (deflection range 0–0.50 inch) compression results are shown graphically in Figure 26. It may be noted that the swarm about the line of least squares indicates fairly good correlation. This is further substantiated by the correlation coefficient of +0.86 (Table XXVI). If all the plotted compression points had been on the line, it would have indicated perfect correlation and the correlation coefficient would have been +1.00. Further, it would have indicated that, if the end-load compression were known, the top-load compression could be accurately predicted. Since the correlation coefficient was not +1.00, such is not the case. Nevertheless, the correlation coefficient of +0.86 indicates that, for the boxes tested, those having the higher end-load compression values would tend also to have the higher top-load compression values. If the correlation coefficient had been +0.96, this tendency would have been even more pronounced.

The correlation between the top-load compression

TABLE XXV

PHYSICAL TEST RESULTS ON BOXES—RUN COMBINATIONS 1 THROUGH 22

Run Combination	Top-Load Compression, lb.	End-Load Compression, lb.	Drum, Falls to Box Failure	Drop, Drops to Box Failure
1	487	634	38	7.9
2	506	628	42	8.1
3	505	523	49	8.6
4	469	592	42	8.3
5	397	423	32	5.8
6	489	611	48	8.1
7	460	469	37	6.5
8	502	620	66	10.1
9	501	614	42	7.6
10	528	646	69	11.2
11	525	668	59	9.6
12	500	624	67	12.0
13	458	478	39	6.9
14	468	656	63	11.1
15	506	602	55	9.8
16	470	653	49	9.3
17	434	459	50	8.5
18	374	399	36	5.6
19	568	682	73	11.4
20	393	411	51	7.8
21	333	361	20	4.8
22	439	608	33	6.3

results in the deflection range 0–0.75 inch and the drum test results is graphically presented in Figure 27. The correlation coefficient (Table XXVI) for this simple correlation was +0.73. The pattern of the points in Figure 27 indicates that the correlation between these two tests is not of a very high order. It is apparent that, in so far as these results are concerned, very little can be predicted regarding the drum test results by considering the top-load compression test (deflection range 0–0.75 inch) results for a given sample. This is illustrated by the five run combinations (Figure 27) with drum values of approximately 49 falls; the top-load compression values for these five run combinations vary from about 390 to 510 pounds.

The correlation between the top-load compression (deflection range 0–0.75 inch) and the drop test values is shown in Figure 28. The correlation coefficient as given in Table XXVI is +0.77. The correlation coefficient, and the pattern of the points, again indicates that the correlation of these two tests is not very high. Further, it indicates that the magnitude of the top-load compression values is a poor criterion of box performance as measured by the 12-inch corner drop test. As the correlation of both the drum and the 12-inch corner drop tests with top-load compression test was

TABLE XXVI

CORRELATION COEFFICIENTS BETWEEN PHYSICAL TEST RESULTS ON BOXES

	Top-Load Compression in Deflection Range		End-Load Compression in Deflection Range			
	0–0.25 in.	0–0.75 in.	0–0.25 in.	0–0.50 in.	Drum	Drop
Top-load compression, 0–0.25 in.	+1.00	+0.77	+0.41	+0.46	−0.66	+0.59
Top-load compression, 0–0.75 in.	+0.77	+1.00	+0.73	+0.86	−0.73	+0.77
End-load compression, 0–0.25 in.	+0.41	+0.73	+1.00	+0.90	−0.49	+0.58
End-load compression, 0–0.50 in.	+0.46	+0.86	+0.90	+1.00	−0.64	+0.74
Drum	+0.66	+0.73	+0.49	+0.64	−1.00	+0.96
Drop	+0.59	+0.77	+0.58	+0.74	−0.96	+1.00

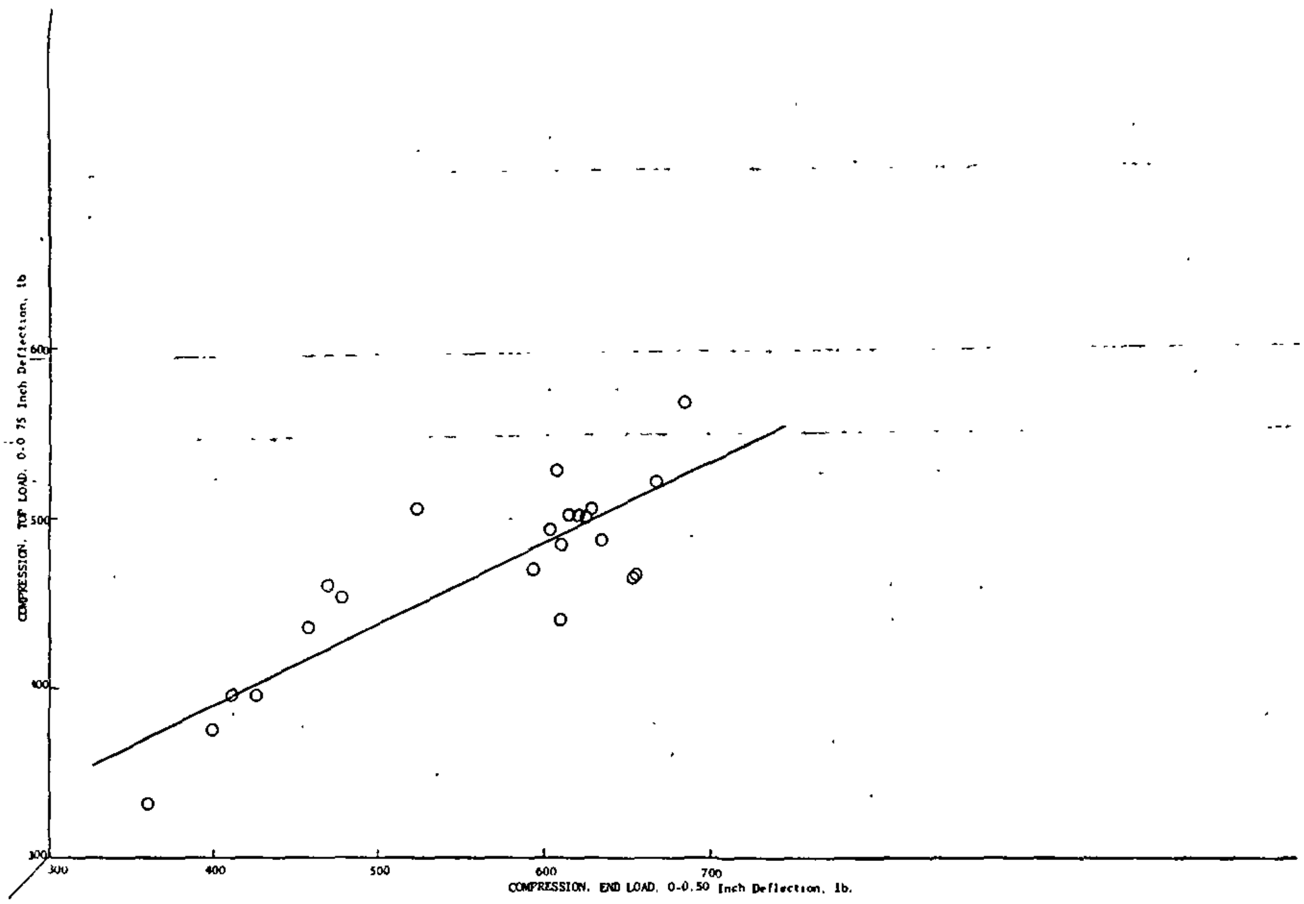

FIGURE 26. Correlation of Top- and End-Load Compression Tests—Run Combinations 1–22.

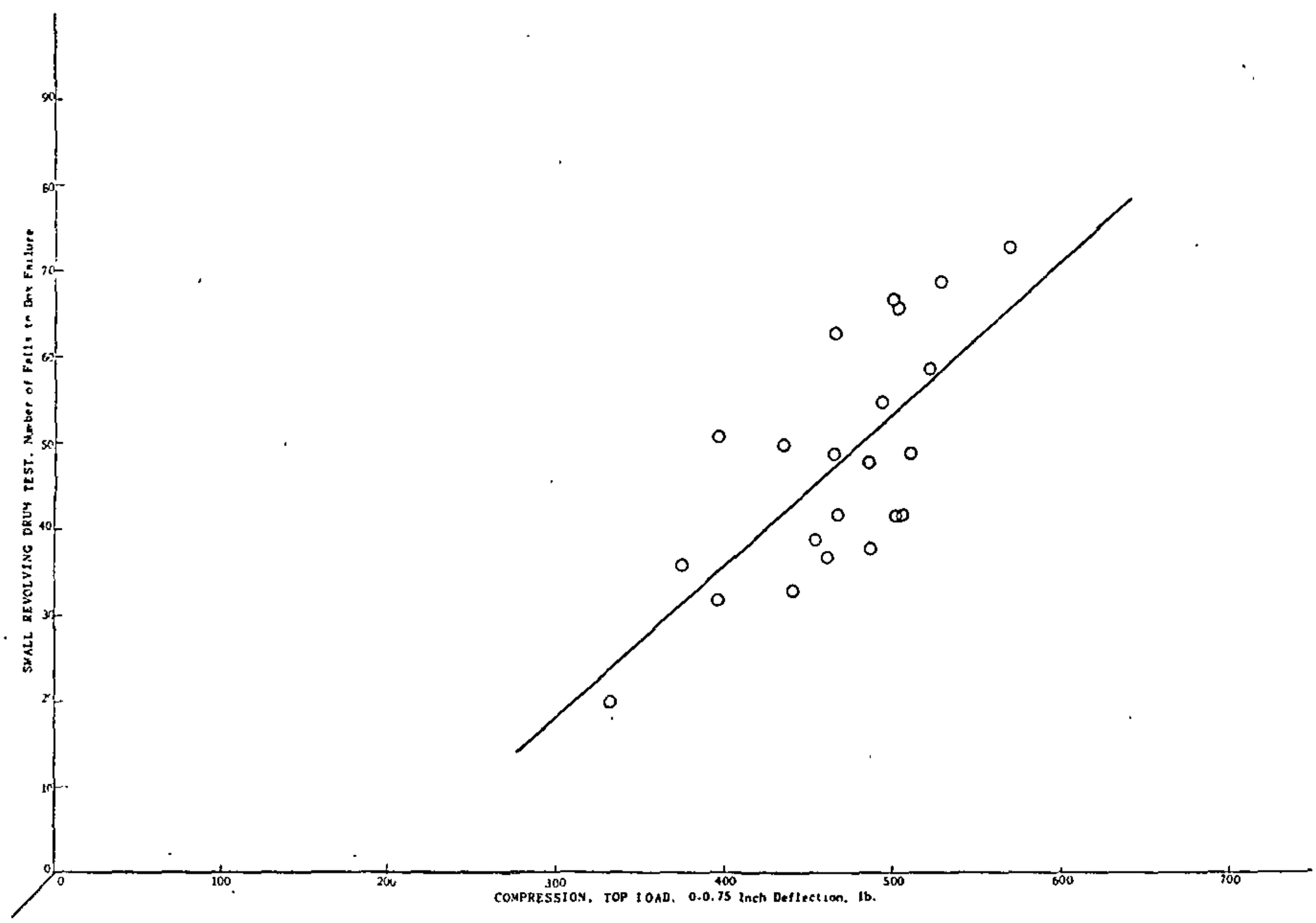

FIGURE 27. Correlation of Top-Load Compression and Drum Tests—Run Combinations 1–22.

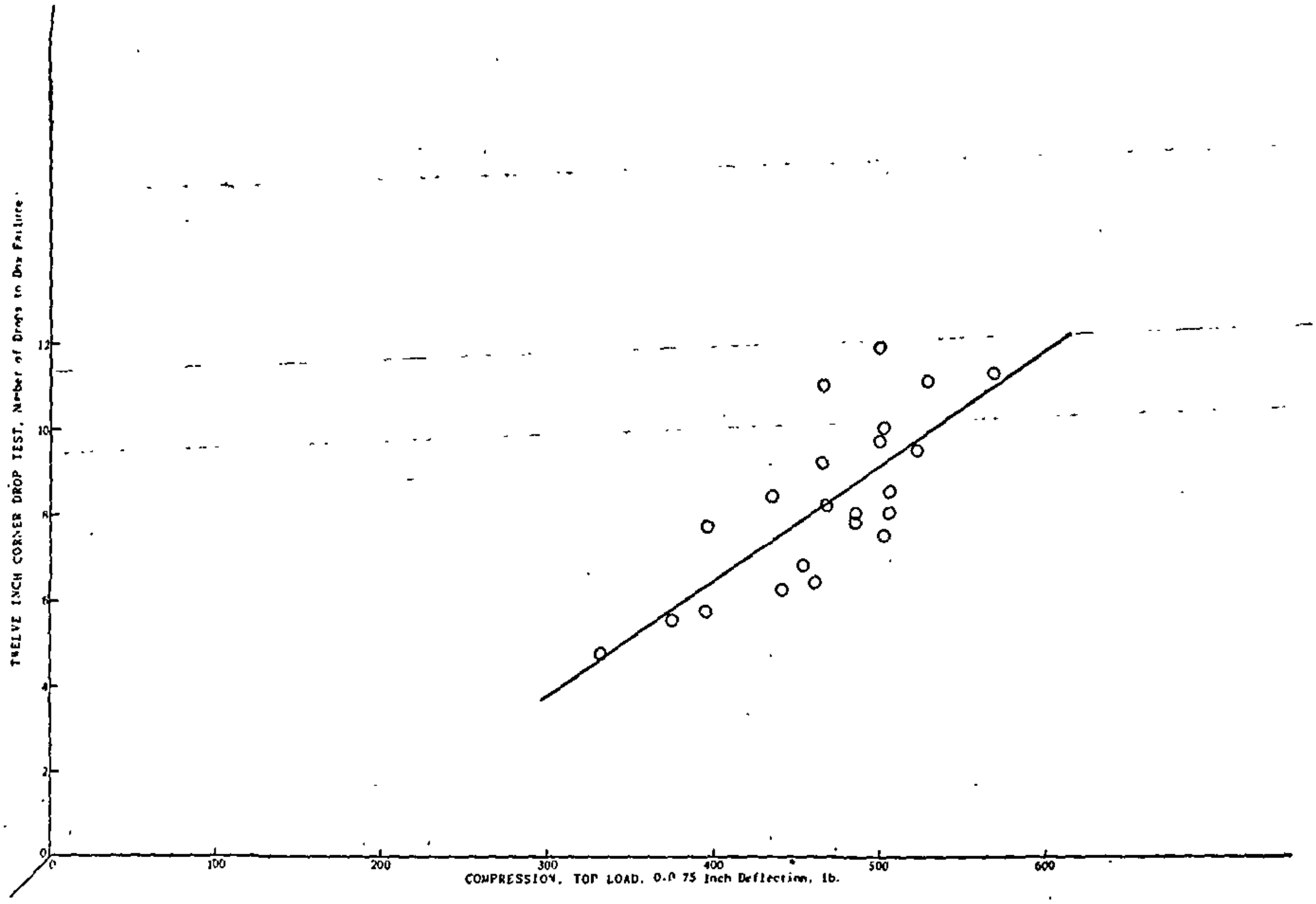

FIGURE 28. Correlation of Top-Load Compression and 12-Inch Corner Drop Tests—Run Combinations 1–22.

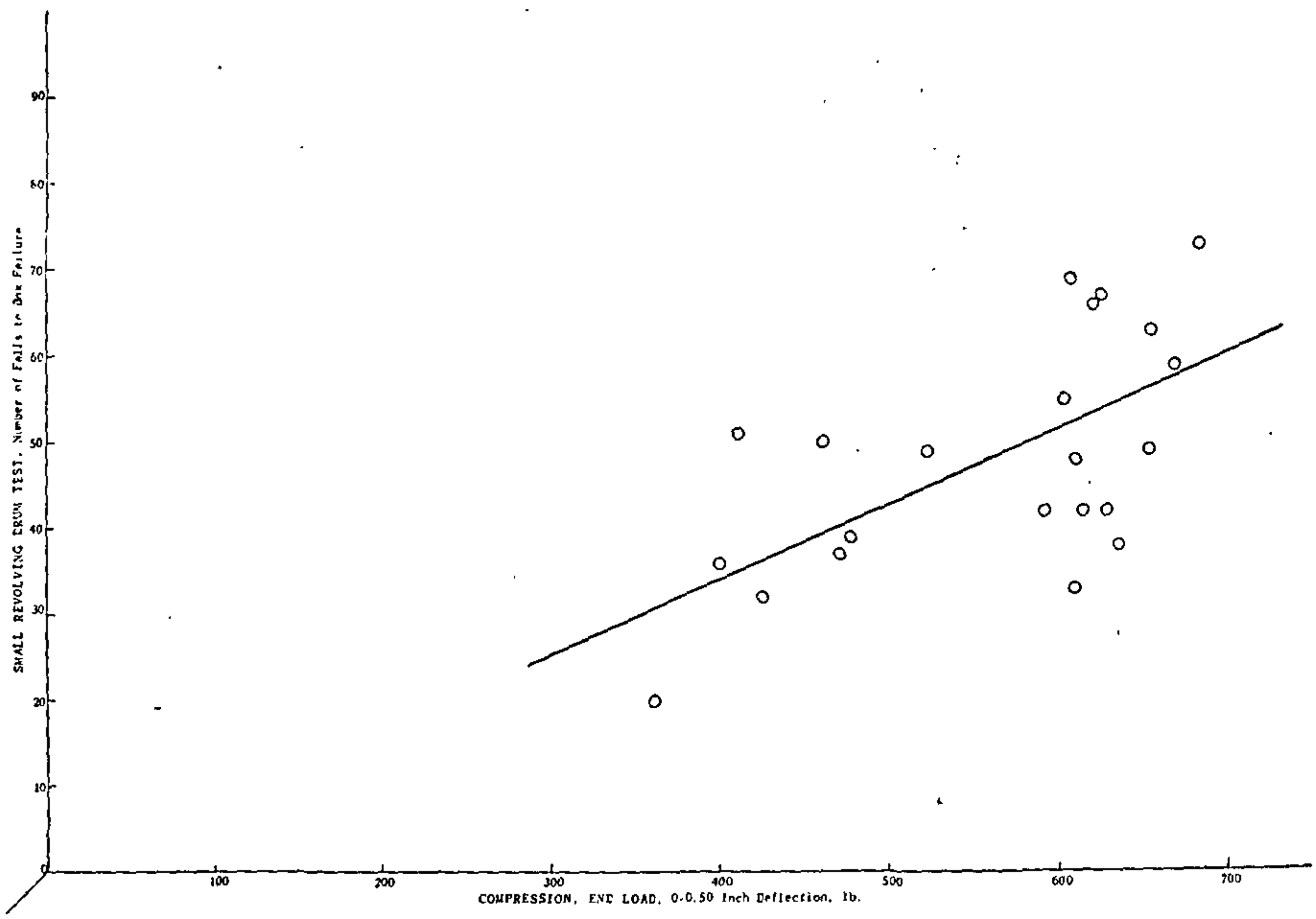

FIGURE 29. Correlation of End-Load Compression and Drum Tests—Run Combinations 1–22.

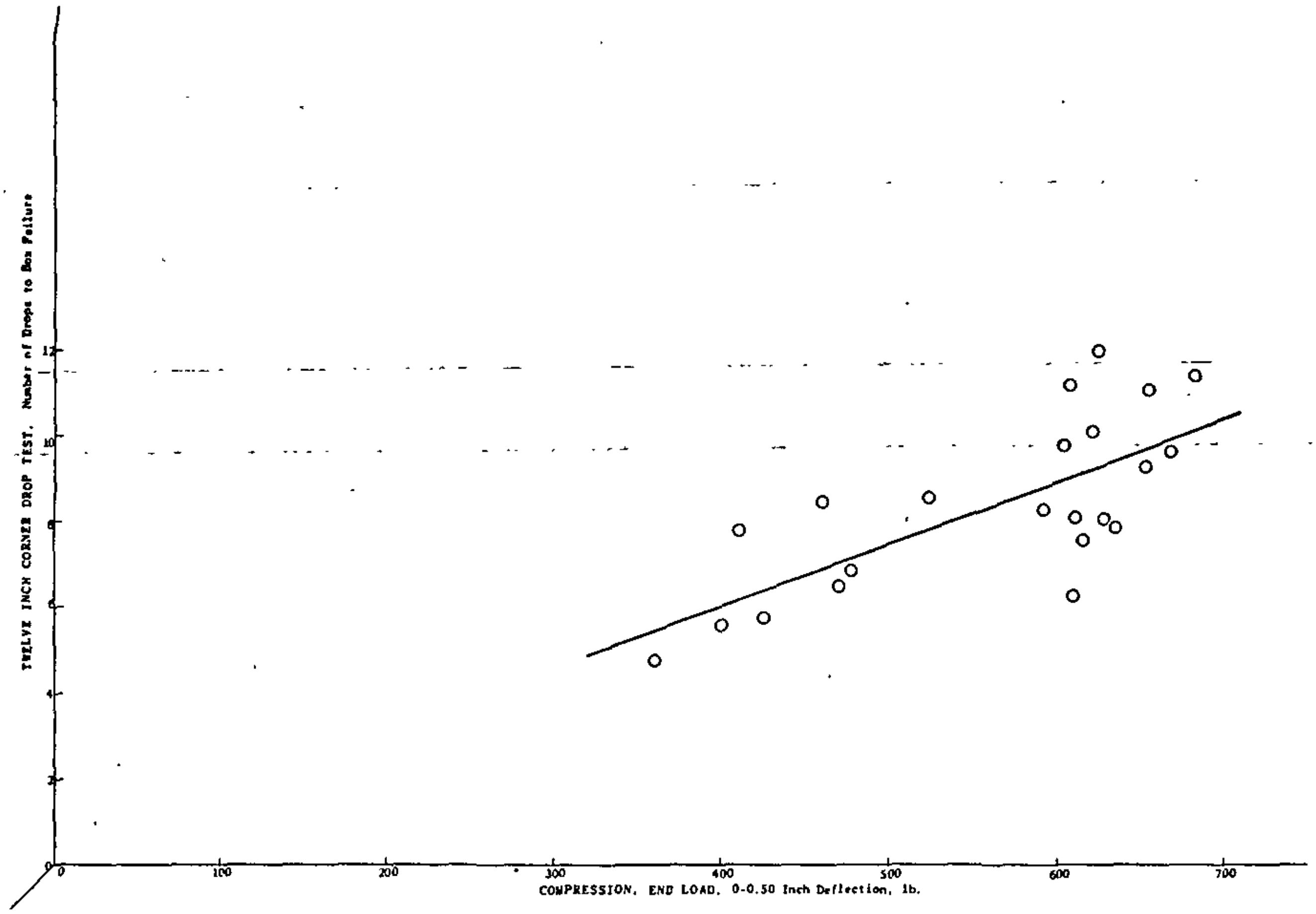

FIGURE 30. Correlation of End-Load Compression and 12-Inch Corner Drop Tests—Run Combinations 1–22.

only fair, it indicates that the characteristics involved in the drum and drop tests are not all measured in the top-load compression test.

The correlation coefficients for the end-load compression (0–0.50 inch deflection range) with the drum and drop test results were +0.64 and +0.74, respectively. The correlations are graphically illustrated in Figures 29 and 30. Both the top-load and end-load compression tests correlate slightly better with the 12-inch corner drop than with the drum test. Also, the top-load compression test correlates slightly better with drum and drop tests than does the end-load compression test.

TABLE XXVII

PHYSICAL TEST RESULTS ON COMBINED BOARD—RUN COMBINATIONS 1 THROUGH 22

Run Combination	Bursting Strength, points	G. E. Puncture, units	G. E. Stiffness, units	Pin Adhesion, lb.	Flat Crush, lb./sq. in.
1	239	217	93	71	28.1
2	240	226	96	67	34.2
3	238	225	90	61	33.8
4	239	203	86	71	25.5
5	232	169	68	70	14.5
6	234	207	85	72	24.0
7	220	194	77	62	23.8
8	230	224	94	72	30.1
9	235	221	89	73	26.3
10	247	226	92	78	25.4
11	236	228	97	75	25.8
12	248	233	87	77	28.4
13	185	191	78	71	26.2
14	243	233	92	78	30.8
15	235	236	95	69	32.7
16	243	221	96	71	31.0
17	214	204	73	71	19.2
18	217	176	70	75	16.2
19	246	238	105	74	33.0
20	240	177	67	70	17.0
21	194	149	65	64	15.7
22	168	215	96	67	35.7

The correlation coefficient between the drum and drop tests was +0.96 (Table XXVI) and is shown by the data graphically presented in Figure 31. A correlation coefficient of +0.96 indicates correlation of a high degree—*i.e.*, both tests appear to measure about the same characteristics of a box. The graph in Figure 31 shows the tightness of the swarm about the line. On the basis of the boxes tested, a box with a high drum value would have, in general, a correspondingly high drop test value. However, it should be emphasized

TABLE XXVIII

CORRELATION COEFFICIENTS BETWEEN PHYSICAL TEST RESULTS ON COMBINED BOARD

	Bursting Strength	G. E. Puncture	G. E. Stiffness	Pin Adhesion	Flat Crush
Bursting strength	+1.00	+0.48	+0.34	+0.39	+0.13
G. E. puncture	+0.48	+1.00	+0.91	+0.35	+0.84
Pin adhesion	+0.39	+0.35	+0.24	+1.00	−0.04
G. E. stiffness	+0.34	+0.91	+1.00	+0.24	+0.90
Flat crush	+0.13	+0.84	+0.90	−0.04	+1.00

that this correlation may or may not apply to boxes of different sizes made from different materials under different conditions of fabrication.

Combined Board

The results of the combined board tests on the twenty-two run combinations are given in Table XXVII. The correlation coefficient for the intercorrelation of the combined board tests—bursting strength, G. E. puncture, G. E. stiffness, flat crush, and pin adhesion—are given in Table XXVIII.

The correlation coefficients show that the bursting strength test has very poor correlation with any of the other combined board tests. The same may be said about the pin adhesion test. On the other hand, G. E. puncture correlates well with G. E. stiffness and fairly well with flat crush, the correlation coefficients being +0.91 and +0.84, respectively. In turn, G. E. stiffness correlates well with flat crush as shown by the correlation coefficient of +0.90. Since the intercorrelation of these three tests (G. E. puncture, G. E. stiffness, and flat crush) is high, it indicates that these three tests measure approximately the same characteristics of the combined board and, since the G. E. puncture test appears to correlate best, it would appear to be the most logical one of the three to be used for a single test evaluation of combined board.

The correlation coefficient between bursting strength and G. E. puncture is *+0.48 and is graphically presented* in Figure 32. The correlation coefficient, as well as the pattern of the points, indicates that the correlation is poor. Therefore, the bursting strength test and the G. E. puncture test tend to measure different physical characteristics of the combined board and predictions concerning the combined board from the results of these two tests would probably differ markedly. On page 37 an indication was given of what the differences in these two tests might mean in terms of the relative performance of the liners and corrugating medium. Further, it was pointed out that the G. E. puncture test tended to give emphasis to the *corrugating* medium and the bursting strength test tended to give emphasis to the liners.

Since the correlation of the G. E. puncture test with the bursting strength test was very poor, indicating that the two tests measure somewhat different physical characteristics, it is interesting to observe which of these tests on the combined board correlates better with the box tests.

Combined Boards and Boxes

The correlation coefficients between combined board tests and box tests are given in Table XXIX. It may be noted that the G. E. puncture test correlates better with all the box tests than does the bursting strength test. The correlation coefficients for the G. E. puncture

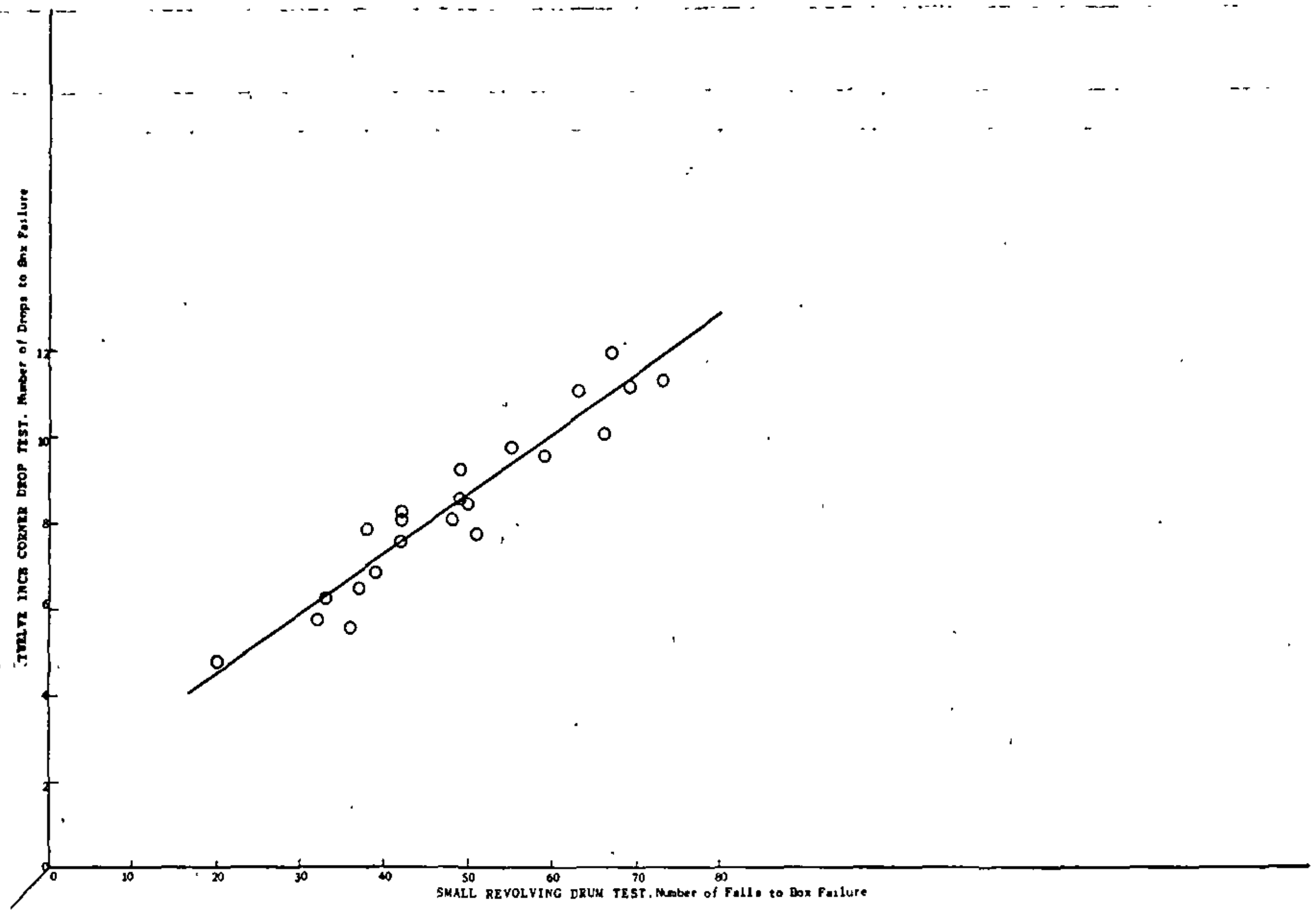

FIGURE 31. Correlation of 12-Inch Corner Drop and Drum Tests—Run Combinations 1–22.

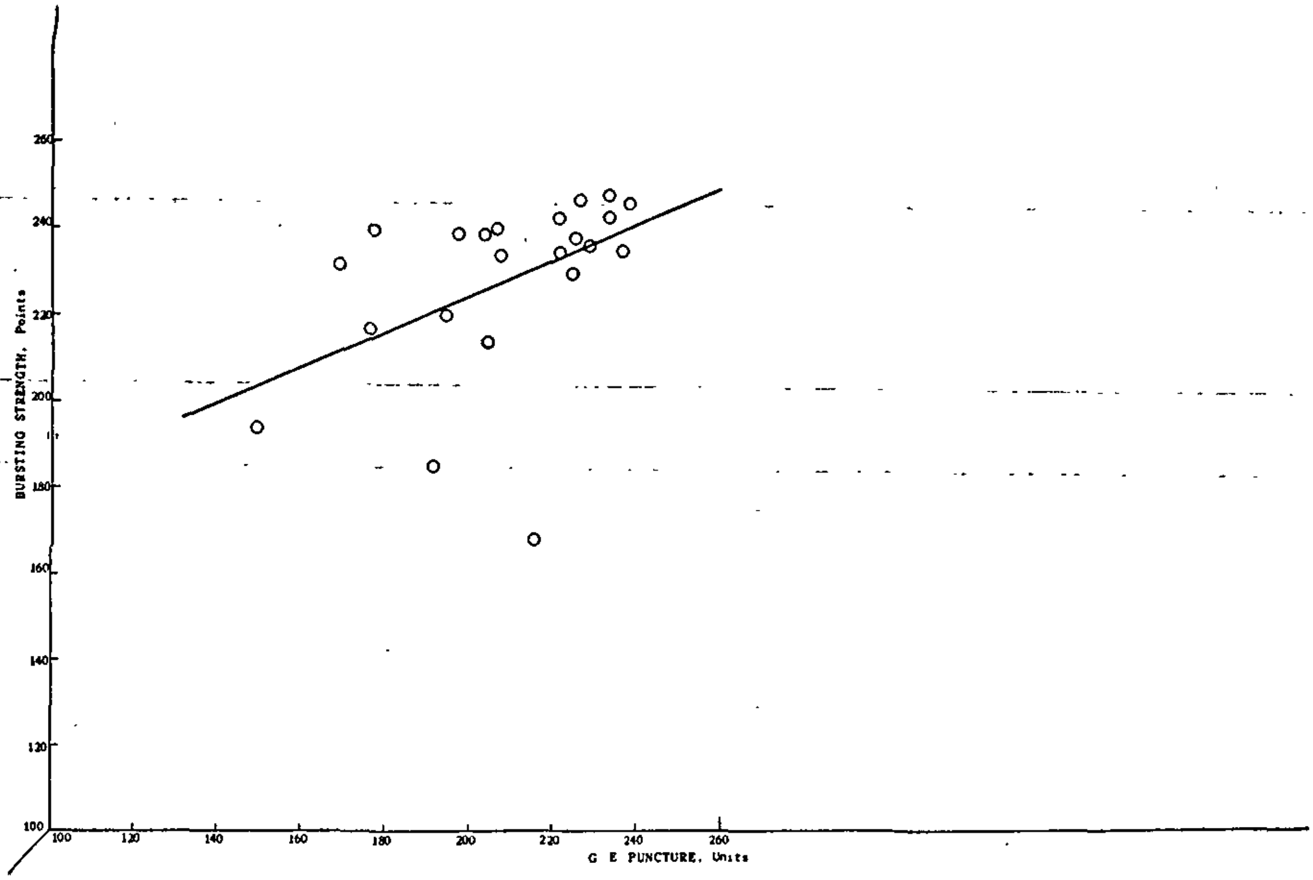

FIGURE 32. Correlation of Bursting Strength and G. E. Puncture Tests—Run Combinations 1-22.

test with top-load (deflection range 0–0.75 inch) and end-load compression (deflection range 0–0.50 inch) were +0.91 and +0.90, respectively, and are graphically illustrated in Figures 33 and 34. On the other hand, correlation coefficients of the bursting strength test with the corresponding box compression tests were +0.52 and +0.45, and are graphically presented in Figures 35 and 36. This comparison indicates that, on the basis of the samples tested, the G. E. puncture test, as a *single* test for combined board, is probably a better criterion of top-load (0–0.75 inch) and end-load compression (0–0.50 inch) than is the bursting strength test. Also, the correlation coefficients for the G. E. puncture test with the drum and drop tests were +0.75 and +0.83, respectively. The graphic presentation of the data may be seen in Figures 37 and 38. The bursting strength test correlation coefficients with the corresponding box tests were +0.61 and +0.66, respectively. These are presented graphically in Figures 39 and 40. This comparison again indicates that, as a *single* test, the G. E. puncture test correlates better with the drum and drop tests than does the bursting strength. On the basis of the results obtained for the twenty-two run combinations studied, the G. E. puncture test results can be used as a means of predicting the results of any one box test almost as well as any of the other box test results. In some cases (top-load compression in the 0–0.75 inch deflection range and end-load compression in the 0–0.50 inch deflection range), it gives a little better prediction than any of the other box tests.

It may be noted that the pin adhesion had very poor correlation with top-load and end-load compression. Although the correlation of pin adhesion results with the drum or drop test results is poor, it is considerably better than the correlation with compressive strength tests.

In general, the G. E. stiffness and flat crush tests

TABLE XXIX

CORRELATION COEFFICIENTS FOR PHYSICAL TESTS ON COMBINED BOARD AND BOXES

	Top-Load Compression in Deflection Range		*End-Load Compression in Deflection Range*			
	0–0.25 in.	0–0.75 in.	0–0.25 in.	0–0.50 in.	Drum	Drop
Bursting strength	+0.61	+0.52	+0.35	+0.45	+0.61	+0.66
G. E. puncture	+0.64	+0.91	+0.83	+0.90	+0.75	+0.83
Pin adhesion	+0.12	+0.29	+0.30	+0.42	+0.61	+0.58
G. E. stiffness	+0.51	+0.87	+0.87	+0.94	+0.58	+0.66
Flat crush	+0.41	+0.74	+0.75	+0.78	+0.42	+0.53

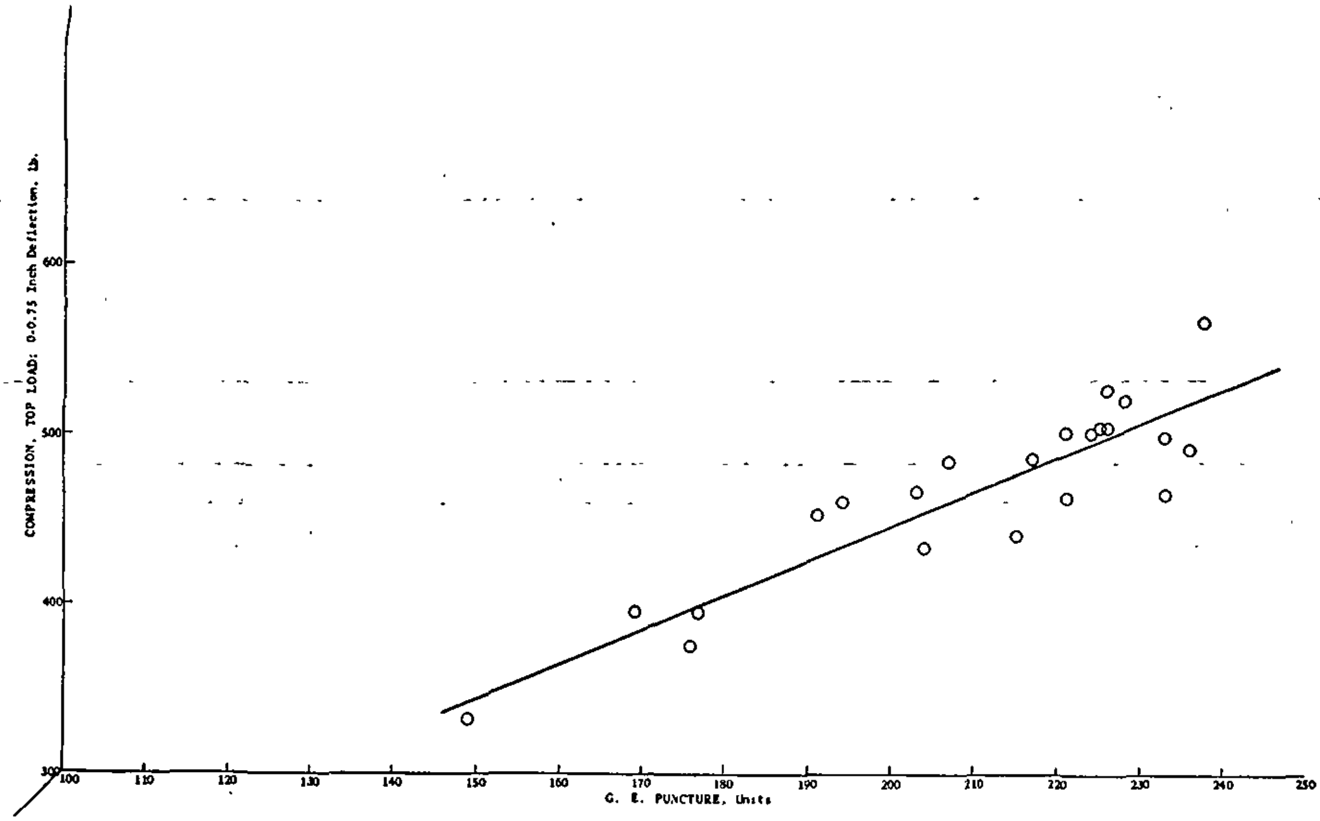

FIGURE 33. Correlation of G. E. Puncture and Top-Load Compression Tests—Run Combinations 1-22.

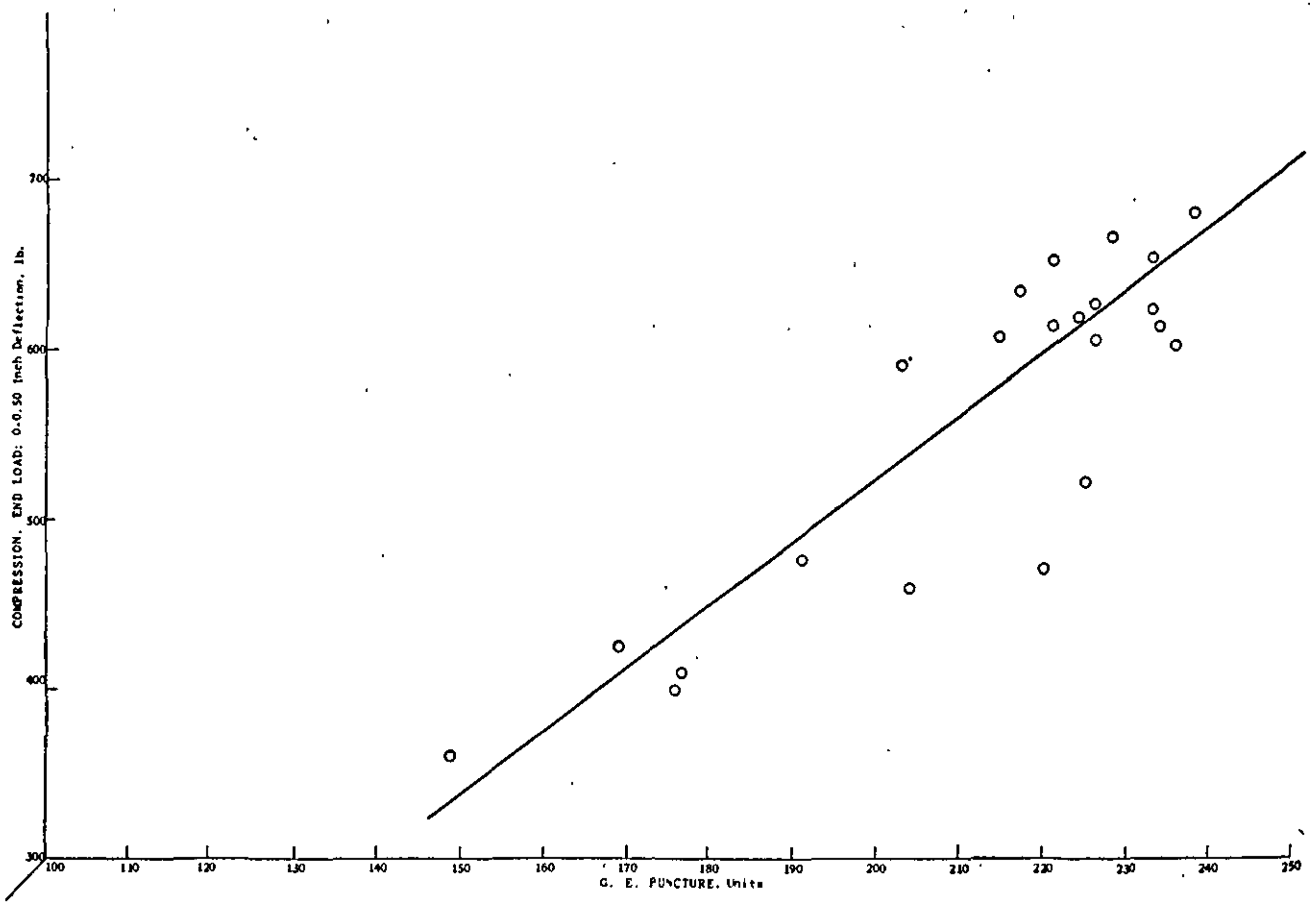

FIGURE 34. Correlation of G. E. Puncture and End-Load Compression Tests—Run Combinations 1-22.

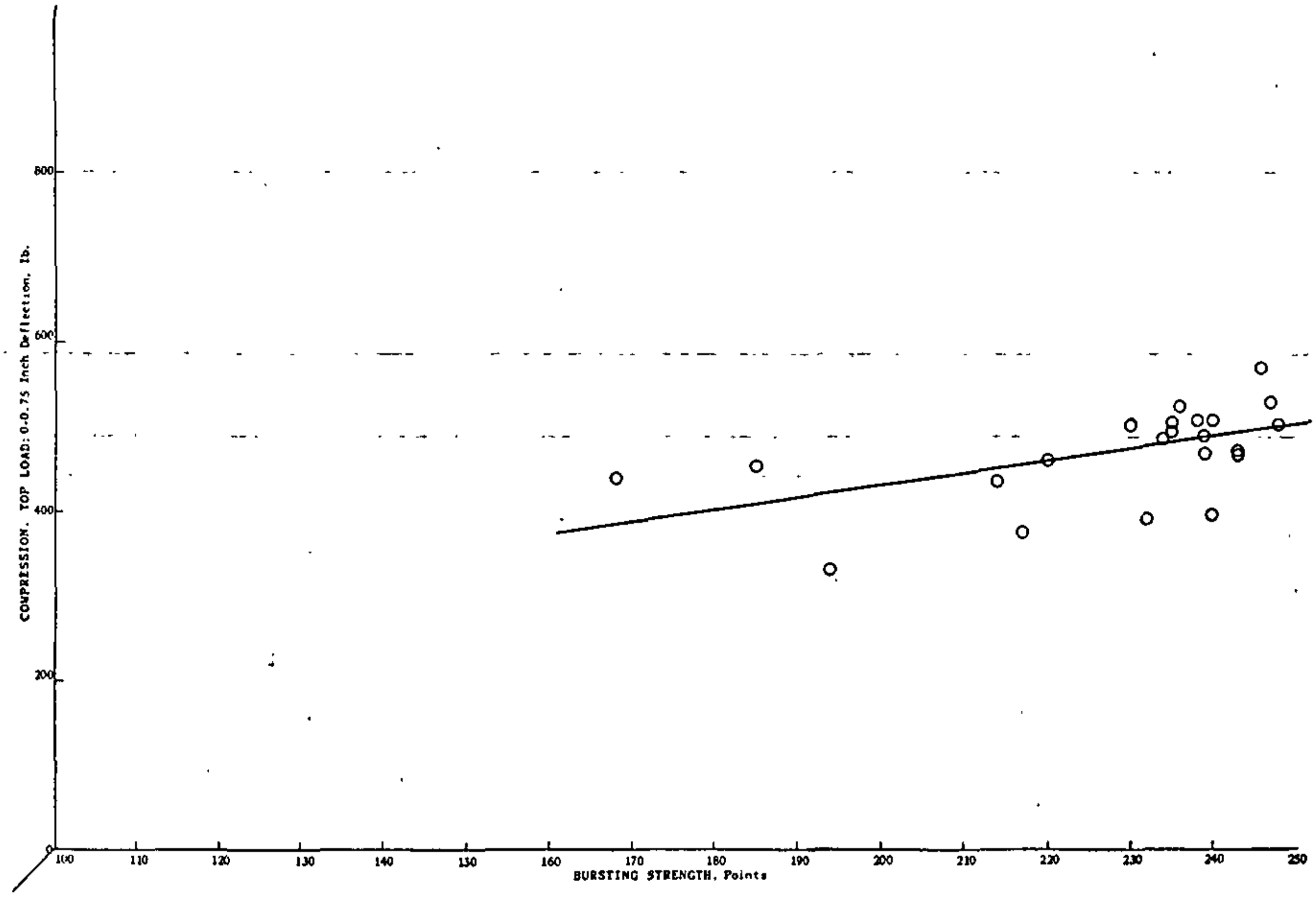

FIGURE 35. Correlation of Bursting Strength and Top-Load Compression Tests—Run Combinations 1–22.

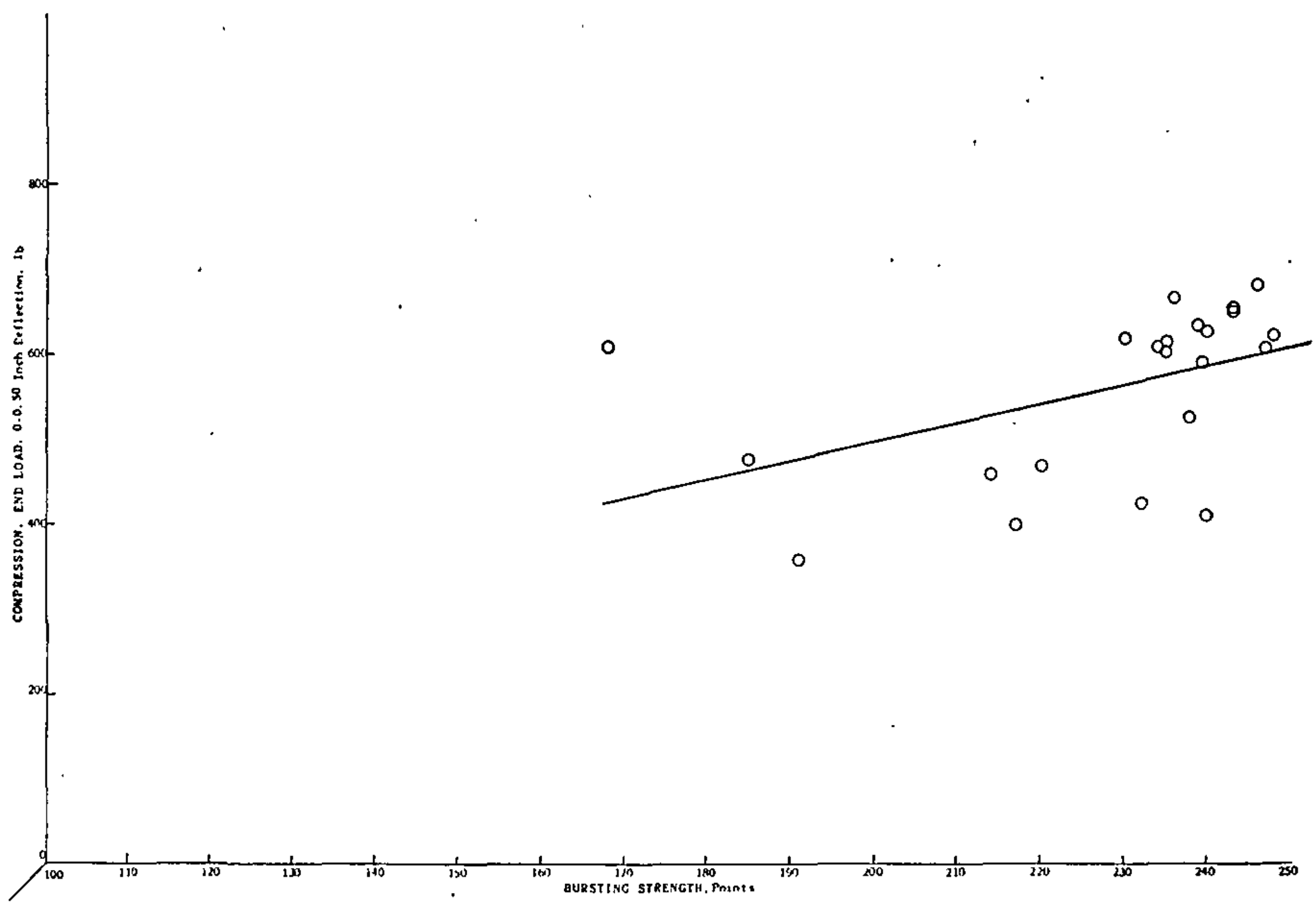

FIGURE 36. Correlation of Bursting Strength and End-Load Compression Tests—Run Combinations 1–22.

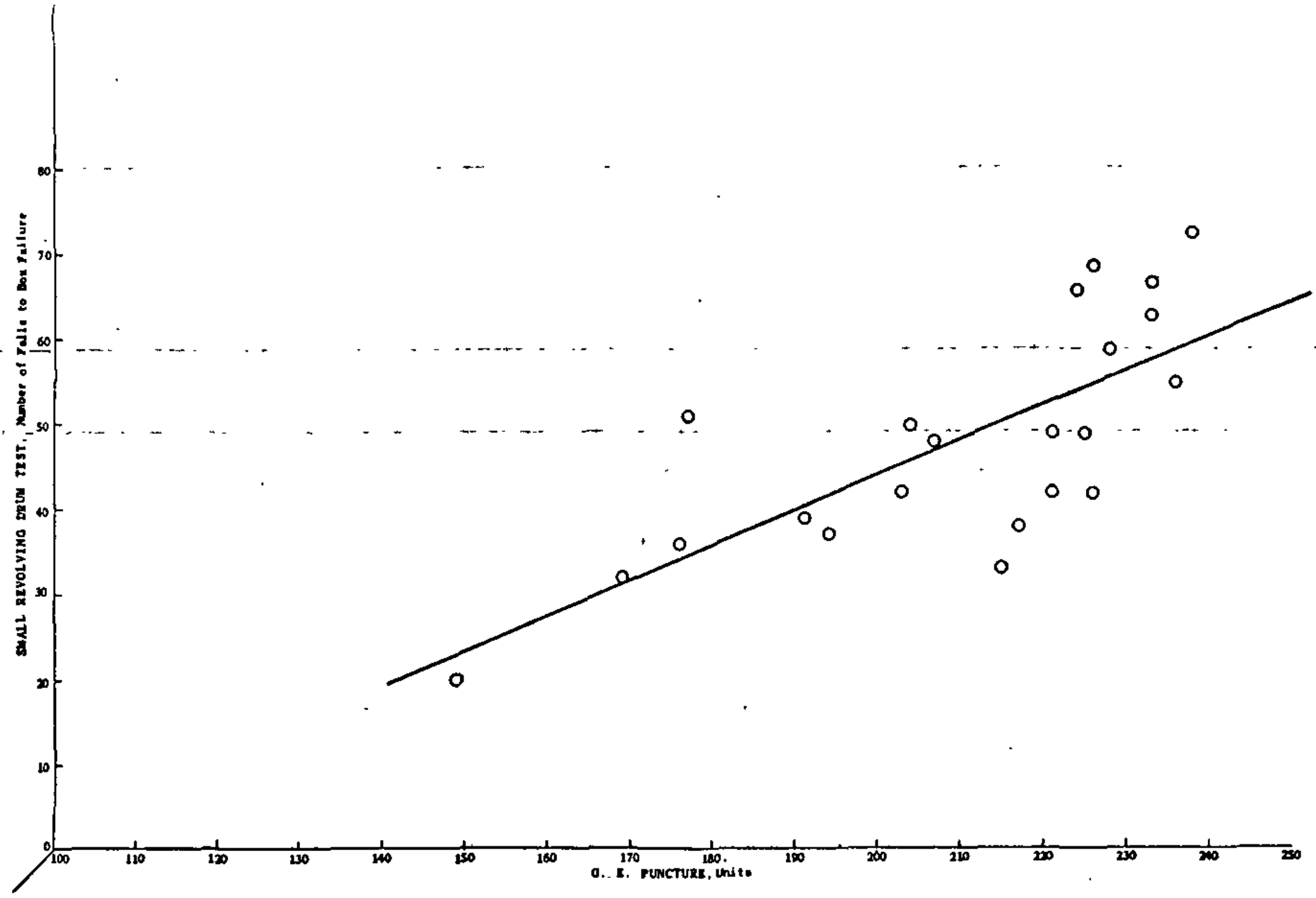

FIGURE 37. Correlation of G. E. Puncture and Drum Tests—Run Combinations 1–22.

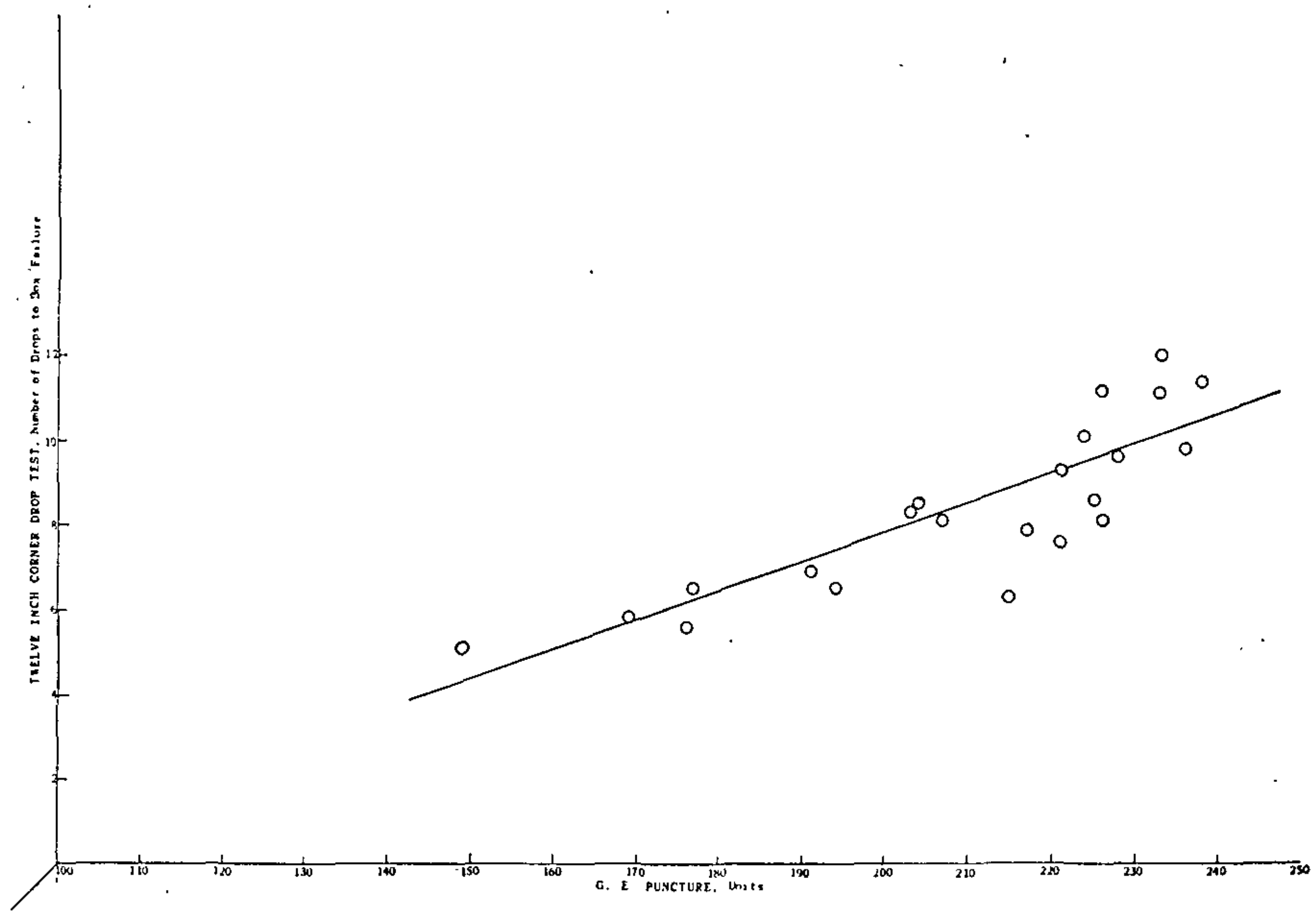

FIGURE 38. Correlation of G. E. Puncture and 12-Inch Corner Drop Tests—Run Combinations 1–22.

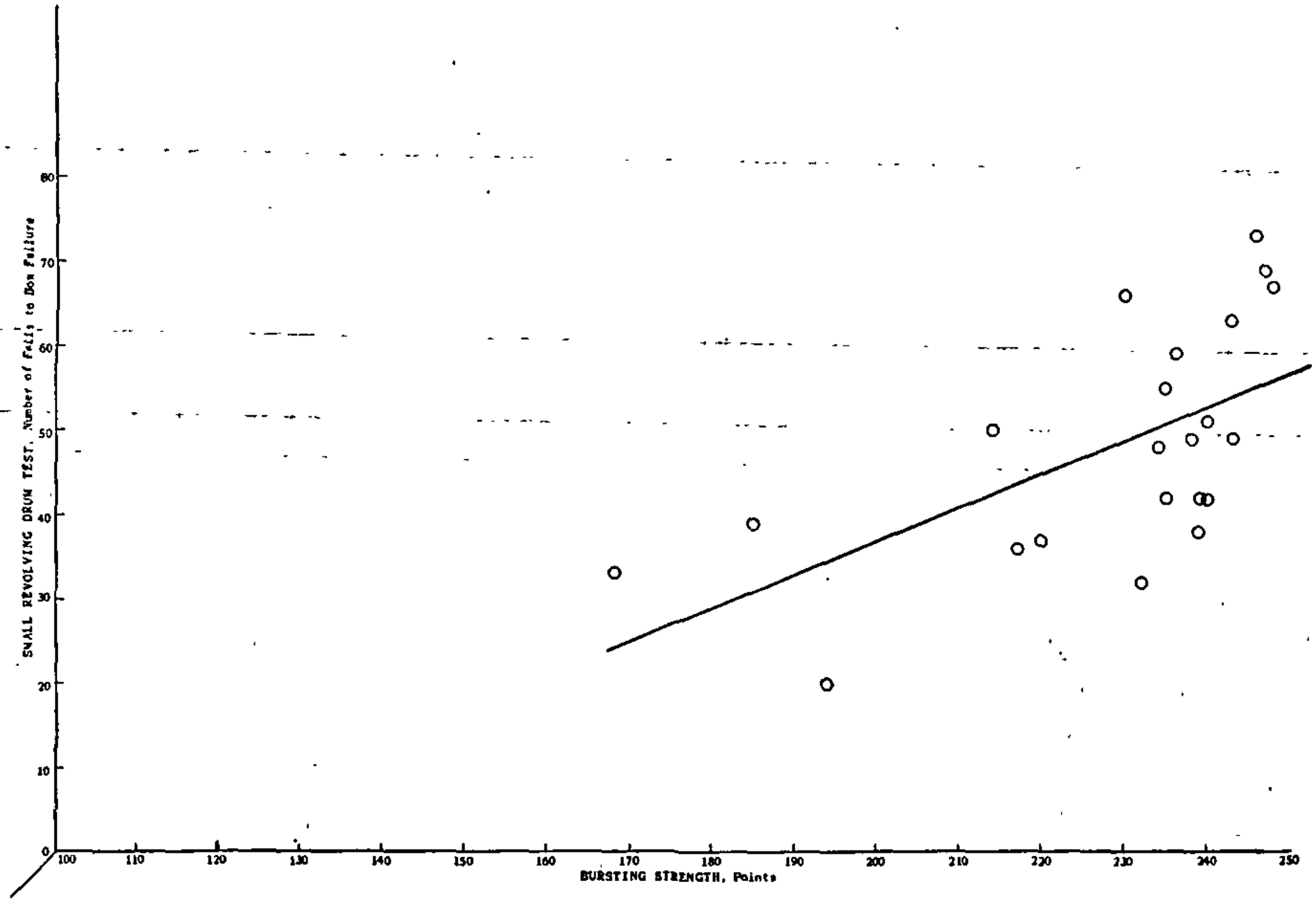

FIGURE 39. Correlation of Bursting Strength and Drum Tests—Run Combinations 1–22.

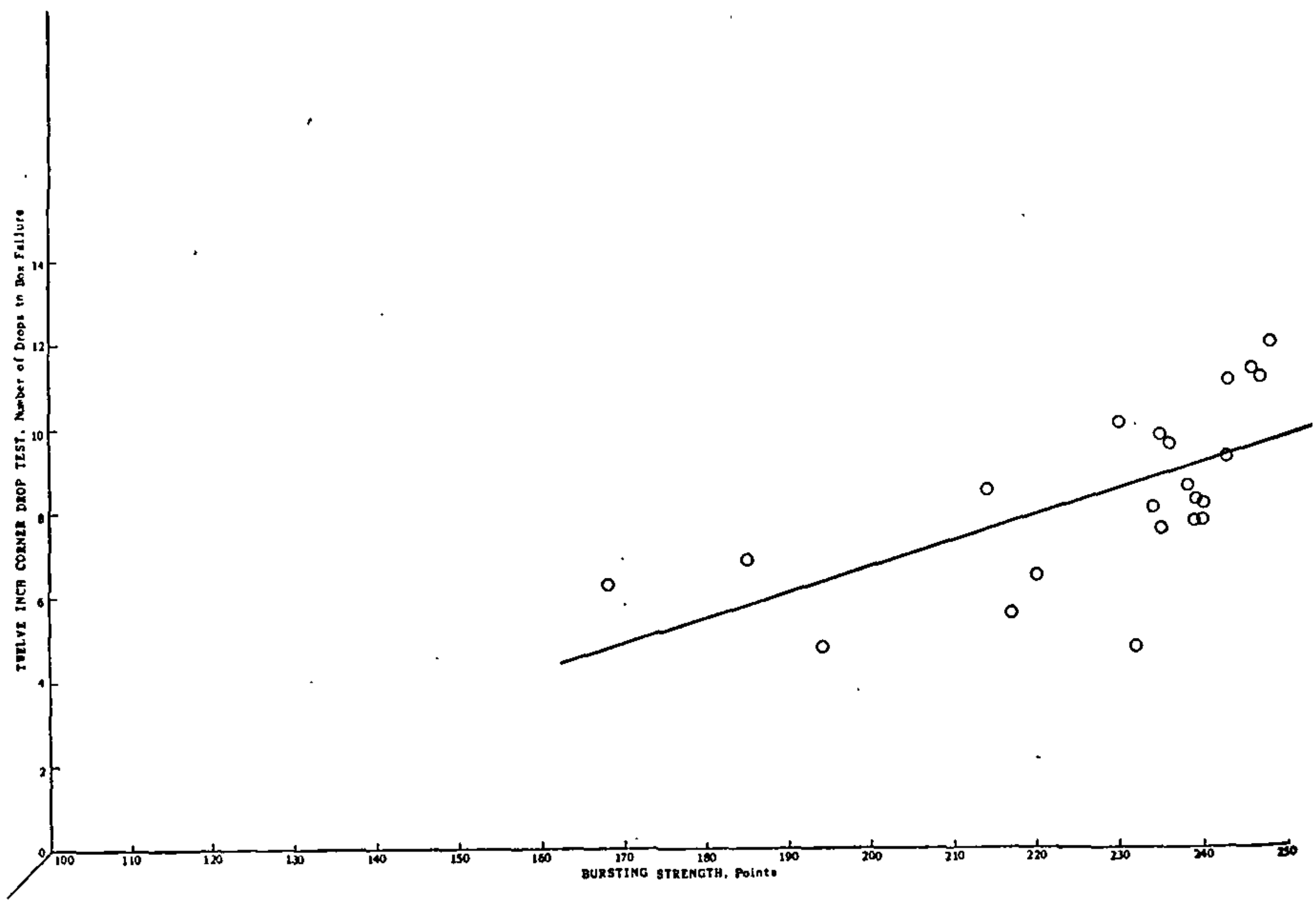

FIGURE 40. Correlation of Bursting Strength and 12-Inch Corner Drop Tests—Run Combinations 1–22.

tend to follow the same correlation trend as the G. E. puncture test. This is to be expected, since it was observed from the data in Table XXVIII that the G. E. puncture test measures many of the same characteristics in the combined board as the G. E. stiffness or flat crush test.

In the preceding discussion, consideration has been given only to simple correlation—*i.e.*, the relationship or correlation between two characteristics. However, in a study of this type, it is often more desirable to determine the most effective manner of weighting different physical tests on combined board in order to obtain the best prediction of box test results. The theory is discussed in Appendix B, where it is shown that a certain weight should be given each test on combined board and that a weighted total should be found.

For example, suppose it is *assumed* that G. E. puncture, flat crush, and bursting strength are separately of use in assigning a laboratory performance value to a sample of combined board. If the three combined board tests are considered jointly, a better evaluation may be made of the performance of the board in question. Thus, if a board has a high G. E. puncture value a good box would normally be expected, but if it has high G. E. puncture, high flat crush, and also high bursting strength, the probability for a good box would be much greater. Similarly, if the board is low in G. E. puncture, flat crush, and bursting strength, a much poorer box would be expected than one made from a combined board with high G. E. puncture, flat crush, and bursting strength values. A complication arises, however, when the G. E. puncture and flat crush values are low but, in contrast, the bursting strength value is high. The question then arises as to how each test should be weighted in order to give the best criterion for box performance. It is readily apparent that a great variety of similar situations can exist which give rise to various degrees of perplexity. However, there exists a statistical technique for dealing precisely with this problem. This technique measures the weight, or degree of importance, which should be attached to the G. E. puncture, flat crush, and bursting strength values in predicting the relative laboratory performance of a box. The statistical technique used for this purpose is known as *multiple regression* and has been successfully used in other fields, most notably in agricultural and psychological research.

To illustrate the application of statistical methods in this type of analysis, it may be assumed that, on some sample lots of materials, data are available on the G. E. puncture, pin adhesion, and bursting strength tests for the combined board and that results for a single test (*e.g.*, the drop test) are known for the finished boxes. The question may then be raised as to what extent the analysis of the values of the combined boards can be used in predicting the magnitude of the box test—*i.e.*, the drop test. The values for the combined boards might merely be added. Alternately, the G. E. puncture arbitrarily might be given a weight factor of 3, pin adhesion a weight factor of 2, and bursting *strength a weight factor of 1.* The possible sets of weight factors which might be arbitrarily assigned are endless. It can be shown, however, that there is a unique combination of combined board tests which will give the *maximal* (maximum) index of laboratory box performance as measured by any one test (e.g., the drop test). The weight factors which will give the maximal index are found by multiple regression. The weight factors thus found are then combined into a common equation so that the individual tests may be considered collectively (multiple correlation) in the prediction of box performance. In this study, therefore, the problem is to determine the most effective manner of weighting the different physical test data in order to obtain the best prediction of box test results. In the next paragraph, consideration will be given to the fundamental question of which physical tests can, in the interest of both efficiency and economy, be eliminated as superfluous.

Table XXX contains the simple coefficients of correlation—first between combined board tests, second between board tests and box tests and, third, between box tests. Inspection of the correlations between combined board tests shows that, in this study, only three of the five combined board tests have essentially independent predictive value. Bursting strength and pin adhesion correlate so poorly with each other and with the other combined board tests as to be effectively independent. For example, bursting strength may not reveal much about the box tests and the information obtained from it is not duplicated by the pin adhesion or the other combined board tests; the same may be said about the pin adhesion test in its relation to the box tests. The G. E. puncture, G. E. stiffness, and flat crush tests, however, are highly correlated with each other. This means that, whatever one test on the combined board indicates about box tests, the others substantially repeat. One of them, then, tells as much as all three. Thus, of the combined board tests used, bursting strength, pin adhesion, and one of the three—G.E. puncture, G. E. stiffness, and flat crush—are the only tests which have independent predictive value.

By consulting the correlations between the combined board tests and box tests, it is possible to determine which of the three tests—G. E. puncture, G. E. stiffness, and flat crush—will best serve the purpose, in conjunction with bursting strength and pin adhesion, in predicting the box tests. It may be observed (see Table XXX) that G. E. puncture is the only one of the three that correlates highly with all the box tests, and thus has precedence over the other two in regard to predictive power.

When only the compressive strengths of the boxes included in this study are considered, the G. E. puncture test is the only independent combined board test which has a markedly high predictive value throughout. Consequently, the results indicate that the G. E. puncture test alone will predict compressive strength nearly as well as G. E. puncture, pin adhesion, and

CORRELATION COEFFICIENTS

Between Physical Tests on Combined Board

	Bursting Strength	G. E. Puncture	G. E. Stiffness	Pin Adhesion	Flat Crush
Bursting strength	+1.00	+0.48	+0.34	+0.39	+0.13
G. E. puncture	+0.48	+1.00	+0.91	+0.35	+0.84
Pin adhesion	+0.39	+0.35	+0.24	+1.00	−0.04
G. E. stiffness	+0.34	+0.91	+1.00	+0.24	+0.90
Flat crush	+0.13	+0.84	+0.90	−0.04	+1.00

Between Physical Tests on Combined Board and Boxes

	Top-Load Compression in Deflection Range		End-Load Compression in Deflection Range			
	0–0.25 in.	0–0.75 in.	0–0.25 in.	0–0.50 in.	Drum	Drop
Bursting strength	+0.61	+0.52	+0.35	+0.45	+0.61	+0.66
G. E. puncture	+0.64	+0.91	+0.83	+0.90	+0.75	+0.83
Pin adhesion	+0.12	+0.29	+0.30	+0.42	+0.61	+0.58
G. E. stiffness	+0.51	+0.87	+0.87	+0.94	+0.58	+0.66
Flat crush	+0.41	+0.74	+0.75	+0.78	+0.42	+0.53

Between Physical Tests on Boxes

Top compression, 0–0.25 in.	+1.00	+0.77	+0.41	+0.46	+0.66	+0.59
Top compression, 0–0.75 in.	+0.77	+1.00	+0.73	+0.86	+0.73	+0.77
End compression, 0–0.25 in.	+0.41	+0.73	+1.00	+0.90	+0.49	+0.58
End compression, 0–0.50 in.	+0.46	+0.86	+0.90	+1.00	+0.64	+0.74
Drum	+0.66	+0.73	+0.49	+0.64	+1.00	+0.96
Drop	+0.59	+0.77	+0.58	+0.74	+0.96	+1.00

bursting strength collectively. Hence, for compression tests, G. E. puncture *alone* will be considered in the ensuing discussion. In drum and drop, all *three* of the independent physical tests are of predictive value and, therefore, the discussion of them will be in terms of all three.

The weighting constants or weight factors obtained and used to determine the predicted values are set forth in Table XXXI. A comparison of the predicted values for each test against the observed laboratory

TABLE XXXI

WEIGHT FACTORS

Box Test	G. E. Puncture	Bursting Strength	Pin Adhesion	Constant
Drum	+0.29195	+0.15411	+1.02300	−120.80
Drop	+0.04972	+0.02468	+0.11679	− 15.92
Top-load compression* (0–0.75 inch)	+2.07741			+ 33.09
End-load compression* (0–0.50 inch)	+3.74869			−224.17

* Based on G. E. puncture test only.

TABLE XXXII

COMPARISON OF OBSERVED AND PREDICTED BOX TESTS

Run Combination	Top-Load Compression, lb. Deflection Range 0–0.75 in.		End-Load Compression, lb. Deflection Range 0–0.50 in.		Drum, No. of Falls to Box Failure		Drop, No. of Drops to Box Failure	
	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
1	487	484	634	589	38	52	7.9	9.1
2	506	503	628	623	42	51	8.1	9.1
3	505	501	523	619	49	44	8.6	8.3
4	469	455	592	537	42	48	8.3	8.4
5	397	384	423	409	32	36	5.8	6.4
6	489	463	611	551	48	49	8.1	8.6
7	460	436	469	503	37	33	6.5	6.4
8	502	498	620	616	66	54	10.1	9.3
9	501	492	614	604	42	55	7.6	9.4
10	528	503	646	623	69	63	11.2	10.5
11	525	507	668	631	59	59	9.6	10.0
12	500	517	624	649	67	64	12.0	10.8
13	458	430	478	492	39	36	6.9	6.4
14	468	517	656	649	63	64	11.1	10.8
15	506	523	602	661	55	55	9.8	9.7
16	470	492	653	601	49	54	9.3	9.4
17	434	457	459	541	50	44	8.5	7.8
18	374	399	399	436	36	41	5.6	7.0
19	568	528	682	668	73	62	11.4	10.6
20	393	401	411	439	51	39	7.8	7.0
21	333	343	361	334	20	18	4.8	3.8
22	439	480	608	582	33	36	6.3	6.7

values is given in Table XXXII and Figures 41, 42, 43, and 44. The multiple correlation coefficient between drum test results and those of the combined board tests—bursting strength, pin adhesion, and G. E. puncture—was +0.86, and between the drop test results and the above-mentioned combined board test results, was +0.91. These two correlation coefficients indicate the predictive value of the combination of the three combined board tests with respect to each box test; that they are markedly greater than the predictive value of any of the individual combined board tests is shown by Table XXX.

The correlation coefficient for G. E. puncture and top-load compression in the deflection range 0–0.75 inch was +0.91. For G. E. puncture and end-load compression in the deflection range 0–0.50 inch, the correlation coefficient was +0.90.

The statistical approach to the problem of determining the relationship between combined board and box tests permits the handling of the data from a large number of sample lots. In addition, it allows the determination of that relationship to be expressed in terms of a numerical figure.

RELATIONSHIP BETWEEN VARIOUS COMPONENT AND BOX TESTS

For years, the general specifications for container board have been weight, caliper, moisture content, and bursting strength. Naturally, at times additional tests have been run depending on the ultimate use of the board. From a practical viewpoint, a manufacturer is vitally interested in knowing the relationship between the test results of the components and those on the boxes made from such components—i.e., which properties of the component materials have a dominant influence on the quality of the boxes made from his paperboard.

The data obtained on the twenty-two run combinations offered a splendid opportunity to study this correlation. Samples of each of the component materials were taken at the beginning, middle, and end of each run combination. These samples were submitted to the following tests: bursting strength, G. E. puncture, ring compression, Elmendorf tear, Amthor tensile, and stretch. It was immediately apparent that this battery of tests—three-fold, because each test was made on the single-face liner, double-face liner, and corrugating medium—presented an inordinate number of factors which might conceivably be related to box performance. In order to study the relationship between the test results on the components and those on the finished boxes made from the components, the data obtained from the twenty-two run combinations were subjected to the same statistical analysis that was used to determine the relation between combined board test results and box test results.

The first step in the application of this analysis was to select, by proper determination, the tests on the components which appeared to have the greatest predictive value. In particular, it was necessary to determine the intercorrelations of all the test results on the components in which machine and across-machine direction results were obtained. The tests which involved such data were Elmendorf tear, ring compression, Amthor tensile, and stretch. The results of the "double tests" on the components which were used in the fabrication of the twenty-two run combinations are given in Table XXXIII. The results obtained on the boxes fabricated from these components are given in Table XXV. The correlation coefficients given in Table XXXIV were calculated from the data in Tables XXXIII and XXV.

From the data in Table XXXIV, it can be seen that the ring compression test values obtained in this study were so poorly related to box test results that they can be eliminated from further consideration at this time. The Elmendorf tear results have a fair degree of correlation with some of the box results and, therefore, warrant further consideration. In addition, it may be observed that the intercorrelation of the Elmendorf tear results in the machine and across-machine directions were consistently high, indicating that, on the basis of the materials studied, the tests in the two directions measure approximately the same characteristic of the components. Accordingly, the average of the Elmendorf tear results in the machine and across-machine directions has been used in the subsequent treatment of the component data in this report. The correlation coefficients obtained for Amthor tensile and stretch indicated moderate correlation with box results and with each other. Therefore, the machine and across-machine direction identities for these tests must be maintained in further study.

In addition to the reduced set of double tests (ring compression omitted and Elmendorf tear in machine and across machine averaged), consideration must be given also to the two single tests—bursting strength and G. E. puncture, which are given in Table XXXV.

From the data in Tables XXXIII, XXXIV, and XXXV, the correlations between component test results—average Elmendorf tear, Amthor tensile (machine and across-machine direction), Amthor stretch (machine and across-machine direction), bursting strength, and G. E. puncture—were calculated and are given in Table XXXVI. Further, the correlation of each component test with each box test is shown. Consideration of these results suggests that average Elmendorf tear should have good predictive value in regard to these twenty-two different lots of boxes, since for no box test does it fail to show, for at least one of the components in each run combination, a correlation coefficient greater than +0.60. The correlation coefficient for the Amthor tensile test values in the machine and across-machine directions shows indifferent correlation with box test results. Amthor stretch in the machine direction shows poor correlation with box tests. On the other hand, Amthor stretch in the across-machine direction shows moderate correlation with box tests and, further, is not highly correlated with average Elmendorf tear. Accordingly, Am-

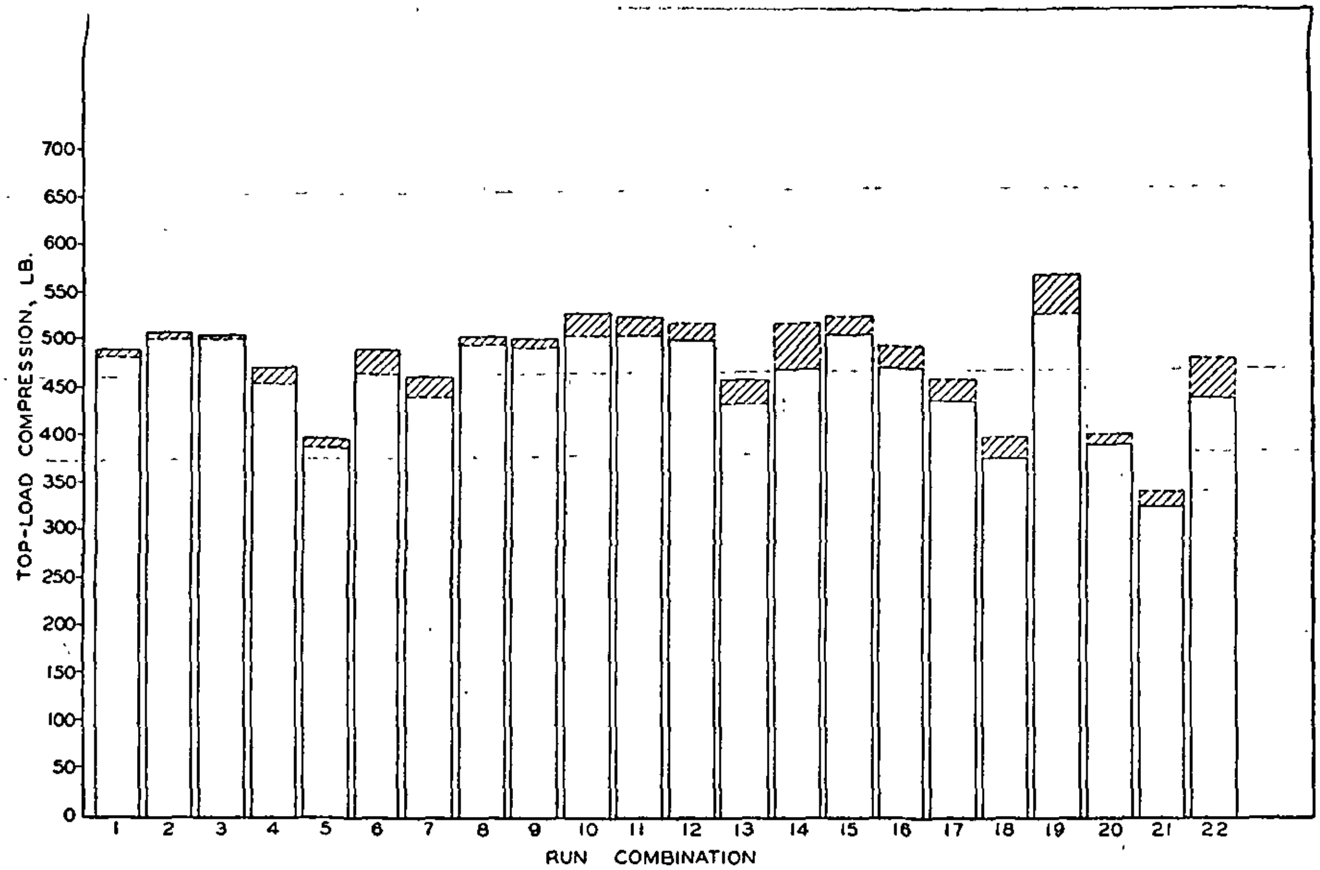

FIGURE 41. Comparison of Observed and Predicted Top-Load Compression Tests (0–0.75 inch)—Based on Combined Board Tests
———— Observed -------------- Predicted

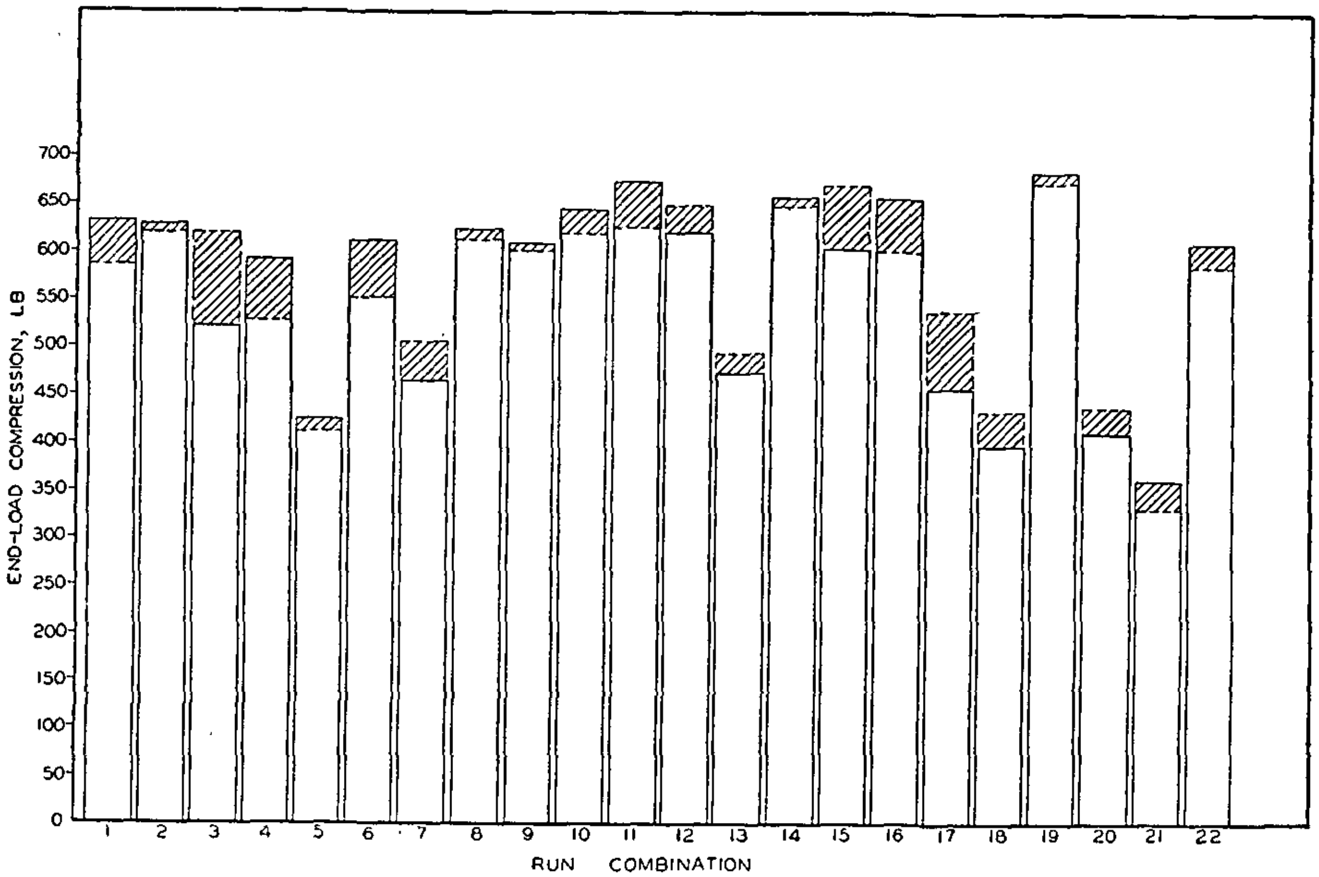

FIGURE 42. Comparison of Observed and Predicted End-Load Compression Tests (0–0.50 inch)—Based on Combined Board Tests
———— Observed -------------- Predicted

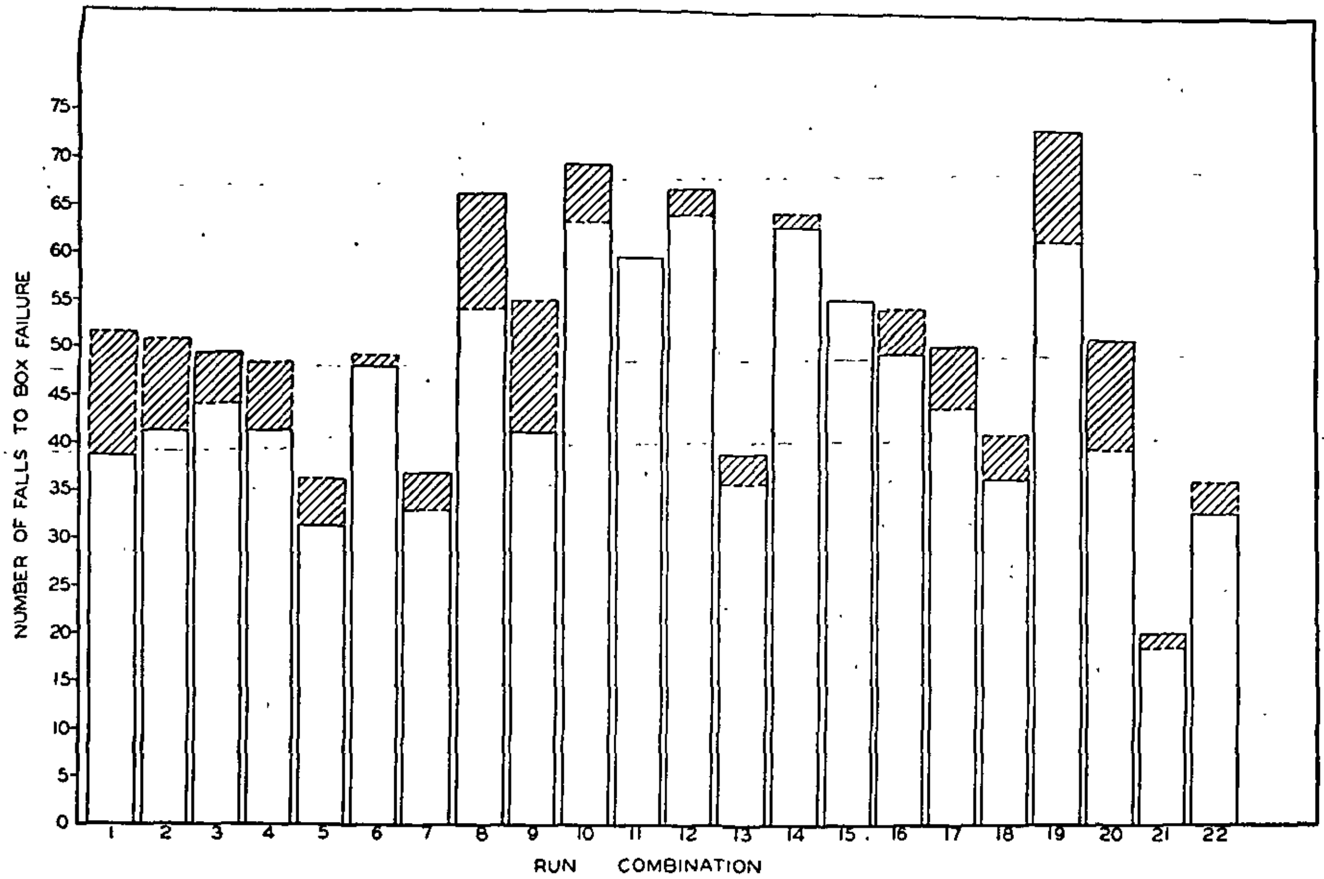

FIGURE 43. Comparison of Observed and Predicted Drum Tests—Based on Combined Board Tests
———— Observed -------------- Predicted

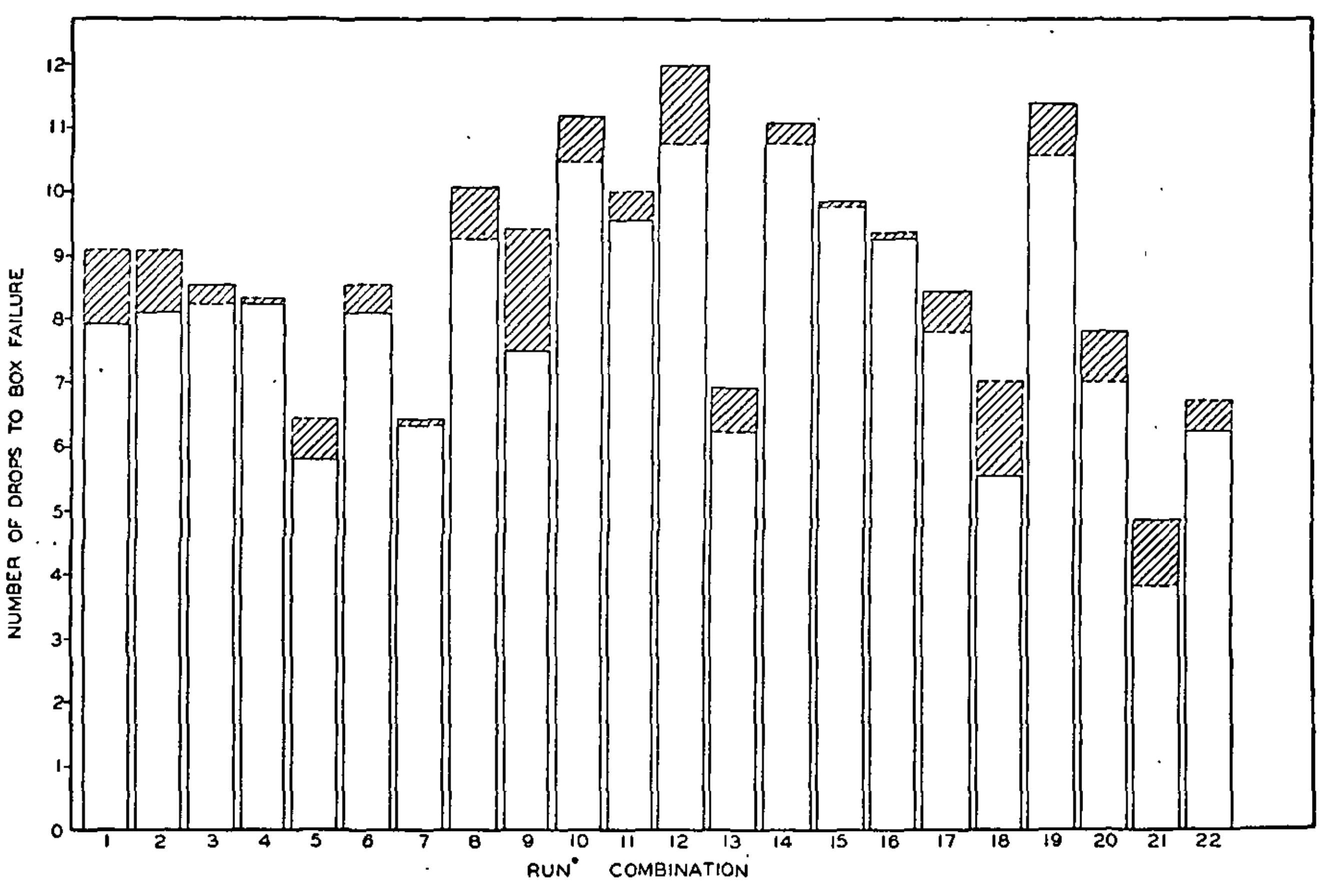

FIGURE 44. Comparison of Observed and Predicted Drop Tests—Based on Combined Board Tests
———— Observed -------------- Predicted

TABLE XXXIII

MACHINE AND ACROSS-MACHINE DIRECTION TEST RESULTS ON LINERS AND CORRUGATING MEDIUMS—RUN COMBINATIONS 1–22

Run Combination	Single-Face Liner								Corrugating Medium								Double-Face Liner							
	Ring Compression, lb.		Elmendorf Tear, g./sheet		Amthor Tensile, lb./in.		Amthor Stretch, %		Ring Compression, lb.		Elmendorf Tear, g./sheet		Amthor Tensile, lb./in.		Amthor Stretch, %		Ring Compression, lb.		Elmendorf Tear, g./sheet		Amthor Tensile, lb./in.		Amthor Stretch, %	
	In	Across	In	Across	In	Across	In	Across	In	Across	In	Across	In	Across	In	Across	In	Across	In	Across	In	Across	In	Across
1	26.5	22.0	331	389	76.0	36.6	1.8	2.8	17.9	11.9	195	268	56.6	21.6	1.7	3.1	30.7	23.8	336	394	84.5	36.9	2.0	3.4
2	27.4	21.9	322	386	75.4	37.5	1.7	2.7	18.2	13.1	198	238	53.2	24.3	1.8	4.2	31.1	23.3	359	397	81.1	38.5	1.8	3.5
3	31.1	24.1	324	386	76.5	37.3	2.0	2.9	19.4	15.8	216	241	56.8	32.8	2.0	4.7	31.5	23.4	350	407	86.2	37.2	2.0	3.2
4	29.4	22.5	315	381	74.7	37.1	2.2	3.0	16.9	13.2	211	235	47.1	23.8	1.5	3.2	31.0	24.1	334	377	82.6	40.9	2.2	3.3
5	29.2	22.9	323	364	75.2	37.2	2.1	2.9	13.0	10.2	109	121	30.1	17.8	1.0	2.1	35.6	26.1	348	394	82.0	38.2	2.5	3.2
6	30.3	23.6	329	377	75.2	36.3	2.1	3.0	19.5	14.4	239	259	51.3	25.1	2.0	4.1	34.0	25.7	346	396	83.1	39.0	2.3	3.5
7	29.3	23.1	335	388	75.1	37.8	2.1	3.1	18.7	13.3	165	196	48.0	22.2	1.9	3.3	28.7	20.8	350	399	82.7	36.3	2.0	3.2
8	26.4	22.3	329	374	76.8	37.9	2.0	3.0	19.1	15.7	259	254	48.4	31.3	1.5	4.7	30.7	22.3	331	376	81.0	36.3	2.2	3.2
9	29.9	24.4	318	367	76.2	38.8	2.0	3.1	19.4	14.6	243	282	55.8	25.7	1.7	3.3	27.8	22.4	301	361	74.5	35.9	1.8	2.6
10	29.4	24.0	382	422	75.4	40.2	2.0	3.5	20.3	15.0	244	281	56.6	26.8	1.6	3.3	28.8	24.1	370	415	80.7	41.2	2.2	3.0
11	30.6	24.7	361	431	86.6	40.4	2.0	3.0	18.9	15.1	244	283	56.7	26.8	1.9	3.4	28.3	22.8	341	400	82.9	35.9	1.9	3.1
12	28.4	21.2	371	452	85.1	36.4	2.3	4.3	18.2	13.0	214	252	53.6	23.1	2.1	3.9	28.9	24.1	408	439	79.8	37.6	2.0	4.4
13	25.1	21.9	305	334	68.4	35.5	1.7	2.9	21.0	14.4	226	250	50.6	23.4	1.9	4.1	25.0	20.8	273	313	63.7	33.1	1.8	2.7
14	31.0	19.4	340	420	86.5	36.8	1.4	3.7	21.2	13.5	226	268	57.0	23.3	2.2	4.0	29.4	20.3	332	416	84.8	36.3	1.8	3.9
15	28.0	22.4	372	380	71.1	42.8	2.1	3.9	18.8	14.0	221	275	54.9	23.3	2.2	4.3	26.1	20.8	397	449	71.0	41.4	1.7	2.8
16	28.6	20.1	320	391	83.0	33.5	1.6	3.4	18.2	13.1	229	278	52.4	23.4	2.0	4.3	25.4	19.2	306	355	77.8	34.6	1.6	3.6
17	26.2	20.2	362	381	68.0	38.2	1.4	3.3	19.2	14.1	208	249	52.4	24.3	1.8	2.9	27.2	21.6	361	402	75.4	42.0	1.6	2.9
18	30.6	23.8	304	371	76.8	36.3	1.7	2.6	21.4	15.8	198	249	52.8	24.6	1.9	2.9	31.4	25.1	310	364	76.6	38.7	1.5	2.3
19	32.4	25.9	381	387	78.2	44.1	1.8	4.0	21.5	16.0	227	254	53.3	26.4	2.0	4.3	29.6	23.3	345	393	77.1	40.6	2.1	3.5
20	32.7	26.9	383	388	84.3	44.3	2.0	4.5	17.2	11.9	177	208	44.5	22.2	1.8	2.8	29.9	23.2	369	402	77.6	42.5	2.1	3.7
21	21.6	16.8	272	280	53.5	29.2	1.1	2.5	19.0	12.4	176	202	45.7	21.4	1.8	2.8	22.8	16.7	279	282	54.6	30.0	1.0	2.3
22	21.5	16.9	265	282	55.1	29.8	1.2	2.5	21.7	15.7	228	254	54.1	26.6	1.8	4.3	22.6	16.1	274	288	54.7	28.4	1.3	2.7
Av.	28.4	22.3	334	379	75.1	37.5	1.8	3.2	19.0	13.9	211	245	51.4	24.6	1.8	3.6	28.9	22.3	337	383	77.0	37.3	1.9	3.2

thor stretch in the across-machine direction has been used to supplement average Elmendorf tear in the predictive relationships. In view of the *relatively* good correlation between the component tests being considered, it appears unfruitful to include bursting strength and G. E. puncture, together with average Elmendorf tear and Amthor stretch in the across-machine direction, in a four-factor relationship with box tests. However, the magnitude of the correlation coefficients for bursting strength and G. E. puncture indicates that they are worthy of alternate consideration. Further, by an argument parallel to that for Elmendorf tear and Amthor stretch, bursting strength and G. E. puncture together look promising in a two-factor relationship of their own.

TABLE XXXIV

CORRELATIONS OF MACHINE AND ACROSS-MACHINE DIRECTION TEST RESULTS WITH EACH OTHER AND WITH PHYSICAL TESTS ON BOXES—RUN COMBINATION 1 THROUGH 22

Tests	Correlation with Physical Tests on Boxes: Drop	Drum	Compression: Top	Compression: End	Correlation Within Double Tests
Single-Face Liner					
Ring compression—in	+0.42	+0.51	+0.36	+0.19	+0.82
Ring compression—across	+0.23	+0.39	+0.39	+0.17	
Elmendorf tear—in	+0.73	+0.78	+0.51	+0.30	+0.78
Elmendorf tear—across	+0.75	+0.72	+0.57	+0.47	
Amthor tensile—in	+0.60	+0.62	+0.43	+0.40	+0.58
Amthor tensile—across	+0.50	+0.62	+0.49	+0.20	
Amthor stretch—in	+0.33	+0.36	+0.45	+0.20	+0.37
Amthor stretch—across	+0.68	+0.68	+0.29	+0.21	
Corrugating Medium					
Ring compression—in	+0.20	+0.25	+0.23	+0.24	+0.80
Ring compression—across	+0.27	+0.40	+0.44	+0.33	
Elmendorf tear—in	+0.61	+0.58	+0.62	+0.68	+0.90
Elmendorf tear—across	+0.55	+0.50	+0.59	+0.69	
Amthor tensile—in	+0.49	+0.42	+0.56	+0.60	+0.54
Amthor tensile—across	+0.36	+0.45	+0.51	+0.37	
Amthor stretch—in	+0.37	+0.32	+0.26	+0.26	+0.55
Amthor stretch—across	+0.49	+0.45	+0.61	+0.60	
Double-Face Liner					
Ring compression—in	+0.09	+0.17	+0.16	+0.05	+0.90
Ring compression—across	+0.21	+0.29	+0.27	+0.06	
Elmendorf tear—in	+0.58	+0.57	+0.39	+0.20	+0.93
Elmendorf tear—across	+0.64	+0.63	+0.50	+0.32	
Amthor tensile—in	+0.46	+0.46	+0.46	+0.33	+0.62
Amthor tensile—across	+0.42	+0.48	+0.28	+0.05	
Amthor stretch—in	+0.37	+0.43	+0.45	+0.25	+0.57
Amthor stretch—across	+0.71	+0.63	+0.45	+0.50	

As mentioned above, the average Elmendorf tear and Amthor stretch in the machine direction appear to have good predictive relationships with box tests. Therefore, the problem is to determine the relationship appropriate for the anticipation of box tests from the component tests: average Elmendorf tear and Amthor stretch in the across-machine direction. The theory is discussed in Appendix B, where it is shown that a certain weight should be given to each test on the components and that a weighted total can then be found as a result of the weight factors determined for each different test under consideration.

It was necessary first to find the weight factors appropriate for estimating the various box tests as shown in Table XXXVII. In order to illustrate fully the use of Table XXXVII, one may consider Run Combination 1, with average Elmendorf tear as shown in Table XXXV and Amthor stretch in the across-machine direction shown in Table XXXIII. The calculation for any box test—*e.g.*, the drop test—is as follows:

The average values for the Elmendorf tear and the Amthor stretch in the across-machine direction for the single-face liner, corrugating medium, and double-face liner fabricated in Run Combination 1 are multiplied by their respective weight factors. For example:

	Observed Test	Weight Factor	Weighted Value
Single-Face Liner			
Average tear	360.0	+0.02298	+ 8.273
Stretch across	2.8	+0.57150	+ 1.600
Corrugating Medium			
Average tear	231.5	+0.01846	+ 4.273
Stretch across	3.1	+0.57991	+ 1.798
Double-Face Liner			
Average tear	365.0	+0.00031	+ 0.113
Stretch across	3.4	+0.98895	+ 3.362
Total			+19.419

The sum of the weighted values is +19.419, to which is added the constant for the particular box test in question. In the case of the drop test the constant was −11.209; thus, the predicted drop value for Run Combination 1 is 8.2 [+19.419 − 11.209 = 8.2]. The observed drop value was 7.9, in contrast to the anticipated or predicted drop value of 8.2. Using this same method of calculation, a set of expected and observed values for any given box test may be prepared, as in Table XXXVIII.

The material in Table XXXVIII is presented graphically in Figures 45–48. The (multiple) correlation coefficients of the predicted and observed values of Table XXXVIII were as follows:

Drop	+0.94
Drum	+0.93
Top-load compression	+0.87
End-load compression	+0.86

It may be noted that the differences between the observed drop values and the values predicted on the basis of the components are quite small. It should be mentioned that the agreement of these two values far exceeds usual statistical experience. It may also be observed that the correlation of predicted and observed

TABLE XXXV*

AVERAGE ELMENDORF TEAR, BURSTING STRENGTH, AND G. E. PUNCTURE VALUES—RUN COMBINATIONS 1-22

Run Combination	Single-Face Liner			Corrugating Medium			Double-Face Liner		
	Average Elmendorf Tear, g./sheet	Bursting Strength, points	G. E. Puncture, units	Average Elmendorf Tear, g./sheet	Bursting Strength, points	G. E. Puncture, units	Average Elmendorf Tear, g./sheet	Bursting Strength, points	G. E. Puncture, units
1	360.0	87	39	231.5	61	19	365.0	90	36
2	354.0	88	37	218.0	61	18	378.0	98	38
3	355.0	89	35	228.5	75	20	378.5	98	39
4	348.0	93	34	223.0	57	20	355.5	107	38
5	343.5	94	34	115.0	31	9	371.0	104	38
6	353.0	96	34	249.0	58	19	371.0	101	38
7	361.5	89	36	180.5	50	15	374.5	87	38
8	351.5	89	35	256.5	53	21	353.5	93	38
9	342.5	92	35	262.5	59	21	331.0	85	35
10	402.0	99	38	262.5	64	21	392.5	96	38
11	396.0	96	38	263.5	62	21	370.5	89	36
12	411.5	104	42	233.0	63	19	423.5	96	50
13	319.5	81	36	238.0	63	17	293.0	78	28
14	380.0	94	38	247.0	62	17	374.0	94	40
15	376.0	90	37	248.0	67	18	423.0	91	42
16	355.5	84	35	253.5	63	19	330.5	85	34
17	371.5	80	38	228.5	62	16	381.5	86	39
18	337.5	87	34	223.5	64	16	337.0	90	31
19	384.0	98	35	240.5	70	17	369.0	100	34
20	385.5	97	36	192.5	52	15	385.5	100	36
21	276.0	57	29	189.0	50	13	280.5	59	30
22	273.5	58	31	241.0	70	18	281.0	56	30

* In those run combinations in which the G. E. puncture data were not available (see Table XLVII), the values used in this table were the averages of the G. E. puncture results for the entire roll.

TABLE XXXVI

CORRELATIONS OF COMPONENT TESTS WITH EACH OTHER AND WITH PHYSICAL TESTS ON BOXES

	Correlations Between Component Tests							Correlations with Physical Tests on Boxes			
	Elmendorf Average Tear	Amthor Tensile		Amthor Stretch		Bursting Strength	G. E. Puncture	Top-Load Compression (0–0.75 in.)	End-Load Compression (0–0.50 in.)	Drum	Drop
		In	Across	In	Across						
Single-Face Liner											
Average tear	+1.00	+0.82	+0.76	+0.60	+0.73	+0.88	+0.84	+0.57	+0.41	+0.79	+0.78
Tensile—in	+0.82	+1.00	+0.58	+0.57	+0.56	+0.86	+0.67	+0.43	+0.40	+0.62	+0.60
Tensile—across	+0.76	+0.58	+1.00	+0.59	+0.66	+0.75	+0.50	+0.49	+0.20	+0.62	+0.50
Stretch—in	+0.60	+0.57	+0.59	+1.00	+0.37	+0.81	+0.44	+0.45	+0.20	+0.36	+0.33
Stretch—across	+0.73	+0.56	+0.66	+0.37	+1.00	+0.60	+0.55	+0.29	+0.21	+0.68	+0.68
Bursting strength	+0.88	+0.86	+0.75	+0.81	+0.60	+1.00	+0.68	+0.55	+0.37	+0.67	+0.63
G. E. puncture	+0.84	+0.67	+0.50	+0.44	+0.55	+0.68	+1.00	+0.52	+0.42	+0.61	+0.68
Corrugated Medium											
Average tear	+1.00	+0.86	+0.62	+0.53	+0.23	+0.75	+0.89	+0.62	+0.70	+0.55	+0.58
Tensile—in	+0.86	+1.00	+0.54	+0.69	+0.54	+0.88	+0.77	+0.56	+0.60	+0.42	+0.49
Tensile—across	+0.62	+0.54	+1.00	+0.21	+0.66	+0.61	+0.70	+0.51	+0.37	+0.45	+0.36
Stretch—in	+0.53	+0.69	+0.21	+1.00	+0.55	+0.70	+0.31	+0.26	+0.26	+0.32	+0.37
Stretch—across	+0.62	+0.54	+0.66	+0.55	+1.00	+0.66	+0.58	+0.61	+0.60	+0.45	+0.49
Bursting strength	+0.75	+0.88	+0.61	+0.70	+0.66	+1.00	+0.65	+0.51	+0.48	+0.39	+0.43
G. E. puncture	+0.89	+0.77	+0.70	+0.31	+0.58	+0.65	+1.00	+0.71	+0.73	+0.51	+0.56
Double-Face Liner											
Average tear	+1.00	+0.70	+0.79	+0.57	+0.63	+0.74	+0.87	+0.46	+0.27	+0.61	+0.63
Tensile—in	+0.70	+1.00	+0.62	+0.75	+0.61	+0.86	+0.58	+0.46	+0.33	+0.46	+0.46
Tensile—across	+0.79	+0.62	+1.00	+0.58	+0.37	+0.82	+0.51	+0.28	+0.05	+0.48	+0.42
Stretch—in	+0.57	+0.75	+0.58	+1.00	+0.57	+0.84	+0.46	+0.45	+0.25	+0.43	+0.37
Stretch—across	+0.63	+0.61	+0.37	+0.57	+1.00	+0.59	+0.69	+0.45	+0.50	+0.63	+0.71
Bursting strength	+0.74	+0.86	+0.82	+0.84	+0.59	+1.00	+0.57	+0.41	+0.22	+0.49	+0.45
G. E. puncture	+0.87	+0.58	+0.51	+0.46	+0.69	+0.57	+1.00	+0.39	+0.32	+0.53	+0.63

TABLE XXXVII

WEIGHT FACTORS FOR AVERAGE ELMENDORF TEAR AND AMTHOR STRETCH (ACROSS-MACHINE DIRECTION) USED IN PREDICTING BOX TESTS

	Top-Load Compression, lb. (0–0.75 in.)	End-Load Compression, lb. (0–0.50 in.)	Drum, Falls to Box Failure	Drop, Drops to Box Failure
		Single-Face Liner		
Av. Elmendorf tear	+ 1.27800	+ 0.03971	+ 0.32721	+0.02298
Amthor stretch across	−32.65825	− 51.91361	+ 4.84894	+0.57150
		Corrugating Medium		
Av. Elmendorf tear	+ 0.25084	+ 1.82131	+ 0.05667	+ 0.01846
Amthor stretch across	+40.38682	+ 16.61161	+ 6.31149	+ 0.57991
		Double-Face Liner		
Av. Elmendorf tear	− 0.06432	+ 0.24949	− 0.08458	+ 0.00031
Amthor stretch across	+ 1.17929	+106.09366	− 0.28012	+ 0.98895
Constant	−66.589	−192.371	−88.588	−11.209

TABLE XXXVIII

COMPARISON OF OBSERVED AND PREDICTED PHYSICAL TEST RESULTS ON BOXES BASED ON AVERAGE ELMENDORF TEAR AND AMTHOR STRETCH (ACROSS-MACHINE DIRECTION) VALUES OF COMPONENTS

Run Combination	Top-Load Compression, lb. Deflection Range 0–0.75 in. Observed	Predicted	End-Load Compression, lb. Deflection Range 0–0.50 in. Observed	Predicted	Drum No. of Falls to Box Failure Observed	Predicted	12-Inch Corner Drop No. of Drops to Box Failure Observed	Predicted
1	487	466	634	602	38	44	7.9	8.2
2	506	502	628	614	42	46	8.1	8.5
3	505	519	523	599	49	51	8.6	8.8
4	469	446	592	564	42	42	8.3	7.8
5	397	371	423	347	32	25	5.8	5.0
6	489	495	611	651	48	49	8.1	9.2
7	460	452	469	478	37	43	6.5	7.4
8	502	520	620	639	66	54	10.1	9.3
9	501	451	614	552	42	46	7.6	7.9
10	528	511	646	655	69	61	11.2	10.5
11	525	525	668	625	59	60	9.6	9.6
12	500	513	624	662	67	68	12.0	11.8
13	458	457	478	531	39	44	6.9	7.3
14	468	502	656	654	63	60	11.1	10.5
15	506	499	602	546	55	58	9.8	9.6
16	470	497	653	643	49	57	9.3	9.7
17	434	454	459	518	50	47	8.5	8.1
18	374	434	399	469	36	36	5.6	6.2
19	568	508	682	588	73	65	11.4	10.4
20	393	420	411	475	51	54	7.8	9.2
21	333	350	361	394	20	18	4.8	4.0
22	439	421	608	556	33	29	6.3	6.2

values for the drum test is very high, but that the correlation for the two compression tests is lower, although still good.

A comparison of the weight factors shown in Table XXXVII indicates that the Elmendorf tear and Amthor stretch characteristics of the single-face liner had a greater influence in predicting drum and drop test results than in predicting the compression results. On the other hand, the characteristics of the corrugating medium were perhaps more significant in predicting top- and end-load compression than were the corresponding characteristics of the single-face liner. The values for the average Elmendorf tear and the Amthor stretch in the across-machine direction for the double-face liner did not appear to influence the predicted box test values nearly as much as the same test values for the single-face liner or corrugating mediums.

It may be recalled that the correlation coefficients for bursting strength and G. E. puncture with box tests indicated that, together, they appeared promising as an alternate for average Elmendorf tear and Amthor stretch in the across-machine direction in a two-factor predictive relationship. As a means of determining their predictive relationship, the results of the bursting strength and G. E. puncture test on the twenty-two run combinations have been subjected to the same statistical treatment as that described for average Elmendorf tear and Amthor stretch in the across-machine direction. The weights appropriate for estimating the various box tests were determined as shown in Table XXXIX. The observed values for drop, drum, top- and end-load compression are compared with the corresponding values predicted from the bursting strength and G. E. puncture results in Table XL. The

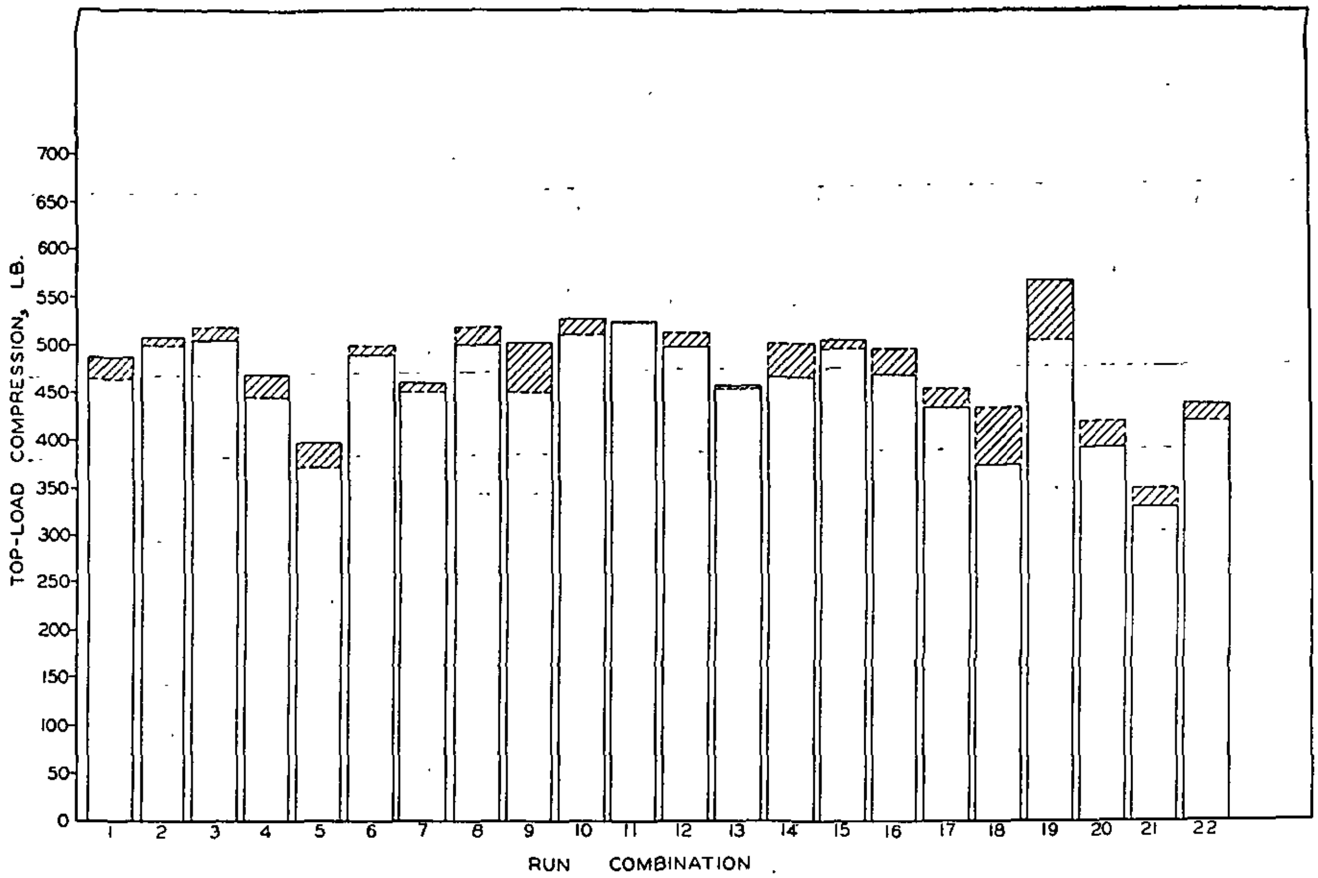

FIGURE 45. Comparison of Observed and Predicted Top-Load Compression Tests (0–0.75 inch)—Based on Elmendorf Tear and Amthor Stretch of Components
———— Observed - - - - - - - Predicted

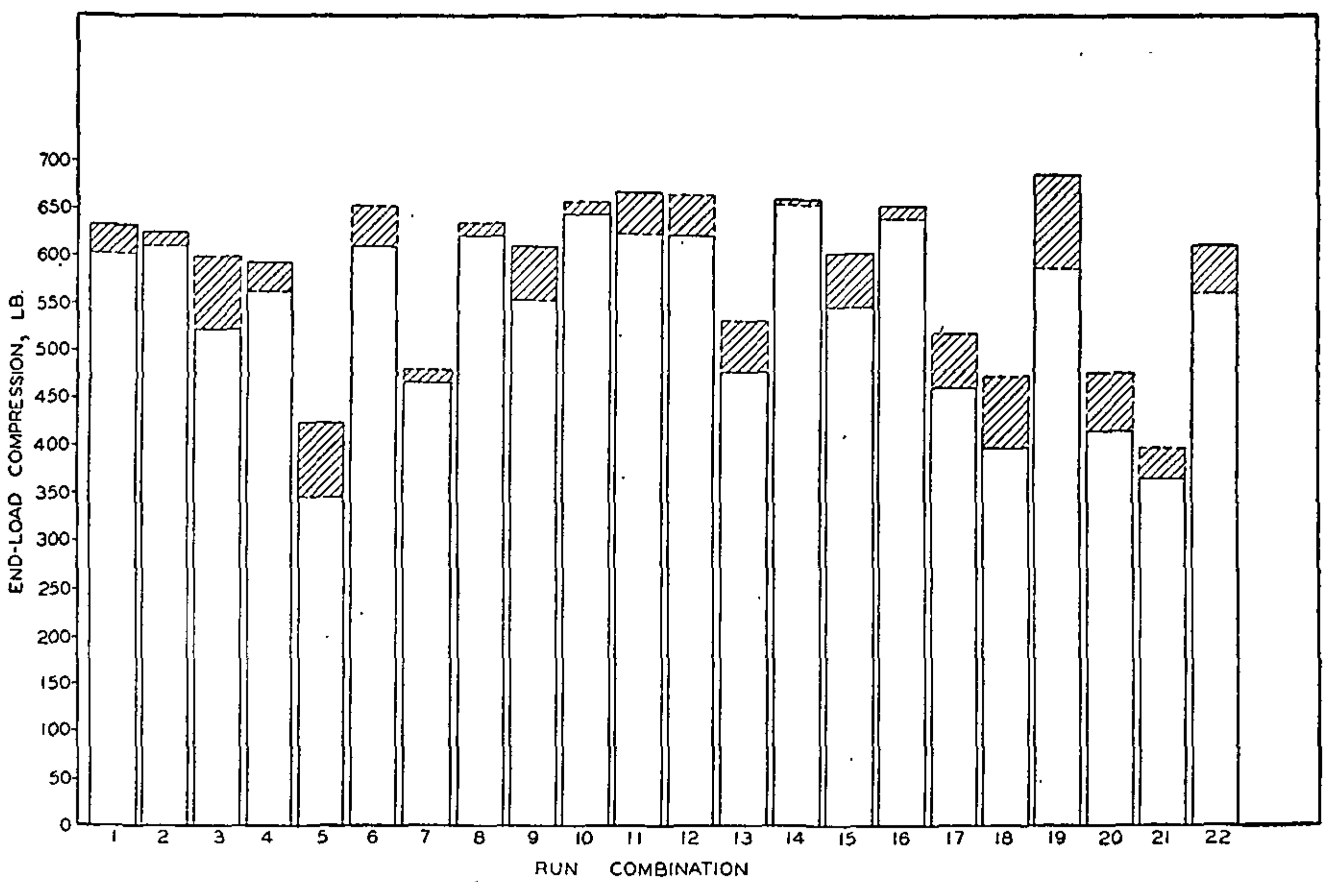

FIGURE 46. Comparison of Observed and Predicted End-Load Compression Tests (0–0.50 inch)—Based on Elmendorf Tear and Amthor Stretch of Components
———— Observed - - - - - - - Predicted

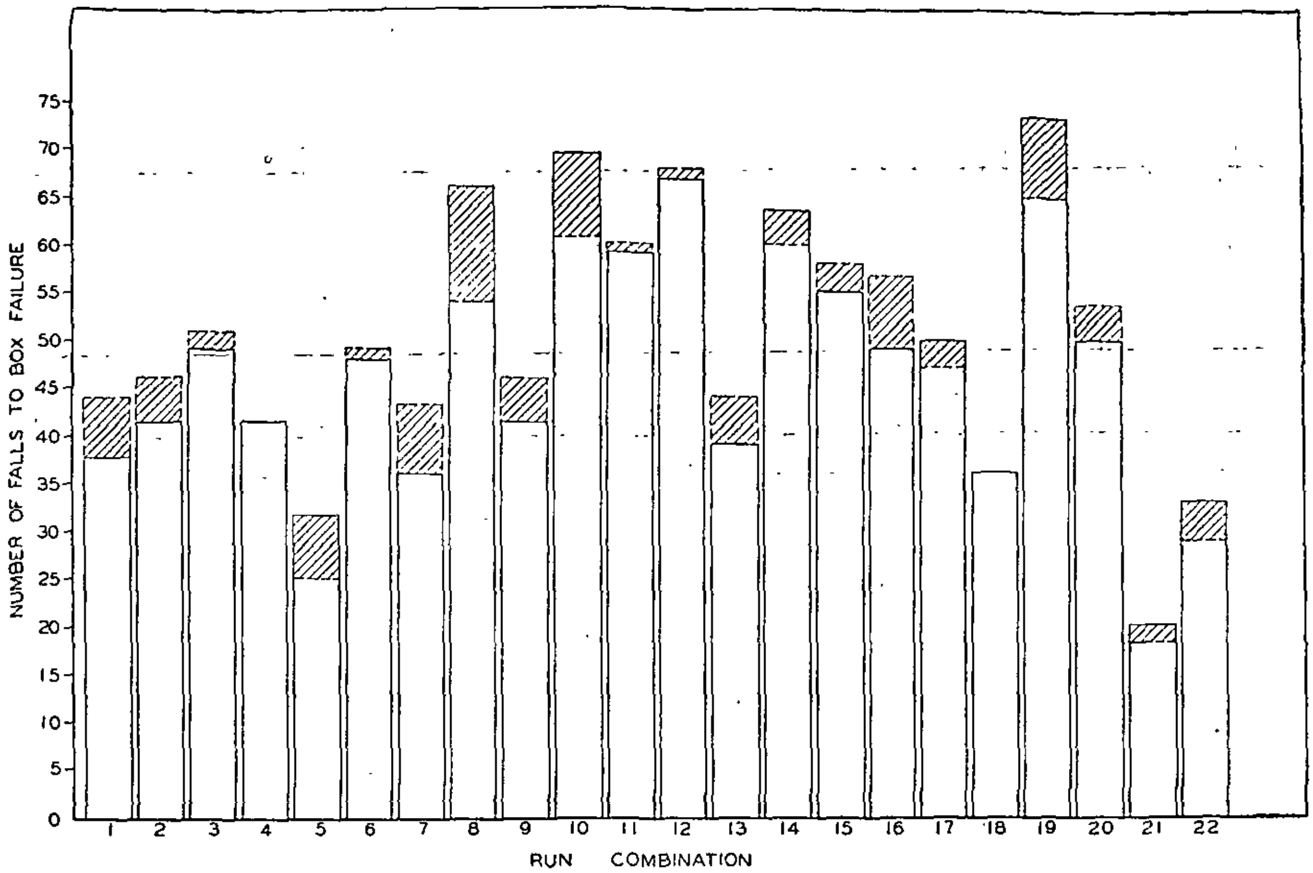

FIGURE 47. Comparison of Observed and Predicted Drum Tests—Based on Elmendorf Tear and Amthor Stretch of Components
———— Observed ------------ Predicted

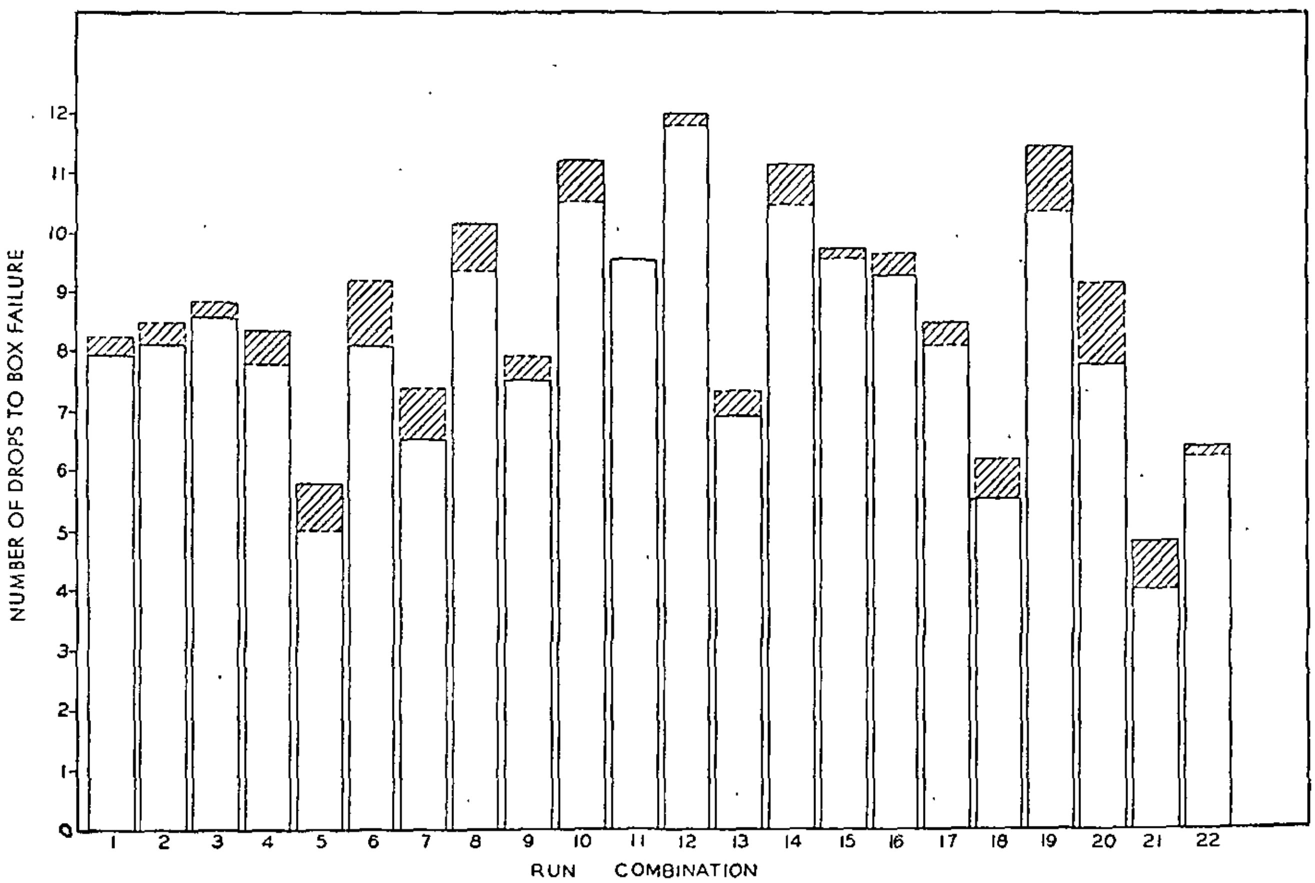

FIGURE 48. Comparison of Observed and Predicted 12-Inch-Corner Drop Test—Based on Elmendorf Tear and Amthor Stretch of Components
———— Observed ------------ Predicted

TABLE XXXIX

WEIGHT FACTORS FOR BURSTING STRENGTH AND G. E. PUNCTURE USED FOR PREDICTING BOX TESTS

	Top-Load Compression, lb. in Deflection Range 0–0.75 in.	End-Load Compression, lb. in Deflection Range 0–0.50 in.	Drum, Number Falls to Box Failure	Drop, Number Drops to Box Failure
Single-Face Liner				
Bursting strength	+ 1.94544	+ 1.66914	+ 0.92141	+ 0.06373
G. E. puncture	+ 0.74108	+ 2.14615	+ 0.17857	+ 0.15159
Corrugating Medium				
Bursting strength	+ 1.44478	+ 0.73725	+ 0.48311	+ 0.06210
G. E. puncture	+ 8.25580	+20.96616	+ 0.43880	+ 0.11191
Double-Face Liner				
Bursting strength	− 0.03887	− 0.73179	− 0.30539	− 0.02331
G. E. puncture	+ 0.56511	+ 2.30802	+ 2.30802	+ 0.14938
Constant	+20.809	−95.603	−68.124	−11.687

results of Table XL are presented graphically in Figures 49, 50, 51, and 52.

In connection with the data given in Table XXXIX, it may be noted that, as in the previous relation (average Elmendorf tear and Amthor stretch in the across-machine direction), the characteristics of the corrugating medium appear to be more important that those of the liners in predicting the compression tests, and that the single-face liner appears to have a greater effect than the double-face liner.

The (multiple) correlation coefficients when bursting strength and G. E. puncture values are used in a two-factor relationship are as follows:

Drop	+0.86
Drum	+0.82
Top-load compression	+0.83
End-load compression	+0.77

It may be seen that, when the box test values were based on the bursting strength and G. E. puncture relationship, the correlation of predicted and observed values was poorer for all the box tests than when the corresponding predictions were based on the relationship between average Elmendorf tear and Amthor stretch in the across-machine direction.

The correlation coefficients are indicative of the probable relationships between the conventional tests currently being used to evaluate Fourdrinier kraft board and boxes. Also, the statistical technique used illustrates a means of handling a large amount of data on components, combined board, and boxes. In addition, it permits the resolution of those data not only into a simple two-factor relationship, but also into a three- or four-factor relationship which is convenient to handle and can be expressed as a numerical value.

In considering the above correlations, it should be borne in mind that these results were based on twenty-two different lots of combined board and boxes which were made under carefully controlled but normal conditions of operation, and are presented herein solely on that basis. Further, the boxes were all of one size and style (namely, 24 No. 2½ can size) and were all scored on the same equipment. Whether the above correlations would apply to combined board and boxes made from different materials and under different conditions of manufacture and conversion can be determined only by further study.

TABLE XL

COMPARISON OF OBSERVED AND PREDICTED BOX PERFORMANCE BASED ON COMPONENT BURSTING STRENGTH AND G. E. PUNCTURE

Run Combination	Top-Load Compression		End-Load Compression		Drum		Drop	
	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
1	487	481	634	594	38	48	7.9	9.0
2	506	474	628	569	42	47	8.1	8.7
3	505	512	523	621	49	56	8.6	9.7
4	469	492	592	603	42	47	8.3	8.4
5	397	365	423	357	32	32	5.8	5.6
6	489	491	611	593	48	52	8.1	8.6
7	460	435	469	504	37	45	6.5	7.9
8	502	488	620	625	66	47	10.1	8.4
9	501	501	614	635	42	53	7.6	8.7
10	528	525	646	656	69	61	11.2	10.1
11	525	516	668	650	59	58	9.6	9.7
12	500	527	624	658	67	71	12.0	12.6
13	458	449	478	527	39	42	6.9	7.1
14	468	481	656	569	63	55	11.1	9.6
15	506	489	602	591	55	56	9.8	10.0
16	470	474	653	581	49	46	9.3	8.1
17	434	445	459	530	50	43	8.5	8.6
18	374	454	399	511	36	45	5.6	7.3
19	568	494	682	556	73	57	11.4	8.9
20	393	452	411	506	51	48	7.8	7.9
21	333	347	361	397	20	17	4.8	4.0
22	439	421	608	525	33	31	6.3	6.2

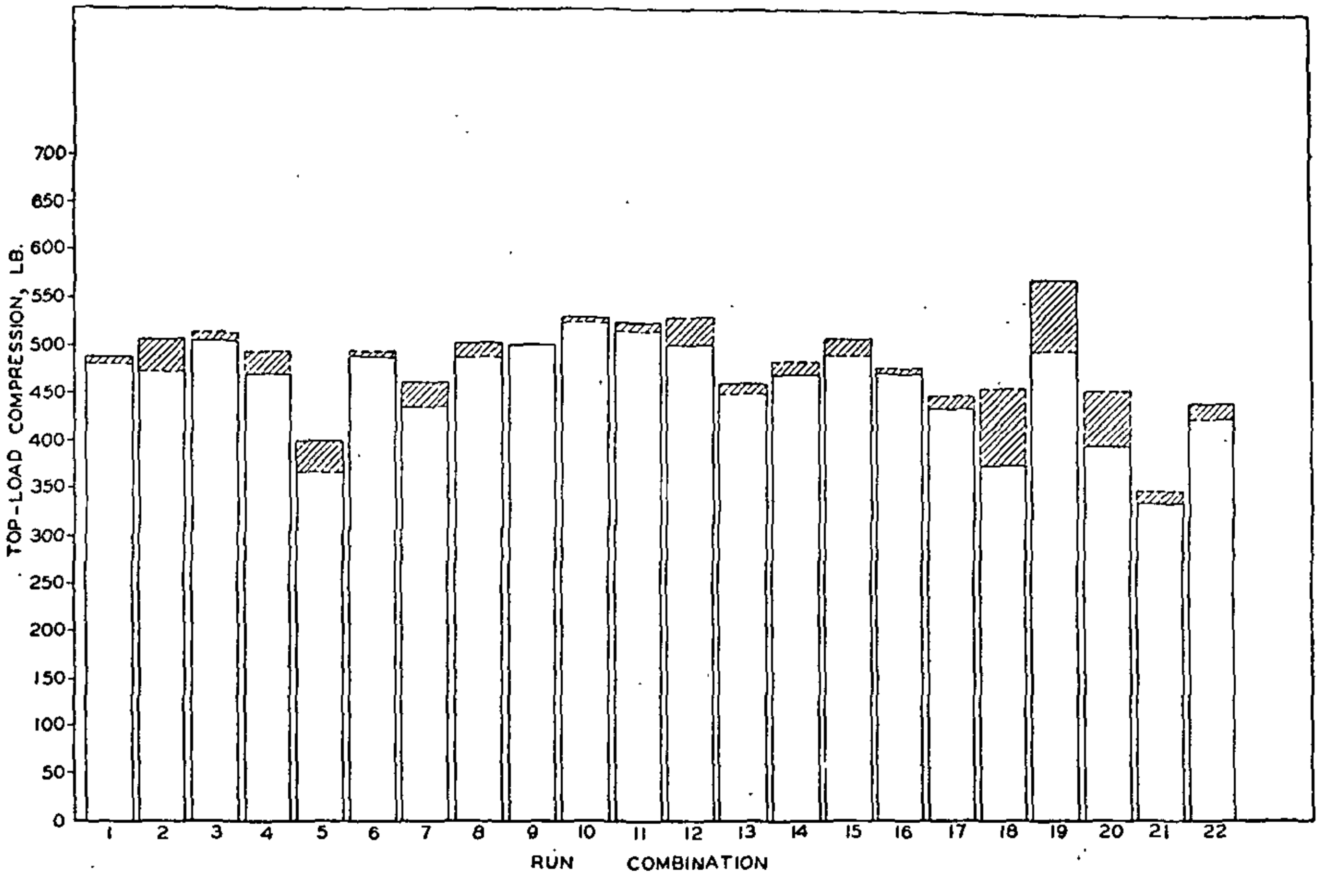

FIGURE 49. Comparison of Observed and Predicted Top-Load Compression Tests (0–0.75 inch)—Based on Bursting Strength and G. E. Puncture of Components
——— Observed - - - - - Predicted

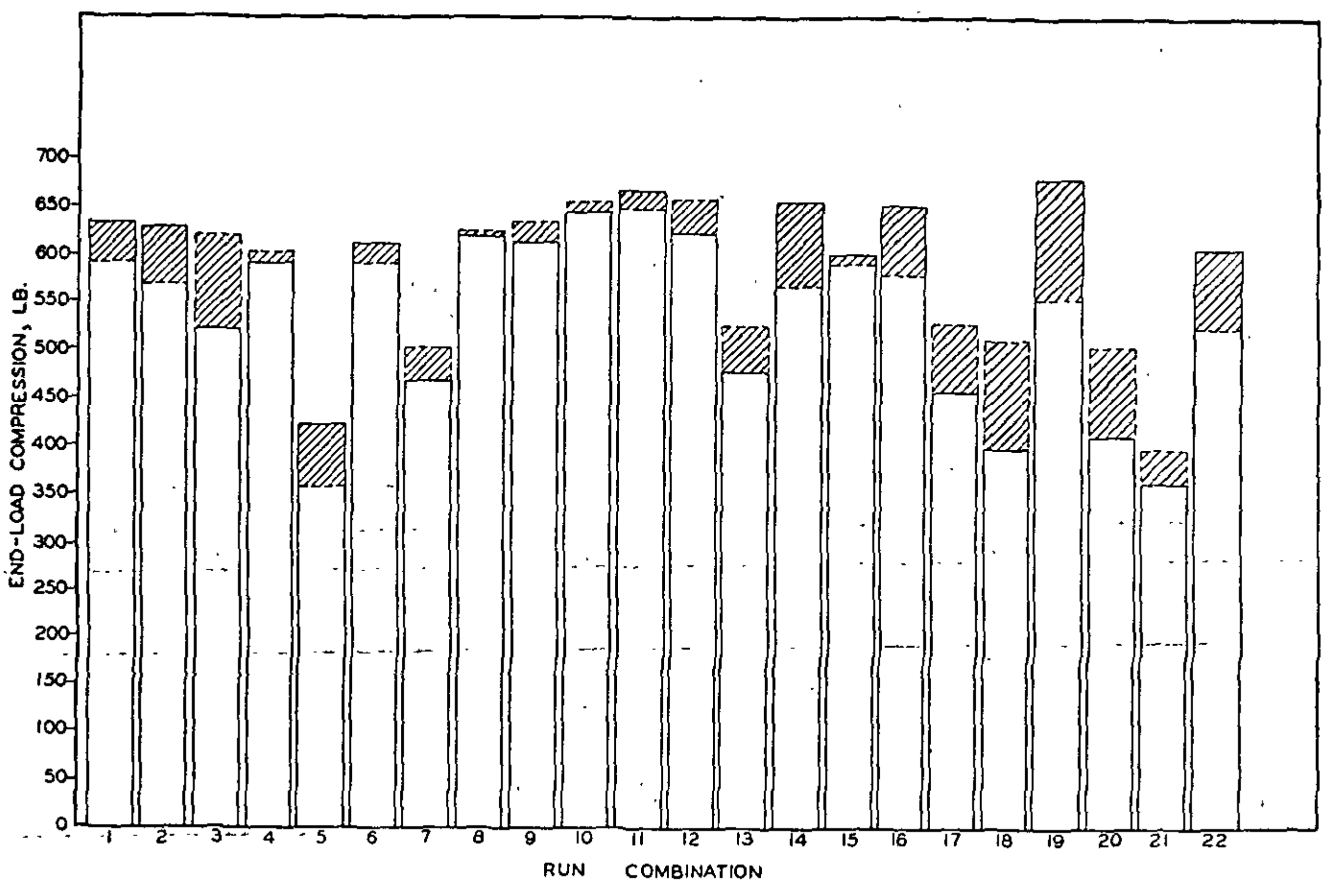

FIGURE 50. Comparison of Observed and Predicted End-Load Compression Tests (0–0.50 inch)—Based on Bursting Strength and G. E. Puncture of Components
——— Observed - - - - - Predicted

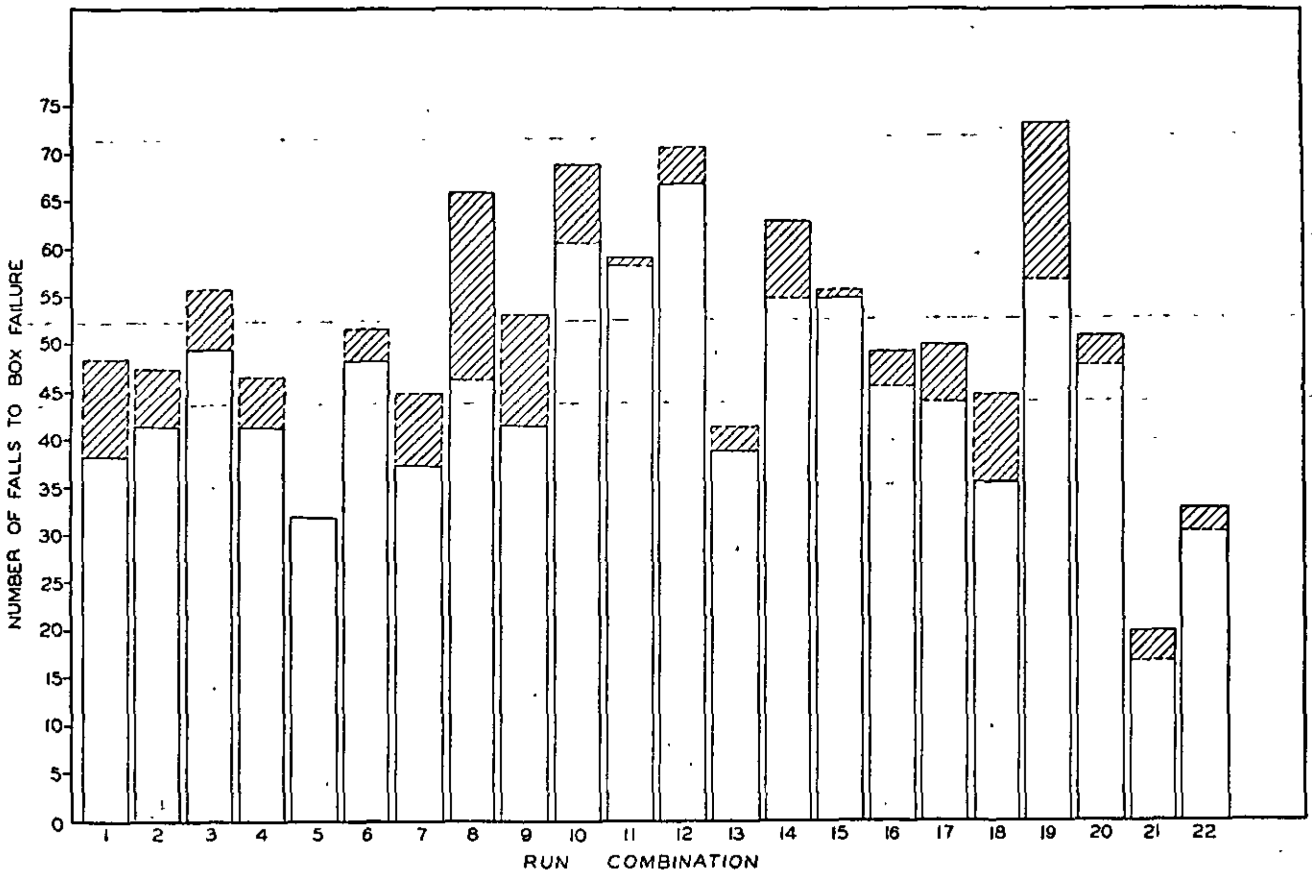

FIGURE 51. Comparison of Observed and Predicted Drum Tests—Based on Bursting Strength and G. E. Puncture of Components
———— Observed ------------ Predicted

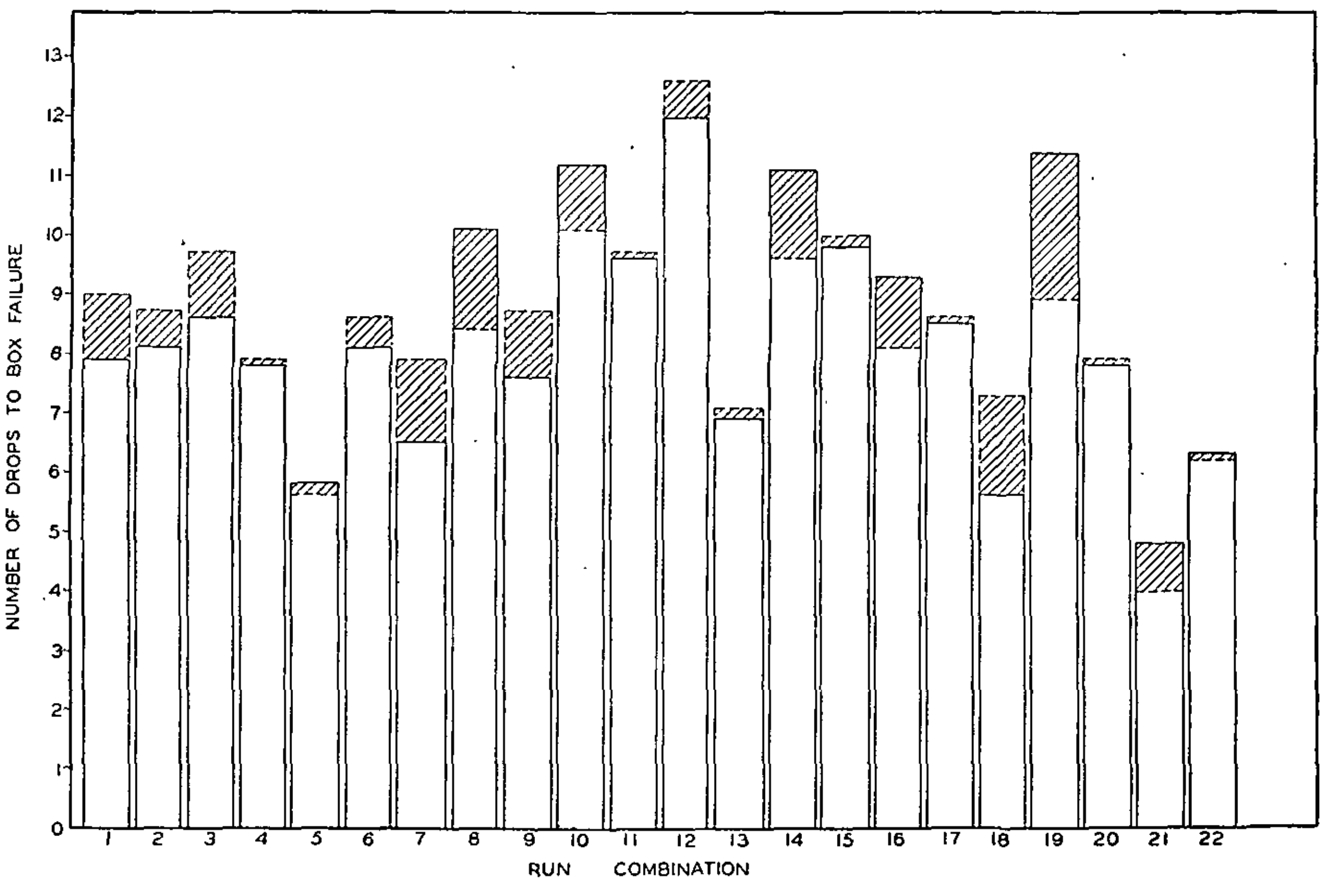

FIGURE 52. Comparison of Observed and Predicted Drop Tests—Based on Bursting Strength and G. E. Puncture of Components.
———— Observed ------------ Predicted

APPENDICES

APPENDIX A

DETAILED TABLES OF TEST RESULTS

The test results obtained for the components, combined boards, and boxes are given in detail in Tables XLI, XLII, and XLIII for Run Combinations 1 through 8, 9 through 18, and 19 through 22, respectively. The drum and drop test data include the number of falls or drops to the first can cut, the first 6-inch tear, and box failure. The top- and end-load compression data are given for the deflection ranges 0–0.25, 0–0.50, and 0–0.75 inch; the maximum loads sustained and the deflection at the maximum loads are also given.

The box test results obtained for each of the various run combinations, as given in the body of this report, were based on the average of tests on an equal number of front and back side boxes. The details of the tests for these two lots of boxes are given in Table XLIV. The physical characteristics of the combined board samples which were taken from these boxes are given in Table XLV.

In addition to the combined board tests on the samples taken from the boxes, tests were made on the unscored blanks which were removed during the fabrication of each run combination; the data for such combined board tests are given in Table XLVI.

The test data obtained on the components at the start, middle, and end of each run combination are shown in Table XLVII. The average values given for the start and end of each run combination were, in general, the averages of the results obtained on three sample lots taken across the roll—front, center, and back. For those rolls which were used in more than one run combination, as well as the samples taken during the middle of each run combination, the values reported are the average of the results obtained on two sample lots—front and back.

The averages given in Table XLVII are based upon the total number of test specimens for a given run combination and are not necessarily the averages of the values reported for a given property in the table.

TABLE XLI

RUN COMBINATIONS 1-8: STANDARD LINER—MILL AVERAGE MEDIUM

Component Strength Tests

Run Combination	I.P.C. Roll No.	Mill Code	Roll Position	Basis Weight (12 x 12/1000), lb.	Caliper, points	Bursting Strength, points	Ring Compression, lb. In	Ring Compression, lb. Across	G. E. Puncture, units	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb./in. In	Amthor Tensile, lb./in. Across	Amthor Stretch, % In	Amthor Stretch, % Across
1	4	A-24	S. F.	42.9	15.1	87	26.5	22.0	39	331	389	76.0	36.6	1.8	2.8
	7	W-8	Corrug.	26.0	9.2	61	17.9	11.9	19	195	268	56.6	21.6	1.7	3.1
	1	A-18	D. F.	41.4	15.4	90	30.7	23.8	36	336	394	84.5	36.9	2.0	3.4
2	4	A-24	S. F.	41.9	15.2	88	27.4	21.9	37	322	386	75.4	37.5	1.7	2.7
	8	U-8	Corrug.	25.9	10.1	61	18.2	13.1	18	198	238	53.2	24.3	1.8	4.2
	1	A-18	D. F.	41.7	15.2	98	31.1	23.3	—	359	397	81.1	38.5	1.8	3.5
3	5	A-27	S. F.	39.8	14.4	89	31.1	24.1	35	324	386	76.5	37.3	2.0	2.9
	9	Z-8	Corrug.	26.4	8.9	75	19.4	15.8	20	216	241	56.8	32.8	2.0	4.7
	1	A-18	D. F.	42.3	15.3	98	31.5	23.4	39	350	407	86.2	37.2	2.0	3.2
4	5	A-27	S. F.	40.1	14.4	93	29.4	22.5	—	315	381	74.7	37.1	2.2	3.0
	10	T-9	Corrug.	26.1	10.0	57	16.9	13.2	20	211	235	47.1	23.8	1.5	3.2
	2	H-6	D. F.	41.6	15.9	107	31.0	24.1	38	334	377	82.6	40.9	2.2	3.3
5	5	A-27	S. F.	40.6	14.5	94	29.2	22.9	—	323	364	75.2	37.2	2.1	2.9
	11	V-7	Corrug.	26.2	10.5	31	13.0	10.2	9	109	121	30.1	17.8	1.0	2.1
	2	H-6	D. F.	41.9	16.2	104	35.6	26.1	—	348	394	82.0	38.2	2.5	3.2
6	5	A-27	S. F.	40.7	14.5	96	30.3	23.6	34	329	377	75.2	36.3	2.1	3.0
	12	X-2	Corrug.	27.1	9.5	58	19.5	14.4	19	239	259	51.3	25.1	2.0	4.1
	2	H-6	D. F.	41.9	16.1	101	34.0	25.7	38	346	396	83.1	39.0	2.3	3.5
7	6	A-28	S. F.	39.9	14.4	89	29.3	23.1	36	335	388	75.1	37.8	2.1	3.1
	13	Y-9	Corrug.	26.0	8.8	50	18.7	13.3	15	165	196	48.0	22.2	1.9	3.3
	3	B-3	D. F.	43.4	16.3	87	28.7	20.8	38	350	399	82.7	36.3	2.0	3.2
8	6	A-28	S. F.	39.9	14.4	89	26.4	22.3	35	329	374	76.8	37.9	2.0	3.0
	14	S-6	Corrug.	26.5	9.9	53	19.1	15.7	21	259	254	48.4	31.3	1.5	4.7
	3	B-3	D. F.	43.4	16.0	93	30.7	22.3	38	331	376	81.0	36.3	2.2	3.2

Combined Board Strength Tests

Run Combination	Weight per 1000 boxes, lb.	Basis Weight (12 x 12/1000), lb.	Bursting Strength, Points	G. E. Puncture, Units	G. E. Stiffness, Units	Pin Adhesion, lb.	H. and D. Crush, lb./sq. in.
1	1047	121	239	217	93	71	28.1
2	1047	122	240	226	96	67	34.2
3	1031	120	238	225	90	61	33.8
4	1038	120	239	203	86	71	25.5
5	1038	120	232	169	68	70	14.5
6	1038	120	234	207	85	72	24.0
7	1044	120	220	194	77	62	23.8
8	1053	122	230	224	94	72	30.1

Box Strength Test

Run Combination	Small Revolving Drum: First Can Cut	Small Revolving Drum: First 6-in. Tear	Small Revolving Drum: Final Box Failure	12-Inch Corner Drop: First Can Cut	12-Inch Corner Drop: First 6-in. Tear	12-Inch Corner Drop: Final Box Failure	Top-Load Compression: Max. Load Sustained in Deflection Range, lb. 0–0.25 in.	0–0.50 in.	0–0.75 in.	Top-Load Compression: Max. Load, lb.	Top-Load Compression: Deflection at Max. Load, in.	End-Load Compression: Max. Load Sustained in Deflection Range, lb. 0–0.25 in.	0–0.50 in.	0–0.75 in.	End-Load Compression: Max. Load, lb.	End-Load Compression: Deflection at Max. Load, in.
1	8	35	38	2.4	7.1	7.9	363	469	487	487	0.44	466	634	634	634	0.36
2	7	38	42	1.8	7.4	8.1	403	501	506	506	0.38	491	628	628	628	0.32
3	8	41	49	1.4	7.4	8.6	456	505	505	505	0.30	441	523	523	523	0.29
4	7	35	42	1.3	7.4	8.3	401	457	469	469	0.40	474	592	592	592	0.32
5	4	27	32	1.1	4.0	5.8	362	380	397	398	0.41	370	423	423	423	0.29
6	8	41	48	1.3	7.1	8.1	388	486	489	489	0.39	423	611	614	614	0.36
7	4	30	37	1.1	5.4	6.5	394	443	460	460	0.41	418	469	469	469	0.23
8	7	53	66	1.9	9.3	10.1	402	496	502	502	0.40	480	620	620	620	0.34

TABLE XLII

RUN COMBINATIONS 9–18: STANDARD CORRUGATED MEDIUM—MILL AVERAGE LINERS

Component Strength Tests

Run Combination	I.P.C. Roll No.	Mill Code	Roll Position	Basis Weight (12 x 12/1000), lb.	Caliper, Points	Bursting Strength, points	Ring Compression, lb. In	Ring Compression, lb. Across	G. E. Puncture, units	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb./in. In	Amthor Tensile, lb./in. Across	Amthor Stretch, % In	Amthor Stretch, % Across
9	15	A-7	S. F.	40.3	13.8	92	29.9	24.4	35	318	367	76.2	38.8	2.0	3.1
	39	U-15	Corrug.	28.0	11.1	59	19.4	14.6	21	243	282	55.8	25.7	1.7	3.3
	16	A-22	D. F.	40.6	14.9	85	27.8	22.4	35	301	361	74.5	35.9	1.8	2.6
10	17	H-11	S. F.	42.2	15.6	99	29.4	24.0	38	382	422	75.4	40.2	2.0	3.5
	39	U-15	Corrug.	27.8	11.0	64	20.3	15.0	—	244	281	56.6	26.8	1.6	3.3
	18	H-8	D. F.	42.3	15.2	96	28.8	24.1	38	370	415	80.7	41.2	2.2	3.6
11	19	B-13	S. F.	43.3	15.7	96	30.6	24.7	38	361	431	86.6	40.4	2.0	3.0
	39	U-15	Corrug.	27.8	10.9	62	18.9	15.1	21	244	283	56.7	26.8	1.9	3.4
	20	B-1	D. F.	41.8	16.1	89	28.3	22.8	36	341	400	82.9	35.9	1.9	3.1
12	21	I-10	S. F.	43.1	14.9	104	28.4	21.2	42	371	452	85.1	36.4	2.3	4.3
	40	X-1	Corrug.	26.8	9.2	63	18.2	13.0	19	214	252	53.6	23.1	2.1	3.9
	22	I-12	D. F.	43.8	15.2	96	28.9	24.1	50	408	439	79.8	37.6	2.0	4.4
13	23	F-5	S. F.	40.3	12.9	81	25.1	21.9	36	305	334	68.4	35.5	1.7	2.9
	40	X-1	Corrug.	26.2	9.2	63	21.0	14.4	17	226	250	50.6	23.4	1.9	4.1
	24	F-6	D. F.	39.6	12.6	78	25.0	20.8	28	273	313	63.7	33.1	1.8	2.7
14	25	C-10	S. F.	42.0	14.5	94	31.0	19.4	38	340	420	86.5	36.8	1.4	3.7
	41	U-20	Corrug.	27.1	11.3	62	21.2	13.5	17	226	268	57.0	23.3	2.2	4.0
	26	C-9	D. F.	42.0	14.7	94	29.4	20.3	40	332	416	84.8	36.3	1.8	3.9
15	27	D-20	S. F.	41.0	14.8	90	28.0	22.4	37	372	380	71.1	42.8	2.1	3.9
	41	U-20	Corrug.	27.0	11.4	67	18.8	14.0	—	221	275	54.9	23.3	2.2	4.3
	28	D-5	D. F.	44.2	16.3	91	26.1	20.8	42	397	449	71.0	41.4	1.7	2.8
16	29	E-5	S. F.	42.6	16.0	84	28.6	20.1	35	320	391	83.0	33.5	1.6	3.4
	41	U-20	Corrug.	27.2	11.4	63	18.2	13.1	19	229	278	52.4	23.4	2.0	4.3
	30	E-3	D. F.	41.9	14.1	85	25.4	19.2	34	306	355	77.8	34.6	1.6	3.6
17	31	G-12	S. F.	41.0	15.5	80	26.2	20.2	38	362	381	68.0	38.2	1.4	3.3
	42	Y-6	Corrug.	26.0	9.3	62	19.2	14.1	16	208	249	52.4	24.3	1.8	2.9
	32	G-1	D. F.	42.6	15.0	86	27.2	21.6	39	361	402	75.4	42.0	1.6	2.9
18	33	J-11	S. F.	41.3	15.0	87	30.6	23.8	34	304	371	76.8	36.3	1.7	2.6
	42	Y-6	Corrug.	26.1	9.3	64	21.4	15.8	16	198	249	52.8	24.6	1.9	2.9
	34	J-3	D. F.	41.9	15.2	90	31.4	25.1	31	310	364	76.6	38.7	1.5	2.3

Combined Board Strength Tests

Run Combination	Weight per 1000 Boxes, lb.	Basis Weight (12 x 12/1000), lb.	Bursting Strength, points	G. E. Puncture, units	G. E. Stiffness, units	Pin Adhesion, lb.	H. and D. Flat Crush, lb./sq. in.
9	1056	121	235	221	89	73	26.3
10	1085	123	247	226	92	78	25.4
11	1076	124	236	228	97	75	25.8
12	1075	124	248	233	87	77	28.4
13	1019	117	185	191	78	71	26.2
14	1079	125	243	233	92	78	30.8
15	1076	124	235	236	95	69	32.7
16	1072	123	243	221	96	71	31.0
17	1044	120	214	204	73	71	19.2
18	1041	120	217	176	70	75	16.2

Box Strength Tests

Run Combination	Small Revolving Drum: First Can Cut	Small Revolving Drum: First 6-in. Tear	Small Revolving Drum: Final Box Failure	12-Inch Corner Drop: First Can Cut	12-Inch Corner Drop: First 6-in. Tear	12-Inch Corner Drop: Final Box Failure	Top-Load Compression: Max. Load Sustained in Deflection Range, lb. 0–0.25 in.	0–0.50 in.	0–0.75 in.	Top-Load: Max. Load, lb.	Top-Load: Deflection at Max. Load, in.	End-Load Compression: Max. Load Sustained in Deflection Range, lb. 0–0.25 in.	0–0.50 in.	0–0.75 in.	End-Load: Max. Load, lb.	End-Load: Deflection at Max. Load, in.
9	6	37	42	1.1	6.8	7.6	404	498	501	501	0.39	490	614	614	614	0.31
10	10	59	69	1.7	10.5	11.2	401	528	528	528	0.40	519	646	646	646	0.31
11	10	47	59	1.8	8.6	9.6	432	515	525	525	0.42	527	668	669	669	0.33
12	14	62	67	3.1	10.7	12.0	395	499	500	500	0.39	433	624	624	624	0.34
13	5	33	39	1.3	6.3	6.9	356	458	458	458	0.39	396	478	478	478	0.31
14	10	56	63	1.8	9.8	11.1	372	466	468	468	0.39	499	656	656	656	0.33
15	7	47	55	2.2	9.4	9.8	393	495	506	506	0.45	461	602	602	602	0.32
16	7	45	49	1.9	8.8	9.3	360	460	470	470	0.43	505	653	653	653	0.35
17	7	44	50	1.7	7.9	8.5	388	432	434	434	0.36	408	459	459	459	0.28
18	7	34	36	1.1	4.4	5.6	363	374	374	374	0.26	371	399	399	399	0.25

TABLE XLIII

RUN COMBINATIONS 19–22: COMBINATIONS OF HIGH- AND LOW-TEST COMPONENTS

COMPONENT STRENGTH TESTS

Run Combination	I.P.C. Roll No.	Mill Code	Roll Position	Basis Weight (12 x 12/1000), lb.	Caliper, points	Bursting Strength, points	Ring Compression, lb. In	Ring Compression, lb. Across	G. E. Puncture, units	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb./in. In	Amthor Tensile, lb./in. Across	Amthor Stretch, % In	Amthor Stretch, % Across
19	35	C-3	S. F.	43.9	14.0	98	32.4	25.9	35	381	387	78.2	44.1	1.8	4.0
	43	U-11	Corrug.	27.5	11.1	70	21.5	16.0	17	227	254	53.3	26.4	2.0	4.3
	36	H-14	D. F.	41.6	15.4	100	29.6	23.3	34	345	393	77.1	40.6	2.1	3.5
20	35	C-3	S. F.	44.3	14.0	97	32.7	26.9	36	383	388	84.3	44.3	2.0	4.5
	44	Y-10	Corrug.	24.9	9.1	52	17.2	11.9	15	177	208	44.5	22.2	1.8	2.8
	36	H-14	D. F.	42.1	15.5	100	29.9	23.2	36	369	402	77.6	42.5	2.1	3.7
21	37	E-1	S. F.	44.3	16.8	57	21.6	16.8	29	272	280	53.5	29.2	1.1	2.5
	44	Y-10	Corrug.	24.8	9.1	50	19.0	12.4	13	176	202	45.7	21.4	1.8	2.8
	38	E-2	D. F.	43.9	17.2	59	22.8	16.7	30	279	282	54.6	30.0	1.0	2.3
22	37	E-1	S. F.	44.9	16.5	58	21.5	16.9	31	265	282	55.1	29.8	1.2	2.5
	43	U-11	Corrug.	27.6	11.1	70	21.7	15.7	18	228	254	54.1	26.6	1.8	4.3
	38	E-2	D. F.	44.6	17.4	56	22.6	16.1	30	274	288	54.7	28.4	1.3	2.7

COMBINED BOARD STRENGTH TESTS

Run Combination	Wt. Per 1000 Boxes, lb.	Basis Weight (12 x 12/1000), lb.	Bursting Strength, points	G. E. Puncture, units	G. E. Stiffness, units	Pin Adhesion, lb.	H. and D. Flat Crush, lb./sq. in.
19	1085	125	246	238	105	74	33.0
20	1056	122	240	177	67	70	17.0
21	1076	124	194	149	65	64	15.7
22	1119	130	168	215	96	67	35.7

BOX STRENGTH TEST

Run Combination	Small Revolving Drum: First Can Cut	Small Revolving Drum: First 6-in. Tear	Small Revolving Drum: Final Box Failure	12-Inch Corner Drop: First Can Cut	12-Inch Corner Drop: First 6-in. Tear	12-Inch Corner Drop: Final Box Failure	Top-Load Compression: Max. Load Sustained in Deflection Range, lb. 0–0.25 in.	Top-Load: 0–0.50 in.	Top-Load: 0–0.75 in.	Top-Load: Max. Load, lb.	Top-Load: Deflection at Max. Load, in.	End-Load Compression: Max. Load Sustained in Deflection Range, lb. 0–0.25 in.	End-Load: 0–0.50 in.	End-Load: 0–0.75 in.	End-Load: Max. Load, lb.	End-Load: Deflection at Max. Load, in.
19	7	62	73	2.1	10.3	11.4	453	566	568	568	0.42	452	682	682	682	0.38
20	7	43	51	1.1	6.5	7.8	387	393	393	393	0.27	388	411	411	411	0.26
21	3	16	20	1.0	3.8	4.8	295	331	333	333	0.36	353	361	361	361	0.24
22	6	30	33	1.1	5.9	6.3	340	414	439	439	0.50	489	608	608	608	0.31

TABLE XLIV
PHYSICAL CHARACTERISTICS OF BOXES

Run Combinations 1–22

Run Combination	Weight per 1000 boxes, lb.			Small Revolving Drum, Falls to — 1st Can Cut			1st 6-Inch Tear			Box Failure		
	Front	Back	Average	Front	Back	Average	Front	Back	Average	Front	Back	Average
1	1056	1038	1047	10	6	8	42	28	35	46	31	38
2	1050	1044	1047	8	6	7	40	35	38	45	38	42
3	1044	1018	1031	13	4	8	49	33	41	55	42	49
4	1032	1044	1038	6	8	7	37	33	35	45	38	42
5	1032	1044	1038	5	3	4	33	20	27	39	25	32
6	1044	1032	1038	12	4	8	49	33	41	55	42	48
7	1062	1026	1044	6	3	4	36	23	30	43	30	37
8	1056	1050	1053	9	6	7	64	42	53	79	53	66
9	1056	1056	1056	6	6	6	35	39	37	41	43	42
10	1082	1088	1085	10	9	10	70	49	59	77	61	69
11	1076	1076	1076	10	9	10	44	49	47	50	68	59
12	1082	1068	1075	17	11	14	60	63	62	67	68	67
13	1026	1012	1019	6	5	5	36	30	33	44	35	39
14	1076	1082	1079	8	13	10	50	62	56	58	69	63
15	1076	1076	1076	8	7	7	47	48	47	55	55	55
16	1068	1076	1072	7	6	7	50	41	45	54	45	49
17	1044	1044	1044	8	7	7	50	39	44	57	44	50
18	1044	1038	1041	7	7	7	44	23	34	47	26	36
19	1088	1082	1085	8	6	7	64	60	62	81	66	73
20	1062	1050	1056	8	5	7	46	40	43	56	45	51
21	1076	1076	1076	3	3	3	17	16	16	22	18	20
22	1112	1126	1119	8	4	6	34	27	30	38	28	33

TABLE XLIV—*Continued*

Top-Load Compression, lb.

Run Combination	Max. Load Sustained in Deflection Range — 0–0.25 in.			0–0.50 in.			0–0.75 in.			Max. Load Sustained			Deflection at Max. Load, in.		
	Front	Back	Average	Front	Back	Average	Front	Back	Average	Front	Back	Average	Front	Back	Average
1	358	368	363	491	447	469	491	483	487	491	483	487	0.35	0.53	0.44
2	384	421	403	508	494	501	508	504	506	508	504	506	0.34	0.42	0.38
3	443	468	456	504	507	505	504	507	505	504	507	505	0.33	0.28	0.30
4	401	401	401	476	438	457	480	458	469	480	458	469	0.36	0.45	0.40
5	350	373	362	371	389	380	389	406	397	390	406	398	0.43	0.39	0.41
6	389	388	388	506	466	486	506	473	489	506	473	489	0.36	0.41	0.39
7	368	421	394	446	439	443	481	439	460	481	439	460	0.52	0.30	0.41
8	410	394	402	510	482	496	511	494	502	511	494	502	0.36	0.45	0.40
9	403	405	404	524	471	498	524	478	501	524	478	501	0.36	0.41	0.39
10	409	393	401	517	538	528	517	538	528	517	538	528	0.38	0.42	0.40
11	423	441	432	532	498	515	542	508	525	542	508	525	0.38	0.45	0.42
12	384	406	395	509	490	499	509	491	500	509	491	500	0.37	0.42	0.39
13	371	341	356	471	444	458	471	444	458	471	444	458	0.35	0.44	0.39
14	361	383	372	483	449	466	483	453	468	483	453	468	0.38	0.39	0.39
15	390	395	393	525	464	495	526	486	506	526	486	506	0.41	0.50	0.45
16	326	394	360	471	449	460	478	462	470	478	462	470	0.41	0.45	0.43
17	396	379	388	449	414	432	449	419	434	449	419	434	0.34	0.39	0.36
18	391	336	363	394	354	374	394	354	374	394	354	374	0.24	0.29	0.26
19	454	453	453	568	564	566	568	568	568	568	568	568	0.37	0.47	0.42
20	399	375	387	401	385	393	401	386	393	401	386	393	0.22	0.32	0.27
21	288	302	295	336	326	331	336	329	333	336	329	333	0.32	0.41	0.36
22	331	349	340	407	421	414	416	463	439	416	463	439	0.43	0.57	0.50

TABLE XLIV

PHYSICAL CHARACTERISTICS OF BOXES

Run Combinations 1-22

Weight of Loaded Sample, lb.			12-Inch Corner Drop, Drops to									
			1st Can Cut			1st 6-Inch Tear			Box Failure			Run Combination
Front	Back	Average	Front	Back	Average	Front	Back	Average	Front	Back	Average	
51.1	50.9	51.0	2.5	2.4	2.4	7.4	6.9	7.1	8.4	7.5	7.9	1
51.1	51.0	51.1	2.4	1.1	1.8	8.5	6.3	7.4	8.8	7.4	8.1	2
51.3	50.8	51.1	1.6	1.3	1.4	8.4	6.5	7.4	9.3	7.9	8.6	3
51.2	51.1	51.2	1.0	1.5	1.3	8.4	6.5	7.4	8.8	7.8	8.3	4
51.2	50.9	51.1	1.0	1.3	1.1	3.9	4.1	4.0	5.8	5.8	5.8	5
51.5	51.4	51.4	1.4	1.1	1.3	7.3	6.9	7.1	8.4	7.8	8.1	6
51.3	51.4	51.3	1.1	1.1	1.1	6.1	4.6	5.4	7.1	5.9	6.5	7
51.0	51.0	51.0	1.9	2.0	1.9	10.1	8.5	9.3	11.3	9.0	10.1	8
50.9	50.8	50.9	1.1	1.0	1.1	7.3	6.3	6.8	8.0	7.3	7.6	9
51.2	51.2	51.2	2.1	1.3	1.7	10.6	10.4	10.5	11.8	10.6	11.2	10
51.0	51.0	51.0	2.5	1.1	1.8	9.6	7.6	8.6	10.5	8.8	9.6	11
50.6	50.5	50.5	2.6	3.5	3.1	10.6	10.8	10.7	11.9	12.1	12.0	12
50.2	50.4	50.3	1.5	1.1	1.3	6.4	6.3	6.3	7.0	6.8	6.9	13
50.8	51.1	50.9	1.9	1.8	1.8	9.4	10.3	9.8	10.6	11.6	11.1	14
51.0	51.2	51.1	2.1	2.3	2.2	8.3	10.5	9.4	8.4	11.3	9.8	15
50.6	50.9	50.7	1.6	2.3	1.9	8.6	8.9	8.8	9.3	9.3	9.3	16
50.6	51.1	50.8	1.9	1.5	1.7	7.9	7.9	7.9	8.5	8.5	8.5	17
50.7	51.1	50.9	1.3	1.0	1.1	4.6	4.1	4.4	6.1	5.0	5.6	18
50.9	51.1	51.0	2.8	1.4	2.1	9.9	10.8	10.3	11.4	11.4	11.4	19
51.0	51.2	51.1	1.1	1.1	1.1	5.9	7.1	6.5	7.8	7.9	7.8	20
51.0	50.7	50.9	1.0	1.0	1.0	3.8	3.8	3.8	4.5	5.1	4.8	21
51.0	50.7	50.9	1.1	1.1	1.1	6.1	5.6	5.9	6.5	6.0	6.3	22

TABLE XLIV—*Continued*

End-Load Compression, lb.

Max. Load Sustained in Deflection Range															
0–0.25 in.			0–0.50 in.			0–0.75 in.			Max. Load Sustained			Deflection at Max. Load, in.			Run Combination
Front	Back	Average	Front	Back	Average	Front	Back	Average	Front	Back	Average	Front	Back	Average	
539	392	466	633	635	634	633	635	634	633	635	634	0.30	0.42	0.36	1
540	443	491	640	616	628	640	616	628	640	616	628	0.29	0.35	0.32	2
470	413	441	506	539	523	506	539	523	506	539	523	0.26	0.31	0.29	3
489	458	474	609	574	592	609	574	592	609	574	592	0.30	0.34	0.32	4
379	361	370	442	405	423	442	405	423	442	405	423	0.30	0.27	0.29	5
490	357	423	691	531	611	691	537	614	691	537	614	0.33	0.39	0.36	6
431	406	418	471	468	469	471	468	469	471	468	469	0.25	0.31	0.28	7
527	433	480	621	619	620	621	619	620	621	619	620	0.29	0.38	0.34	8
564	416	490	636	593	614	636	593	614	636	593	614	0.27	0.36	0.31	9
594	454	519	682	614	646	682	614	646	682	614	646	0.29	0.33	0.31	10
563	491	527	676	659	668	676	661	669	676	661	669	0.29	0.38	0.33	11
466	399	433	644	604	624	644	604	624	644	604	624	0.32	0.35	0.34	12
441	351	396	515	442	478	515	442	478	515	442	478	0.29	0.34	0.31	13
515	483	499	681	631	656	681	631	656	681	631	656	0.31	0.34	0.33	14
511	411	461	603	601	602	603	601	602	603	601	602	0.28	0.35	0.32	15
543	466	505	677	630	653	677	630	653	677	630	653	0.31	0.39	0.35	16
428	389	408	469	449	459	469	449	459	469	449	459	0.25	0.32	0.28	17
389	353	371	416	383	399	416	383	399	416	383	399	0.24	0.26	0.25	18
440	463	452	688	676	682	688	676	682	688	676	682	0.36	0.39	0.38	19
441	334	388	463	359	411	463	359	411	463	359	411	0.26	0.26	0.26	20
379	328	353	393	329	361	393	329	361	393	329	361	0.25	0.22	0.24	21
508	471	489	622	594	608	622	594	608	622	594	608	0.30	0.33	0.31	22

TABLE XLV

PHYSICAL CHARACTERISTICS OF COMBINED BOARD

COMPARISON OF FRONT AND BACK SAMPLES

Run Combination	Roll Combination I.P.C.	Basis Weight (12 x 12/1000), lb.			Bursting Strength, points			G. E. Puncture, units			G. E. Stiffness, units			Pin Adhesion, lb.			H. and D. Flat Crush, lb./sq. in.		
		Front	Back	Average	Front	Back	Average	Front	Back	Average	Front	Back	Average	Front	Back	Average	Front	Back	Average
1	4-7-1	122	120	121	237	241	239	220	214	217	93	93	93	72	69	71	28.0	28.2	28.1
2	4-8-1	123	121	122	236	244	240	230	222	226	97	94	96	69	65	67	34.3	34.0	34.2
3	5-9-1	121	118	120	237	239	238	231	220	225	90	90	90	60	63	61	35.5	32.3	33.8
4	5-10-2	119	121	120	232	246	239	196	210	203	83	88	86	70	71	71	26.4	24.7	25.5
5	5-11-2	119	120	120	232	232	232	174	165	169	70	67	68	71	69	70	15.0	13.5	14.5
6	5-12-2	120	120	120	228	240	234	212	203	207	90	79	85	72	72	72	25.0	22.9	24.0
7	6-13-3	122	118	120	226	213	220	203	184	194	81	74	77	69	56	62	23.6	23.9	23.8
8	6-14-3	123	121	122	236	224	230	226	223	224	97	91	94	73	70	72	24.2	36.1	30.1
9	15-39-16	120	122	121	232	237	235	221	221	221	91	87	89	72	74	73	27.3	25.2	26.3
10	17-39-18	124	121	123	241	253	247	219	233	226	96	87	92	76	79	78	24.8	25.9	25.4
11	19-39-20	123	124	124	235	236	236	227	229	228	97	98	97	77	73	75	25.5	26.1	25.8
12	21-40-22	125	123	124	244	251	248	239	227	233	91	83	87	78	75	77	30.0	26.9	28.4
13	23-40-24	117	117	117	184	186	185	192	189	191	85	72	78	73	70	71	27.8	24.6	26.2
14	25-41-26	124	125	125	240	246	243	235	231	233	91	92	92	78	77	78	30.7	30.9	30.8
15	27-41-28	124	124	124	233	238	235	239	232	236	97	93	95	72	67	69	33.8	31.7	32.7
16	29-41-30	123	123	123	246	240	243	222	220	221	99	92	96	72	70	71	31.0	30.9	31.0
17	31-42-32	120	120	120	216	211	214	211	196	204	75	71	73	69	73	71	21.6	16.9	19.2
18	33-42-34	120	119	120	221	213	217	183	169	176	72	69	70	78	72	75	16.1	16.5	16.2
19	35-43-36	125	125	125	252	240	246	237	239	238	106	103	105	75	73	74	30.1	35.9	33.0
20	35-44-36	122	121	122	247	233	240	185	169	177	72	63	67	69	71	70	16.4	17.6	17.0
21	37-44-38	123	124	124	236	152	194	146	152	149	65	65	65	63	65	64	15.9	15.3	15.7
22	37-43-38	128	131	130	167	170	168	211	218	215	95	97	96	65	69	67	36.2	35.2	35.7

TABLE XLVI

PHYSICAL CHARACTERISTICS OF COMBINED BOARD

COMPARISON OF RESULTS OBTAINED ON SAMPLES TAKEN FROM BOXES WITH RESULTS OBTAINED ON FLAT STOCK

Run Combination	Roll Combination	Basis Weight (12 x 12/1000), lb.	Caliper, points		Bursting Strength, points		G. E. Puncture, units		G. E. Stiffness, units		H. and D. Flat Crush, lb./sq. in.	
			Box Samples	Flat Stock	Box Samples	Flat Stock	Box Samples	Flat Stock	Box Samples	Flat Stock	Box Samples	Flat Stock
1	4-7-1	121	105.2	115.9	239	240	217	217	93	91	28.1	28.7
2	4-8-1	122	110.9	116.4	240	233	226	219	96	94	34.2	32.2
3	5-9-1	120	106.2	104.6	238	245	225	221	90	71	33.8	22.7
4	5-10-2	120	112.2	115.1	239	243	203	203	86	86	25.5	25.2
5	5-11-2	120	96.8	109.7	232	242	169	177	68	66	14.5	15.9
6	5-12-2	120	110.3	112.3	234	237	207	210	85	85	24.0	28.0
7	6-13-3	120	106.6	111.6	220	226	194	197	77	73	23.8	21.2
8	6-14-3	122	107.4	112.3	230	231	224	225	94	86	30.1	27.6
9	15-39-16	121	108.6	114.0	235	230	221	224	89	85	26.3	24.5
10	17-39-18	123	113.6	116.0	247	253	226	226	92	92	25.4	26.5
11	19-39-20	124	109.5	116.5	236	224	228	236	97	93	25.8	25.6
12	21-40-22	124	113.7	111.1	248	251	233	218	87	74	28.4	23.6
13	23-40-24	117	108.7	107.2	185	192	191	190	78	70	26.2	23.4
14	25-41-26	125	115.1	115.6	243	248	233	228	92	90	30.8	31.0
15	27-41-28	124	116.1	116.0	235	230	236	240	95	94	32.7	28.0
16	29-41-30	123	115.2	116.1	243	228	221	213	96	87	31.0	29.0
17	31-42-32	120	105.2	113.3	214	213	204	213	73	78	19.2	20.7
18	33-42-34	120	98.0	99.7	217	223	176	177	70	58	16.2	14.6
19	35-43-36	125	115.1	114.4	246	247	238	234	105	93	33.0	31.9
20	35-44-36	122	100.9	104.6	240	243	177	183	67	61	17.0	15.3
21	37-44-38	124	103.8	106.6	194	144	149	157	65	59	15.7	13.8
22	37-43-38	130	116.5	119.2	168	157	215	216	96	101	35.7	36.6

Note: Averages based on totals.

TABLE XLVII

PHYSICAL CHARACTERISTICS OF COMPONENT MATERIALS

Single-Face Liner

Run Combination	Institute File Number	I.P.C. Roll No.	Mill Code	Place Sampled	Basis Weight (12 x 12 /1000), lb.	Caliper, points	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb./in. width In	Amthor Tensile, lb./in. width Across	Amthor Stretch, % In	Amthor Stretch, % Across
1	119638/40	4	A-24	Start	43.4	15.0	88	39	26.0	22.3	337	397	77.0	36.4	1.9	2.9
	119641/42			Middle	—	—	—	—	—	—	—	—	—	—	—	—
	119643/44			End	41.4	15.2	85	—	28.0	21.3	314	365	72.9	37.3	1.6	2.6
				Average	42.9	15.1	87	39	26.5	22.0	331	389	76.0	36.6	1.8	2.8
2	119643/44	4	A-24	Start	41.4	15.2	85	—	28.0	21.3	314	365	72.9	37.3	1.6	2.6
	119660/61			Middle	41.2	15.3	93	—	29.9	21.9	329	383	75.6	36.3	1.7	2.7
	119662/64			End	42.5	15.1	87	37	25.5	22.2	321	396	76.2	38.3	1.7	2.7
				Average	41.9	15.2	88	37	27.4	21.9	322	386	75.4	37.5	1.7	2.7
3	119677/79	5	A-27	Start	39.5	14.4	87	35	32.7	24.8	335	390	76.1	37.4	1.8	2.7
	119680/81			Middle	40.0	14.3	92	—	29.3	25.0	328	394	76.2	37.8	1.9	3.1
	119682/83			End	39.9	14.3	90	—	30.6	22.1	302	372	77.6	36.7	2.2	2.9
				Average	39.8	14.4	89	35	31.1	24.1	324	386	76.5	37.3	2.0	2.9
4	119682/83	5	A-27	Start	39.9	14.3	90	—	30.6	22.1	302	372	77.6	36.7	2.2	2.9
	119697/98			Middle	40.2	14.5	95	—	28.2	23.0	328	390	71.7	37.5	2.1	3.1
	119699/70			End	No Sample	—	—	—	—	—	—	—	—	—	—	—
				Average	40.1	14.4	93	—	29.4	22.5	315	381	74.7	37.1	2.2	3.0

Corrugating Medium

Run Combination	Institute File Number	I.P.C. Roll No.	Mill Code	Basis Weight (12 x 12 1000), lb.	Caliper, points	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb./in. width In	Amthor Tensile, lb./in. width Across	Amthor Stretch, % In	Amthor Stretch, % Across
1	119654/47	7	W-8	25.7	9.2	60	19	17.4	11.8	182	266	55.9	21.0	1.6	3.0
	119648/49			—	—	—	—	—	—	—	—	—	—	—	—
	119650/52			26.2	9.2	61	19	18.5	12.0	213	272	57.3	22.2	1.7	3.1
				26.0	9.2	61	19	17.9	11.9	195	268	56.6	21.6	1.7	3.1
2	119665/57	8	U-8	26.4	10.1	61	19	18.7	13.2	200	241	55.9	24.9	1.8	4.1
	119668/69			—	—	—	—	—	—	—	—	—	—	—	—
	119670/72			25.4	10.1	61	17	17.7	13.0	197	235	50.4	23.6	1.8	4.2
				25.9	10.1	61	18	18.2	13.1	198	238	53.2	24.3	1.8	4.2
3	119684/86	9	Z-8	26 4	9.0	71	19	20.0	15.5	220	242	56.8	32.3	1.8	4.6
	119687/88			26.1	8.7	77	—	22.2	16.8	210	233	52.2	34.1	2.2	4.9
	119689/91			26.5	9.0	78	20	17.0	15.4	217	245	59.8	32.5	2.1	4.7
				26.4	8.9	75	20	19.4	15.8	216	241	56.8	32.8	2.0	4.7
4	119701/03	10	T-9	26.1	10.0	57	20	17.8	14.1	215	234	47.2	23.8	1.5	3.1
	119704/05			26 0	9.9	58	—	16.6	13.3	209	234	48.5	24.0	1.8	3.5
	119706/08			26.1	10.0	56	20	16.1	12.2	209	237	46.2	23.8	1.4	3.0
				26.1	10.0	57	20	16.9	13.2	211	235	47.1	23.8	1.5	3.2

Double-Face Liner

Run Combination	Institute File Number	I.P.C. Roll No.	Mill Code	Basis Weight (12 x 12 /1000), lb.	Caliper, points	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf tear, g./sheet In	Elmendorf tear, g./sheet Across	Amthor Tensile, lb./in. width In	Amthor Tensile, lb./in. width Across	Amthor Stretch, % In	Amthor Stretch, % Across
1	119653/55	1	A-18	41.5	15.4	91	36	31.4	23.7	327	391	85.1	35.9	1.9	2.9
	119656/57			41.2	15.2	87	—	28.4	23.9	362	403	82.8	40.2	2.3	4.7
	119658/59			—	—	—	—	—	—	—	—	—	—	—	—
				41.4	15.4	90	36	30.7	23.8	336	394	84.5	36.9	2.0	3.4
2	119658/59	1	A-18	—	—	—	—	—	—	—	—	—	—	—	—
	119673/74			41.1	15.1	97	—	31.8	22.3	381	402	78.4	38.9	1.7	3.5
	119675/76			42.2	15.2	98	—	30.5	24.4	337	393	83.9	38.0	2.0	3.4
				41.7	15.2	98	—	31.1	23.3	359	397	81.1	38.5	1.8	3.5
3	119675/76	1	A-18	42.2	15.2	98	—	30.5	24.4	337	393	83.9	38.0	2.0	3.4
	119692/93			42.3	15.3	99	—	35.8	24.0	352	407	86.3	38.0	2.1	3.4
	119694/96			42 4	15.5	98	39	29.5	22.3	358	416	87.6	36.1	1.9	2.9
				42.3	15.3	98	39	31.5	23.4	350	407	86.2	37.2	2.0	3.2
4	119709/11	2	H-6	41.7	15.9	108	38	31.3	24.0	337	376	82.1	41.6	2.1	3.2
	119712/13			41.1	15.9	105	—	30.2	24.5	326	379	84.1	38.8	2.5	3.5
	119714/15			—	—	—	—	—	—	—	—	—	—	—	—
				41.6	15.9	107	38	31.0	24.1	334	377	82.6	40.9	2.2	3.3

TABLE XLVII—*Continued*

PHYSICAL CHARACTERISTICS OF COMPONENT MATERIALS

Single-Face Liner

Run Combination	Institute File Number	I.P.C. Roll No.	Mill Code	Place Sampled	Basis Weight (12 x 12 /1000), lb.	Caliper, points	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb.		Elmendorf Tear, g./sheet		Amthor Tensile, lb./in. width		Amthor Stretch, %	
									In	Across	In	Across	In	Across	In	Across
5	119699/70	5	A-27	Start	—	—	—	—	—	—	—	—	—	—	—	—
	119716/17			Middle	40.4	14.5	93	—	29.5	22.8	328	356	75.2	37.9	2.1	3.0
	119718/19			End	40.7	14.4	94	—	28.8	23.1	318	373	75.1	36.5	2.2	2.9
				Average	40.6	14.5	94	—	29.2	22.9	323	364	75.2	37.2	2.1	2.9
6	119718/19	5	A-27	Start	40.7	14.4	94	—	28.8	23.1	318	373	75.1	36.5	2.2	2.9
	119732/33			Middle	41.2	14.3	99	—	32.3	24.7	339	374	75.3	37.6	2.0	2.9
	119734/36			End	40.4	14.7	—	34	29.4	23.0	329	381	75.2	35.4	2.1	3.0
				Average	40.7	14.5	96	34	30.3	23.6	329	377	75.2	36.3	2.1	3.0
7	119750/52	6	A-28	Start	39.8	14.2	86	36	29.4	23.0	338	380	73.1	37.4	2.0	3.1
	119753/54			Middle	40.1	14.6	94	—	29.5	22.4	328	401	72.4	38.1	2.0	3.2
	119755/56			End	39.9	14.6	92	—	28.9	23.9	339	388	80.8	38.1	2.4	3.1
				Average	39.9	14.4	89	36	29.3	23.1	335	388	75.1	37.8	2.1	3.1
8	119755/56	6	A-28	Start	39.9	14.6	92	—	28.9	23.9	339	388	80.8	38.1	2.4	3.1
	119772/73			Middle	39.7	14.1	88	—	26.7	17.9	344	378	74.6	37.2	1.7	2.8
	119774/76			End	40.0	14.5	88	35	24.7	24.1	311	363	75.6	38.3	1.8	3.1
				Average	39.9	14.4	89	35	26.4	22.3	329	374	76.8	37.9	2.0	3.0

Corrugating Medium

Run Combination	Institute File Number	I.P.C. Roll No.	Mill Code	Basis Weight (12 x 12 /1000), lb.	Caliper, points	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb.		Elmendorf Tear, g./sheet		Amthor Tensile, lb./in. width		Amthor Stretch, %	
								In	Across	In	Across	In	Across	In	Across
5	119720/22	11	V-7	26.2	10.6	31	10	12.3	9.8	108	111	30.1	17.7	0.9	1.9
	119723/24			26.5	10.2	27	—	13.5	10.6	107	134	30.9	18.4	1.1	2.1
	119725/27			26.0	10.6	33	8	13.3	10.3	112	121	29.5	17.6	1.2	2.3
				26.2	10.5	31	9	13.0	10.2	109	121	30.1	17.8	1.0	2.1
6	119737/39	12	X-2	26.8	9.5	59	19	19.2	15.1	227	254	51.4	25.2	2.0	3.9
	119740/41			27.4	9.3	60	—	22.1	15.3	235	266	52.9	24.0	2.3	4.3
	119742/44			27.2	9.7	56	20	18.0	13.0	253	260	50.3	25.6	1.8	4.0
				27.1	9.5	58	19	19.5	14.4	239	259	51.3	25.1	2.0	4.1
7	119757/59	13	Y-9	26.1	8.7	49	15	20.7	14.4	167	192	47.8	22.0	1.9	3.1
	119760/61			25.9	8.8	53	—	17.9	12.8	160	209	47.7	22.4	1.9	3.5
	119762/64			25.9	8.8	50	15	17.3	12.6	167	192	48.4	22.3	2.0	3.5
				26.0	8.8	50	15	18.7	13.3	165	196	48.0	22.2	1.9	3.3
8	119777/79	14	S-6	26.5	9.8	51	21	18.5	15.8	263	251	50.0	31.9	1.6	4.9
	119780/81			26.7	10.0	56	—	20.4	15.3	257	251	46.7	31.8	1.2	4.8
	119782/84			26.3	9.8	54	21	18.9	16.0	255	259	48.0	30.4	1.5	4.4
				26.5	9.9	53	21	19.1	15.7	259	254	48.4	31.3	1.5	4.7

Double-Face Liner

Run Combination	Institute File Number	I.P.C. Roll No.	Mill Code	Basis Weight (12 x 12 /1000), lb.	Caliper, points	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb.		Elmendorf Tear, g./sheet		Amthor Tensile, lb./in. width		Amthor Stretch, %	
								In	Across	In	Across	In	Across	In	Across
5	119714/15	2	H-6	No Sample	—	—	—	—	—	—	—	—	—	—	—
	119728/29			42.1	16.2	103	—	34.5	26.4	338	394	79.8	38.5	2.4	3.1
	119730/31			41.6	16.3	105	—	36.7	25.8	258	394	84.2	37.8	2.5	3.3
				41.9	16.2	104	—	35.6	26.1	248	394	82.0	38.2	2.5	3.2
6	119730/31	2	H-6	41.6	16.3	105	—	36.7	25.8	358	394	84.2	37.8	2.5	3.3
	119745/46			41.0	15.9	101	—	34.1	25.8	338	386	84.1	39.8	2.5	3.7
	119747/49			42.7	16.2	100	38	32.1	25.6	343	404	81.7	39.4	2.1	3.4
				41.9	16.1	101	38	34.0	25.7	346	396	83.1	39.0	2.3	3.5
7	119765/67	3	B-3	44.1	16.4	86	38	29.4	21.8	363	425	82.6	36.4	1.8	3.3
	119768/69			43.0	16.3	91	—	29.2	20.9	339	390	85.7	36.6	2.3	3.2
	119770/71			42.9	16.2	86	—	27.1	19.3	342	369	79.8	35.9	2.1	3.2
				43.4	16.3	87	38	28.7	20.8	350	399	82.7	36.3	2.0	3.2
8	119770/71	3	B-3	42.9	16.2	86	—	27.1	19.3	342	369	79.8	35.9	2.1	3.2
	119785/86			43.4	16.3	90	—	34.6	23.2	334	369	80.3	36.7	2.0	3.1
	119787/89			43.7	15.7	98	38	30.4	23.6	322	385	82.3	36.2	2.3	3.3
				43.4	16.0	93	38	30.7	22.3	331	376	81.0	36.3	2.2	3.2

TABLE XLVII—*Continued*

PHYSICAL CHARACTERISTICS OF COMPONENT MATERIALS

Single-Face Liner

Run Combination	Institute File Number	I.P.C. Roll No.	Mill Code	Place Sampled	Basis Weight (12 x 12 /1000), lb.	Caliper, points	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb./in. width In	Amthor Tensile, lb./in. width Across	Amthor Stretch, % In	Amthor Stretch, % Across
9	119790/92	15	A-7	Start	40.2	13.6	90	35	29.5	26.0	315	362	76.4	38.4	2.1	3.2
	119793/94			Middle	40.7	14.0	93	—	30.5	23.6	326	367	74.4	39.5	1.8	3.0
	119795/97			End	40.1	13.8	93	35	29.8	23.4	316	372	77.2	38.9	2.1	3.0
				Average	40.3	13.8	92	35	29.9	24.4	318	367	76.2	38.8	2.0	3.1
10	119813/15	17	H-11	Start	42.1	15.7	99	38	29.6	23.5	369	420	76.7	40.3	2.1	3.6
	119816/17			Middle	42.0	15.9	99	—	31.2	24.0	354	410	73.4	40.4	1.8	3.7
	119818/20			End	42.4	15.4	98	38	28.0	24.6	415	431	75.5	40.0	2.1	3.4
				Average	42.2	15.6	99	38	29.4	24.0	382	422	75.4	40.2	2.0	3.5
11	119833/35	19	B-13	Start	42.6	15.5	93	37	30.4	23.3	366	436	83.3	39.3	1.7	3.1
	119836/37			Middle	43.1	15.6	96	—	33.4	26.6	328	396	88.2	41.5	1.8	2.8
	119838/40			End	44.1	15.9	99	40	29.0	24.9	379	449	88.8	40.8	2.5	3.0
				Average	43.3	15.7	96	38	30.6	24.7	361	431	86.6	40.4	2.0	3.0
12	119854/56	21	I-10	Start	43.1	14.9	104	41	27.9	21.7	375	454	84.1	36.9	2.4	4.4
	119857/58			Middle	42.8	14.8	98	—	32.4	21.0	359	447	83.3	36.1	1.9	4.0
	119859/61			End	43.4	14.9	105	42	27.6	20.8	373	452	87.4	36.2	2.3	4.3
				Average	43.1	14.9	104	42	28.4	21.2	371	452	85.1	36.4	2.3	4.3

Corrugating Medium

Run Combination	Institute File Number	I.P.C. Roll No.	Mill Code	Basis Weight (12 x 12 /1000), lb.	Caliper, points	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb./in. width In	Amthor Tensile, lb./in. width Across	Amthor Stretch, % In	Amthor Stretch, % Across
9	119798/800	39	U-15	27.6	11.1	57	21	18.2	14.0	240	278	51.7	25.3	1.6	3.2
	119801/02			28.6	11.3	62	—	20.6	14.5	244	295	62.0	25.3	2.1	3.2
	119803/04			27.9	11.0	62	—	20.1	15.8	249	276	55.9	26.8	1.4	3.3
				28.0	11.1	59	21	19.4	14.6	243	282	55.8	25.7	1.7	3.3
10	119803/04	39	U-15	27.9	11.0	62	—	20.1	15.8	249	276	55.9	26.8	1.4	3.3
	119821/22			27.6	11.0	63	—	21.5	14.0	231	279	55.5	25.2	1.5	3.0
	119823/24			28.0	10.9	66	—	19.5	15.3	252	288	58.5	28.3	1.8	3.5
				27.8	11.0	64	—	20.3	15.0	244	281	56.6	26.8	1.6	3.3
11	119823/24	39	U-15	28.0	10.9	66	—	19.5	15.3	252	288	58.5	28.3	1.8	3.5
	119841/42			27.7	11.0	65	—	20.3	16.9	233	263	54.1	26.9	1.7	3.2
	119843/45			27.7	10.9	59	21	17.7	13.8	245	293	57.1	25.8	2.1	3.5
				27.8	10.9	62	21	18.9	15.1	244	283	56.7	26.8	1.9	3.4
12	119862/64	40	X-1	27.0	9.2	64	19	16.0	11.8	216	261	54.0	24.0	2.1	3.7
	119865/66			26.6	9.1	61	—	19.0	15.0	203	244	53.1	22.1	2.0	3.9
	119867/68			26.8	9.3	61	—	22.8	13.0	222	245	53.4	22.5	2.1	4.3
				26.8	9.2	63	19	18.2	13.0	214	252	53.6	23.1	2.1	3.9

Double-Face Liner

Run Combination	Institute File Number	I.P.C. Roll No.	Mill Code	Basis Weight (12 x 12 /1000), lb.	Caliper, points	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb./in. width In	Amthor Tensile, lb./in. width Across	Amthor Stretch, % In	Amthor Stretch, % Across
9	119805/07	16	A-22	39.5	14.9	83	35	28.2	21.6	282	342	72.3	35.3	1.7	2.6
	119808/09			41.2	15.1	86	—	27.8	22.5	293	370	74.8	36.5	1.7	2.7
	119810/12			41.3	14.8	85	37	27.3	23.0	326	375	76.5	36.2	1.9	2.7
				40.6	14.9	85	35	27.8	22.4	301	361	74.5	35.9	1.8	2.6
10	119825/27	18	H-8	42.2	15.0	94	37	28.2	23.0	382	430	80.9	41.4	2.3	3.7
	119828/29			42.0	15.6	99	—	32.3	24.4	361	399	83.0	40.1	2.4	3.3
	119830/32			42.5	15.2	96	38	26.9	25.1	365	409	79.0	41.8	2.0	3.8
				42.3	15.2	96	38	28.8	24.1	370	415	80.7	41.2	2.2	3.6
11	119846/48	20	B-1	41.4	16.3	80	36	27.0	21.9	371	446	84.0	34.5	1.8	3.3
	119849/50			41.9	15.9	89	—	34.4	25.0	307	366	85.7	37.1	2.0	3.0
	119851/53			42.2	16.0	98	36	25.6	22.4	333	377	80.0	36.4	2.1	3.1
				41.8	16.1	89	36	28.3	22.8	341	400	82.9	35.9	1.9	3.1
12	119869/71	22	I-12	43.8	15.4	97	49	28.9	24.7	435	452	79.8	37.2	2.0	5.2
	119872/73			43.7	15.4	101	—	31.9	23.9	386	425	81.2	37.0	2.1	3.9
	119874/76			43.9	15.0	92	50	27.0	23.6	395	435	79.0	38.4	2.0	4.0
				43.8	15.2	96	50	28.9	24.1	408	439	79.8	37.6	2.0	4.4

TABLE XLVII—*Continued*

PHYSICAL CHARACTERISTICS OF COMPONENT MATERIALS

Single-Face Liner

Run Combination	Institute File Number	I.P.C. Roll No.	Mill Code	Place Sampled	Basis Weight (12 x 12 /1000), lb.	Caliper, points	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb./in. width In	Amthor Tensile, lb./in. width Across	Amthor Stretch, % In	Amthor Stretch, % Across
13	119877/79	23	F-5	Start	38.5	12.9	81	37	24.0	21.2	299	326	65.6	35.1	1.2	2.9
	119880/81			Middle	41.8	12.8	82	—	27.8	23.7	306	333	73.5	36.4	2.4	3.3
	119882/84			End	41.2	12.8	82	35	24.6	21.4	311	343	68.0	35.2	1.8	2.8
				Average	40.3	12.9	81	36	25.1	21.9	305	334	68.4	35.5	1.7	2.9
14	119898/900	25	C-10	Start	42.7	14.5	93	38	31.5	18.8	346	433	91.0	36.9	1.5	3.6
	119901/02			Middle	40.9	14.4	95	—	30.2	20.4	331	401	79.7	36.8	1.3	3.9
	119903/05			End	—	—	—	—	—	—	—	—	—	—	—	—
				Average	42.0	14.5	94	38	31.0	19.4	340	420	86.5	36.8	1.4	3.7
15	119921/23	27	D-20	Start	40.6	14.5	90	36	29.0	22.8	372	382	71.7	42.0	2.1	3.9
	119924/25			Middle	41.4	15.1	100	—	30.7	21.8	363	375	75.0	41.5	2.2	3.8
	119926/28			End	41.1	14.9	87	37	25.1	22.6	381	382	68.0	44.4	2.0	4.0
				Average	41.0	14.8	90	37	28.0	22.4	372	380	71.1	42.8	2.1	3.9
16	119941/43	29	E-5	Start	42.5	15.9	85	35	29.0	20.2	347	418	87.2	33.6	1.7	3.5
	119944/45			Middle	43.0	16.1	82	—	28.1	19.5	290	358	84.6	33.5	1.6	3.1
	119946/48			End	42.4	16.0	83	34	28.6	20.3	314	388	77.7	33.4	1.5	3.4
				Average	42.6	16.0	84	35	28.6	20.1	320	391	83.0	33.5	1.6	3.4
17	119962/64	31	G-12	Start	41.2	15.5	78	39	23.5	17.5	368	389	66.5	37.5	1.4	3.3
	119965/66			Middle	41.0	15.6	79	—	28.3	20.8	340	366	67.3	37.6	1.4	3.5
	119967/69			End	40.8	15.3	83	38	27.5	22.5	370	382	69.9	38.9	1.5	3.3
				Average	41.0	15.5	80	38	26.2	20.2	362	381	68.0	38.2	1.4	3.3

Corrugating Medium

Run Combination	Institute File Number	I.P.C. Roll No.	Mill Code	Basis Weight (12 x 12 /1000), lb.	Caliper, points	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb./in. width In	Amthor Tensile, lb./in. width Across	Amthor Stretch, % In	Amthor Stretch, % Across
13	119867/68	40	X-1	26.8	9.3	61	—	22.8	13.0	222	245	53.4	22.5	2.1	4.3
	119885/86			25.9	9.1	61	—	21.3	15.0	240	257	50.0	22.7	2.0	3.8
	119887/89			26.1	9.2	64	17	20.3	14.4	220	247	50.1	24.1	1.8	4.3
				26.2	9.2	63	17	21.0	14.4	226	250	50.6	23.4	1.9	4.1
14	119906/08	41	U-20	27.2	11.3	60	17	21.7	13.2	227	261	55.2	23.1	1.9	3.9
	119909/10			27.3	11.4	65	—	21.6	13.7	220	279	57.8	24.7	2.4	4.1
	119911/12			26.6	11.1	62	—	19.1	13.6	231	268	58.7	22.2	2.3	4.0
				27.1	11.3	62	17	21.2	13.5	226	268	57.0	23.3	2.2	4.0
15	119911/12	41	U-20	26.6	11.1	62	—	19.1	13.6	231	268	58.7	22.2	2.3	4.0
	119929/30			27.2	11.7	77	—	18.5	15.0	222	277	53.9	24.5	2.1	4.4
	119931/32			27.1	11.3	62	—	18.9	13.3	211	279	52.1	23.2	2.2	4.4
				27.0	11.4	67	—	18.8	14.0	221	275	54.9	23.3	2.2	4.3
16	119931/32	41	U-20	27.1	11.3	62	—	18.9	13.3	211	279	52.1	23.2	2.2	4.4
	119949/50			27.0	11.2	61	—	19.1	13.0	239	273	51.4	22.4	1.8	4.1
	119951/53			27.5	11.6	64	19	17.1	13.0	235	281	53.4	24.3	1.9	4.4
				27.2	11.4	63	19	18.2	13.1	229	278	52.4	23.4	2.0	4.3
17	119970/72	42	Y-6	26.2	9.3	62	16	19.6	14.7	208	249	53.6	24.7	1.7	3.1
	119973/74			26.1	9.4	61	—	18.7	13.4	220	253	52.7	23.7	1.9	2.7
	119975/76			25.6	9.2	65	—	19.3	14.1	198	244	50.5	24.2	1.8	3.0
				26.0	9.3	62	16	19.2	14.1	208	249	52.4	24.3	1.8	2.9

Double-Face Liner

Run Combination	Institute File Number	I.P.C. Roll No.	Mill Code	Basis Weight (12 x 12 /1000), lb.	Caliper, points	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb /in. width In	Amthor Tensile, lb /in. width Across	Amthor Stretch, % In	Amthor Stretch, % Across
13	119890/92	24	F-6	39.5	12.8	77	29	22.7	19.2	287	319	62.6	32.8	1.8	2.6
	119893/94			40.0	12.5	79	—	26.7	22.3	267	306	61.8	33.3	1.5	2.4
	119895/97			39.4	12.4	78	26	26.2	21.3	262	313	66.2	33.4	2.1	2.9
				39.6	12.6	78	28	25.0	20.8	273	313	63.7	33.1	1.8	2.7
14	119913/15	26	C-9	41.9	14.7	90	39	29.4	19.7	330	409	83.9	36.0	1.7	3.9
	119916/17			41.5	14.9	93	—	28.4	19.9	334	381	87.8	36.3	1.9	3.9
	119918/20			42.4	14.5	97	41	30.0	21.1	332	447	83.6	36.6	1.7	3.9
				42.0	14.7	94	40	29.4	20.3	332	416	84.8	36.3	1.8	3.9
15	119933/35	28	D-5	44.3	16.3	89	42	26.3	20.8	385	462	70.1	40.3	1.8	2.7
	119936/37			44.0	16.2	94	—	28.4	20.9	382	423	70.5	42.0	1.9	2.9
	119938/40			44.2	16.3	92	42	24.3	20.7	418	454	72.2	42.2	1.6	2.9
				44.2	16.3	91	42	26.1	20.8	397	449	71.0	41.4	1.7	2.8
16	119954/56	30	E-3	41.4	14.5	79	33	25.9	18.9	310	355	75.2	34.1	1.6	3.5
	119957/58			42.9	13.8	93	—	24.8	19.0	322	362	82.0	35.4	1.8	3.9
	119959/61			41.8	14.1	85	34	25.4	19.5	291	349	77.6	34.5	1.6	3.5
				41.9	14.1	85	34	25.4	19.2	306	355	77.8	34.6	1.6	3.6
17	119977/79	32	G-1	42.3	15.1	84	38	26.9	21.8	355	399	75.8	41.3	1.5	2.8
	119980/81			43.2	14.8	86	—	27.2	21.8	382	432	75.8	42.4	1.6	3.0
	119982/84			42.5	14.9	88	40	27.4	21.3	352	386	74.8	42.5	1.7	2.9
				42.6	15.0	86	39	27.2	21.6	361	402	75.4	42.0	1.6	2.9

TABLE XLVII—*Continued*

PHYSICAL CHARACTERISTICS OF COMPONENT MATERIALS

Single-Face Liner

Run Combination	Institute File Number	I.P.C. Roll No.	Mill Code	Place Sampled	Basis Weight (12 x 12 /1000), lb.	Caliper, points	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb./in. width In	Amthor Tensile, lb./in. width Across	Amthor Stretch, % In	Amthor Stretch, % Across
18	119985/87	33	J-11	Start	41.0	15.1	86	34	29.4	23.9	296	354	76.6	35.7	2.0	2.9
	119988/89			Middle	41.2	14.8	90	—	31.0	23.6	303	364	75.2	35.8	1.9	2.8
	119990/92			End	41.6	15.1	88	33	31.5	23.8	313	391	78.0	37.3	1.3	2.2
				Average	41.3	15.0	87	34	30.6	23.8	304	371	76.8	36.3	1.7	2.6
19	120006/08	35	C-3	Start	44.1	14.0	100	35	31.3	25.2	365	395	77.5	42.8	2.0	3.6
	120009/10			Middle	43.3	14.0	97	—	35.0	25.9	387	384	75.5	45.5	1.5	4.3
	120011/12			End	44.2	14.0	96	—	31.6	27.0	400	377	81.8	44.6	1.9	4.4
				Average	43.9	14.0	98	35	32.4	25.9	381	387	78.2	44.1	1.8	4.0
20	120011/12	35	C-3	Start	44.2	14.0	96	—	31.6	27.0	400	377	81.8	44.6	1.9	4.4
	120028/29			Middle	44.3	14.0	99	—	32.8	27.2	380	380	87.1	43.1	2.1	4.5
	120030/32			End	44.3	14.1	96	36	33.3	26.7	374	401	84.0	44.9	2.1	4.5
				Average	44.3	14.0	97	36	32.7	26.9	383	388	84.3	44.3	2.0	4.5
21	120045/47	37	E-1	Start	43.9	16.9	55	29	22.4	16.9	260	273	52.9	29.1	1.2	2.4
	120048/49			Middle	44.4	17.1	57	—	21.2	17.5	298	282	50.7	29.9	1.0	2.5
	120050/51			End	44.9	16.5	61	—	20.9	16.2	264	287	57.3	28.8	1.1	2.5
				Average	44.3	16.8	57	29	21.6	16.8	272	280	53.5	29.2	1.1	2.5
22	120050/51	37	E-1	Start	44.9	16.5	61	—	20.9	16.2	264	287	57.3	28.8	1.1	2.5
	120064/65			Middle	44.8	16.5	52	—	21.6	17.2	266	280	55.5	30.6	1.2	2.6
	120066/68			End	44.9	16.6	59	31	21.9	17.3	265	280	53.3	29.9	1.2	2.4
				Average	44.9	16.5	58	31	21.5	16.9	265	282	55.1	29.8	1.2	2.5

NOTE: Averages based on totals.

Corrugating Medium

Run Combination	Institute File Number	I.P.C. Roll No.	Mill Code	Basis Weight (12 x 12 /1000), lb.	Caliper, points	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb./in. width In	Amthor Tensile, lb./in. width Across	Amthor Stretch, % In	Amthor Stretch, % Across
18	119975/76	42	Y-6	25.6	9.2	65	—	19.3	14.1	198	244	50.5	24.2	1.8	3.0
	119993/94			26.0	9.3	64	—	18.5	13.2	197	255	53.7	23.9	1.9	2.7
	119995/97			26.4	9.3	64	16	24.0	18.1	200	249	53.7	25.3	2.1	2.9
				26.1	9.3	64	16	21.4	15.8	198	249	52.8	24.6	1.9	2.9
19	120013/15	43	U-11	27.5	11.0	73	16	22.0	16.8	233	257	53.1	26.9	1.9	4.3
	120016/17			27.2	11.0	69	—	19.5	13.5	216	260	53.2	24.9	2.2	4.5
	120018/20			27.6	11.2	68	17	22.3	16.9	228	246	53.6	27.0	2.1	4.2
				27.5	11.1	70	17	21.5	16.0	227	254	53.3	26.4	2.0	4.3
20	120033/35	44	Y-10	25.0	9.1	52	15	15.9	12.3	180	218	43.8	22.6	1.9	2.9
	120036/37			24.8	9.2	51	—	17.6	11.9	169	199	45.3	21.8	1.7	2.6
	120038/39			24.7	9.1	52	—	18.7	11.3	180	200	44.6	22.0	1.9	2.9
				24.9	9.1	52	15	17.2	11.9	177	208	44.5	22.2	1.8	2.8
21	120038/39	44	Y-10	24.7	9.1	52	—	18.7	11.3	180	200	44.6	22.0	1.9	2.9
	120052/53			25.6	9.3	51	—	21.1	15.3	179	203	45.2	21.5	1.7	2.4
	120054/56			24.3	8.9	49	13	17.9	11.3	172	201	46.7	21.0	1.9	2.9
				24.8	9.1	50	13	19.0	12.4	176	202	45.7	21.4	1.8	2.8
22	120018/20	43	U-11	27.6	11.2	68	17	22.3	16.9	228	246	53.6	27.0	2.1	4.2
	120069/70			27.5	10.9	76	—	19.8	14.2	226	249	54.9	25.5	2.0	4.6
	120071/73			27.7	11.1	68	19	22.4	15.6	229	264	54.2	27.0	1.4	4.2
				27.6	11.1	70	18	21.7	15.7	228	254	54.1	26.6	1.8	4.3

Doube-Face Liner

Run Combination	Institute File Number	I P.C. Roll No.	Mill Code	Basis Weight (12 x 12 /1000) lb.	Caliper, points	Bursting Strength, points	G. E. Puncture, units	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb./in. width In	Amthor Tensile, lb./in. width Across	Amthor Stretch, % In	Amthor Stretch, % Across
18	119998/120000	34	J-3	41.9	15.1	86	31	31.7	25.1	321	370	75.9	39.0	1.0	2.6
	120001/02			42.1	15.1	87	--	30.9	24.3	316	355	76.8	38.4	2.0	2.3
	120003/05			41.8	15.3	94	31	31.5	25.7	294	364	77.2	38.5	1.6	2.0
				41.9	15.2	90	31	31.4	25.1	310	364	76.6	38.7	1.5	2.3
19	120021/23	36	H-14	41.5	15.4	102	34	30.8	24.6	340	394	74.6	40.1	1.8	3.5
	120024/25			41.4	15.2	96	—	29.4	22.7	344	385	78.1	39.8	2.2	3.4
	120026/27			42.0	15.5	101	—	28.1	22.1	353	398	80.0	42.2	2.4	3.5
				41 6	15.4	100	34	29.6	23.3	345	393	77.1	40.6	2.1	3.5
20	120026/27	36	H-14	42.0	15.5	101	—	28.1	22.1	353	398	80.0	42.2	2.4	3.5
	120040/41			42.2	15.5	96	—	30.2	24.6	379	403	74.3	42.6	2.2	3.9
	120042/44			42.0	15.5	101	36	30.8	22.9	373	403	78.1	42.8	1.8	3.7
				42.1	15.5	100	36	29.9	23.2	369	402	77.6	42.5	2.1	3.7
21	120057/59	38	E-2	43.3	17 1	63	30	22.8	17.5	290	286	55.8	30.2	1.1	2.3
	120060/61			44.2	17.0	59	—	20.1	14.8	282	288	52.7	29.8	0.9	2.4
	120062/63			44.6	17.3	50	—	24.1	16.3	262	274	53.6	29.7	0.9	2.3
				43.9	17.2	59	30	22.8	16.7	279	282	54.6	30.0	1.0	2.3
22	120062/63	38	E-2	44.6	17.3	50	—	24.1	16.3	262	274	53.6	29.7	0.9	2.3
	120074/75			44.7	17.4	51	—	22.9	15.4	288	300	52.4	29.1	1.5	3.1
	120076/78			44.5	17.4	60	30	21.4	16.4	272	290	57.0	27.1	1.4	2.6
				44.6	17.4	56	30	22.6	16.1	274	288	54.7	28.4	1.3	2.7

APPENDIX B

THEORY OF STATISTICAL ANALYSIS

During the experimental work reported in the preceding pages, a large number of data were obtained on the various physical properties of the component materials, the combined boards fabricated from these components; and the boxes manufactured from the combined board. Because of the obvious economic, as well as technical considerations, it was important to determine whether a relationship existed between the properties of the combined board or its components and those of the resulting boxes. If it were possible to establish such a relationship, and thus predict, with a fair degree of approximation, the physical characteristics of boxes from those of either the components or the combined board, such predictions would have considerable technological and economic value for the manufacturer, fabricator, converter, and consumer of paperboard products. As discussed on page 49 of this report, such relationships can best be established by means of statistical analysis. The theory involved and the method of application are discussed in the following paragraphs.

This section is not intended as a complete derivation and explanation of the techniques involved in statistical analysis. Such a presentation would be too involved to be included in a report of this nature. However, it is believed that the following material is sufficient to enable anyone acquainted with the mathematics involved to calculate any of the values presented in the report.

In this report statistical methods have been employed to predict laboratory performance test results from tests made upon the component material and combined board. This prediction is based upon the technique known as multiple correlation. For linear functions of the type considered in this work, the following general formula is used:

$$Y=a_0+a_1x_1+a_2x_2+a_3x_3, \qquad (1)$$

when Y is the predicted laboratory performance test value, a_0, a_1, a_2, and a_3 are numerical constants or weight factors, and x_1, x_2, and x_3 are the test results on which the prediction is based.

Using the method of least squares (a well-established statistical practice) and minimizing the variation successively for each constant, the following set of equations is obtained.

$$\begin{aligned} a_0n+a_1\sum x_1+a_2\sum x_2+a_3\sum x_3&=\sum y\\ a_0\sum x_1+a_1\sum x_1^2+a_2\sum x_1x_2+a_3\sum x_1x_3&=\sum x_1y\\ a_0\sum x_2+a_1\sum x_1x_2+a_2\sum x_2^2+a_3\sum x_2x_3&=\sum x_2y\\ a_0\sum x_3+a_1\sum x_1x_3+a_2\sum x_2x_3+a_3\sum x_3^2&=\sum x_3y \end{aligned} \qquad (2)$$

where, in addition to the given nomenclature;

$\sum$ = summation of,
n = number of experimental items, and
y = observed laboratory performance results.

The method of multiple correlation illustrated above can be applied to any group of compatible data. However, the value of the results obtained depends upon the reliability of the prediction. In other words, if the predicted values for any laboratory performance test are close to the experimental values obtained in an actual test, the prediction is of practical significance.

In order to illustrate fully the work in Equation (2), the actual calculations for determining the relationship between the use of drop test values (y) and average tear (machine and across-machine direction) for 3 components is presented. Table I contains the quantities necessary to set up an equation such as (1). The data in this table include the three average tear values (x_1, x_2, and x_3), the square (x_1^2, etc.) of each value, the cross-products [x_1x_2 (single-face average tear times corrugating medium average tear), etc.], the drop value (y) and, finally, the cross-products (x_1y, etc.). At the foot of each column is the total which is used in the simultaneous equations. The equations resulting from Table I are as follow:

$$\begin{aligned} 22\,a_0+7{,}837.5\,a_1+5{,}025.0\,a_2+7{,}919.5\,a_3&=185.3\\ 7{,}837.5\,a_0+2{,}817{,}138.75\,a_1+1{,}795{,}925.75\,a_2&\\ +2{,}845{,}789.50\,a_3&=67{,}142.90\\ 5{,}025.0\,a_0+1{,}795{,}925.75\,a_1+1{,}172{,}472.00\,a_2&\\ +1{,}809{,}179.00\,a_3&=43{,}153.45\\ 7{,}919.5\,a_0+2{,}845{,}789.50\,a_1+1{,}809{,}179.00\,a_2&\\ +2{,}881{,}893.75\,a_3&=67{,}715.25 \end{aligned} \qquad (3)$$

The constants found by solving equations (3) are

$$\begin{aligned} a_0&=-11.499\\ a_1&=+0.03307\\ a_2&=+0.02576\\ a_3&=+0.00627 \end{aligned} \qquad (4)$$

The constants in (4) can be substituted in Equation (1) to obtain the predicted value Y.

$$Y=-11.499+0.03307x_1+0.02576x_2+0.00627x_3. \qquad (5)$$

The predicted values for the drop test for Runs 1 through 22 [as calculated from equation (5) by the use of data obtained in the present work] are given in Table II.

In future work, where average tear is known, similar predictions of drop values may be made.

The reliability of such predictions are judged by cal-

TABLE I

THE RELATIONSHIP BETWEEN DROP AND AVERAGE TEAR FOR EACH OF THREE COMPONENTS

QUANTITIES NECESSARY TO SET UP SIMULTANEOUS EQUATIONS

Single-Face Tear, x_1	Corrugating Medium Tear, x_2	Double-Face Tear, x_3	x_1^2	x_2^2	x_3^2	x_1x_2	x_1x_3	x_2x_3	Drop Test, y	x_1y	x_2y	x_3y
360.0	231.5	365.0	129,600.00	53,592.25	133,225.00	83,340.00	131,400.00	84,497.50	7.9	2,844.00	1,828.85	2,883.50
354.0	218.0	378.0	125,316.00	47,524.00	142,884.00	77,172.00	133,812.00	82,404.00	8.1	2,867.40	1,765.80	3,061.80
355.0	228.5	378.5	126,025.00	52,212.25	143,262.25	81,117.50	134,367.50	86,487.25	8.6	3,053.00	1,965.10	3,255.10
348.0	223.0	355.5	121,104.00	49,729.00	126,380.25	77,604.00	123,714.00	79,276.50	8.3	2,888.40	1,850.90	2,950.65
343.5	115.0	371.0	117,992.25	13,225.00	137,641.00	39,502.50	127,438.50	42,665.00	5.8	1,992.30	667.00	2,151.80
353.0	249.0	371.0	124,609.00	62,001.00	137,641.00	87,897.00	130,963.00	92,379.00	8.1	2,859.30	2,016.90	3,005.10
361.5	180.5	374.5	130,682.25	32,580.25	140,250.25	65,250.75	135,381.75	67,597.25	6.5	2,349.75	1,173.25	2,434.25
351.5	256.5	353.5	123,552.25	65,792.25	124,962.25	90,159.75	124,255.25	90,672.75	10.1	3,550.15	2,590.65	3,570.35
342.5	262.5	331.0	117,306.25	68,906.25	109,561.00	89,906.25	113,367.50	86,887.50	7.6	2,603.00	1,995.00	2,515.60
402.0	262.5	392.5	161,604.00	68,906.25	154,056.25	105,525.00	157,785.00	103,031.25	11.2	4,502.40	2,940.00	4,396.00
396.0	263.5	370.5	156,816.00	69,432.25	137,270.25	104,346.00	146,718.00	97,626.75	9.6	3,801.60	2,529.60	3,556.80
411.5	233.0	423.5	169,332.25	54,289.00	179,352.25	95,879.50	174,270.25	98,675.50	12.0	4,938.00	2,796.00	5,082.00
319.5	238.0	293.0	102,080.25	56,644.00	85,849.00	76,041.00	93,613.50	69,734.00	6.9	2,204.55	1,642.20	2,021.70
380.0	247.0	374.0	144,400.00	61,009.00	139,876.00	93,860.00	142,120.00	92,378.00	11.1	4,218.00	2,741.70	4,151.40
376.0	248.0	423.0	141,376.00	61,504.00	178,929.00	93,248.00	159,048.00	104,904.00	9.8	3,684.80	2,430.40	4,145.40
355.5	253.5	330.5	126,380.25	64,262.25	109,230.25	90,119.25	117,492.75	83,781.75	9.3	3,306.15	2,357.55	3,073.65
371.5	228.5	381.5	138,012.25	52,212.25	145,542.25	84,887.75	141,727.25	87,172.75	8.5	3,157.75	1,942.25	3,242.75
337.5	223.5	337.0	113,906.25	49,952.25	113,569.00	75,431.25	113,737.50	75,319.50	5.6	1,890.00	1,251.60	1,887.20
384.0	240.5	369.0	147,456.00	57,840.25	136,161.00	92,352.00	141,696.00	88,744.50	11.4	4,377.60	2,741.70	4,206.60
385.5	192.5	385.5	148,610.25	37,056.25	148,610.25	74,208.75	148,610.25	74,208.75	7.8	3,006.90	1,501.50	3,006.90
276.0	189.0	280.5	76,176.00	35,721.00	78,680.25	52,164.00	77,418.00	53,014.50	4.8	1,324.80	907.20	1,346.40
273.5	241.0	281.0	74,802.25	58,081.00	78,961.00	65,913.50	76,853.50	67,721.00	6.3	1,723.05	1,518.30	1,770.30
7,837.5	5,025.0	7,919.5	2,817,138.75	1,172,472.00	2,881,893.75	1,795,925.75	2,845,789.50	1,809,179.00	185.3	67,142.90	43,153.45	67,715.25

TABLE II

PREDICTED VALUES OF DROP FROM AVERAGE TEAR

Lot	$+0.03307x_1$	$+0.02576x_2$	$+0.00627x_3$	Sum—11.499
1	11.91	5.96	2.29	8.7
2	11.71	5.62	2.37	8.2
3	11.74	5.89	2.37	8.5
4	11.51	5.74	2.23	8.0
5	11.36	2.96	2.33	5.1
6	11.67	6.41	2.33	8.9
7	11.95	4.65	2.35	7.5
8	11.62	6.61	2.22	9.0
9	11.33	6.76	2.08	8.7
10	13.29	6.76	2.46	11.0
11	13.10	6.79	2.32	10.7
12	13.61	6.00	2.66	10.8
13	10.57	6.13	1.84	7.0
14	12.57	6.36	2.34	9.8
15	12.43	6.39	2.65	10.0
16	11.76	6.53	2.07	8.9
17	12.29	5.89	2.39	9.1
18	11.16	5.76	2.11	7.5
19	12.70	6.20	2.31	9.7
20	12.75	4.96	2.42	8.6
21	9.13	4.87	1.76	4.3
22	9.04	6.21	1.76	5.5

culating the correlation coefficients. This involves the following relationships:

$$R = \sqrt{\frac{v_1 - v_2}{v_1}},^* \qquad (6)$$

where R = the correlation coefficient, and v_1 and v_2 are *variances*. *Variances* are a statistical measure of scattering of individual values. They are based upon the

TABLE III

THE COMPARISON OF OBSERVED VALUES OF DROP WITH THOSE THAT MIGHT HAVE BEEN PREDICTED FROM AVERAGE TEAR, IN THE PRESENT WORK

Lot	Prediction Y	Observation y	Difference $y-\bar{y}$	Difference $y-Y$	$(y-\bar{y})^2$	$(y-Y)^2$
1	8.7	7.9	−0.5	−0.8	0.25	0.64
2	8.2	8.1	−0.3	−0.1	0.09	0.01
3	8.5	8.6	+0.2	+0.1	0.04	0.01
4	8.0	8.3	−0.1	+0.3	0.01	0.09
5	5.1	5.8	−2.6	+0.7	6.76	0.49
6	8.9	8.1	−0.3	−0.8	0.09	0.64
7	7.5	6.5	−1.9	−1.0	3.61	1.00
8	9.0	10.1	+1.7	+1.1	2.89	1.21
9	8.7	7.6	−0.8	−1.1	0.64	1.21
10	11.0	11.2	+2.8	+0.2	7.84	0.04
11	10.7	9.6	+1.2	−1.1	1.44	1.21
12	10.8	12.0	+3.6	+1.2	12.96	1.44
13	7.0	6.9	−1.5	−0.1	2.25	0.01
14	9.8	11.1	+2.7	+1.3	7.29	1.69
15	10.0	9.8	+1.4	−0.2	1.96	0.04
16	8.9	9.3	+0.9	+0.4	0.81	0.16
17	9.1	8.5	+0.1	−0.6	0.01	0.36
18	7.5	5.6	−2.8	−1.9	7.84	3.61
19	9.7	11.4	+3.0	+1.7	9.00	2.89
20	8.6	7.8	−0.6	−0.8	0.36	0.64
21	4.3	4.8	−3.6	+0.5	12.96	0.25
22	5.5	6.3	−2.1	+0.8	4.41	0.64
Sum	185.5	185.3	+0.5	−0.2	83.51	18.28
Mean		8.4				

* This is the general formula for the correlation coefficient. The formula actually used in this work is given on page 38. For linear correlations of the type encountered in this work, the two formulas are identical. The general formula lends itself more readily to theoretical discussions, whereas the formula used in the actual calculations lends itself more readily to machine calculations.

so-called mean square relationship and are calculated as follows:

$$v_1 = \sum (y - \bar{y})^2$$
$$v_2 = \sum (y - Y)^2 \qquad (7)$$

where $\sum$ = summation of,
y = experimental values,
Y = predicted values, and
$\bar{y}$ = the mean of the experimental values.

If R is unity, perfect correlation exists; that is, all experimental values are precisely the same as the predicted values. If the predicted values have no relation to the experimental values—i.e., there is no correlation—the value of R will be 0. It should be stated in a precautionary way, that this is not a linear relationship and a R value of 0.8 does *not* indicate a correlation twice as good as one of 0.4. However, the higher the value of R, the more reliable the prediction.

In Table III, the observed values (y) of drop are compared with those (Y) that might have been predicted from average tear in the present work. The average $\bar{y}$ is 8.4. The values of $y - \bar{y}$ and of $y - Y$ are used to calculate v_1 and v_2 in Equation (7), from which R can be calculated according to Equation (6).

$$v_1 = 83.51$$
$$v_2 = 18.28 \qquad (8)$$
$$R = \sqrt{\frac{83.51 - 18.28}{83.51}} = 0.88.$$

It will be seen that, since R is near unity, a good correspondence between Y and y was obtained in the present work.

tend to follow the same correlation trend as the G. E. puncture test. This is to be expected, since it was observed from the data in Table XXVIII that the G. E. puncture test measures many of the same characteristics in the combined board as the G. E. stiffness or flat crush test.

In the preceding discussion, consideration has been given only to simple correlation—*i.e.*, the relationship or correlation between two characteristics. However, in a study of this type, it is often more desirable to determine the most effective manner of weighting different physical tests on combined board in order to obtain the best prediction of box test results. The theory is discussed in Appendix B, where it is shown that a certain weight should be given each test on combined board and that a weighted total should be found.

For example, suppose it is *assumed* that G. E. puncture, flat crush, and bursting strength are separately of use in assigning a laboratory performance value to a sample of combined board. If the three combined board tests are considered jointly, a better evaluation may be made of the performance of the board in question. Thus, if a board has a high G. E. puncture value a good box would normally be expected, but if it has high G. E. puncture, high flat crush, and also high bursting strength, the probability for a good box would be much greater. Similarly, if the board is low in G. E. puncture, flat crush, and bursting strength, a much poorer box would be expected than one made from a combined board with high G. E. puncture, flat crush, and bursting strength values. A complication arises, however, when the G. E. puncture and flat crush values are low but, in contrast, the bursting strength value is high. The question then arises as to how each test should be weighted in order to give the best criterion for box performance. It is readily apparent that a great variety of similar situations can exist which give rise to various degrees of perplexity. However, there exists a statistical technique for dealing precisely with this problem. This technique measures the weight, or degree of importance, which should be attached to the G. E. puncture, flat crush, and bursting strength values in predicting the relative laboratory performance of a box. The statistical technique used for this purpose is known as *multiple regression* and has been successfully used in other fields, most notably in agricultural and psychological research.

To illustrate the application of statistical methods in this type of analysis, it may be assumed that, on some sample lots of materials, data are available on the G. E. puncture, pin adhesion, and bursting strength tests for the combined board and that results for a single test (*e.g.*, the drop test) are known for the finished boxes. The question may then be raised as to what extent the analysis of the values of the combined boards can be used in predicting the magnitude of the box test—*i.e.*, the drop test. The values for the combined boards might merely be added. Alternately, the G. E. puncture arbitrarily might be given a weight factor of 3, pin adhesion a weight factor of 2, and bursting strength a weight factor of 1. The possible sets of weight factors which might be arbitrarily assigned are endless. It can be shown, however, that there is a unique combination of combined board tests which will give the ***maximal*** (maximum) index of laboratory box performance as measured by any one test (e.g., the drop test). The weight factors which will give the maximal index are found by multiple regression. The weight factors thus found are then combined into a common equation so that the individual tests may be considered collectively (multiple correlation) in the prediction of box performance. In this study, therefore, the problem is to determine the most effective *manner of weighting the different physical test data* in order to obtain the best prediction of box test results. In the next paragraph, consideration will be given to the fundamental question of which physical tests can, in the interest of both efficiency and economy, be eliminated as superfluous.

Table XXX contains the simple coefficients of correlation—first between combined board tests, second between board tests and box tests and, third, between box tests. Inspection of the correlations between combined board tests shows that, in this study, only three of the five combined board tests have essentially independent predictive value. Bursting strength and pin adhesion correlate so poorly with each other and with the other combined board tests as to be effectively independent. For example, bursting strength may not reveal much about the box tests and the information obtained from it is not duplicated by the pin adhesion or the other combined board tests; the same may be said about the pin adhesion test in its relation to the box tests. The G. E. puncture, G. E. stiffness, and flat crush tests, however, are highly correlated with each other. This means that, whatever one test on the combined board indicates about box tests, the others substantially repeat. One of them, then, tells as much as all three. Thus, of the combined board tests used, bursting strength, pin adhesion, and one of the three—G.E. puncture, G. E. stiffness, and flat crush—are the only tests which have independent predictive value.

By consulting the correlations between the combined board tests and box tests, it is possible to determine which of the three tests—G. E. puncture, G. E. stiffness, and flat crush—will best serve the purpose, in conjunction with bursting strength and pin adhesion, in predicting the box tests. It may be observed (see Table XXX) that G. E. puncture is the only one of the three that correlates highly with all the box tests, and thus has precedence over the other two in regard to predictive power.

When only the compressive strengths of the boxes included in this study are considered, the G. E. puncture test is the only independent combined board test which has a markedly high predictive value throughout. Consequently, the results indicate that the G. E. puncture test alone will predict compressive strength nearly as well as G. E. puncture, pin adhesion, and

TABLE XXX

CORRELATION COEFFICIENTS

Between Physical Tests on Combined Board

	Bursting Strength	G. E. Puncture	G. E. Stiffness	Pin Adhesion	Flat Crush
Bursting strength	+1.00	+0.48	+0.34	+0.39	+0.13
G. E. puncture	+0.48	+1.00	+0.91	+0.35	+0.84
Pin adhesion	+0.39	+0.35	+0.24	+1.00	−0.04
G. E. stiffness	+0.34	+0.91	+1.00	+0.24	+0.90
Flat crush	+0.13	+0.84	+0.90	−0.04	+1.00

Between Physical Tests on Combined Board and Boxes

	Top-Load Compression in Deflection Range		End-Load Compression in Deflection Range			
	0–0.25 in.	0–0.75 in.	0–0.25 in.	0–0.50 in.	Drum	Drop
Bursting strength	+0.61	+0.52	+0.35	+0.45	+0.61	+0.66
G. E. puncture	+0.64	+0.91	+0.83	+0.90	+0.75	+0.83
Pin adhesion	+0.12	+0.29	+0.30	+0.42	+0.61	+0.58
G. E. stiffness	+0.51	+0.87	+0.87	+0.94	+0.58	+0.66
Flat crush	+0.41	+0.74	+0.75	+0.78	+0.42	+0.53

Between Physical Tests on Boxes

Top compression, 0–0.25 in.	+1.00	+0.77	+0.41	+0.46	+0.66	+0.59
Top compression, 0–0.75 in.	+0.77	+1.00	+0.73	+0.86	+0.73	+0.77
End compression, 0–0.25 in.	+0.41	+0.73	+1.00	+0.90	+0.49	+0.58
End compression, 0–0.50 in.	+0.46	+0.86	+0.90	+1.00	+0.64	+0.74
Drum	+0.66	+0.73	+0.49	+0.64	+1.00	+0.96
Drop	+0.59	+0.77	+0.58	+0.74	+0.96	+1.00

bursting strength collectively. Hence, for compression tests, G. E. puncture *alone* will be considered in the ensuing discussion. In drum and drop, all *three* of the independent physical tests are of predictive value and, therefore, the discussion of them will be in terms of all three.

The weighting constants or weight factors obtained and used to determine the predicted values are set forth in Table XXXI. A comparison of the predicted values for each test against the observed laboratory

TABLE XXXI

WEIGHT FACTORS

Box Test	G. E. Puncture	Bursting Strength	Pin Adhesion	Constant
Drum	+0.29195	+0.15411	+1.02300	−120.80
Drop	+0.04972	+0.02468	+0.11679	− 15.92
Top-load compression* (0–0.75 inch)	+2.07741			+ 33.09
End-load compression* (0–0.50 inch)	+3.74869			−224.17

* Based on G. E. puncture test only.

TABLE XXXII

COMPARISON OF OBSERVED AND PREDICTED BOX TESTS

Run Combination	Top-Load Compression, lb. Deflection Range 0–0.75 in.		End-Load Compression, lb. Deflection Range 0–0.50 in.		Drum, No. of Falls to Box Failure		Drop, No. of Drops to Box Failure	
	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
1	487	484	634	589	38	52	7.9	9.1
2	506	503	628	623	42	51	8.1	9.1
3	505	501	523	619	49	44	8.6	8.3
4	469	455	592	537	42	48	8.3	8.4
5	397	384	423	409	32	36	5.8	6.4
6	489	463	611	551	48	49	8.1	8.6
7	460	436	469	503	37	33	6.5	6.4
8	502	498	620	616	66	54	10.1	9.3
9	501	492	614	604	42	55	7.6	9.4
10	528	503	646	623	69	63	11.2	10.5
11	525	507	668	631	59	59	9.6	10.0
12	500	517	624	649	67	64	12.0	10.8
13	458	430	478	492	39	36	6.9	6.4
14	468	517	656	649	63	64	11.1	10.8
15	506	523	602	661	55	55	9.8	9.7
16	470	492	653	601	49	54	9.3	9.4
17	434	457	459	541	50	44	8.5	7.8
18	374	399	399	436	36	41	5.6	7.0
19	568	528	682	668	73	62	11.4	10.6
20	393	401	411	439	51	39	7.8	7.0
21	333	343	361	334	20	18	4.8	3.8
22	439	480	608	582	33	36	6.3	6.7

values is given in Table XXXII and Figures 41, 42, 43, and 44. The multiple correlation coefficient between drum test results and those of the combined board tests—bursting strength, pin adhesion, and G. E. puncture—was +0.86, and between the drop test results and the above-mentioned combined board test results, was +0.91. These two correlation coefficients indicate the predictive value of the combination of the three combined board tests with respect to each box test; that they are markedly greater than the predictive value of any of the individual combined board tests is shown by Table XXX.

The correlation coefficient for G. E. puncture and top-load compression in the deflection range 0–0.75 inch was +0.91. For G. E. puncture and end-load compression in the deflection range 0–0.50 inch, the correlation coefficient was +0.90.

The statistical approach to the problem of determining the relationship between combined board and box tests permits the handling of the data from a large number of sample lots. In addition, it allows the determination of that relationship to be expressed in terms of a numerical figure.

RELATIONSHIP BETWEEN VARIOUS COMPONENT AND BOX TESTS

For years, the general specifications for container board have been weight, caliper, moisture content, and bursting strength. Naturally, at times additional tests have been run depending on the ultimate use of the board. From a practical viewpoint, a manufacturer is vitally interested in knowing the relationship between the test results of the components and those on the boxes made from such components—i.e., which properties of the component materials have a dominant influence on the quality of the boxes made from his paperboard.

The data obtained on the twenty-two run combinations offered a splendid opportunity to study this correlation. Samples of each of the component materials were taken at the beginning, middle, and end of each run combination. These samples were submitted to the following tests: bursting strength, G. E. puncture, ring compression, Elmendorf tear, Amthor tensile, and stretch. It was immediately apparent that this battery of tests—three-fold, because each test was made on the single-face liner, double-face liner, and corrugating medium—presented an inordinate number of factors which might conceivably be related to box performance. In order to study the relationship between the test results on the components and those on the finished boxes made from the components, the data obtained from the twenty-two run combinations were subjected to the same statistical analysis that was used to determine the relation between combined board test results and box test results.

The first step in the application of this analysis was to select, by proper determination, the tests on the components which appeared to have the greatest predictive value. In particular, it was necessary to determine the intercorrelations of all the test results on the components in which machine and across-machine direction results were obtained. The tests which involved such data were Elmendorf tear, ring compression, Amthor tensile, and stretch. The results of the "double tests" on the components which were used in the fabrication of the twenty-two run combinations are given in Table XXXIII. The results obtained on the boxes fabricated from these components are given in Table XXV. The correlation coefficients given in Table XXXIV were calculated from the data in Tables XXXIII and XXV.

From the data in Table XXXIV, it can be seen that the ring compression test values obtained in this study were so poorly related to box test results that they can be eliminated from further consideration at this time. The Elmendorf tear results have a fair degree of correlation with some of the box results and, therefore, warrant further consideration. In addition, it may be observed that the intercorrelation of the Elmendorf tear results in the machine and across-machine directions were consistently high, indicating that, on the basis of the materials studied, the tests in the two directions measure approximately the same characteristic of the components. Accordingly, the average of the Elmendorf tear results in the machine and across-machine directions has been used in the subsequent treatment of the component data in this report. The correlation coefficients obtained for Amthor tensile and stretch indicated moderate correlation with box results and with each other. Therefore, the machine and across-machine direction identities for these tests must be maintained in further study.

In addition to the reduced set of double tests (ring compression omitted and Elmendorf tear in machine and across machine averaged), consideration must be given also to the two single tests—bursting strength and G. E. puncture, which are given in Table XXXV.

From the data in Tables XXXIII, XXXIV, and XXXV, the correlations between component test results—average Elmendorf tear; Amthor tensile (machine and across-machine direction), Amthor stretch (machine and across-machine direction), bursting strength, and G. E. puncture—were calculated and are given in Table XXXVI. Further, the correlation of each component test with each box test is shown. Consideration of these results suggests that average Elmendorf tear should have good predictive value in regard to these twenty-two different lots of boxes, since for no box test does it fail to show, for at least one of the components in each run combination, a correlation coefficient greater than +0.60. The correlation coefficient for the Amthor tensile test values in the machine and across-machine directions shows indifferent correlation with box test results. Amthor stretch in the machine direction shows poor correlation with box tests. On the other hand, Amthor stretch in the across-machine direction shows moderate correlation with box tests and, further, is not highly correlated with average Elmendorf tear. Accordingly, Am-

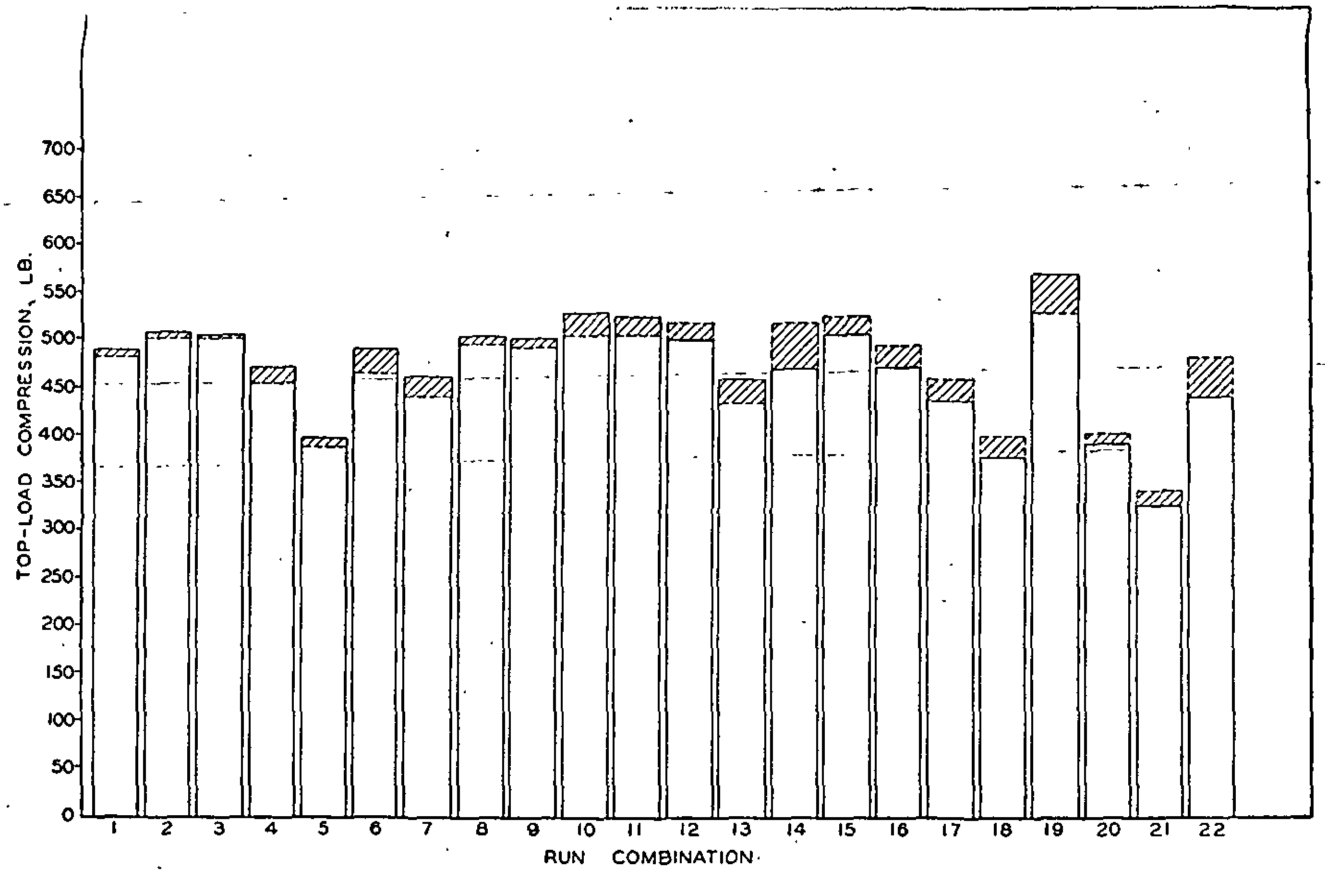

FIGURE 41. Comparison of Observed and Predicted Top-Load Compression Tests (0–0.75 inch)—Based on Combined Board Tests
———— Observed ------------ Predicted

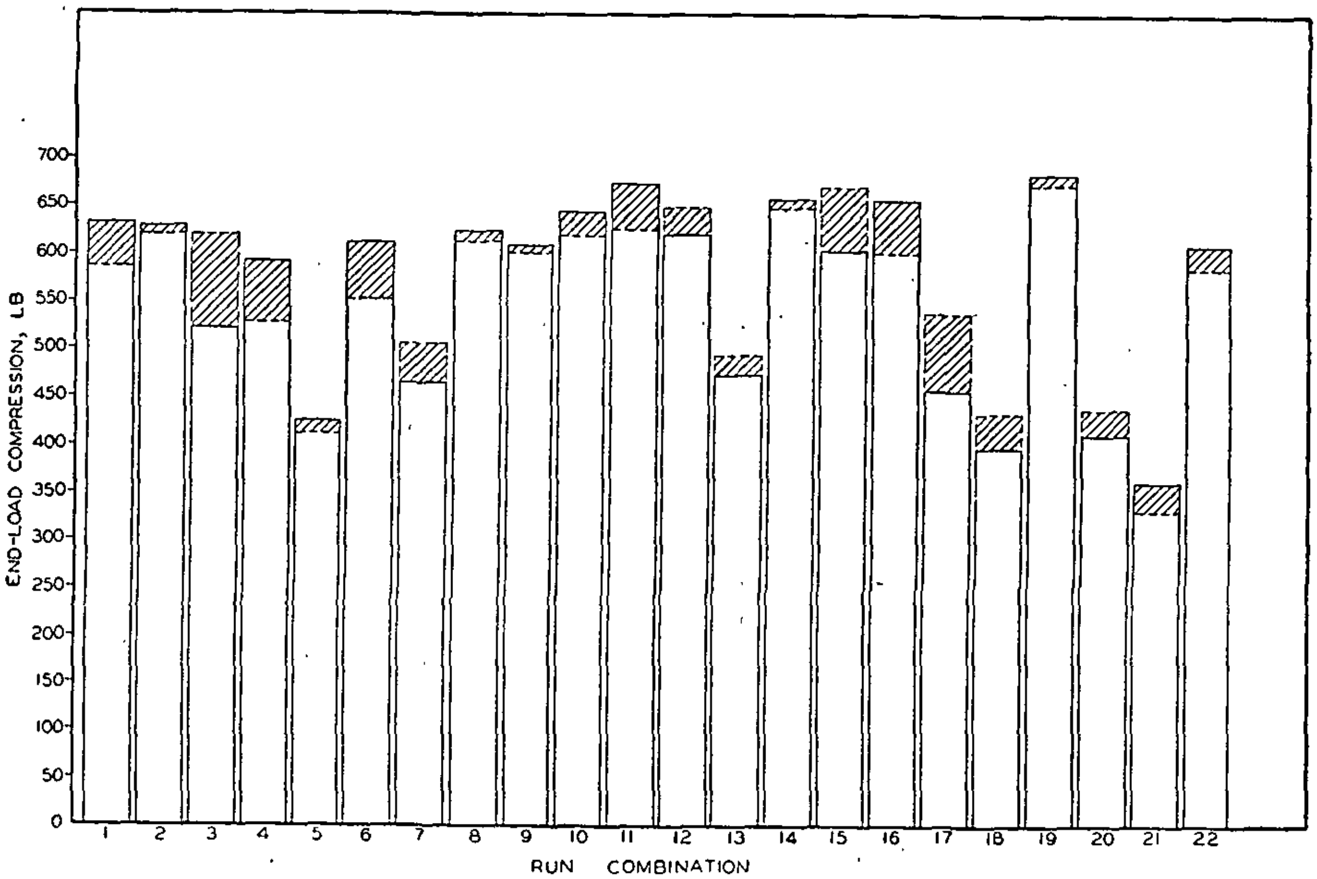

FIGURE 42. Comparison of Observed and Predicted End-Load Compression Tests (0–0.50 inch)—Based on Combined Board Tests
———— Observed ------------ Predicted

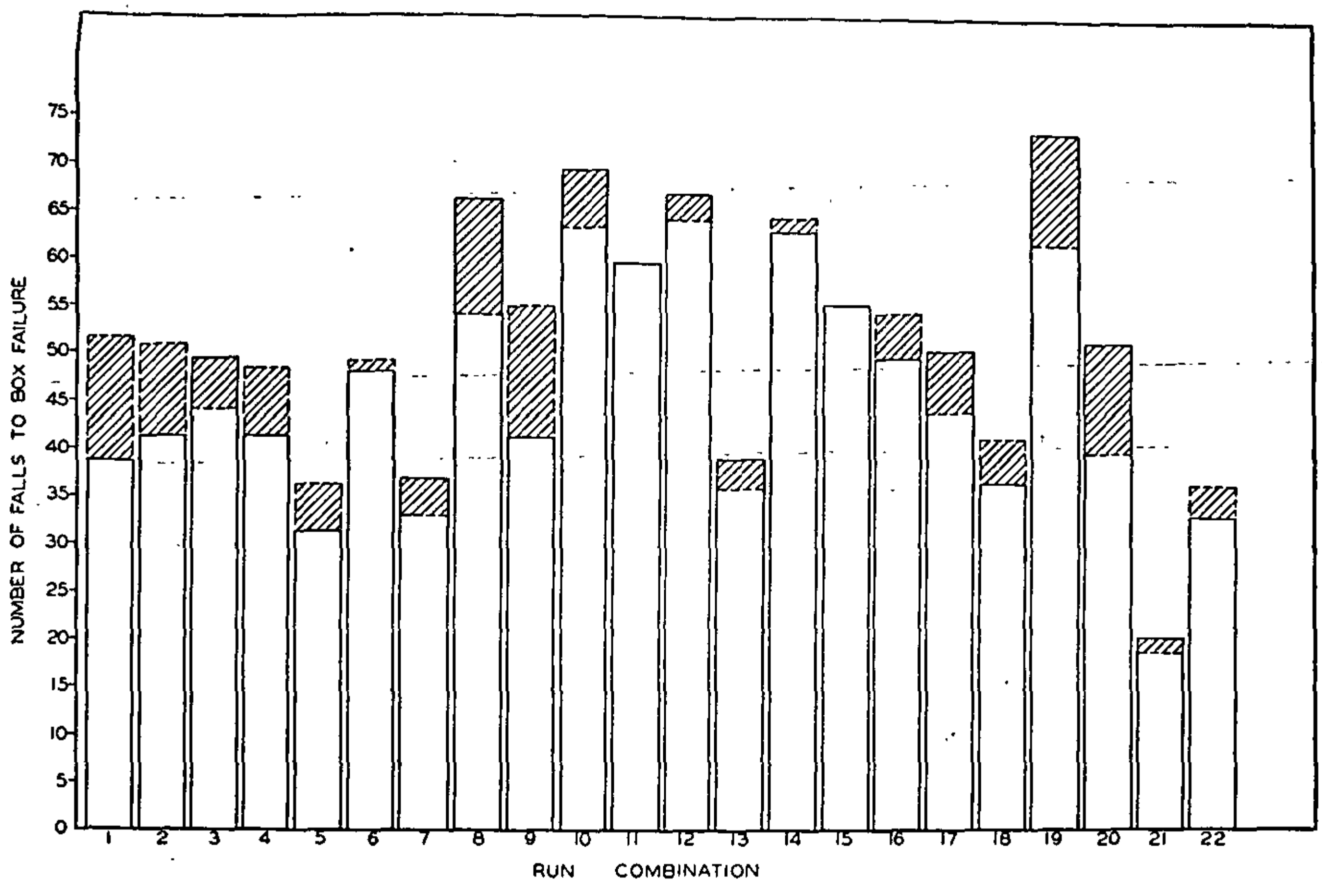

FIGURE 43. Comparison of Observed and Predicted Drum Tests—Based on Combined Board Tests
——— Observed ------------ Predicted

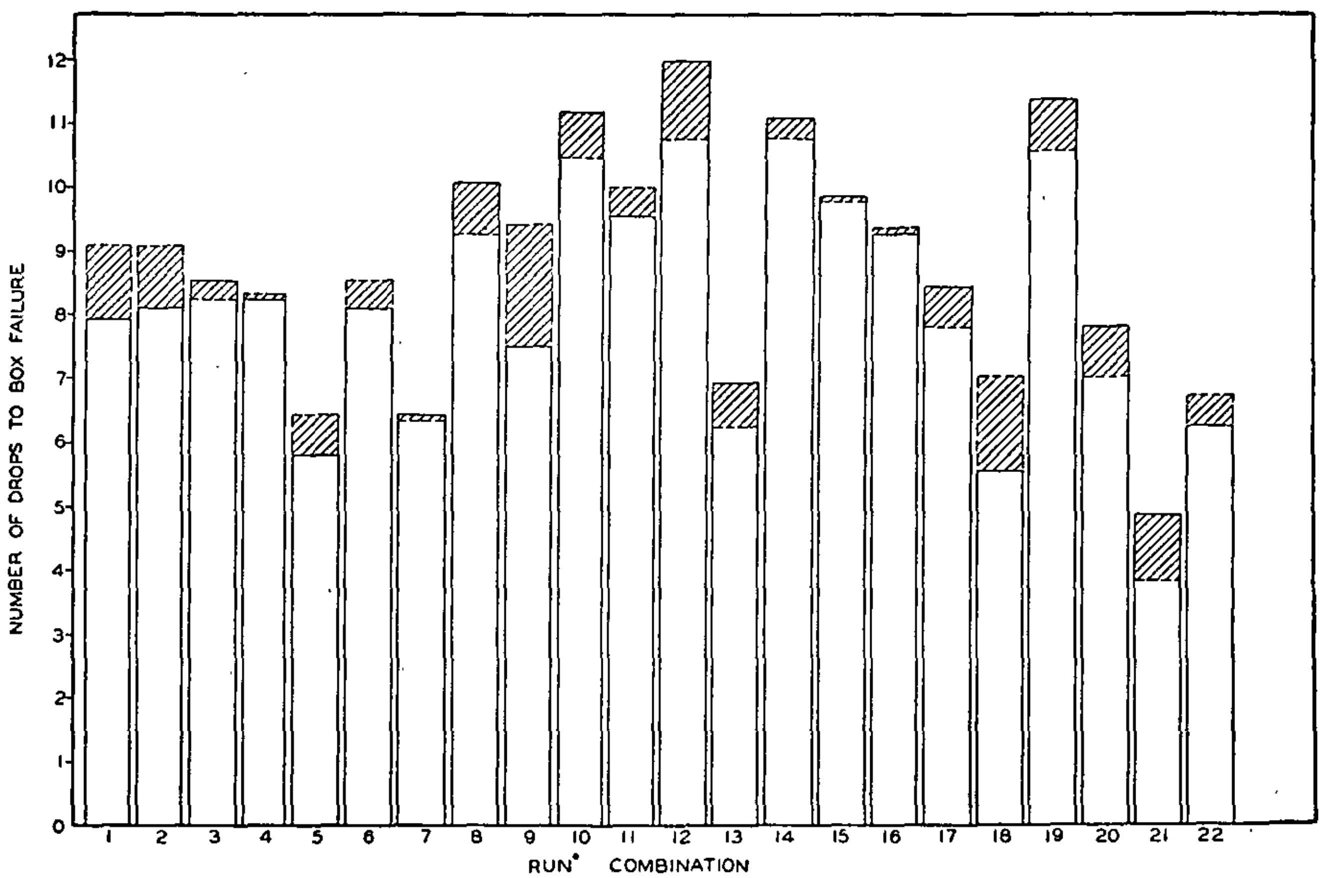

FIGURE 44. Comparison of Observed and Predicted Drop Tests—Based on Combined Board Tests
——— Observed ------------ Predicted

TABLE XXXIII

MACHINE AND ACROSS-MACHINE DIRECTION TEST RESULTS ON LINERS AND CORRUGATING MEDIUMS—RUN COMBINATIONS 1–22

Single-Face Liner

Run Combination	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb./in. In	Amthor Tensile, lb./in. Across	Amthor Stretch, % In	Amthor Stretch, % Across
1	26.5	22.0	331	389	76.0	36.6	1.8	2.8
2	27.4	21.9	322	386	75.4	37.5	1.7	2.7
3	31.1	24.1	324	386	76.5	37.3	2.0	2.9
4	29.4	22.5	315	381	74.7	37.1	2.2	3.0
5	29.2	22.9	323	364	75.2	37.2	2.1	2.9
6	30.3	23.6	329	377	75.2	36.3	2.1	3.0
7	29.3	23 1	335	388	75.1	37.8	2.1	3.1
8	26.4	22.3	329	374	76.8	37.9	2.0	3.0
9	29.9	24.4	318	367	76.2	38.8	2.0	3.1
10	29.4	24.0	382	422	75.4	40.2	2.0	3.5
11	30.6	24.7	361	431	86.6	40.4	2.0	3.0
12	28.4	21.2	371	452	85.1	36.4	2.3	4.3
13	25.1	21.9	305	334	68.4	35.5	1.7	2.9
14	31.0	19.4	340	420	86.5	36.8	1.4	3.7
15	28.0	22.4	372	380	71.1	42.8	2.1	3.9
16	28.6	20.1	320	391	83.0	33.5	1.6	3.4
17	26.2	20.2	362	381	68.0	38.2	1.4	3.3
18	30.6	23.8	304	371	76.8	36.3	1.7	2.6
19	32.4	25.9	381	387	78.2	44.1	1.8	4.0
20	32.7	26.9	383	388	84.3	44.3	2.0	4.5
21	21.6	16.8	272	280	53.5	29.2	1.1	2.5
22	21.5	16.9	265	282	55.1	29.8	1.2	2.5
Av.	28.4	22.3	334	379	75.1	37.5	1.8	3.2

Corrugating Medium

Run Combination	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb./in. In	Amthor Tensile, lb./in. Across	Amthor Stretch, % In	Amthor Stretch, % Across
1	17.9	11.9	195	268	56.6	21.6	1.7	3.1
2	18.2	13.1	198	238	53.2	24.3	1.8	4.2
3	19.4	15.8	216	241	56.8	32.8	2.0	4.7
4	16.9	13.2	211	235	47.1	23.8	1.5	3.2
5	13.0	10.2	109	121	30.1	17.8	1.0	2.1
6	19.5	14.4	239	259	51.3	25.1	2.0	4.1
7	18.7	13.3	165	196	48.0	22.2	1.9	3.3
8	19.1	15.7	259	254	48.4	31.3	1.5	4.7
9	19.4	14.6	243	282	55.8	25.7	1.7	3.3
10	20.3	15.0	244	281	56.6	26.8	1.6	3.3
11	18.9	15.1	244	283	56.7	26.8	1.9	3.4
12	18.2	13.0	214	252	53.6	23.1	2.1	3.9
13	21.0	14.4	226	250	50.6	23.4	1.9	4.1
14	21.2	13.5	226	268	57.0	23.3	2.2	4.0
15	18.8	14.0	221	275	54.9	23.3	2.2	4.3
16	18.2	13.1	229	278	52.4	23.4	2.0	4.3
17	19.2	14.1	208	249	52.4	24.3	1.8	2.9
18	21.4	15.8	198	249	52.8	24.6	1.9	2.9
19	21.5	16.0	227	254	53.3	26.4	2.0	4.3
20	17.2	11.9	177	208	44.5	22.2	1.8	2.8
21	19.0	12.4	176	202	45.7	21.4	1.8	2.8
22	21.7	15.7	228	254	54.1	26.6	1.8	4.3
Av.	19.0	13.9	211	245	51.4	24.6	1.8	3.6

Double-Face Liner

Run Combination	Ring Compression, lb. In	Ring Compression, lb. Across	Elmendorf Tear, g./sheet In	Elmendorf Tear, g./sheet Across	Amthor Tensile, lb./in. In	Amthor Tensile, lb./in. Across	Amthor Stretch, % In	Amthor Stretch, % Across
1	30.7	23.8	336	394	84.5	36.9	2.0	3.4
2	31.1	23.3	359	397	81.1	38.5	1.8	3.5
3	31.5	23.4	350	407	86.2	37.2	2.0	3.2
4	31.0	24.1	334	377	82.6	40.9	2.2	3.3
5	35.6	26.1	348	394	82.0	38.2	2.5	3.2
6	34.0	25.7	346	396	83.1	39.0	2.3	3.5
7	28.7	20.8	350	399	82.7	36.3	2.0	3.2
8	30.7	22.3	331	376	81.0	36.3	2.2	3.2
9	27.8	22.4	301	361	74.5	35.9	1.8	2.6
10	28.8	24.1	370	415	80.7	41.2	2.2	3.6
11	28.3	22.8	341	400	82.9	35.9	1.9	3.1
12	28.9	24.1	408	439	79.8	37.6	2.0	4.4
13	25.0	20.8	273	313	63.7	33.1	1.8	2.7
14	29.4	20.3	332	416	84.8	36.3	1.8	3.9
15	26.1	20.8	397	449	71.0	41.4	1.7	2.8
16	25.4	19.2	306	355	77.8	34.6	1.6	3.6
17	27.2	21.6	361	402	75.4	42.0	1.6	2.9
18	31.4	25.1	310	364	76.6	38.7	1.5	2.3
19	29.6	23.3	345	393	77.1	40.6	2.1	3.5
20	29.9	23.2	369	402	77.6	42.5	2.1	3.7
21	22.8	16.7	279	282	54.6	30.0	1.0	2.3
22	22.6	16.1	274	288	54.7	28.4	1.3	2.7
Av.	28.9	22.3	337	383	77.0	37.3	1.9	3.2

that stretch in the across-machine direction has been used to supplement average Elmendorf tear in the predictive relationships. In view of the *relatively* good correlation between the component tests being considered, it appears unfruitful to include bursting strength and G. E. puncture, together with average Elmendorf tear and Amthor stretch in the across-machine direction, in a four-factor relationship with

TABLE XXXIV

CORRELATIONS OF MACHINE AND ACROSS-MACHINE DIRECTION TEST RESULTS WITH EACH OTHER AND WITH PHYSICAL TESTS ON BOXES—RUN COMBINATION 1 THROUGH 22

Tests	Correlation with Physical Tests on Boxes: Drop	Drum	Compression: Top	End	Correlation Within Double Tests
Single-Face Liner					
Ring compression—in	+0.42	+0.51	+0.36	+0.19	+0.82
Ring compression—across	+0.23	+0.39	+0.39	+0.17	
Elmendorf tear—in	+0.73	+0.78	+0.51	+0.30	+0.78
Elmendorf tear—across	+0.75	+0.72	+0.57	+0.47	
Amthor tensile—in	+0.60	+0.62	+0.43	+0.40	+0.58
Amthor tensile—across	+0.50	+0.62	+0.49	+0.20	
Amthor stretch—in	+0.33	+0.36	+0.45	+0.20	+0.37
Amthor stretch—across	+0.68	+0.68	+0.29	+0.21	
Corrugating Medium					
Ring compression—in	+0.20	+0.25	+0.23	+0.24	+0.80
Ring compression—across	+0.27	+0.40	+0.44	+0.33	
Elmendorf tear—in	+0.61	+0.58	+0.62	+0.68	+0.90
Elmendorf tear—across	+0.55	+0.50	+0.59	+0.69	
Amthor tensile—in	+0.49	+0.42	+0.56	+0.60	+0.54
Amthor tensile—across	+0.36	+0.45	+0.51	+0.37	
Amthor stretch—in	+0.37	+0.32	+0.26	+0.26	+0.55
Amthor stretch—across	+0.49	+0.45	+0.61	+0.60	
Double-Face Liner					
Ring compression—in	+0.09	+0.17	+0.16	+0.05	+0.90
Ring compression—across	+0.21	+0.29	+0.27	+0.06	
Elmendorf tear—in	+0.58	+0.57	+0.39	+0.20	+0.93
Elmendorf tear—across	+0.64	+0.63	+0.50	+0.32	
Amthor tensile—in	+0.46	+0.46	+0.46	+0.33	+0.62
Amthor tensile—across	+0.42	+0.48	+0.28	+0.05	
Amthor stretch—in	+0.37	+0.43	+0.45	+0.25	+0.57
Amthor stretch—across	+0.71	+0.63	+0.45	+0.50	

box tests. However, the magnitude of the correlation coefficients for bursting strength and G. E. puncture indicates that they are worthy of alternate consideration. Further, by an argument parallel to that for Elmendorf tear and Amthor stretch, bursting strength and G. E. puncture together look promising in a two-factor relationship of their own.

As mentioned above, the average Elmendorf tear and Amthor stretch in the machine direction appear to have good predictive relationships with box tests. Therefore, the problem is to determine the relationship appropriate for the anticipation of box tests from the component tests: average Elmendorf tear and Amthor stretch in the across-machine direction. The theory is discussed in Appendix B, where it is shown that a certain weight should be given to each test on the components and that a weighted total can then be found as a result of the weight factors determined for each different test under consideration.

It was necessary first to find the weight factors appropriate for estimating the various box tests as shown in Table XXXVII. In order to illustrate fully the use of Table XXXVII, one may consider Run Combination 1, with average Elmendorf tear as shown in Table XXXV and Amthor stretch in the across-machine direction shown in Table XXXIII. The calculation for any box test—*e.g.*, the drop test—is as follows:

The average values for the Elmendorf tear and the Amthor stretch in the across-machine direction for the single-face liner, corrugating medium, and double-face liner fabricated in Run Combination 1 are multiplied by their respective weight factors. For example:

	Observed Test	Weight Factor	Weighted Value
Single-Face Liner			
Average tear	360.0	+0.02298	+ 8.273
Stretch across	2.8	+0.57150	+ 1.600
Corrugating Medium			
Average tear	231.5	+0.01846	+ 4.273
Stretch across	3.1	+0.57991	+ 1.798
Double-Face Liner			
Average tear	365.0	+0.00031	+ 0.113
Stretch across	3.4	+0.98895	+ 3.362
Total			+19.419

The sum of the weighted values is +19.419, to which is added the constant for the particular box test in question. In the case of the drop test the constant was −11.209; thus, the predicted drop value for Run Combination 1 is 8.2 [+19.419−11.209=8.2]. The observed drop value was 7.9, in contrast to the anticipated or predicted drop value of 8.2. Using this same method of calculation, a set of expected and observed values for any given box test may be prepared, as in Table XXXVIII.

The material in Table XXXVIII is presented graphically in Figures 45–48. The (multiple) correlation coefficients of the predicted and observed values of Table XXXVIII were as follows:

Drop	+0.94
Drum	+0.93
Top-load compression	+0.87
End-load compression	+0.86

It may be noted that the differences between the observed drop values and the values predicted on the basis of the components are quite small. It should be mentioned that the agreement of these two values far exceeds usual statistical experience. It may also be observed that the correlation of predicted and observed

TABLE XXXV*

AVERAGE ELMENDORF TEAR, BURSTING STRENGTH, AND G. E. PUNCTURE VALUES—RUN COMBINATIONS 1–22

Run Combination	Single-Face Liner: Average Elmendorf Tear, g./sheet	Single-Face Liner: Bursting Strength, points	Single-Face Liner: G. E. Puncture, units	Corrugating Medium: Average Elmendorf Tear, g./sheet	Corrugating Medium: Bursting Strength, points	Corrugating Medium: G. E. Puncture, units	Double-Face Liner: Average Elmendorf Tear, g./sheet	Double-Face Liner: Bursting Strength, points	Double-Face Liner: G. E. Puncture, units
1	360.0	87	39	231.5	61	19	365.0	90	36
2	354.0	88	37	218.0	61	18	378.0	98	38
3	355.0	89	35	228.5	75	20	378.5	98	39
4	348.0	93	34	223.0	57	20	355.5	107	38
5	343.5	94	34	115.0	31	9	371.0	104	38
6	353.0	96	34	249.0	58	19	371.0	101	38
7	361.5	89	36	180.5	50	15	374.5	87	38
8	351.5	89	35	256.5	53	21	353.5	93	38
9	342.5	92	35	262.5	59	21	331.0	85	35
10	402.0	99	38	262.5	64	21	392.5	96	38
11	396.0	96	38	263.5	62	21	370.5	89	36
12	411.5	104	42	233.0	63	19	423.5	96	50
13	319.5	81	36	238.0	63	17	293.0	78	28
14	380.0	94	38	247.0	62	17	374.0	94	40
15	376.0	90	37	248.0	67	18	423.0	91	42
16	355.5	84	35	253.5	63	19	330.5	85	34
17	371.5	80	38	228.5	62	16	381.5	86	39
18	337.5	87	34	223.5	64	16	337.0	90	31
19	384.0	98	35	240.5	70	17	369.0	100	34
20	385.5	97	36	192.5	52	15	385.5	100	36
21	276.0	57	29	189.0	50	13	280.5	59	30
22	273.5	58	31	241.0	70	18	281.0	56	30

* In those run combinations in which the G. E. puncture data were not available (see Table XLVII), the values used in this table were the averages of the G. E. puncture results for the entire roll.

TABLE XXXVI

CORRELATIONS OF COMPONENT TESTS WITH EACH OTHER AND WITH PHYSICAL TESTS ON BOXES

	Correlations Between Component Tests: Elmendorf Average Tear	Amthor Tensile: In	Amthor Tensile: Across	Amthor Stretch: In	Amthor Stretch: Across	Bursting Strength	G. E. Puncture	Correlations with Physical Tests on Boxes: Top-Load Compression (0–0.75 in.)	End-Load Compression (0–0.50 in.)	Drum	Drop
Single-Face Liner											
Average tear	+1.00	+0.82	+0.76	+0.60	+0.73	+0.88	+0.84	+0.57	+0.41	+0.79	+0.78
Tensile—in	+0.82	+1.00	+0.58	+0.57	+0.56	+0.86	+0.67	+0.43	+0.40	+0.62	+0.60
Tensile—across	+0.76	+0.58	+1.00	+0.59	+0.66	+0.75	+0.50	+0.49	+0.20	+0.62	+0.50
Stretch—in	+0.60	+0.57	+0.59	+1.00	+0.37	+0.81	+0.44	+0.45	+0.20	+0.36	+0.33
Stretch—across	+0.73	+0.56	+0.66	+0.37	+1.00	+0.60	+0.55	+0.29	+0.21	+0.68	+0.68
Bursting strength	+0.88	+0.86	+0.75	+0.81	+0.60	+1.00	+0.68	+0.55	+0.37	+0.67	+0.63
G. E. puncture	+0.84	+0.67	+0.50	+0.44	+0.55	+0.68	+1.00	+0.52	+0.42	+0.61	+0.68
Corrugated Medium											
Average tear	+1.00	+0.86	+0.62	+0.53	+0.23	+0.75	+0.89	+0.62	+0.70	+0.55	+0.58
Tensile—in	+0.86	+1.00	+0.54	+0.69	+0.54	+0.88	+0.77	+0.56	+0.60	+0.42	+0.49
Tensile—across	+0.62	+0.54	+1.00	+0.21	+0.66	+0.61	+0.70	+0.51	+0.37	+0.45	+0.36
Stretch—in	+0.53	+0.69	+0.21	+1.00	+0.55	+0.70	+0.31	+0.26	+0.26	+0.32	+0.37
Stretch—across	+0.62	+0.54	+0.66	+0.55	+1.00	+0.66	+0.58	+0.61	+0.60	+0.45	+0.49
Bursting strength	+0.75	+0.88	+0.61	+0.70	+0.66	+1.00	+0.65	+0.51	+0.48	+0.39	+0.43
G. E. puncture	+0.89	+0.77	+0.70	+0.31	+0.58	+0.65	+1.00	+0.71	+0.73	+0.51	+0.56
Double-Face Liner											
Average tear	+1.00	+0.70	+0.79	+0.57	+0.63	+0.74	+0.87	+0.46	+0.27	+0.61	+0.63
Tensile—in	+0.70	+1.00	+0.62	+0.75	+0.61	+0.86	+0.58	+0.46	+0.33	+0.46	+0.46
Tensile—across	+0.79	+0.62	+1.00	+0.58	+0.37	+0.82	+0.51	+0.28	+0.05	+0.48	+0.42
Stretch—in	+0.57	+0.75	+0.58	+1.00	+0.57	+0.84	+0.46	+0.45	+0.25	+0.43	+0.37
Stretch—across	+0.63	+0.61	+0.37	+0.57	+1.00	+0.59	+0.69	+0.45	+0.50	+0.63	+0.71
Bursting strength	+0.74	+0.86	+0.82	+0.84	+0.59	+1.00	+0.57	+0.41	+0.22	+0.49	+0.45
G. E. puncture	+0.87	+0.58	+0.51	+0.46	+0.69	+0.57	+1.00	+0.39	+0.32	+0.53	+0.63

TABLE XXXVII

WEIGHT FACTORS FOR AVERAGE ELMENDORF TEAR AND AMTHOR STRETCH (ACROSS-MACHINE DIRECTION) USED IN PREDICTING BOX TESTS

	Top-Load Compression, lb. (0–0.75 in.)	End-Load Compression, lb. (0–0.50 in.)	Drum, Falls to Box Failure	Drop, Drops to Box Failure
Single-Face Liner				
Av. Elmendorf tear	+ 1.27800	+ 0.03971	+ 0.32721	+0 02298
Amthor stretch across	−32.65825	− 51.91361	+ 4.84894	+0.57150
Corrugating Medium				
Av. Elmendorf tear	+ 0.25084	+ 1.82131	+ 0.05667	+ 0.01846
Amthor stretch across	+40.38682	+ 16.61161	+ 6.31149	+ 0.57991
Double-Face Liner				
Av. Elmendorf tear	− 0.06432	+ 0.24949	− 0.08458	+ 0.00031
Amthor stretch across	+ 1.17929	+106.09366	− 0.28012	+ 0.98895
Constant	−66.589	−192.371	−88.588	−11.209

TABLE XXXVIII

COMPARISON OF OBSERVED AND PREDICTED PHYSICAL TEST RESULTS ON BOXES BASED ON AVERAGE ELMENDORF TEAR AND AMTHOR STRETCH (ACROSS-MACHINE DIRECTION) VALUES OF COMPONENTS

Run Combination	Top-Load Compression, lb.		End-Load Compression, lb.		Drum		12-Inch Corner Drop	
	Deflection Range 0–0.75 in.		Deflection Range 0–0.50 in.		No. of Falls to Box Failure		No. of Drops to Box Failure	
	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
1	487	466	634	602	38	44	7.9	8.2
2	506	502	628	614	42	46	8.1	8.5
3	505	519	523	599	49	51	8.6	8.8
4	469	446	592	564	42	42	8.3	7.8
5	397	371	423	347	32	25	5.8	5.0
6	489	495	611	651	48	49	8.1	9.2
7	460	452	469	478	37	43	6.5	7.4
8	502	520	620	639	66	54	10.1	9.3
9	501	451	614	552	42	46	7.6	7.9
10	528	511	646	655	69	61	11.2	10.5
11	525	525	668	625	59	60	9.6	9.6
12	500	513	624	662	67	68	12.0	11.8
13	458	457	478	531	39	44	6.9	7.3
14	468	502	656	654	63	60	11.1	10.5
15	506	499	602	546	55	58	9.8	9.6
16	470	497	653	643	49	57	9.3	9.7
17	434	454	459	518	50	47	8.5	8.1
18	374	434	399	469	36	36	5.6	6.2
19	568	508	682	588	73	65	11.4	10.4
20	393	420	411	475	51	54	7.8	9.2
21	333	350	361	394	20	18	4 8	4.0
22	439	421	608	556	33	29	6.3	6.2

values for the drum test is very high, but that the correlation for the two compression tests is lower, although still good.

A comparison of the weight factors shown in Table XXXVII indicates that the Elmendorf tear and Amthor stretch characteristics of the single-face liner had a greater influence in predicting drum and drop test results than in predicting the compression results. On the other hand, the characteristics of the corrugating medium were perhaps more significant in predicting top- and end-load compression than were the corresponding characteristics of the single-face liner. The values for the average Elmendorf tear and the Amthor stretch in the across-machine direction for the double-face liner did not appear to influence the predicted box test values nearly as much as the same test values for the single-face liner or corrugating mediums.

It may be recalled that the correlation coefficients for bursting strength and G. E. puncture with box tests indicated that, together, they appeared promising as an alternate for average Elmendorf tear and Amthor stretch in the across-machine direction *in a two-factor* predictive relationship. As a means of determining their predictive relationship, the results of the bursting strength and G. E. puncture test on the twenty-two run combinations have been subjected to the same statistical treatment as that described for average Elmendorf tear and Amthor stretch in the across-machine direction. The weights appropriate for estimating the various box tests were determined as shown in Table XXXIX. The observed values for drop, drum, top- and end-load compression are compared with the corresponding values predicted from the bursting strength and G. E. puncture results in Table XL. The

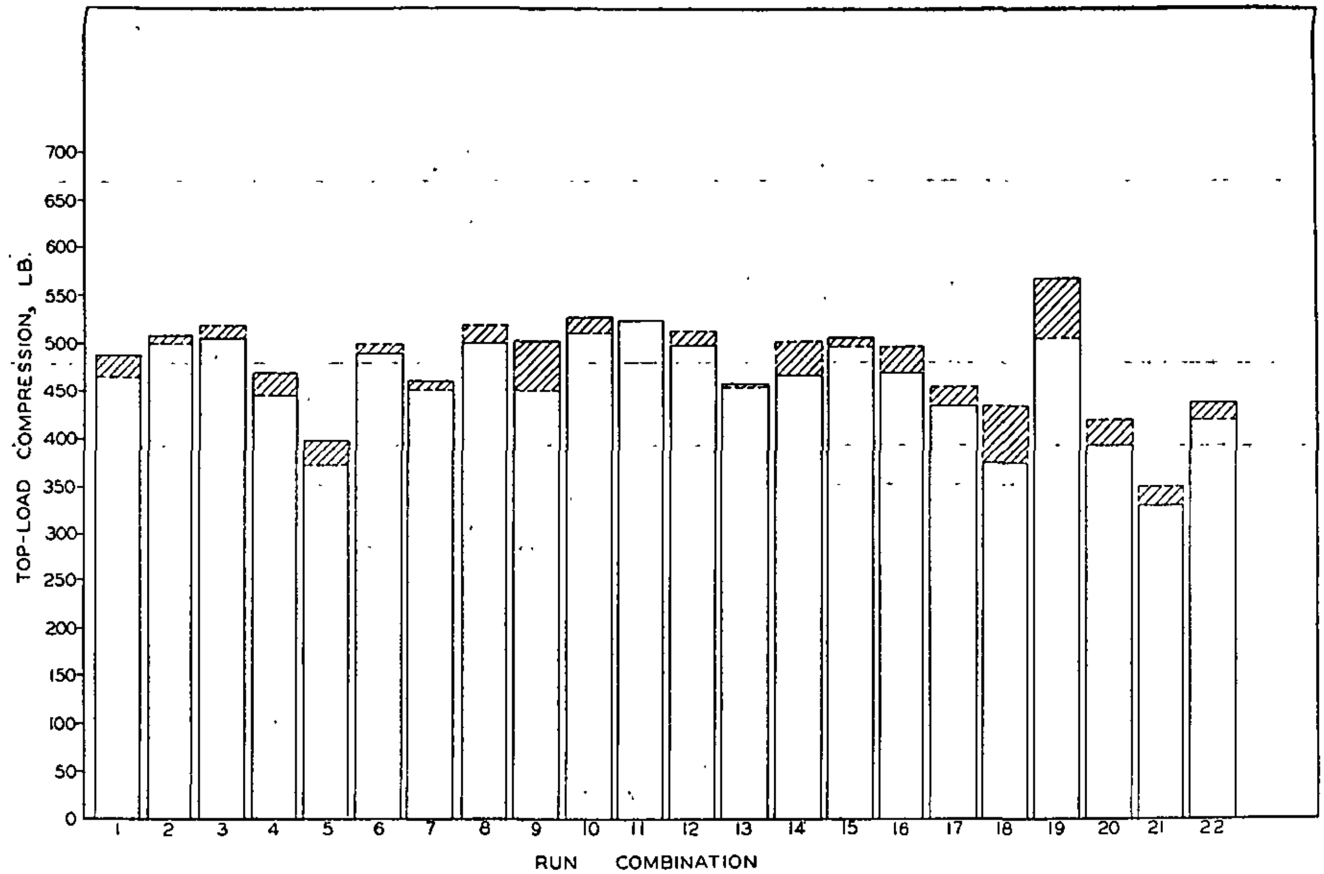

FIGURE 45. Comparison of Observed and Predicted Top-Load Compression Tests (0–0.75 inch)—Based on Elmendorf Tear and Amthor Stretch of Components
———— Observed ------------ Predicted

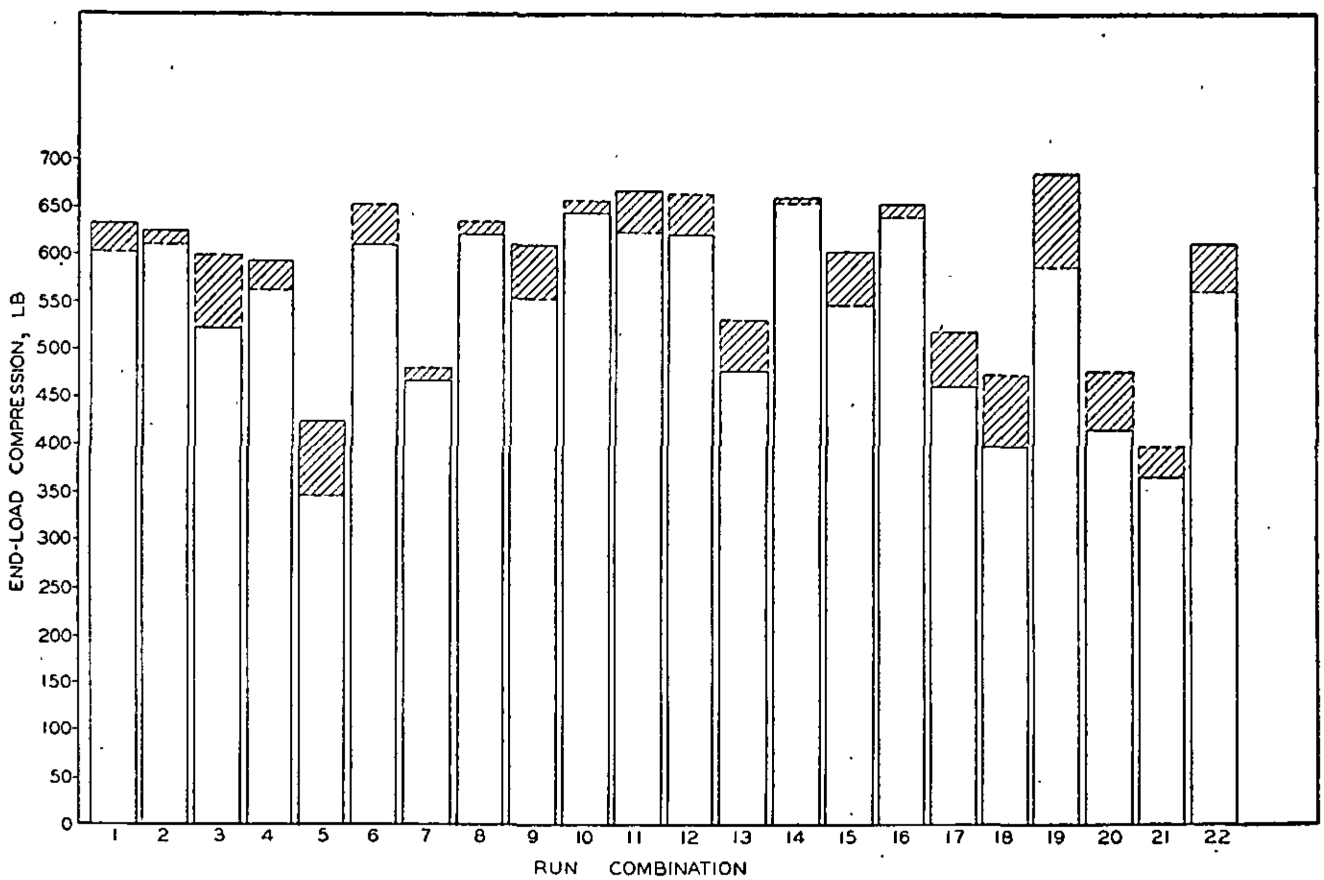

FIGURE 46. Comparison of Observed and Predicted End-Load Compression Tests (0–0.50 inch)—Based on Elmendorf Tear and Amthor Stretch of Components
———— Observed ------------ Predicted

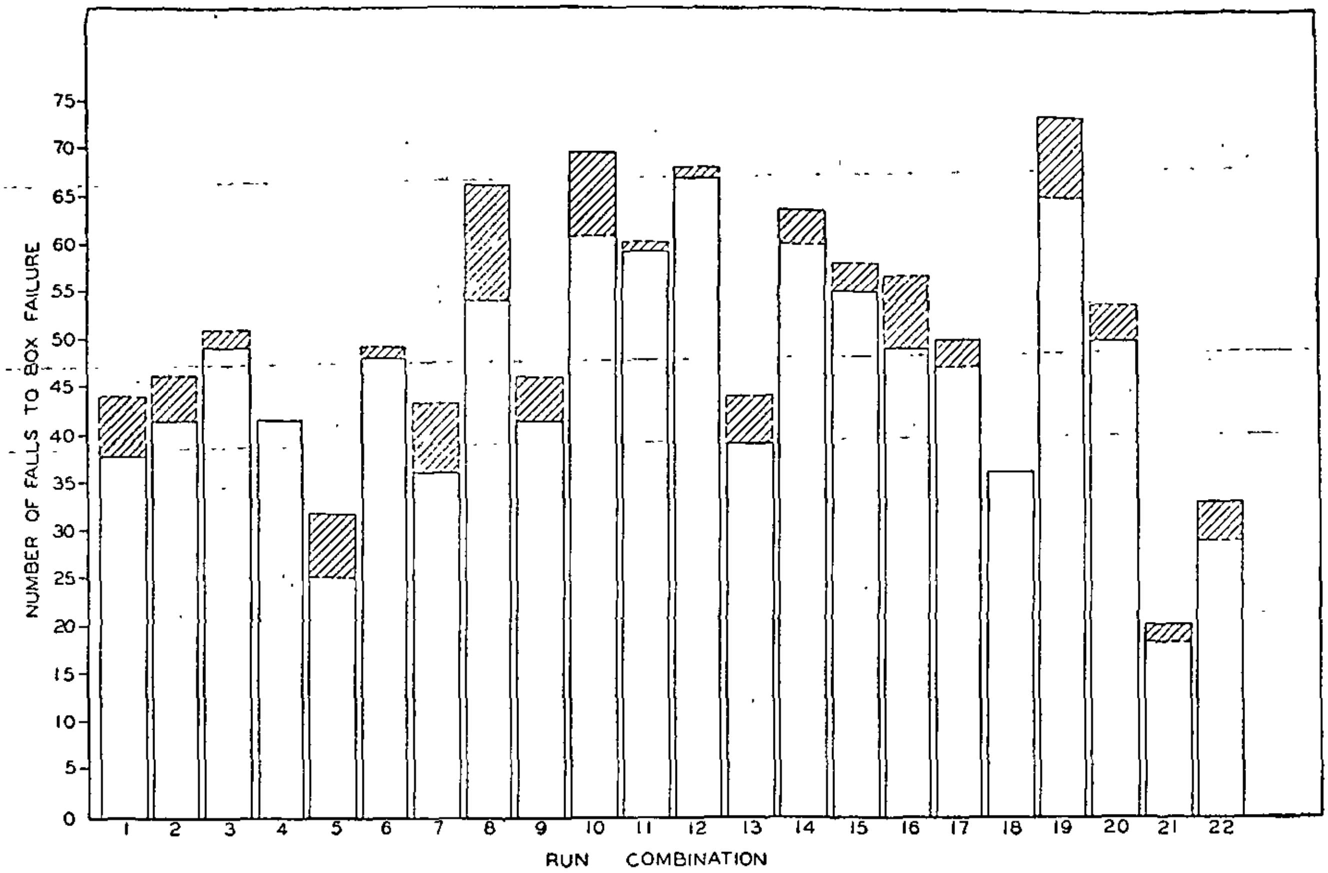

FIGURE 47. Comparison of Observed and Predicted Drum Tests—Based on Elmendorf Tear and Amthor Stretch of Components
———— Observed ------------ Predicted

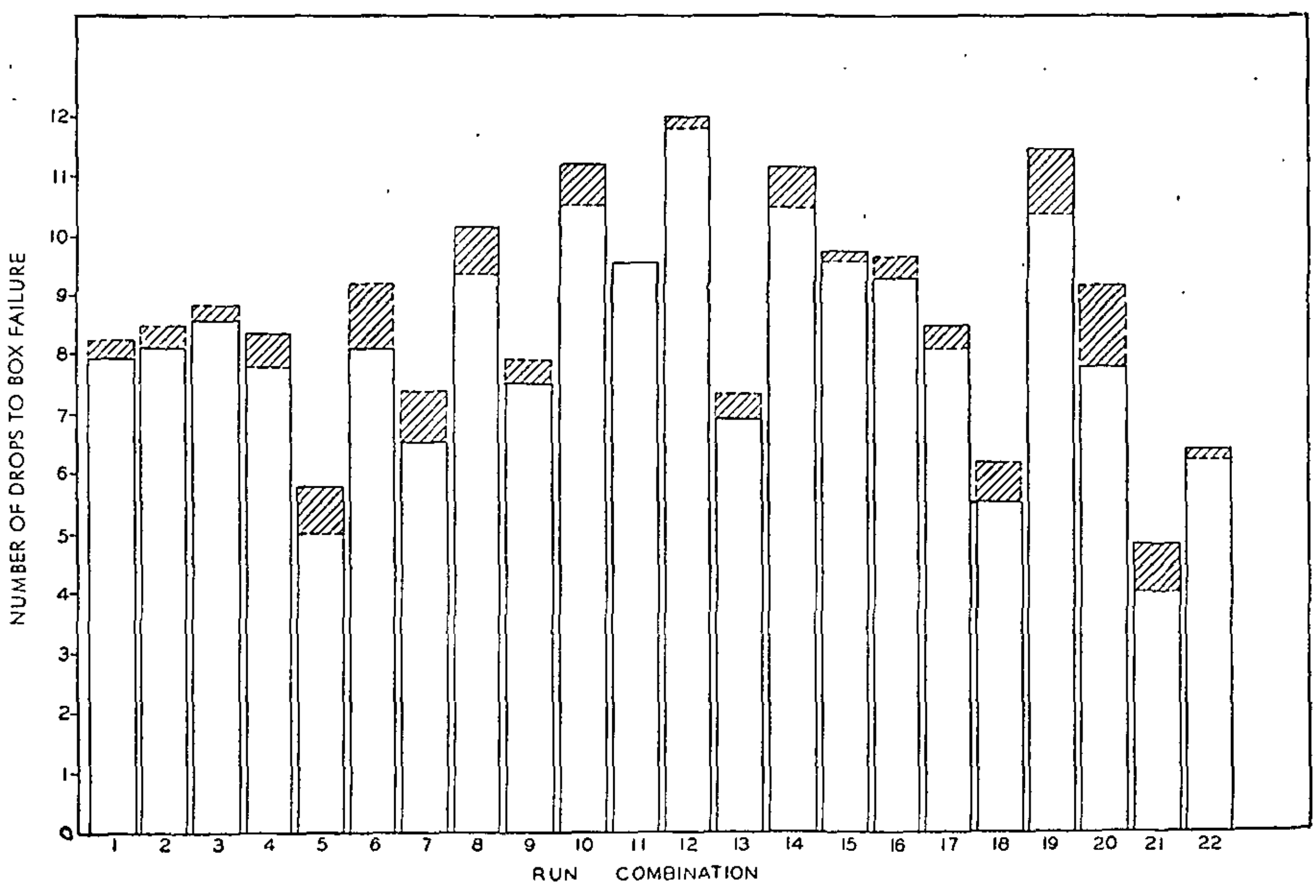

FIGURE 48. Comparison of Observed and Predicted 12-Inch-Corner Drop Test—Based on Elmendorf Tear and Amthor Stretch of Components
———— Observed ------------ Predicted