STUDY OF PAPER BOARD QUALITY

AS RELATED TO

FIBER BOX PERFORMANCE

REPORT NUMBER 3

Special Studies 2. Influence of Liner Weight, Medium Stiffness, and Other Related Factors on the Performance of Combined Board and Boxes

INSTITUTE OF
PAPER CHEMISTRY
Appleton Wisconsin

REPORT TO

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

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April, 1955

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A STUDY OF PAPER BOARD QUALITY AS RELATED TO FIBER BOX PERFORMANCE

Special Studies 2. Influence of Liner Weight, Medium Stiffness, and Other Related Factors on the Performance of Combined Board and Boxes

SUMMARY

This report presents the results of a fabrication run which was designed to provide information on several topics of wide interest to the container board industry, namely, (1) the relationship between box performance and the G. E. puncture test on combined board and components and the relationship between the G. E. puncture test on components and combined board and conventional tests on these same materials and (2) the relationship of liner weight and corrugating medium stiffness to box compression.

The scope of the fabrication run was broad. It encompassed liners ranging in weight from 26 to 90 lb. and corrugating mediums varying in stiffness (as measured by combined board flat crush) from 14.5 to 69.9 p.s.i. The entire range of liner weights was fabricated with each of the corrugating mediums. In addition, runs were made to study the effects of unbalanced liners, type and amount of adhesive, flute type, and liner density. A total of 38 different combinations of liners and mediums was fabricated. The combined board of each of the run combinations was converted into an R.S.C. taped box with the following inside dimensions: 12-3/16 by 12-3/16 by 12-3/8 inches, using starch as the adhesive. The corrugating and converting operations were carried out under carefully controlled but normal operating conditions.

Samples of the component materials, combined board and boxes were taken from each run combination. All samples were preconditioned at not higher than 35% R.H. and 73 ± 3.5° F. prior to being conditioned and tested in an atmosphere maintained at 50 ± 2% R.H. and 73 ± 3.5° F.

The component materials were tested for basis weight, caliper, bursting strength, ring compression, tensile, stretch, G. E. puncture (liners only), Concora medium test (mediums only), and Single-fluter test (mediums only). The combined board samples were tested for basis weight, caliper, bursting strength, G. E. puncture, G. E. stiffness, flat crush, and pin adhesion. The box samples were tested for top- and end-load compression.

The data obtained have been analyzed statistically to provide an interpretation of the intimacy of the relationships between the G. E. puncture test and conventional tests on components, combined board, and boxes.

The Effect of Liner Weight

To evaluate the effect of liner weight, balanced combined boards were fabricated with 26-lb., 42-lb., 52-lb., 69-lb., and 90-lb. W.F. Fourdrinier kraft liners. The entire range of liners was fabricated with five mediums which varied in stiffness (as measured by combined board flat crush) from 14.5 to 69.9 p.s.i., thus providing the opportunity to determine the effect of liner weight at each stiffness level.

At each medium stiffness level, an increase in liner weight produced an increase in top- and end-load box compression results.

The following combined board tests increased as liner weight increased: basis weight, caliper, bursting strength, G. E. puncture, and G. E. stiffness.

The Effect of Corrugating Medium Stiffness

The effect of corrugating medium stiffness was observed by fabricating each liner weight with five mediums varying in stiffness (as measured by combined board flat crush) from 14.5 to 69.9 p.s.i. The mediums were combined with five weights of liners: 26-lb., 42-lb., 52-lb., 69-lb. and 90-lb.

At each liner weight level, an increase in corrugating medium stiffness was accompanied by an increase in top- and end-load box compression.

The combined board results indicate that varying the medium stiffness had little effect on most of the tests except where the change in flat crush was also associated with a change in the basis weight and caliper of the corrugating medium. Exceptions to this observation were the G. E. puncture and G. E. stiffness tests, both of which increased as medium stiffness increased.

The Effect of Liner Density

The densities of three 42-lb. kraft liners were varied by finishing them with light, medium, and heavy calendering to determine its effect on combined board and box properties. The liners thus finished varied in density from 36.4 to 40.8 lb. per cu. ft. Each liner was combined with three corrugating mediums of the following average combined board flat crush characteristics: 10.3, 28.4, and 69.9 p.s.i.

The box compression results show that liner density had little effect on their magnitude.

Of the various combined board tests, only bursting strength and G. E. stiffness were affected, both tests showing increases with increasing liner density.

The Effect of Position of Liners of Different Weights

Run Combinations 104 and 105 were made with unbalanced liner weights of 38 and 47-lb. Run Combination

104 had a 38-lb. single-face liner and 47-lb. double-face liner and the order was reversed for Run Combination 105. Both combinations were fabricated with the same corrugating medium.

The top- and end-load box compression results show that with the lower weight liner on the inside, the boxes sustained a slightly higher end-load compression. However, when the position was reversed (lower weight on the outside), the boxes sustained a higher top-load compression. The differences in compression strength were not large enough to advocate one form of construction in preference to the other.

Reversing the liner positions had no effect on the combined board results.

The Effect of the Type of Flute (A versus B)

Runs 85, 106, 107, and 108 were fabricated with similar 42-lb. liners and 26-lb. semichemical corrugating mediums, the only intentional variables being the adhesive and the flute. Runs 85 and 106 were A-flute board fabricated with starch and silicate adhesive, respectively; runs 107 and 108 were B-flute board fabricated with starch and silicate adhesive, respectively.

The top-load compression values for the A-flute boxes were higher than those for the B-flute boxes for both starch and silicate adhesive. However, the end-load box compression results for the B-flute boxes were slightly higher than those for the A-flute boxes.

The combined board results indicate that basis weights were nearly the same for the A-flute and B-flute boards; B-flute caliper was naturally lower; A-flute boards had slightly higher G. E. puncture values but slightly lower bursting strength values than the B-flute boards. Also G. E. stiffness values for the A-flute board were considerably higher. As would be expected, the B-flute flat crush results were higher.

The Effect of the Type of Adhesive (Starch versus Silicate)

Runs 85, 106, 107, and 108 were fabricated from similar 42-lb. kraft liners and 26-lb. semichemical corrugating medium, the only intentional variables being the flute and the adhesive, a situation which provided an opportunity to study not only the effect of flute construction, A versus B, both combined with the same adhesive (as discussed above), but also the effect of the adhesive itself on A- and B-flute boards.

The results show that A-flute and B-flute boxes fabricated with silicate adhesive exhibited higher top- and end-load box compression results than those fabricated with starch adhesive. The A- and B-flute end-load compression values were approximately the same for starch and silicate adhesives.

With regard to the combined board tests, it was observed that the basis weight results were slightly higher for the A- and B-flute boards fabricated with silicate adhesive. The other tests—caliper, bursting strangth, G. E. puncture, G. E. stiffness, flat crush, and normal adhesion—did not appear to be affected by the type of adhesive.

The Effect of the Amount of Adhesive

Run Combinations 85, 86, and 87 were fabricated with the same 42-lb. kraft liners and a standard 26-lb. semichemical corrugating medium into A-flute board, the only variable being the amount of starch adhesive applied which was varied by changing the clearance between the adhesive pickup and wiper rolls. Run Combination 86 was fabricated with a "light" adhesive application (0.008-inch clearance); Run Combination 85 with a "regular" adhesive application (0.012-inch clearance); and Run Combination 87 with a "heavy" adhesive application (0.015-inch clearance).

The results indicate that for "regular" and "heavy" applications of adhesive, the top-load box compression test results were higher than for the "light" application. However, the end-load box compression test results were approximately the same for the "regular" adhesive application and the "light" adhesive application, and somewhat lower for the "heavy" application than for the "light" application. The so-called "regular" application of adhesive appeared to yield the best top- and end-load box compression.

Of the combined board tests, the following increased as the amount of adhesive increased: basis weight, bursting strength, G. E. puncture, G. E. stiffness, and normal adhesion. Caliper and flat crush remained relatively unchanged.

Statistical Analysis of Data

The statistical analysis of the data was undertaken to illuminate the relationship between (1) the G. E. puncture test and conventional tests on components and combined board and (2) box compression and the G. E. puncture test on combined board.

To determine these relationships, the data have been divided into two groups. In one group, there are 16 different samples involving liners within the narrow range of 38 to 47 lb. In the other group there are 36 different samples covering the broad range of 26 to 90 lb.

The combined board tests for both populations were intercorrelated and it was noted that the most precise relationship involved the G. E. puncture and G. E. stiffness tests.

The correlation coefficients for the relationship of four combined board tests—bursting strength, G. E. puncture, G. E. stiffness, and flat crush—to top-load and end-load box compression indicate that the relationship between G. E. puncture and box compression is substantially better than that between bursting strength and box compression.

The correlation coefficients for the relationships of various liner and corrugating medium tests to combined board and box tests (16 samples) show (1) that none of the liner tests correlate well with the combined board tests, (2) that none of the corrugating medium tests correlate well with combined board bursting strength but all seem to correlate fairly well with the G. E. puncture and G. E. stiffness tests on combined board, (3) that the liner tests do not correlate as well as the corrugating medium tests with box compression. These observations can be explained by the fact that the range of liner properties was narrower than the range of corrugating medium properties for the 16-sample population.

When the population is expanded to 36 samples (covering a much broader range of liner properties than the 16 samples), the relationships change considerably. All the liner tests correlate well with combined board bursting strength followed in order by G. E. puncture and G. E. stiffness. The corrugating medium tests do not correlate well with any of the combined board tests. Of the liner tests, bursting strength and cross-machine direction liner ring compression exhibit the best correlation coefficients for both top-load and end-load box compression followed very closely by cross-machine direction tensile. None of the corrugating medium tests correlate well with either combined board or box tests.

Multiple correlations—i.e., relating several tests to another—were carried out to investigate the possibility of relating various liner and corrugating medium tests to the G. E. puncture test of the corresponding combined board. Fair correlations were obtained in the case of the 36-sample population by relating, for example, liner ring compression (in) and corrugating medium ring compression (in) [or Single-fluter or Concora in place of corrugating medium ring compression (in)] to combined board G. E. puncture. A fair correlation was also obtained by relating liner tensile (across) and corrugating medium tensile (across) to combined board G. E. puncture. These coefficients indicate that we do not have currently a test or tests for the components which will adequately predict the G. E. puncture of the combined board.

INTRODUCTION

The objective of the fabrication run which is the subject of this report was to develop information on several topics of wide interest to the container board industry. One of these topics concerned the G. E. puncture test. Specifically, this study was designed to illuminate the relationship between the G. E. puncture test and conventional tests on component and combined board materials. In addition, it was desired to investigate the relationship between box performance and the G. E. puncture test on combined board. Another matter of great interest embraced by this fabrication run was a problem of long standing: Given liners of various weights and corrugating mediums of various stiffnesses, how should the converter combine them for maximum economy at a given performance level? Apart from these two objectives was another of considerable importance: Materials were needed to carry forward incipient studies such as printability and case sealing.

Surveying the objectives mentioned above, those responsible for the designing of the fabrication run were immediately aware of one fact: its scope must be broad enough to cover the entire range of material combinations currently being manufactured. This idea was implemented by the decision to fabricate corrugating mediums at five flat-crush levels (20, 30, 35, 40, and 50 p.s.i.) with Fourdrinier kraft liners at five weight levels (26, 42, 52, 69, and 90-lb.) into A-flute board and boxes (RSC size 12 by 12 by 12) using starch adhesive. Thus, it would be possible to determine the effect of varying medium stiffness at a given liner weight and, conversely, the effect of varying liner weight at a given medium stiffness. Several additional combinations were proposed for the purpose of studying the influence of flute, type and amount of adhesive, and balanced versus unbalanced liner weights. In addition, it was agreed that an effort should be made to vary the linerboard density at a given weight level in order to study its effect on strength properties. This selection of materials, flutes, and adhesives provided the base needed for a comprehensive study of the original objectives.

One of the original objectives of this fabrication run, as was mentioned earlier, was to develop information regarding the relationship between the G. E. puncture test and conventional tests on component and combined board materials. Previous work has indicated that the G. E. puncture test correlates better with box performance than any other *single* combined board or component test. When a test shows promise as a measure of quality, it is logical to inquire further about it; for although the merits of the G. E. puncture test have been fairly well demonstrated, it has been the opinion of some investigators that too little is known about the factors which influence the test to advocate its indiscriminate use. To provide a firm foundation of information, it was considered necessary, first, to collect comprehensive data relating other established properties to the G. E. puncture test and, second, to investigate the influence of factors associated with fabrication and construction. The scope of this study, which has been discussed previously, was purposely broadened to provide as reliable information as possible about these factors.

This broadened scope also provided an excellent opportunity to study further the relationship between box performance and the strength properties of the combined board and component materials. The importance of such a study of corrugated board is apparent when it is realized that corrugated board is a structure whose main elements are the single-face liner, corrugating medium, and double-face liner. The proper distribution of strength among these three elements to obtain a corrugated board of the most desirable characteristics is a complicated problem; but from the viewpoints of economy and performance, it merits more than cursory attention. The question may well be asked: At what level of liner weight and medium stiffness will the greatest economy of materials be obtained for a given level of box performance? The economic importance of knowledge of this type to the manufacturers of paperboard is readily apparent.

Briefly summarized, the objectives of this fabrication run were threefold: (1) To determine the effect on combined board and box performance of varying medium stiffness at a given liner weight and, conversely, the effect of varying liner weight at a given medium stiffness; (2) to illuminate the relationship between the G. E. puncture test and conventional tests on component and combined board materials and also the relationship between box performance and the G. E. puncture test on combined board; and (3) to provide materials needed for carrying forward studies in various other phases of the Fourdrinier Kraft Board Institute's long range research program.

MATERIALS USED FOR FABRICATION

Liners and Corrugating Mediums

The study as outlined (see Figure 1) called for Fourdrinier kraft liners over a wide range of basis weights, namely: 26, 38, 42, 47, 52, 69 and 90 pounds. In order to maintain the manufacturing variables at a minimum, it was decided that the liners should be manufactured by one mill. This would permit the production of liners of different grade weights on the same machine and from the same general stock and, where desired, liners of varying density within a given grade weight. This was desirable in line with the objectives of the fabrication run. It may be noted in Table I that the liners were all produced at the Springhill mill of the International Paper Company.

As outlined (see Figure 1) the program involved the fabrication of five sets of different weight liners with each of five different mediums. The stiffness, as measured by flat crush, ranged from 20 to 50 p.s.i. with intermediate levels of 30, 35, and 40 p.s.i. Because of the wide range of flat crush desired, it was not possible to obtain the medium from one given mill. Consequently, rolls of commercial medium were obtained from selected producers, and it was hoped they would exhibit the desired flat crush levels. Considerable difficulty was experienced in obtaining a medium with a flat crush in the range of 20 p.s.i. After considerable searching, three rolls of bogus corrugating medium were located which exhibited extremely low flat crush characteristics and were, therefore, selected as the low flat crush medium. All the other mediums were semichemical mediums. Because of the inability to find a commercial medium exhibiting a flat crush of 50 p.s.i., it was decided that, rather than make a special run of heavy weight medium, two rolls of the 35 p.s.i. medium would be laminated for the high flat crush. The exact levels of the high- and low flat crush mediums were not of primary importance as long as they provided a sufficient range of flat crush. The average flat crush levels obtained for the various mediums used in the fabrication are given in Table I, together with the name of the supplier.

TABLE I
MATERIALS USED FOR FABRICATION

Grade	Manufacturer	Number of Rolls
Liners		
26-lb. WF	International Paper Company, Springhill, Louisiana	2
42-lb. WF (Light calendering)	International Paper Company, Springhill, Louisiana	2
42-lb. WF (Medium calendering)	International Paper Company, Springhill, Louisiana	6
42-lb. WF (Heavy calendering)	International Paper Company, Springhill, Louisiana	2
90-lb. WF	International Paper Company, Springhill, Louisiana	10
38-lb. WF	International Paper Company, Springhill, Louisiana	2
52-lb. WF	International Paper Company, Springhill, Louisiana	3
47-lb. WF	International Paper Company, Springhill, Louisiana	2
69-lb. WF	International Paper Company, Springhill, Louisiana	4

Corrugating Mediums

Flat Crush Level, p.s.i. Desired Average	Flat Crush Level, p.s.i. Actual Average	Type	Weight, lb.	Manufacturer	Number of Rolls
20	14.5	Bogus	26	Densen-Banner*	3
30	27.8	Semichemical	26	West Va. Pulp and Paper Co.	3
35	29.1	Semichemical	26	International Paper Company	2
40	39.5	Semichemical	33	Gaylord Container Corp.	2
50	69.9**	Semichemical	2-26	International Paper Company	4

*Manufacturer is unknown; rolls were obtained from Densen-Banner who are converters.
**Two rolls of the 35 p.s.i. flat crush medium were laminated when the fabrication run was made.

The fabrication schedule for the above materials is presented in Table II.

Adhesive

The starch adhesive used for the fabrication of these materials was a commercial grade of Bondcor C obtained from Stein, Hall and Co., Inc. The silicate of soda adhesive was also a commercial grade, 41° Bé., and was obtained from Grasselli Chemicals Department, E. I. du Pont de Nemours and Co., Inc.

Run No.	Corrugating Medium: Type	Corrugating Medium: Flat Crush Level, p.s.i.	Liner
71	26-lb. Bogus	20	
72	26-lb. Semichemical	30	
73	26-lb. Semichemical	35	26-lb.
74	33-lb. Semichemical	40	
75	2-26-lb. Semichemical	50	
76	2-26-lb. Semichemical	50	
77	26-lb. Semichemical	35	42-lb. Light calendering
78	26-lb. Bogus	20	
79	26-lb. Bogus	20	
80	26-lb. Semichemical	35	42-lb. Heavy calendering
81	2-26-lb. Semichemical	50	
82	2-26-lb. Semichemical	50	
83	33-lb. Semichemical	40	
84	26-lb. Semichemical	35	
85	26-lb. Semichemical	30	42-lb. Medium calendering
86	26-lb. Semichemical	30 25% less adhesive	
87	26-lb. Semichemical	30 30% more adhesive	
88	26-lb. Bogus	20	
89	26-lb. Bogus	20	
90	26-lb. Semichemical	30	
91	26-lb. Semichemical	35	52-lb.
92	33-lb. Semichemical	40	
93	2-26-lb. Semichemical	50	
94	2-26-lb. Semichemical	50	
95	33-lb. Semichemical	40	
96	26-lb. Semichemical	35	69-lb.
97	26-lb. Semichemical	30	
98	26-lb. Bogus	20	
99	26-lb. Bogus	20	
100	26-lb. Semichemical	30	
101	26-lb. Semichemical	35	90-lb.
102	33-lb. Semichemical	40	
103	2-26-lb. Semichemical	50	
104	26-lb. Semichemical	30	38-lb. S.F. and 47-lb. D.F.
105	26-lb. Semichemical	30	47-lb. S.F. and 38-lb. D.F.
106	26-lb. Semichemical	30 A-Flute silicate	
107	26-lb. Semichemical	30 B-Flute starch	42-lb. Medium calendering
108	26-lb. Semichemical	30 B-Flute silicate	

FIGURE 1. Outline of Fabrication Study

TABLE II

FABRICATION SCHEDULE

Run Combination	Liners* Single-face and Double-face	Corrugating Medium Type	Flat Crush, p.s.i.	Flute	Adhesive
71	26-lb. WF	26-lb. Bogus	20	A	Starch
72	26-lb. WF	26-lb. Semichemical	30	A	Starch
73	26-lb. WF	26-lb. Semichemical	35	A	Starch
74	26-lb. WF	33-lb. Semichemical	40	A	Starch
75	26-lb. WF	2-26-lb. Semichemical (laminated)	50	A	Starch
76	42-lb. WF, light calendering	2-26-lb. Semichemical (laminated)	50	A	Starch
77	42-lb. WF, light calendering	26-lb. Semichemical	35	A	Starch
78	42-lb. WF, light calendering	26-lb. Bogus	20	A	Starch
79	42-lb. WF, heavy calendering	26-lb. Bogus	20	A	Starch
80	42-lb. WF, heavy calendering	26-lb. Semichemical	35	A	Starch
81	42-lb. WF, heavy calendering	2-26-lb. Semichemical (laminated)	50	A	Starch
82	42-lb. WF, medium calendering	2-26-lb. Semichemical (laminated)	50	A	Starch
83	42-lb. WF, medium calendering	33-lb. Semichemical	40	A	Starch
84	42-lb. WF, medium calendering	26-lb. Semichemical	35	A	Starch
85	42-lb. WF, medium calendering	26-lb. Semichemical	30	A	Starch
86	42-lb. WF, medium calendering	26-lb. Semichemical	30	A	Starch (light application)
87	42-lb. WF, medium calendering	26-lb. Semichemical	30	A	Starch (heavy application)
88	42-lb. WF, medium calendering	26-lb. Bogus	20	A	Starch
89	52-lb. WF	26-lb. Bogus	20	A	Starch
90	52-lb. WF	26-lb. Semichemical	30	A	Starch
91	52-lb. WF	26-lb. Semichemical	35	A	Starch
92	52-lb. WF	33-lb. Semichemical	40	A	Starch
93	52-lb. WF	2-26-lb. Semichemical (laminated)	50	A	Starch
94	69-lb. WF	2-26-lb. Semichemical (laminated)	50	A	Starch
95	69-lb. WF	33-lb. Semichemical	40	A	Starch
96	69-lb. WF	26-lb. Semichemical	35	A	Starch
97	69-lb. WF	26-lb. Semichemical	30	A	Starch
98	69-lb. WF	26-lb. Bogus	20	A	Starch
99	90-lb. WF	26-lb. Bogus	20	A	Starch
100	90-lb. WF	26-lb. Semichemical	30	A	Starch
101	90-lb. WF	26-lb. Semichemical	35	A	Starch
102	90-lb. WF	33-lb. Semichemical	40	A	Starch
103	90-lb. WF	2-26-lb. Semichemical (laminated)	50	A	Starch
104	S.F. 38-lb.; D.F. 47-lb.	26-lb. Semichemical	30	A	Starch
105	S.F. 47-lb.; D.F. 38-lb.	26-lb. Semichemical	30	A	Starch
106	42-lb. WF, medium calendering	26-lb. Semichemical	30	A	Silicate
107	42-lb. WF, medium calendering	26-lb. Semichemical	30	B	Starch
108	42-lb. WF, medium calendering	26-lb. Semichemical	30	B	Silicate

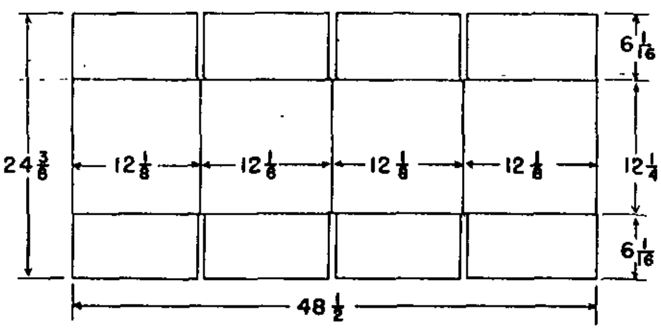
*All liners were Fourdrinier kraft.

CORRUGATOR OPERATING DATA

Run Combination	Sampling Period Time Start	Sampling Period Time End	Machine Speed, lineal ft./min.	Single-Facer Temperatures, °F. Liner Preheater	Single-Facer Temperatures, °F. Pressure Roll	Single-Facer Temperatures, °F. Corrugating Roll Bottom	Single-Facer Temperatures, °F. Corrugating Roll Top	Single-Facer Temperatures, °F. Corrugating Medium Preheater	Double-Backer Data Wrap, % Single-faced Board Preheater	Double-Backer Data Wrap, % Double-faced Liner Preheater	Double-Backer Data Hot Plate Temperature, °F.	Steam Pressure, lb./in.²	Adhesive Roll Clearance, inches S.F.	Adhesive Roll Clearance, inches D.F.
71	7:40 a.m.	7:50 a.m.	300	325F 347B	325F 320B	300F 320B	310F 300B	350F 350B	50	10	303	153	0.010	0.010
72	8:00 a.m.	8:05 a.m.	300	340F 340B	335F 335B	345F 340B	345F 345B	350F 350B	50	10	286	149	0.010	0.010
73	8:10 a.m.	8:15 a.m.	305	350F 350B	350F 345B	344F 333B	330F 333B	358F 363B	50	10	280	148	0.012	0.012
74	8:20 a.m.	8:25 a.m.	316	—	—	—	—	—	50	10	275	148	0.012	0.012
75	8:55 a.m.	9:05 a.m.	160	350F 350B	355F 350B	345F 350B	350F 348B	350F 360B	50	10	287	149	0.012	0.012
76	9:10 a.m.	9:20 a.m.	156	—	—	—	—	—	50	10	289	150	0.012	0.012
77	9:30 a.m.	9:40 a.m.	320	350F 350B	350F 350B	340F 345B	348F 340B	348F 348B	50	10	293	150	0.012	0.012
78	9:45 a.m.	9:55 a.m.	320	—	—	—	—	—	50	10	291	147	0.012	0.012
79	10:00 a.m.	10:05 a.m.	320	—	—	—	—	—	50	10	294	151	0.012	0.012
80	10:06 a.m.	10:10 a.m.	320	—	—	—	—	—	50	10	292	149	0.012	0.012
81	10:15 a.m.	10:25 a.m.	160	352F 350B	352F 340B	340F 340B	335F 338B	340F 345B	50	10	290	149	0.012	0.012
82	10:26 a.m.	10:35 a.m.	170	—	—	—	—	—	62.5	10	290	151	0.012	0.012
83	10:40 a.m.	10:49 a.m.	320	350F 343B	343F 317B	340F 340B	337F 338B	340F 350B	62.5	10	288	147	0.012	0.012
84	10:50 a.m.	10:55 a.m.	320	—	—	—	—	—	62.5	10	291	147	0.012	0.012
85	10:56 a.m.	11:00 a.m.	320	—	—	—	—	—	62.5	10	288	149	0.012	0.012
86	11:10 a.m.	11:15 a.m.	322	340F 345B	335F 338B	340F 340B	335F 338B	340F 340B	62.5	10	290	150	0.008	0.012
87	11:20 a.m.	11:30 a.m.	310	335F 335B	340F 335B	340F 340B	340F 338B	335F 340B	62.5	10	288	150	0.015	0.012
88	11:35 a.m.	11:45 a.m.	300	340F 350B	335F 338B	340F 336B	338F 340B	338F 348B	62.5	10	293	149	0.012	0.012
				340F 345B	330F 345B	335F 335B	340F 345B	330F 345B			313			
90	11:50 a.m.	11:55 a.m.	320	—	—	—	—	—	62.5	10	290	154	0.012	0.012
91	11:56 a.m.	12:04 p.m.	320	—	—	—	—	—	62.5	10	291	150	0.012	0.012
92	12:05 p.m.	12:10 p.m.	324	—	—	—	—	—	62.5	10	286	147	0.012	0.012
93	12:15 p.m.	12:25 p.m.	160	325F 340B	335F 350B	340F 345B	338F 340B	350F 343B	62.5	10	286	145	0.012	0.012
94	12:30 p.m.	12:40 p.m.	160	—	—	—	—	—	62.5	10	286	152	0.012	0.012
95	12:45 p.m.	12:55 p.m.	268	335F 350B	350F 350B	345F 340B	345F 340B	345 360	62.5	90	289	146	0.012	0.012
96	1:00 p.m.	1:05 p.m.	272	—	—	—	—	—	62.5	90	292	148	0.012	0.012
97	1:10 p.m.	1:15 p.m.	280	—	—	—	—	—	62.5	90	291	149	0.012	0.012
98	1:16 p.m.	1:21 p.m.	256	—	—	—	—	—	62.5	90	293	151	0.012	0.012
99	1:22 p.m.	1:26 p.m.	266	—	—	—	—	—	62.5	90	293	145	0.012	0.012
100	1:30 p.m.	1:35 p.m.	276	—	—	—	—	—	62.5	90	290	151	0.012	0.012
101	1:36 p.m.	1:45 p.m.	165	—	—	—	—	—	62.5	90	293	145	0.012	0.012
102	1:46 p.m.	1:55 p.m.	176	350F 342B	335F 350B	335F 340B	335F 345B	350F 360B	62.5	90	291	142	0.012	0.012
103	2:05 p.m.	2:10 p.m.	150	—	—	—	—	—	62.5	90	294	144	0.012	0.012
104*				335F 350B	340F 350B	320F 325B	330F 340B	350F 360B			293			
105*				335F 340B	330F 360B	330F 320B	330F 330B	350F 345B			294			
106*				340F 340B	360F 350B	315F 315B	330F 340B	345F 345B			299			
107*				330F 350B	370F 370B	310F 305B	340F 330B	340F 360B			288			
108*				320F 320B	360F 345B	270F 270B	330F 330B	345F 330B			294			

*These runs were fabricated on March 10, 1954, whereas the remainder of the runs were fabricated on September 12, 1953.

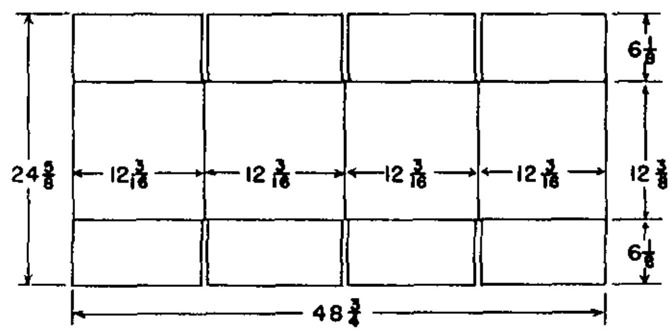
The materials described above were shipped to the Menasha Wooden Ware Corporation where the fabrication was carried out on an 85-inch Langston corrugator equipped with a triplex slitter and creaser and a duplex cutoff. The corrugator operating data are shown in Table III, and the adhesive data in Table IV. Combinations 71 to 88 and 90 to 103 were fabricated on September 12, 1953, and Combinations 89 and 104 to 108 were fabricated on March 10, 1954. Throughout the fabrications, box blanks and flat stock were saved only when the corrugator was producing satisfactory board. At the beginning and end of each run combination, samples were taken from each component roll (the full width of the rolls). Approximately 150 box blanks were taken from the front and back cutoff positions, respectively, giving a total of 300 box blanks per combination. Two hundred sheets of flat stock—50 by 72 inches—were taken from the front cutoff position for each combination.



B-Flute Boxes

FIGURE 1A. Scoring and Slotting Specifications

The box blank samples and flat stock samples for each run combination were placed on skids and carefully identified to avoid any possible confusion in later operations. The box blanks were allowed to season for several days before they were run on the printer-slotter. The A-flute box blanks were scored, slotted and printed on a 64 by 120-inch Langston printer-slotter.



A-Flute Boxes

FIGURE 2. Scoring and Slotting Specifications

The scoring and slotting dimensions are shown in Figure 1a. The B-flute box blanks were scored, slotted, and printed on a 42 by 90-inch Langston printer-slotter. The scoring and slotting dimensions are shown in Figure 2.

TABLE IV

STARCH ADHESIVE DATA

Time	Single-Face Liner Temperature, °F.	Viscosity, sec.*	Gel Point, °F.	Time	Double-Face Liner Temperature, °F.	Viscosity, sec.*	Gel Point, °F.
			Sept. 12, 1953				
7:10 a.m., Sept. 12, 1953	86	25		7:10 a.m., Sept. 12, 1953	88	45	
8:10 a.m., Sept. 12, 1953	86	26		8:10 a.m., Sept. 12, 1953	86	51	
9:10 a.m., Sept. 12, 1953	86	25		9:10 a.m., Sept. 12, 1953	86	51	
11:10 a.m., Sept. 12, 1953	86	25½		11:10 a.m., Sept. 12, 1953	86	53	
1:10 p.m., Sept. 12, 1953	86	25		1:10 p.m., Sept. 12, 1953	80	52	
			March 10, 1954				
6:45 a.m., March 10, 1954	78	37	144	7:00 a.m., March 10, 1954	82	124	136
7:30 a.m., March 10, 1954	86	40		8:00 a.m., March 10, 1954	86	82	
8:30 a.m., March 10, 1954	82	35					

SILICATE ADHESIVE DATA

March 10, 1954

Specific gravity	1.393
Temperature, °F.	73
Degree Baumé	41

*The Institute of Paper Chemistry viscometer (water = 15.3 seconds at 73° F.)

TESTING PROCEDURE

The testing of the various samples obtained from the fabrication runs may be divided into three parts. First, physical tests were performed on the samples of the component materials from which the combined board was fabricated. Second, physical tests were made on the combined board; and, third, the boxes which were fabricated from the combined board were evaluated for their compression strength.

Component Tests

Each component sample included specimens selected across the full width of the rolls. The sampling was carried out at the start and end of each combination. The component samples were preconditioned for at least 24 hours in an atmosphere maintained at a temperature of 73 ± 3.5° F. and a relative humidity less than 35%, then conditioned for at least 48 hours in an atmosphere of 50 ± 2% relative humidity and a temperature of 73 ± 3.5° F. Testing was done in the latter atmosphere.

The following physical testing was carried out on the liners: caliper, basis weight, bursting strength, ring compression, tensile, stretch, and G. E. puncture. These same tests were carried out on the corrugating mediums with the exception that G. E. puncture was omitted and the Concora medium test and Single-fluter test were added. The following number of readings were obtained for each average result referred to in this report:

Liners	
Caliper	20
Basis weight	1000 in.² minimum
Bursting strength	20 (10 up and 10 down)
Ring compression	20 (10 in and 10 across)
Tensile and stretch	20 (10 in and 10 across)
G. E. puncture	10 (5 up and 5 down)

Corrugating Mediums	
Caliper	20
Basis weight	1000 in.² minimum
Bursting strength	20 (10 up and 10 down)
Ring compression	20 (10 in and 10 across)
Tensile and stretch	20 (10 in and 10 across)
Concora medium test	10 (in only)
Single-fluter test	10 (in only)

Combined Board Tests

Each combination involved not only the fabrication of box blanks, but also the fabrication of sheets of flat stock which were 50 inches wide and 72 inches long. The combined board specimens were preconditioned and conditioned like the component samples before they were tested. The combined board tests which were performed on specimens randomly selected were the following: basis weight, caliper, bursting strength, G. E. puncture, G. E. stiffness, flat crush, and pin adhesion.

The following number of readings were obtained for each average result given in this report:

Caliper	20
Basis weight	5 (12 x 12-inch sheets)
Bursting strength	20 (10 best up and 10 best down)
G. E. puncture	20 (10 best up, in and across) (10 best down, in and across)
G. E. stiffness	20 (10 best up, in and across) (10 best down, in and across)
Flat crush	20
Pin adhesion	10

Box Tests

From the box blanks fabricated for each combination, fifteen specimens were selected randomly from the front and fifteen from the back for processing through the box shop—i.e., slotting, scoring, and taping. Ten of these boxes (5 front and 5 back) were selected for top-load compression tests and a similar number was selected for end-load compression. Prior to being tested, the boxes were first preconditioned for at least 24 hours in an atmosphere maintained at 73° F. and less than 35% R.H. They were next placed in an atmosphere maintained at 73° F. and 50% R.H. for 24 hours. At the end of this period, the top and bottom flaps were sealed with silicate of soda after being flexed outward 90° and inward 180° to the closed position. After being sealed, the boxes were conditioned 48 hours in the 50% R.H. atmosphere before they were tested.

DISCUSSION OF RESULTS

The Effect of Varying Liner Weight at Five Levels of Combined Board Flat Crush

The three structural elements of combined board and boxes made therefrom are the single-face liner, the double-face liner, and the corrugating medium. One of the objectives of this fabrication run was to determine the effects on combined board and box strength of varying the liner weight at each of five flat crush levels. To achieve this objective, balanced combined boards were fabricated with 26, 42, 52, 69, and 90-lb. WF Fourdrinier kraft liners. Each of the liners in this range was fabricated with corrugating mediums at five levels of combined board flat crush which were originally planned to be 20, 30, 35, 40, and 50 p.s.i., thus giving a total of 25 combinations. However, the average combined board flat crush levels actually attained were 14.5, 27.8, 29.1, 39.5, and 69.9 p.s.i.

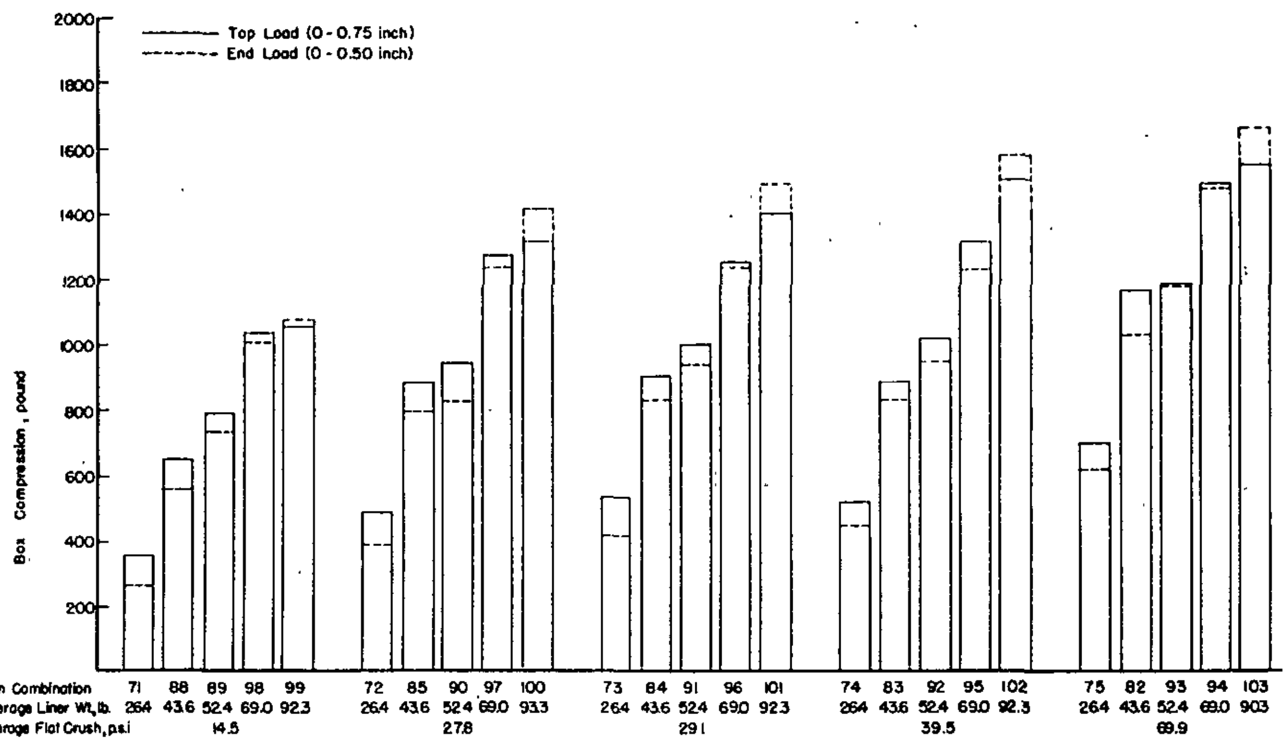


FIGURE 3. Compression Tests on A-flute Boxes Made with Balanced Liners of Various Weights Each Fabricated with Corrugating Mediums at Five Levels of Combined Board Flat Crush Showing the Effect of Varying Liner Weight at Each Level of Flat Crush

The Effect of Liner Weight on Box Characteristics

The top- and end-load compression results obtained for the boxes fabricated with liners varying in weight from 26 to 90 lb. and corrugating mediums at five different levels of combined board flat crush are shown in Table V and graphically presented in Figures 3, 3a, and 3b. It may be noted that at each level of flat crush the top- and end-load box compression results increased quite uniformly as the liner weight increased. However, the box compression values for both top-load and end-load for a given medium (see Figures 3a and 3b) appeared to level off in the vicinity above a 70-lb. liner weight beyond which a further increase in weight at a given flat crush level did not result in an increase in box compression of any real consequence. This phenomenon was exhibited by all the samples. Also, it may be observed that the compression results were lowest for

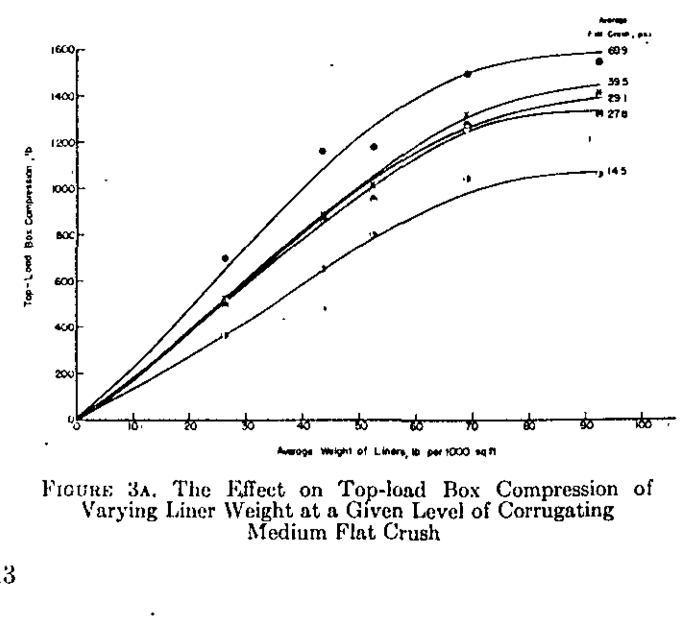


FIGURE 3A. The Effect on Top-load Box Compression of Varying Liner Weight at a Given Level of Corrugating Medium Flat Crush

TABLE V

A COMPARISON OF THE PHYSICAL CHARACTERISTICS OF A-FLUTE BOXES SHOWING THE EFFECT OF VARYING THE LINER WEIGHT AT A GIVEN LEVEL OF CORRUGATING MEDIUM FLAT CRUSH

	Liner		Corrugating Medium		Combined Board	Boxes					
						Top-Load Compression			End-Load Compression		
	Basis Weight, lb.					Max. Load in Pounds Sustained in Deflection Ranges			Max. Load in Pounds Sustained in Deflection Ranges		
Run Combination	S.F. Liner	D.F. Liner	Type	Basis Weight, lb.	Flat Crush, p.s.i.	0-0.75 in.	0-1.00 in.	Deflection At Max. Load, inch	0-0.50 in.	0-1.00 in.	Deflection At Max. Load, inch
71	26.5	26.2	Bogus	27.6	11.0	360	380	0.64	260	260	0.34
88	43.5	43.6	Bogus	27.6	10.1	650	650	0.52	555	560	0.45
89	52.3	52.6	Bogus	29.6	16.0	795	795	0.57	730	735	0.45
98	68.9	69.2	Bogus	30.5	17.9	1040	1100	0.74	995	1010	0.50
99	92.2	92.4	Bogus	30.5	17.3	1060	1145	0.82	1080	1235	0.66
				Average	14.5						
72	26.5	26.2	Semichemical	26.9	29.0	490	490	0.58	390	390	0.44
85	43.5	43.6	Semichemical	26.8	27.9	865	890	0.68	800	800	0.38
90	52.5	52.4	Semichemical	26.8	27.5	950	950	0.66	830	830	0.39
97	68.9	69.2	Semichemical	26.9	27.2	1275	1280	0.69	1210	1240	0.50
100	92.2	92.4	Semichemical	26.8	27.6	1320	1380	0.76	1410	1420	0.49
				Average	27.8						
73	26.5	26.2	Semichemical	27.0	28.4	515	535	0.64	405	420	0.50
84	43.5	43.6	Semichemical	27.3	28.8	870	910	0.72	835	835	0.38
91	52.5	52.4	Semichemical	27.3	27.5	985	1000	0.70	930	940	0.42
96	68.9	69.2	Semichemical	27.4	27.1	1260	1260	0.70	1240	1265	0.46
101	92.2	92.4	Semichemical	27.4	33.7	1405	1470	0.76	1500	1510	0.50
				Average	29.1						
74	26.5	26.2	Semichemical	32.2	40.1	520	520	0.58	450	450	0.46
83	43.5	43.6	Semichemical	32.4	41.0	890	995	0.86	820	830	0.40
92	52.5	52.4	Semichemical	32.2	41.6	1015	1060	0.74	950	950	0.44
95	68.9	69.2	Semichemical	32.2	38.4	1320	1380	0.76	1230	1340	0.58
102	92.2	92.4	Semichemical	32.2	36.2	1420	1485	0.78	1530	1580	0.59
				Average	39.5						
75	26.5	26.2	Laminated Semichemical	54.8	69.4	695	700	0.64	610	620	0.38
82	43.5	43.6	Laminated Semichemical	54.2	68.1	1160	1170	0.68	1015	1030	0.46
93	52.5	52.4	Laminated Semichemical	55.2	73.1	1180	1185	0.71	1175	1210	0.52
94	68.9	69.2	Laminated Semichemical	55.2	69.2	1495	1495	0.70	1460	1480	0.54
103	90.0	90.6	Laminated Semichemical	55.4	69.6	1545	1600	0.78	1660	1820	0.58
				Average	69.9						

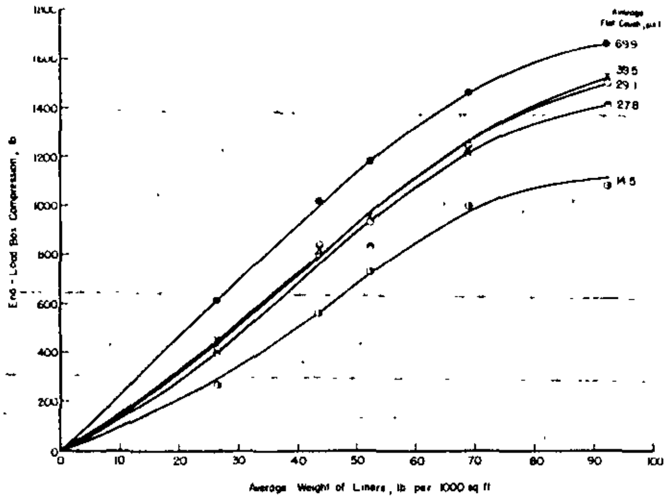


FIGURE 3B. The Effect on End-load Box Compression of Varying Liner Weight at a Given Level of Corrugating Medium Flat Crush

the combinations which were fabricated with the corrugating medium having the lowest flat crush and highest for the combinations which were fabricated with the corrugating medium having the highest flat crush. It may be noted further that at the intermediate levels of flat crush—27.8, 29.1, and 39.5 p.s.i.—the increase in box compression achieved by increasing the liner weight was about the same. The conclusion that may be reached from the data presented is that for a given level of flat crush strength, the greater the average weight of the liners used, the higher will be the compressive strength of the corresponding boxes.

The Effect of Liner Weight on Combined Board Characteristics

The results of the combined board tests are shown in Table VI. Graphs of the combined board results showing the effect on strength properties achieved by increasing

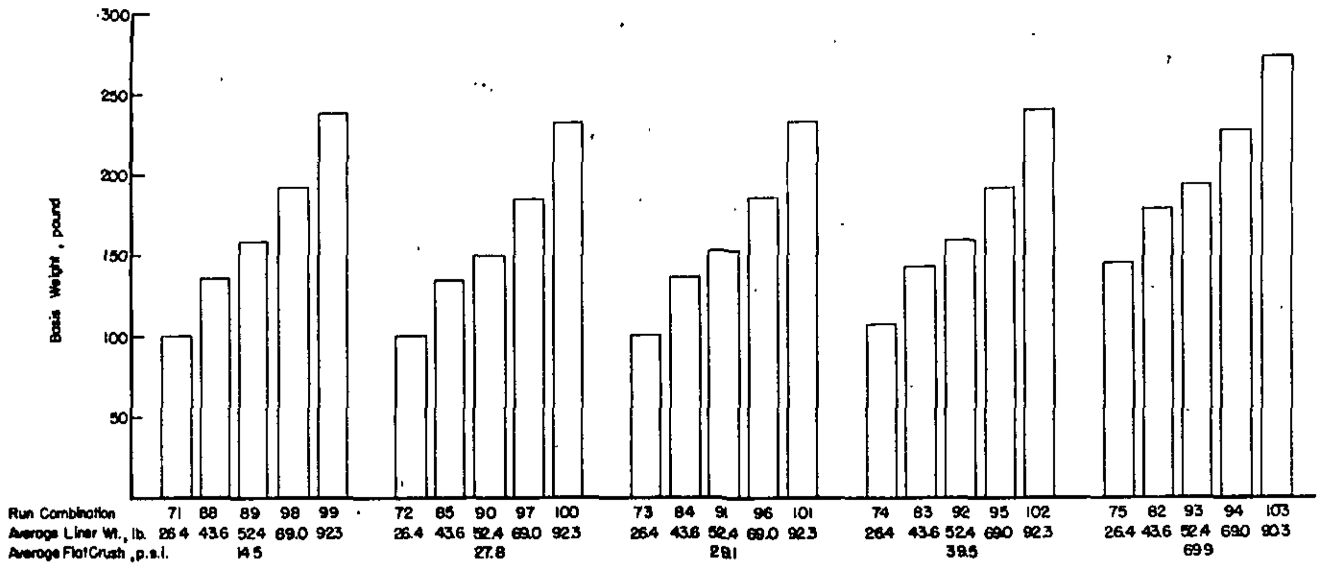


FIGURE 4. Basis Weight Test Results on A-flute Combined Boards Made with Balanced Liners of Various Weights Each Fabricated with Corrugating Mediums at Five Levels of Combined Board Flat Crush Showing the Effect of Varying Liner Weight at Each Level of Flat Crush

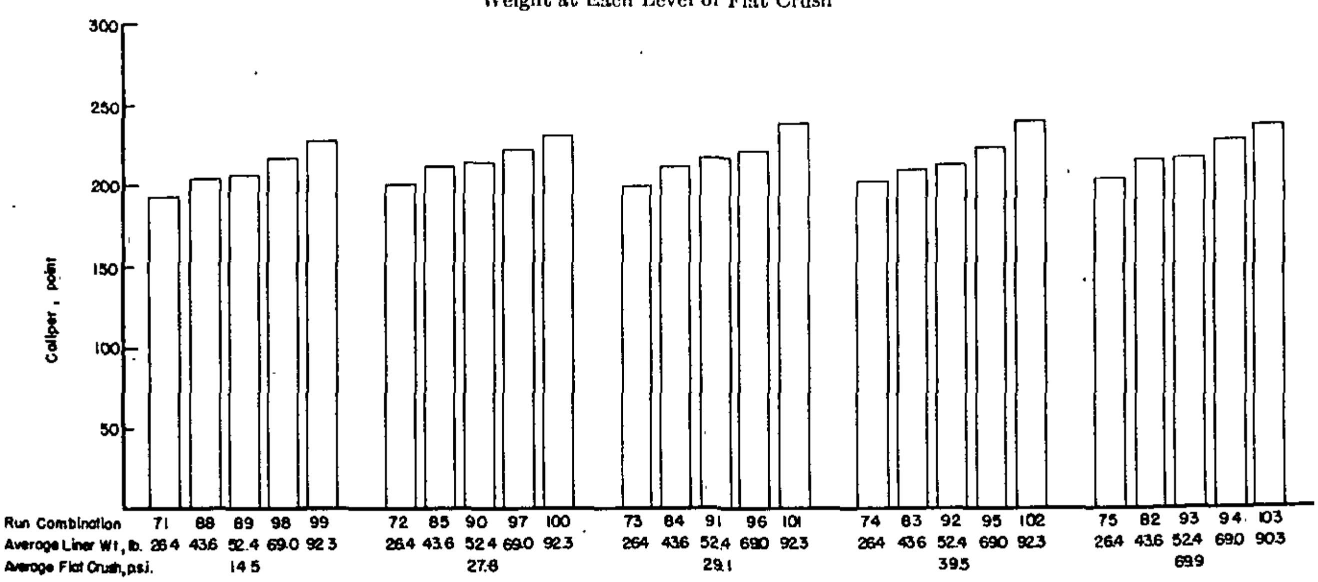


FIGURE 5. Caliper Test Results on A-flute Combined Boards Made with Balanced Liners of Various Weights Each Fabricated with Corrugating Mediums at Five Levels of Combined Board Flat Crush Showing the Effect of Varying Liner Weight at Each Level of Flat Crush

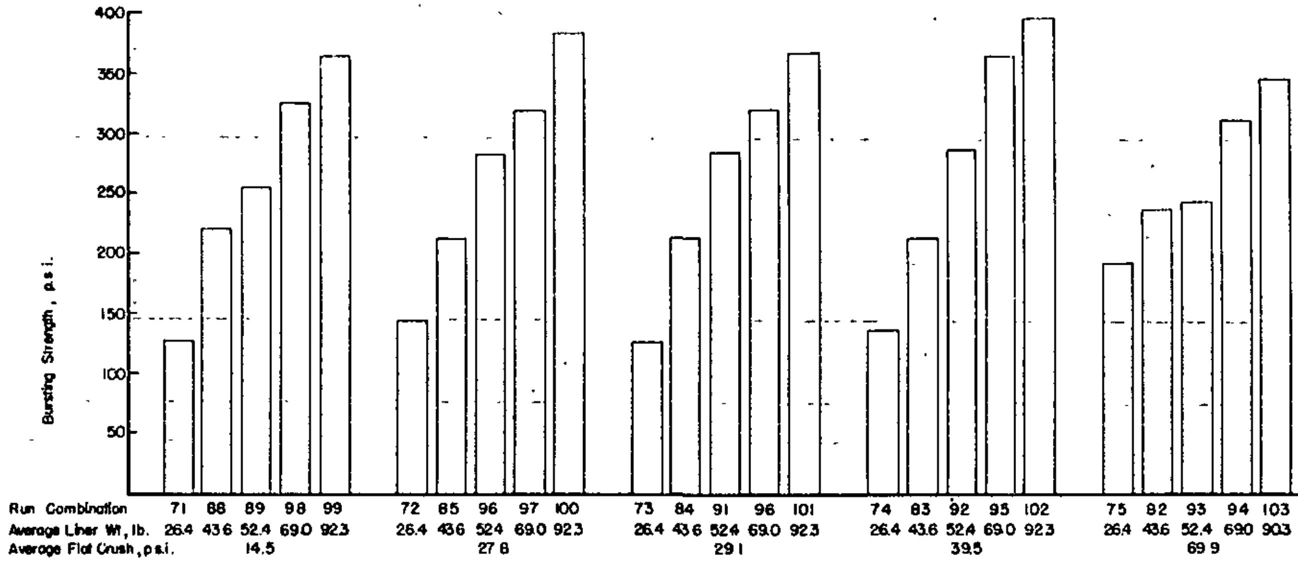


FIGURE 6. Bursting Strength Test Results on A-flute Combined Boards Made with Balanced Liners of Various Weights Each Fabricated with Corrugating Mediums at Five Levels of Combined Board Flat Crush Showing the Effect of Varying Liner Weight at Each Level of Flat Crush

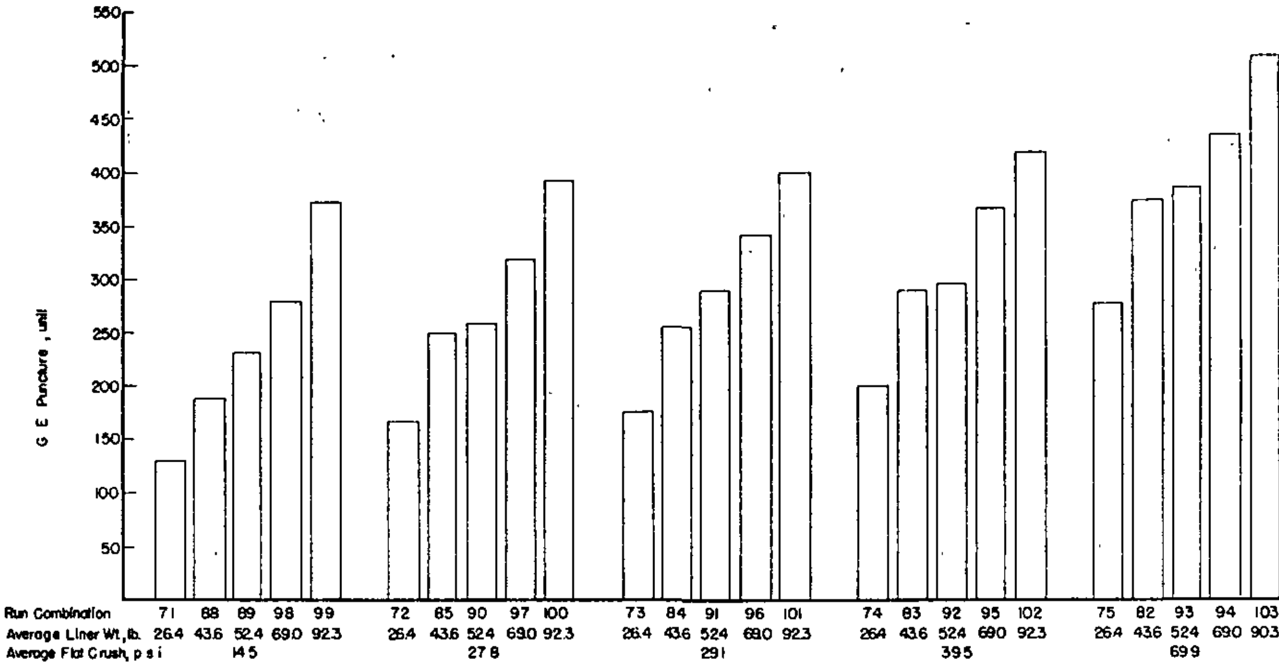


FIGURE 7. G. E. Puncture Test Results on A-flute Combined Boards Made with Balanced Liners of Various Weights Each Fabricated with Corrugating Mediums at Five Levels of Combined Board Flat Crush Showing the Effect of Varying Liner Weight at Each Level of Flat Crush

liner weight at five levels of flat crush are presented in Figures 4, 5, 6, 7, 8, and 9 for basis weight, caliper, bursting strength, G. E. puncture, bursting strength versus G. E. puncture, and G. E. stiffness. It may be noted in Figures 4 and 5 that basis weight and caliper increased uniformly at each flat crush level as the weight of the liners increased. The charts illustrating the relationship of increasing weight to bursting strength and G. E. puncture—Figures 6 and 7—show that both tests increased at each flat crush level as liner weight increased. The flat crush level appeared to affect the magnitude of the G. E. puncture results considerably more than the bursting strength results.

In Figure 8 the relationship of bursting strength and G. E. puncture to increasing liner weight is shown in one graph to facilitate comparison. It may be seen from the results plotted in Figure 8 that, for the samples fabricated with the 14.5-p.s.i. flat crush medium, the bursting strength appeared to increase at a greater rate with increasing liner weight than did the G. E. puncture. However, at the higher flat crush levels the reverse was observed, particularly when the laminated medium was used. Figure 9 presents the relationship of G. E. stiffness to liner weight, and it may be seen that the test results increased uniformly with increasing liner weight. It may be observed further that the general level of stiffness values increased as the flat crush level increased. From the data

TABLE VI

PHYSICAL CHARACTERISTICS OF A-FLUTE COMBINED BOARDS SHOWING THE EFFECT OF VARYING THE LINER WEIGHT AT A GIVEN LEVEL OF CORRUGATING MEDIUM FLAT CRUSH

Run Combination	Liner Basis Weight, lb.		Corrugating Medium		Combined Board							
	S.F. Liner	D.F. Liner	Type	Basis Weight, lb.	Basis Weight, lb.	Caliper, pt.	Bursting Strength, p.s.i.	G. E. Puncture, units	G. E. Stiffness, units	Normal Adhesion, lb. per 6 sq. in. D.F. Liner	Normal Adhesion, lb. per 6 sq. in. S.F. Liner	Flat Crush, p.s.i.
71	26.5	26.2	Bogus	27.6	100	193	126	128	63	49	62	11.0
88	43.5	43.6	Bogus	27.6	134	205	220	186	97	51	59	10.1
89	52.3	52.6	Bogus	29.6	158	206	254	230	118	47	67	16.0
98	68.9	69.2	Bogus	30.5	192	217	326	279	129	54	62	17.9
99	92.2	92.4	Bogus	30.5	237	227	366	368	165	56	61	17.3
72	26.5	26.2	Semichemical	26.9	99	201	143	164	102	74	53	29.0
85	43.5	43.6	Semichemical	26.8	134	211	211	248	152	66	79	27.9
90	52.5	52.4	Semichemical	26.8	150	214	274	258	164	69	71	27.5
97	68.9	69.2	Semichemical	26.9	185	222	336	318	195	71	89	27.2
100	92.2	92.4	Semichemical	26.8	232	231	384	392	224	67	76	27.6
73	26.5	26.2	Semichemical	27.0	100	200	134	174	101	42	69	28.4
84	43.5	43.6	Semichemical	27.3	135	211	212	255	167	64	78	28.8
91	52.5	52.4	Semichemical	27.3	152	216	284	288	180	59	74	27.5
96	68.9	69.2	Semichemical	27.4	185	222	319	341	221	74	94	27.1
101	92.2	92.4	Semichemical	27.4	232	238	368	400	222	60	89	33.7
74	26.5	26.2	Semichemical	32.2	106	201	136	199	112	37	59	40.1
83	43.5	43.6	Semichemical	32.4	142	210	212	290	187	63	78	41.0
92	52.5	52.4	Semichemical	32.2	158	213	285	296	190	65	61	41.6
95	68.9	69.2	Semichemical	32.2	191	223	364	365	225	79	74	38.4
102	92.2	92.4	Semichemical	32.2	239	239	396	419	224	65	73	36.2
75	26.5	26.2	Laminated Semichemical	54.8	144	204	190	279	171	50	46	69.4
82	43.5	43.6	Laminated Semichemical	54.2	178	215	236	372	243	70	70	68.1
93	52.5	52.4	Laminated Semichemical	55.2	194	216	240	386	262	72	66	73.1
94	68.9	69.2	Laminated Semichemical	55.2	229	227	310	433	275	79	72	69.2
103	90.0	90.6	Laminated Semichemical	55.4	272	235	346	508	314	77	64	69.6

TABLE VIII
PHYSICAL CHARACTERISTICS OF CORRUGATING MEDIUMS

Run Combination	Grade and Type	Basis Weight, lb.	Caliper, pt.	Bursting Strength, p.s.i.	Ring Compression, lb. In	Ring Compression, lb. Across	Tensile, lb. per inch In	Tensile, lb. per inch Across	Stretch, % In	Stretch, % Across	Single-Fluter Test, p.s.i.	Concora Med. Test, p.s.i.
71	26-lb. Bogus	27.6	10.5	27	29.8	20.3	24.7	10.8	1.0	2.5	18.6	12.8
78, 79	26-lb. Semichemical	27.4	10.2	28	29.8	21.2	24.1	10.9	1.0	2.5	19.4	12.8
88	26-lb. Semichemical	27.6	10.7	30	28.5	20.8	24.0	10.7	1.0	2.5	18.2	13.0
89	26-lb. Semichemical	29.6	11.8	36	43.6	32.1	26.8	14.0	1.2	2.2	25.2	19.1
98, 99	26-lb. Semichemical	30.5	12.0	35	42.4	30.6	27.9	14.1	1.3	2.0	29.8	19.6
72	26-lb. Semichemical	26.9	10.9	40	53.6	40.0	37.4	16.9	1.5	2.5	42.7	33.0
85, 86, 87, 90	26-lb. Semichemical	26.8	10.8	40	50.8	40.1	37.1	16.6	1.5	2.4	42.3	33.4
97	26-lb. Semichemical	26.9	11.1	40	50.0	39.2	37.1	16.2	1.5	2.3	42.1	33.4
100	26-lb. Semichemical	26.8	10.6	41	52.1	41.5	36.9	17.6	1.5	2.2	42.5	32.1
104	26-lb. Semichemical	26.9	10.7	40	50.6	39.0	36.0	16.8	1.4	2.4	37.3	31.3
105	26-lb. Semichemical	26.9	10.6	40	52.2	36.6	35.8	16.8	1.4	2.3	37.6	31.7
106	26-lb. Semichemical	26.8	10.6	40	50.0	34.8	36.0	16.3	1.4	2.2	37.9	31.8
107	26-lb. Semichemical	26.8	10.6	40	55.0	41.9	37.2	17.9	1.5	2.2	37.5	32.4
108	26-lb. Semichemical	26.6	10.6	41	53.6	40.8	37.4	17.8	1.5	2.2	37.1	31.5
73	26-lb. Semichemical	27.0	11.0	48	60.4	43.3	47.3	18.9	1.4	2.4	46.3	32.8
77	26-lb. Semichemical	27.0	11.1	48	60.0	44.6	47.6	19.2	1.4	2.7	46.8	33.6
80	26-lb. Semichemical	27.2	11.0	49	63.4	45.4	47.2	18.7	1.4	2.6	47.5	33.2
84	26-lb. Semichemical	27.3	10.9	51	63.1	45.4	48.3	18.6	1.5	2.4	47.3	33.1
91	26-lb. Semichemical	27.3	10.9	51	61.4	44.4	49.0	18.8	1.4	2.4	47.6	33.0
96	26-lb. Semichemical	27.4	10.9	48	61.8	43.8	47.9	18.9	1.4	2.5	49.4	33.4
101	26-lb. Semichemical	27.4	10.4	54	57.6	41.4	49.6	20.1	1.6	2.6	49.9	38.2
75*, 76*	26-lb. Semichemical	27.4	11.0	48	62.4	44.0	46.8	20.0	1.4	2.6	47.4	33.2
81*, 82*	26-lb. Semichemical	27.1	11.1	48	61.4	42.4	46.6	19.4	1.4	2.5	45.6	32.0
93*, 94*	26-lb. Semichemical	27.6	11.0	50	63.0	43.0	45.6	19.2	1.4	2.4	45.5	31.4
103*	26-lb. Semichemical	27.7	10.8	50	63.6	44.2	45.7	19.6	1.4	2.6	45.7	32.6

*Two 26-lb. semichemical corrugating mediums were laminated for this run.

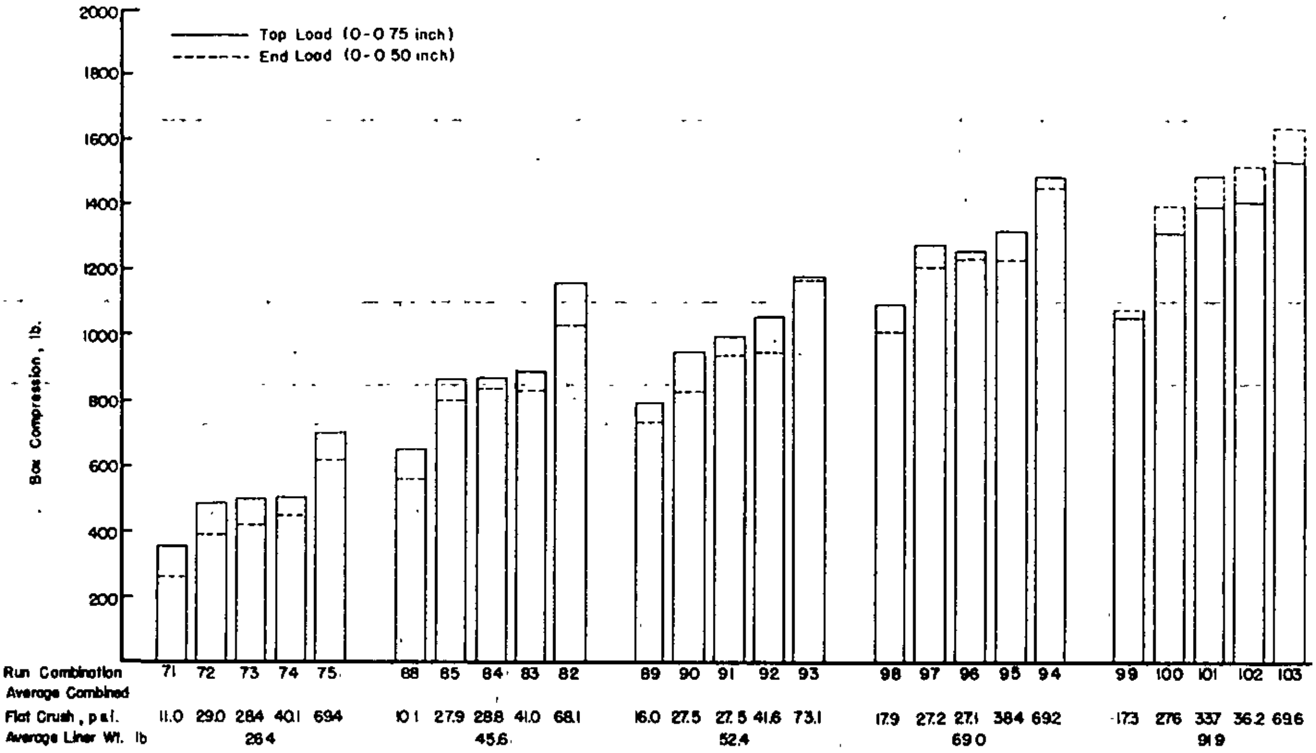


Figure 10. Compression Tests on A-flute Boxes Made with Balanced Liners of Various Weights Each Fabricated with Corrugating Mediums at Five Levels of Combined Board Flat Crush Showing the Effect of Varying Flat Crush at Each Level of Liner Weight

different corrugating mediums varying in average combined board flat crush strength from 14.5 to 69.9 p.s.i.

The Effect of Corrugating Medium Stiffness on Box Compression

The top- and end-load compression results obtained for five weights of liner—26, 42, 52, 69, and 90-lb.—each fabricated with five different corrugating mediums varying in average combined board flat crush from 14.5 to 69.9 lb per square inch are shown in Table IX and graphically illustrated in Figures 10, 10a, and 10b where it may be observed from the tabular and graphic presentations that at each level of liner weight an increase in the combined board flat crush was accompanied by an increase in box compression. This was true at each of the nominal levels of liner weight—i.e., 26-lb., 42-lb., 52-lb., 69-lb. and 90-lb.

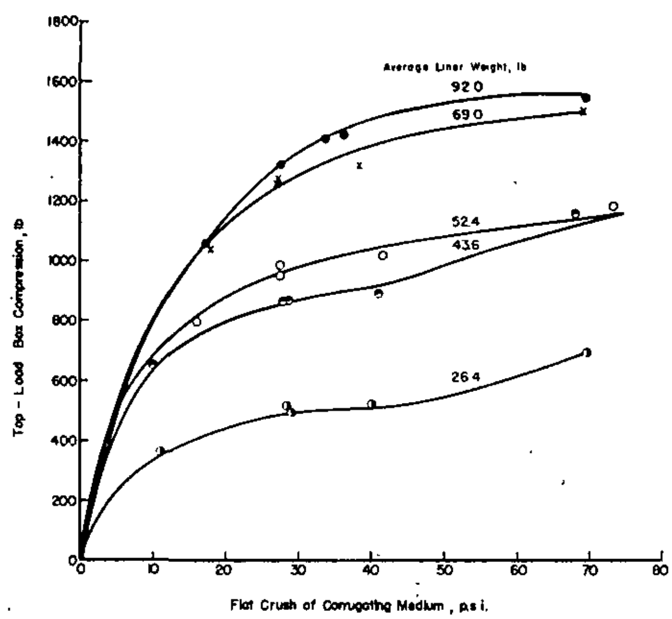


Figure 10a. The Effect on End-load Box Compression of Varying Corrugating Medium Flat Crush at a Given Level of Liner Weight

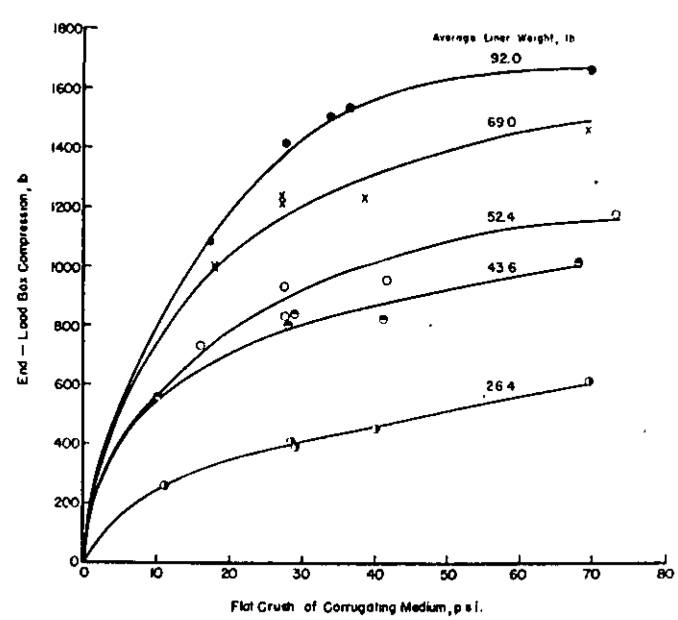


Figure 10b. The Effect on Top-load Box Compression of Varying Corrugating Medium Flat Crush at a Given Level of Liner Weight

TABLE IX

A COMPARISON OF THE PHYSICAL CHARACTERISTICS OF A-FLUTE BOXES SHOWING THE EFFECT OF VARYING THE FLAT CRUSH OF THE CORRUGATING MEDIUM AT A GIVEN LINER WEIGHT LEVEL

Run Combination	Liners: Basis Weight, lb. S.F. Liner	Liners: Basis Weight, lb. D.F. Liner	Corrugating Medium: Type	Corrugating Medium: Basis Weight, lb.	Combined Board: Flat Crush, p.s.i.	Boxes: Top-Load Compression: Max. Load in Pounds Sustained in Deflection Ranges 0-0.75 in.	Boxes: Top-Load Compression: Max. Load in Pounds Sustained in Deflection Ranges 0-1.00 in.	Boxes: Top-Load Compression: Deflection At Max. Load, inch	Boxes: End-Load Compression: Max. Load in Pounds Sustained in Deflection Ranges 0-0.50 in.	Boxes: End-Load Compression: Max. Load in Pounds Sustained in Deflection Ranges 0-1.00 in.	Boxes: End-Load Compression: Deflection At Max. Load, inch
71	26.5	26.2	Bogus	27.6	11.0	360	380	0.64	260	260	0.34
72	26.5	26.2	Semichemical	26.9	29.0	490	490	0.58	390	390	0.44
73	26.5	26.2	Semichemical	27.0	28.4	515	535	0.64	405	420	0.50
74	26.5	26.2	Semichemical	32.2	40.1	520	520	0.58	450	450	0.46
75	26.5	26.2	Laminated Semichemical	54.8	69.4	695	700	0.64	610	620	0.38
88	43.5	43.6	Bogus	27.6	10.1	650	650	0.52	555	560	0.45
85	43.5	43.6	Semichemcial	26.8	27.9	865	890	0.68	800	800	0.38
84	43.5	43.6	Semichemical	27.3	28.8	870	910	0.72	835	835	0.38
83	43.5	43.6	Semichemical	32.4	41.0	890	995	0.86	820	830	0.40
82	43.5	43.6	Laminated Semichemical	54.2	68.1	1160	1170	0.68	1015	1030	0.46
89	52.3	52.6	Bogus	29.6	16.0	795	795	0.57	730	735	0.45
90	52.5	52.4	Semichemical	26.8	27.5	950	950	0.66	830	830	0.39
91	52.5	52.4	Semichemical	27.3	27.5	985	1000	0.70	930	940	0.42
92	52.5	52.4	Semichemical	32.2	41.6	1015	1060	0.74	950	950	0.44
93	52.5	52.4	Laminated Semichemical	55.2	73.1	1180	1185	0.71	1175	1210	0.52
98	68.9	69.2	Bogus	30.5	17.9	1040	1100	0.74	995	1010	0.50
97	68.9	69.2	Semichemical	26.9	27.2	1275	1280	0.69	1210	1240	0.50
96	68.9	69.2	Semichemical	27.4	27.1	1260	1260	0.70	1240	1265	0.46
95	68.9	69.2	Semichemical	32.2	38.4	1320	1380	0.76	1230	1340	0.58
94	68.9	69.2	Laminated Semichemical	55.2	69.2	1495	1495	0.70	1460	1480	0.54
99	92.2	92.4	Bogus	30.5	17.3	1060	1145	0.82	1080	1235	0.66
100	92.2	92.4	Semichemical	26.8	27.6	1320	1380	0.76	1410	1420	0.49
101	92.2	92.4	Semichemical	27.4	33.7	1405	1470	0.76	1500	1510	0.50
102	92.2	92.4	Semichemical	32.2	36.2	1420	1485	0.78	1530	1580	0.59
103	90.0	90.6	Laminated Semichemical	55.4	69.6	1545	1600	0.78	1660	1820	0.58

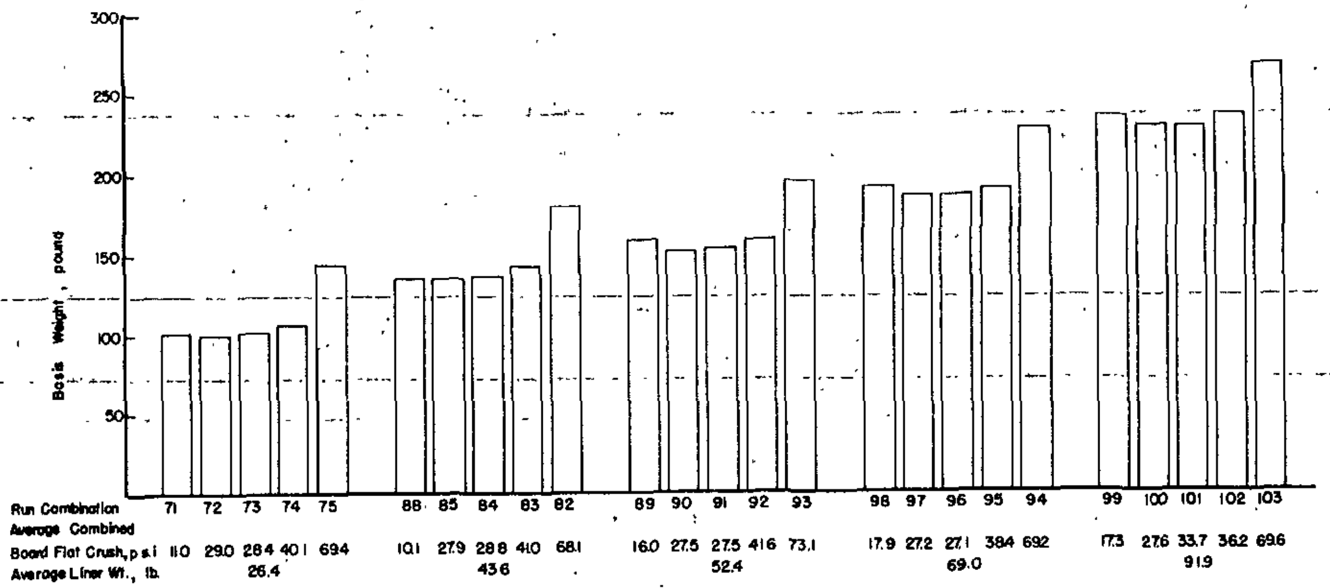


Figure 11. Basis Weight Test Results on A-flute Combined Boards Made with Balanced Liners of Various Weights Each Fabricated with Corrugating Mediums at Five Levels of Combined Board Flat Crush Showing the Effect of Varying Flat Crush at Each Level of Liner Weight

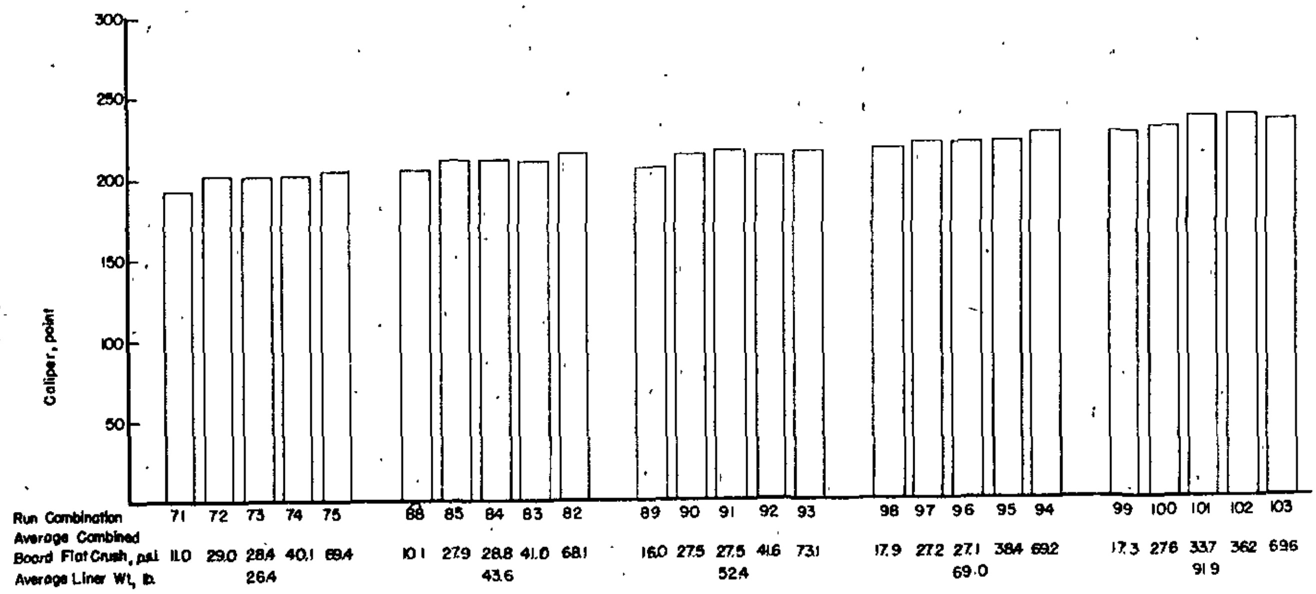


Figure 12. Caliper Test Results on A-flute Combined Boards Made with Balanced Liners of Various Weights Each Fabricated with Corrugating Mediums at Five Levels of Combined Board Flat Crush Showing the Effect of Varying Flat Crush at Each Level of Liner Weight

However, the observation may be made in Figures 10a and 10b that the increase in box compression achieved by increasing the flat crush of the medium 10 p.s.i. in the lower range was considerably greater than the increase achieved by an equivalent change in flat crush in the higher range—i.e., the magnitude of box compression values for a given liner weight tended to level off as the flat crush values increased, and finally reached a point where a further increase in flat crush would not increase box compression materially.

The Effect of Corrugating Medium Stiffness on Combined Board Characteristics

The test results obtained on the combined boards fabricated with liners varying in weight from 26 to 90 lb., each combined with five corrugating mediums of various stiffness characteristics, are shown in Table X and illustrated by graphs in Figures 11 to 17. Graphs of the basis weight and caliper results are presented in Figures 11 and 12 from which it may be observed that at a given liner weight level, varying the flat crush of the board had no apparent effect on the basis weight and caliper test results except where the change in flat crush was also associated with a change in the basis weight and caliper of the corrugating medium.

The bursting strength results shown in Figure 13 indicate that there appears to be no direct relationship between combined board bursting strength and the flat crush of the corrugating medium at a given liner weight level. Thus, it appears that with few exceptions, bursting

TABLE X

PHYSICAL CHARACTERISTICS OF A-FLUTE COMBINED BOARDS SHOWING THE EFFECT OF VARYING THE FLAT CRUSH OF THE CORRUGATING MEDIUM AT A GIVEN LINER WEIGHT LEVEL

Run Combination	Liners Basis Weight, lb. S.F. Liner	Liners Basis Weight, lb. D.F. Liner	Corrugating Medium Type	Corrugating Medium Basis Weight, lb.	Combined Board Basis Weight, lb.	Combined Board Caliper, pt.	Combined Board Bursting Strength, p.s.i.	Combined Board G.E. Puncture, units	Combined Board G.E. Stiffness, units	Normal Adhesion, lb. per 6 sq. in. D.F. Liner	Normal Adhesion, lb. per 6 sq. in. S.F. Liner	Flat Crush, p.s.i.
71	26.5	26.2	Bogus	27.6	100	193	126	128	63	49	62	11.0
72	26.5	26.2	Semichemical	26.9	99	201	143	164	102	74	53	29.0
73	26.5	26.2	Semichemical	27.0	100	200	134	174	101	42	69	28.4
74	26.5	26.2	Semichemical	32.2	106	201	136	199	112	37	59	40.1
75	26.5	26.2	Laminated Semichemical	54.8	144	204	190	279	171	50	46	69.4
88	43.5	43.6	Bogus	27.6	134	205	220	186	97	51	59	10.1
85	43.5	43.6	Semichemical	26.8	134	211	211	248	152	66	79	27.9
84	43.5	43.6	Semichemical	27.3	135	211	212	255	167	64	78	28.8
83	43.5	43.6	Semichemical	32.4	142	210	212	290	187	63	78	41.0
82	43.5	43.6	Laminated Semichemical	54.2	178	215	236	372	243	70	70	68.1
89	52.3	52.6	Bogus	29.6	158	206	254	230	118	47	67	16.0
90	52.5	52.4	Semichemical	26.8	150	214	274	258	164	69	71	27.5
91	52.5	52.4	Semichemical	27.3	152	216	284	288	180	59	74	27.5
92	52.5	52.4	Semichemical	32.2	158	213	285	296	190	65	61	41.6
93	52.5	52.4	Laminated Semichemical	55.2	194	216	240	386	262	72	66	73.1
98	68.9	69.2	Bogus	30.5	192	217	326	279	129	54	62	17.9
97	68.9	69.2	Semichemical	26.9	185	222	336	318	195	71	89	27.2
96	68.9	69.2	Semichemical	27.4	185	222	319	341	221	74	94	27.1
95	68.9	69.2	Semichemical	32.2	191	223	364	365	225	79	74	38.4
94	68.9	69.2	Laminated Semichemical	55.2	229	227	310	433	275	79	72	69.2
99	92.2	92.4	Bogus	30.5	237	227	366	368	165	56	61	17.3
100	92.2	92.4	Semichemical	26.8	232	231	384	392	224	67	76	27.6
101	92.2	92.4	Semichemical	27.4	232	238	368	400	222	60	89	33.7
102	92.2	92.4	Semichemical	32.2	239	239	396	419	224	65	73	36.2
103	90.0	90.6	Laminated Semichemical	55.4	272	235	346	508	314	77	64	69.6

strength is primarily a function of the liners. It also may be observed that, at the two lowest levels of liner weight—i.e., 26 and 42-lb.—the bursting strength results for the samples fabricated with laminated mediums were higher than those fabricated with only a single medium. However, at the higher levels of liner weight the samples fabricated with the laminated medium exhibited lower bursting strengths. This is probably the result of "double-pops" which have a greater influence on the test results at the higher bursting strength levels.

Figure 14 presents the G. E. puncture results and it may be noted quite readily that at any one of the five liner weight levels, an increase in corrugating medium flat crush resulted in an increase in the G. E. puncture test, thus, indicating that unlike the bursting strength test, the G. E. puncture test is dependent on the corrugating medium as well as on the liners.

The G. E. puncture and bursting strength results are shown together in Figure 15 for comparative purposes. Examination of the data indicates that increasing the corrugating medium stiffness at a given level of liner weight has a considerably greater effect on the G. E. puncture test results than on the bursting strength test results. This tends to confirm previous investigations which have shown that the corrugating medium characteristics contribute significantly to the G. E. puncture test results but are of considerably less importance to the bursting strength results.

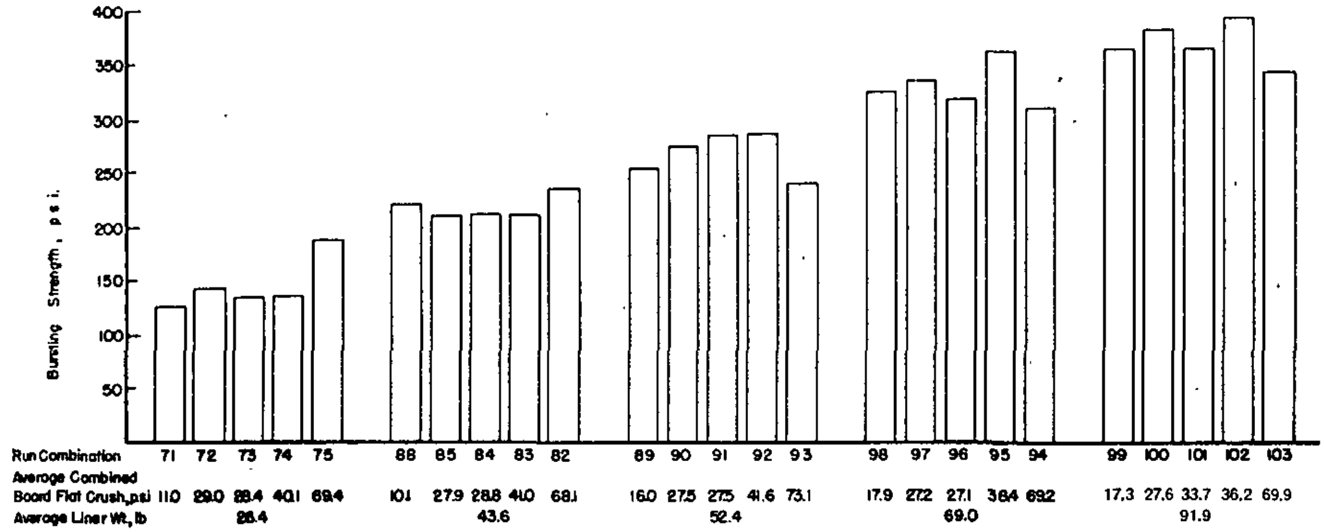


FIGURE 13. Bursting Strength Test Results on A-flute Combined Boards Made with Balanced Liners of Various Weights Each Fabricated with Corrugating Mediums at Five Levels of Combined Board Flat Crush Showing the Effect of Varying Flat Crush at Each Level of Liner Weight

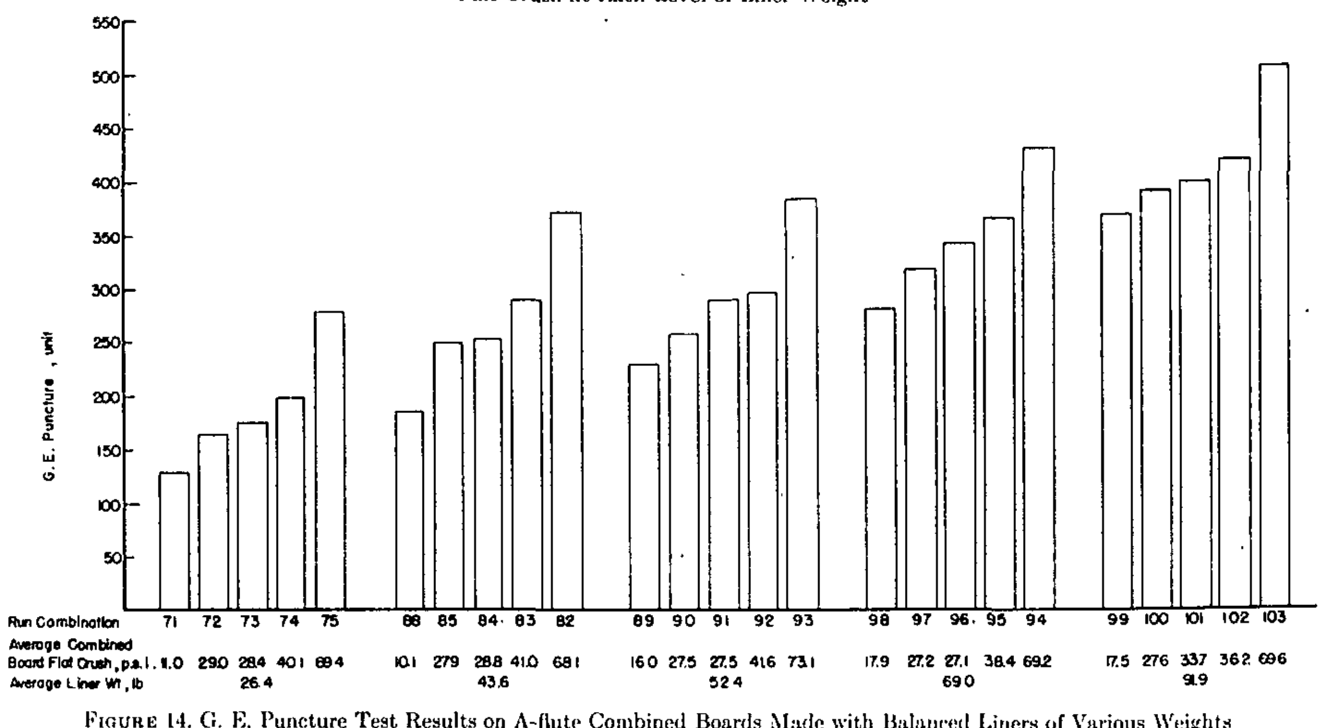


FIGURE 14. G. E. Puncture Test Results on A-flute Combined Boards Made with Balanced Liners of Various Weights Each Fabricated with Corrugating Mediums at Five Levels of Combined Board Flat Crush Showing the Effect of Varying Flat Crush at Each Level of Liner Weight

Shown graphically in Figure 16 are the G. E. stiffness results. The results at each liner weight level show that increasing the corrugating medium stiffness also increases the G. E. stiffness of the combined board, thus indicating that the stiffness of the medium contributes to the stiffness of the board as measured by this test.

The normal adhesion results for the various combinations are shown in Figure 17 where it may be noted that corrugating medium stiffness had no specific effect on the strength of the bonding of the board.

The Effect of Liner Density

The densities of three 42-lb. kraft liners were varied by finishing them with light, medium, and heavy calendering to determine its effect on combined board and box characteristics. The liners which were finished this way varied in density from 36.4 to 40.8 lb. per cu. ft. Each liner was combined with three corrugating mediums of the following average flat crush characteristics: 10.3, 28.4, and 69.9 p.s.i.

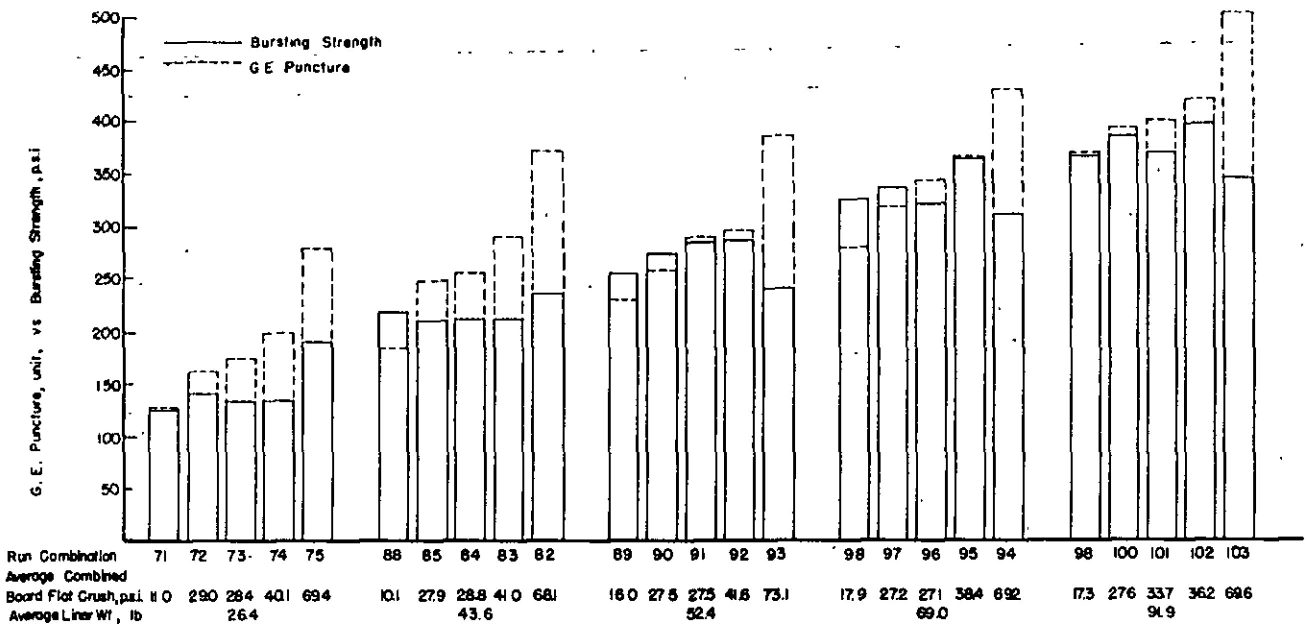


Figure 15. Comparison of Bursting Strength versus G. E. Puncture Test Results on A-flute Combined Boards made with Balanced Liners of Various Weights Each Fabricated with Corrugating Mediums at Five Levels of Combined Board Flat Crush Showing the Effect of Varying Flat Crush at Each Level of Liner Weight

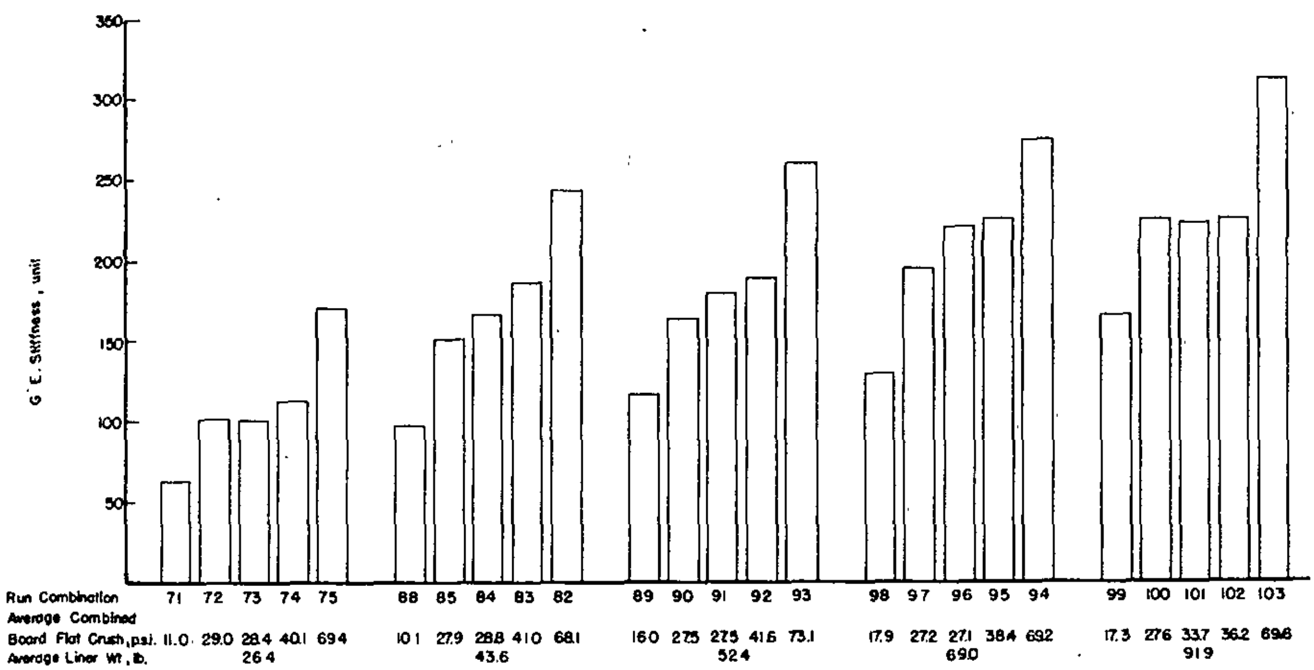


Figure 16. G. E. Stiffness Test Results on A-flute Combined Boards Made with Balanced Liners of Various Weights Each Fabricated with Corrugating Mediums at Five Levels of Combined Board Flat Crush Showing the Effect of Varying Flat Crush at Each Level of Liner Weight

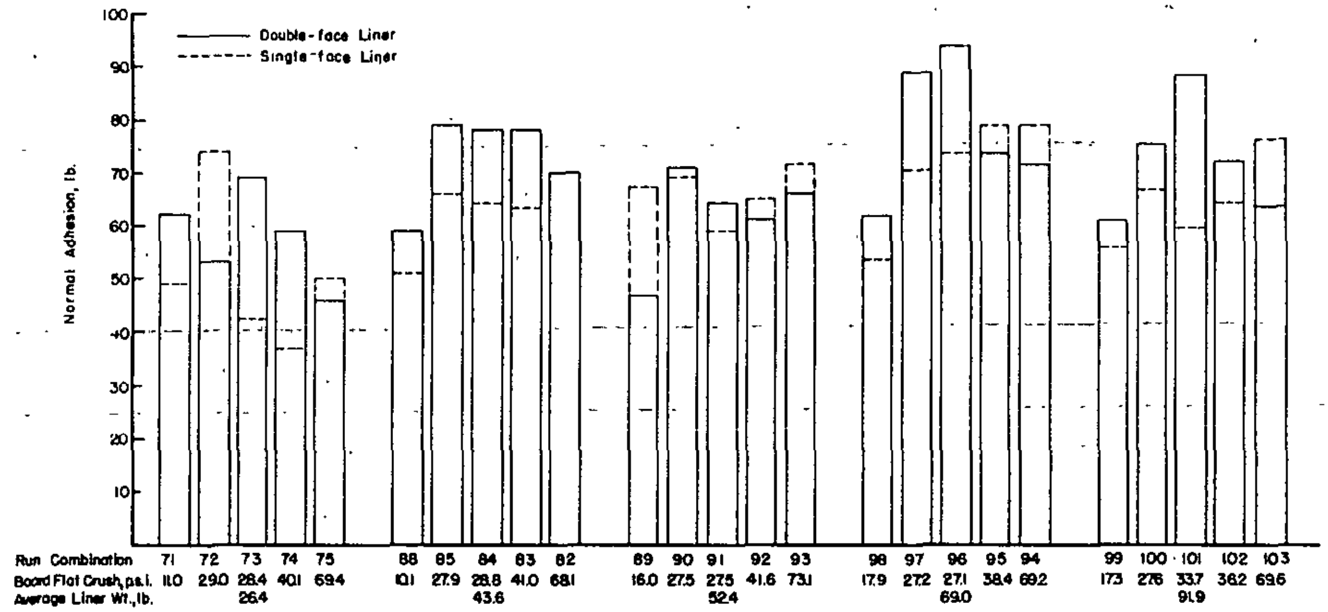


Figure 17. Normal Adhesion Test Results on A-flute Combined Boards Made with Balanced Liners of Various Weights Each Fabricated with Corrugating Mediums at Five Levels of Combined Board Flat Crush Showing the Effect of Varying Flat Crush at Each Level of Liner Weight

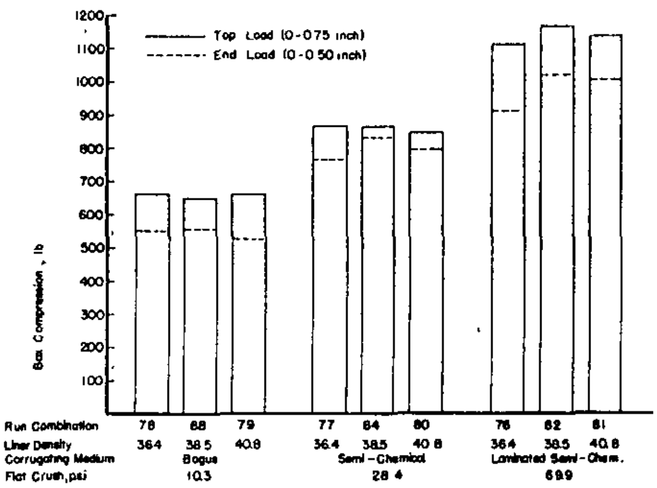


Figure 18. Compression Tests on A-flute Boxes Made with Liners of Various Densities Each Fabricated with Corrugating Mediums at Three Levels of Combined Board Flat Crush

The Effect of Liner Density on Box Compression

The top- and end-load box compression results obtained for the three levels of liner density and corrugating medium stiffness are given in Table XI and presented graphically in Figure 18. Examination of the tabular and graphic presentations indicates that the liner density in the range studied did not appear to have a significant effect on the top- and end-load box compression results. This observation is based on only three comparisons and thus should not be interpreted as conclusive evidence, but rather only as indicative.

The Effect of Liner Density on Combined Board Characteristics

The combined board data are given in Table XII and presented graphically in Figures 19 to 25. The combined board basis weight and caliper results are shown in Figures 19 and 20, respectively. The variations noted in basis weight and caliper of the combined board as the liner density varied were very small and apparently insignificant.

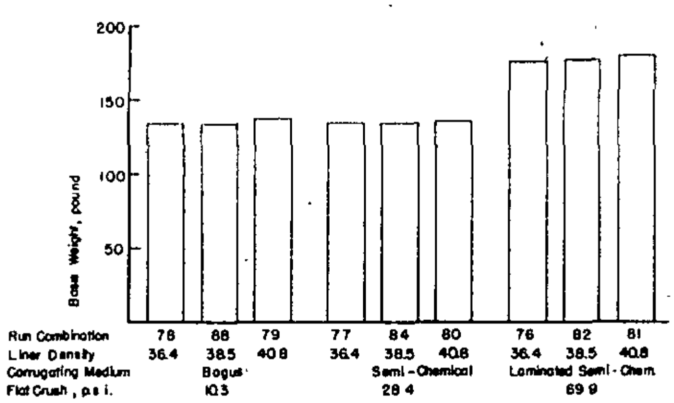


Figure 19. Basis Weight Test Results of A-flute Combined Boards Made with Liners of Various Densities Each Fabricated with Corrugating Mediums at Three Levels of Combined Board Flat Crush

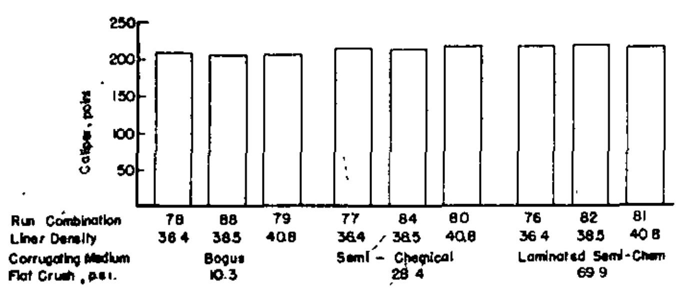


Figure 20. Caliper Test Results of A-flute Combined Boards Made with Liners of Various Densities Each Fabricated with Corrugating Mediums at Three Levels of Combined Board Flat Crush

TABLE XI

THE EFFECT OF LINER DENSITY ON THE COMPRESSION STRENGTH OF A-FLUTE BOXES

Run Combination	Average Liner Characteristics (Balanced Construction): Basis Weight, lb.	Caliper, pt.	Apparent Density, lb./cu. ft.	Corrugating Medium: Type	Combined Board: Flat Crush, p.s.i.	Boxes — Top-Load Compression: Max. Load in Pounds Sustained in Deflection Ranges 0-0.75 in.	0-1.00 in.	Deflection At Max. Load, inch	Boxes — End-Load Compression: Max. Load in Pounds Sustained in Deflection Ranges 0-0.50 in.	0-1.00 in.	Deflection At Max. Load, inch
78	43.4 LC	14.3	36.4	Bogus	10.4	660	660	0.51	550	550	0.36
88	43.6 MC	13.6	38.5	Bogus	10.1	650	650	0.52	555	560	0.45
79	44.2 HC	13.0	40.8	Bogus	10.5	660	660	0.54	525	525	0.39
				Average	10.3						
77	43.4 LC	14.3	36.4	Semichemical	27.9	870	870	0.69	770	770	0.38
84	43.6 MC	13.6	38.5	Semichemical	28.8	870	910	0.72	835	835	0.38
80	44.2 HC	13.0	40.8	Semichemical	28.6	850	850	0.66	800	800	0.40
				Average	28.4						
76	43.4 LC	14.3	36.4	Laminated Semichemical	72.5	1110	1110	0.68	910	925	0.46
82	43.6 MC	13.6	38.5	Laminated Semichemical	68.1	1160	1170	0.68	1015	1030	0.46
81	44.2 HC	13.0	40.8	Laminated Semichemical	69.2	1130	1140	0.70	1000	1020	0.46
				Average	69.9						

TABLE XII

THE EFFECT OF LINER DENSITY ON THE PHYSICAL CHARACTERISTICS OF A-FLUTE COMBINED BOARDS

Run Combination	Average Liner Data: Basis Weight, lb.	Caliper, pt.	Apparent Density, lb./cu. ft.	Bursting Strength, p.s.i.	G.E. Puncture, units	Corrugating Medium: Type	Combined Board: Basis Weight, lb.	Caliper, pt.	Bursting Strength, p.s.i.	G.E. Puncture, units	G.E. Stiffness, units	Normal Adhesion, lb./6 sq. in.: D.F. Liner	S.F. Liner	Flat Crush, p.s.i.
78	43.4 LC	14.3	36.4	98	34	Bogus	135	208	202	194	91	61	61	10.4
88	43.6 MC	13.6	38.5	106	34	Bogus	134	205	220	186	97	51	59	10.1
79	44.2 HC	13.0	40.8	108	34	Bogus	138	205	224	191	101	62	63	10.5
77	43.4 LC	14.3	36.4	98	34	Semichemical	135	212	212	259	162	62	86	27.9
84	43.6 MC	13.6	38.5	106	34	Semichemical	135	211	212	255	167	64	78	28.8
80	44.2 HC	13.0	40.8	108	34	Semichemical	136	214	224	272	172	69	71	28.6
76	43.4 LC	14.3	36.4	98	34	Laminated Semichemical	177	215	231	362	221	71	49	72.5
82	43.6 MC	13.6	38.5	106	34	Laminated Semichemical	178	215	236	372	243	70	70	68.1
81	44.2 HC	13.0	40.8	108	34	Laminated Semichemical	180	214	241	390	262	67	65	69.2

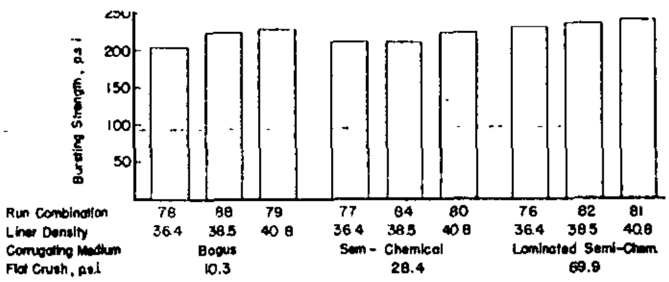


FIGURE 21. Bursting Strength Test Results of A-flute Combined Boards Made with Liners of Various Densities Each Fabricated with Corrugating Mediums at Three Levels of Combined Board Flat Crush

The bursting strength results presented in Figure 21 graphically indicate that an increase in liner density resulted in a slight increase in the bursting strength of the combined board.

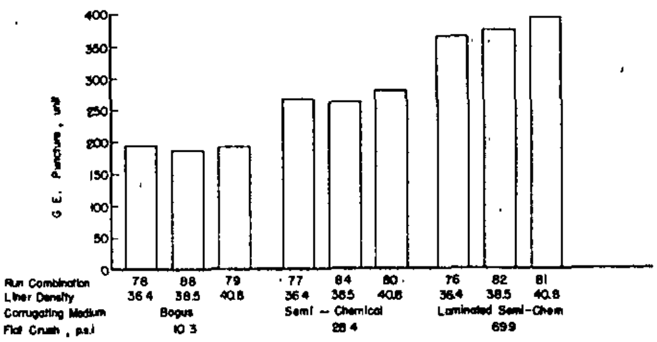


FIGURE 22. G. E. Puncture Test Results of A-flute Combined Boards Made with Liners of Various Densities Each Fabricated with Corrugating Mediums at Three Levels of Combined Board Flat Crush

It may be seen in Figure 22 that the combined board G. E. puncture results appear to increase as the density increases although the difference may not be significant.

The bursting strength and G. E. puncture results are presented togther in Figure 23 for comparative purposes. At the highest corrugating medium stiffness level, the contribution made by the laminated medium to the G. E. puncture result was much greater than its contribution to

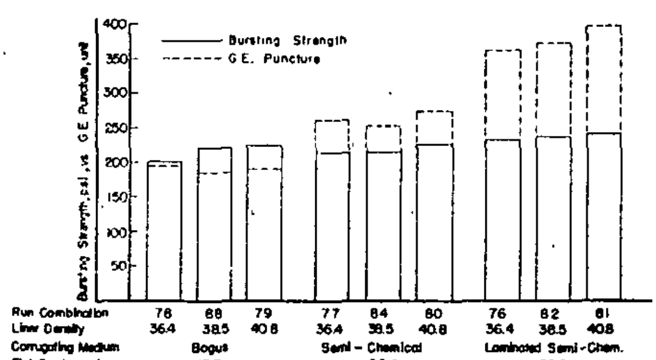


FIGURE 23. Comparison of Bursting Strength versus G. E. Puncture Test Results for A-flute Combined Boards Made with Liners of Various Densities Each Fabricated with Corrugating Mediums at Three Levels of Combined Board Flat Crush

the bursting strength result, again illustrating the influence which the medium has on the G. E. puncture results.

The combined board G. E. stiffness test results are shown in Figure 24. Examination of the graphic data in-

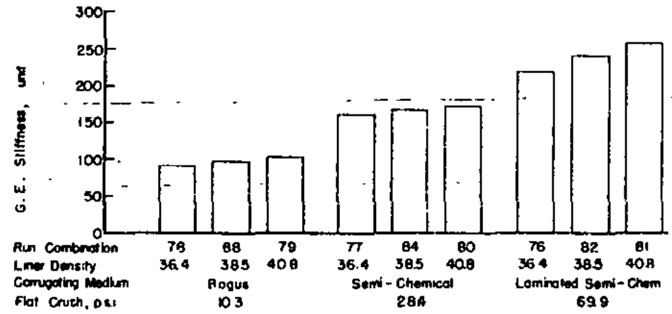


FIGURE 24. G. E. Stiffness Test Results of A-flute Combined Boards Made with Liners of Various Densities Each Fabricated with Corrugating Mediums at Three Levels of Combined Board Flat Crush

dicates that an increase in liner density was accompanied by an increase in the G. E. stiffness of the combined board.

The normal adhesion results shown in Figure 25 indicate that liner density in the range studied did not affect the magnitude of the bonding strength of the board.

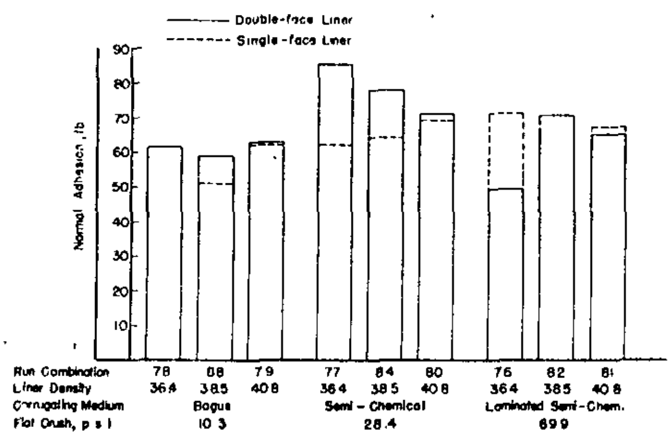


FIGURE 25. Normal Adhesion Test Results of A-flute Combined Boards Made with Liners of Various Densities Each Fabricated with Corrugating Mediums at Three Levels of Combined Board Flat Crush

THE EFFECT OF POSITION OF LINERS OF DIFFERENT WEIGHTS

Effect of Liner Position on Box Compression

Run Combinations 104 and 105 were made with unbalanced liner weights of 38 and 47 lb. Run Combination 104 had a 38-lb. single-face liner and 47-lb. double-face liner. This order was reversed for Run Combination 105. Both combinations were fabricated with the same corrugating medium. The top- and end-load box compression results are given in Table XIII and shown in graphic form in Figure 26. Observation of these data shows that with the lower weight liner on the inside, the boxes sustained a

TABLE XIII

THE EFFECT OF UNBALANCED LINER WEIGHTS ON THE COMPRESSION CHARACTERISTICS OF A-FLUTE BOXES

	Liners		Corrugating Medium		Combined Board	Boxes					
	Basis Weight, lb.					Top-Load Compression			End-Load Compression		
						Max. Load in Pounds Sustained in Deflection Ranges			Max. Load in Pounds Sustained in Deflection Ranges		
Run Combination	S.F. Liner	D.F. Liner	Type	Basis Weight, lb.	Flat Crush, p.s.i.	0-0.75 in.	0-1.00 in.	Deflection At Max. Load, inch	0-0.50 in.	0-1.00 in.	Deflection at Max. Load, inch
104	38.7	48.2	Semichemical	26.9	27.8	795	795	0.58	740	750	0.44
105	47.7	38.6	Semichemical	26.9	27.3	850	850	0.57	710	710	0.44

TABLE XIV

THE EFFECT OF UNBALANCED LINER WEIGHTS ON THE PHYSICAL CHARACTERISTICS OF A-FLUTE COMBINED BOARDS

	Liners Basis Weight, lb.		Corrugating Medium		Combined Board							
										Normal Adhesion, lb. per 6 sq. in.		
Run Combination	S.F. Liner	D.F. Liner	Type	Basis Weight, lb.	Basis Weight, lb.	Caliper, pt.	Bursting Strength, p.s.i.	G.E. Puncture, units	G.E. Stiffness, units	S.F. Liner	D.F. Liner	Flat Crush, p.s.i.
104	38.7	48.2	Semichemical	26.9	135	207	222	229	145	80	62	27.8
105	47.7	38.6	Semichemical	26.9	133	207	221	228	141	75	74	27.3

TABLE XV

THE EFFECT OF THE TYPE OF FLUTE CONSTRUCTION ON THE COMPRESSION CHARACTERISTICS OF BOXES

		Average Liner Characteristics			Corrugating Medium		Combined Board	Boxes					
								Top-Load Compression			End-Load Compression		
								Max. Load in Pounds Sustained in Deflection Ranges			Max. Load in Pounds Sustained in Deflection Ranges		
Run Combination	Flute	Basis Weight, lb.	Caliper, pt.	Bursting Strength, p.s.i.	Type	Basis Weight, lb.	Flat Crush, p.s.i.	0-0.75 in.	0-1.00 in.	Deflection At Max. Load, in.	0-0.50 in.	0-1.00 in.	Deflection At Max. Load, in
						(Starch Adhesive)							
85	A	43.6	13.7	106	Semichemical	26.8	27.9	865	890	0.68	800	800	0.38
107	B	43.2	13.4	108	Semichemical	26.8	48.9	735	735	0.40	810	810	0.23
						(Silicate Adhesive)							
106	A	43.1	13.4	108	Semichemical	26.8	26.4	960	960	0.62	795	800	0.46
108	B	43.2	13.4	107	Semichemical	26.6	57.3	840	840	0.46	830	830	0.26

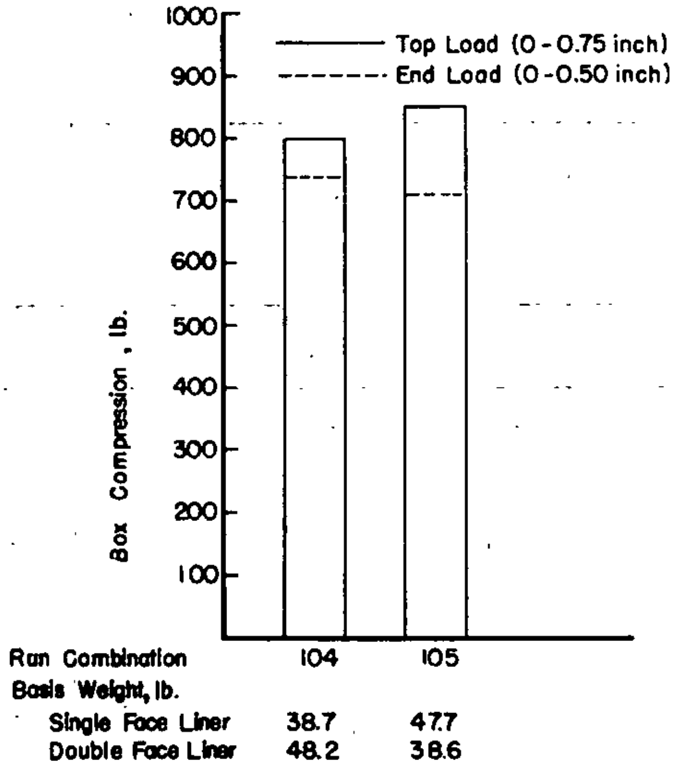


FIGURE 26. Compression Tests on A-flute Boxes Made with Unbalanced Liners

slightly higher end-load compression. However, when this position was reversed (lower weight on the outside), the boxes sustained a higher top-load compression. The differences noted do not appear to be of enough significance to advocate one form of construction in preference to the other.

Effect of Liner Position on Combined Board Characteristics

The combined board test results for Run Combinations 104 and 105 are presented in Table XIV. No graphic

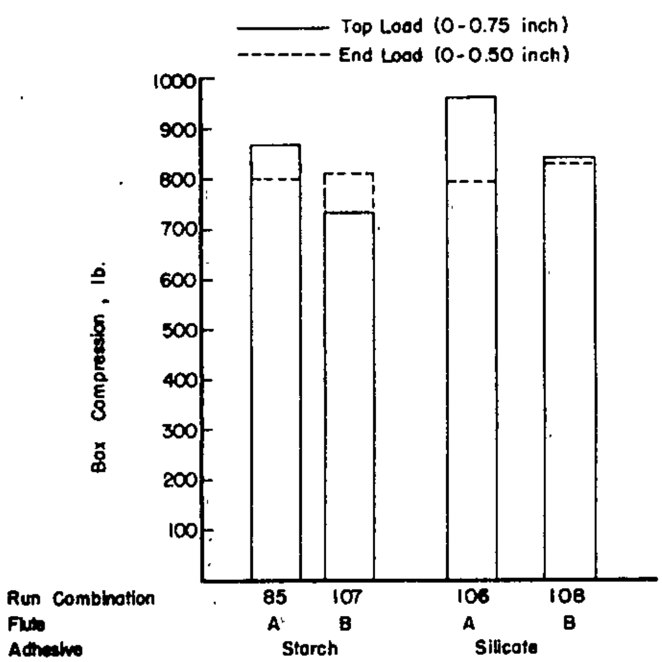


FIGURE 27. Compression Tests on A-flute and B-flute Boxes Made with the Same Adhesive

presentations of these data are given because of the fact that the results are nearly identical, there being very little difference in combined board strength by virtue of the liner positions being reversed.

THE EFFECT OF THE TYPE OF FLUTE (A VERSUS B)

Effect on Box Compression

Runs 85, 106, 107, and 108 were fabricated with similar 42-lb. liners and 26-lb. semichemical corrugating medium, the only intentional variables being the adhesive and the flute. The top- and end-load box compression test results are given in Table XV and are shown graphically in Figure 27. It may be seen that the top-load compression values for the A-flute boxes were higher than those for the B-flute boxes for both starch and silicate adhesive. However, as expected, the end-load box compression values for the B-flute boxes were slightly higher than those for the A-flute boxes.

Effect on Combined Board Characteristics

The comparisons of A- versus B-flute combined board properties are presented in Table XVI and illustrated graphically in Figures 28 and 29. The basis weight, caliper, and bursting strength versus G. E. puncture comparisons given in Figure 28 show that the basis weight of the B-flute combined board fabricated with starch adhesive was

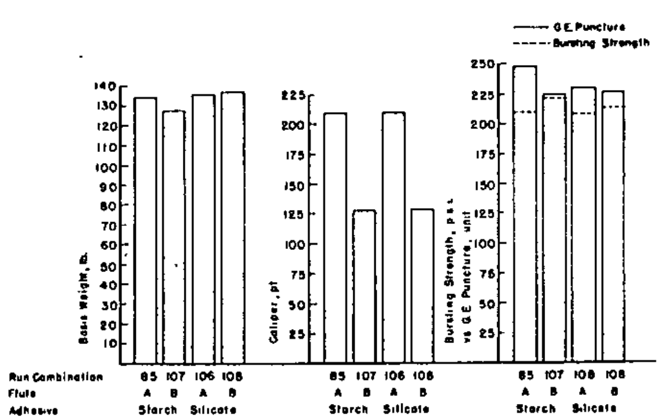


FIGURE 28. Basis Weight, Caliper, Bursting Strength, and G. E. Puncture Test Results of A-flute and B-flute Combined Board Made with the Same Adhesive

slightly lower than that for the A-flute. In the case of the board adhered with silicate, the basis weights for A- and B-flute were approximately the same. The decrease in combined board caliper associated with changing from A- to B-flute was very nearly the same for both adhesives. The comparison of bursting strength versus G. E. puncture indicates that the A-flute boards had slightly higher G. E. puncture values than the B-flute boards but slightly lower bursting strength values were associated with the A-flute boards than the B-flute.

In Figure 29 graphic presentations of the G. E. stiffness, normal adhesion, and flat crush test results are given. It may be seen that the G. E. stiffness values for A-flute board were considerably higher than for B-flute. The

TABLE XVI

THE EFFECT OF THE TYPE OF FLUTE CONSTRUCTION ON THE PHYSICAL CHARACTERISTICS OF COMBINED BOARDS FABRICATED WITH A STANDARD SEMICHEMICAL CORRUGATING MEDIUM

		Average Liner Characteristics			Combined Board							
Run Combination	Flute	Basis Weight, lb.	Caliper, pt.	Bursting Strength, p.s.i.	Basis Weight, lb.	Caliper, pt.	Bursting Strength, p.s.i.	G. E. Puncture, units	G. E. Stiffness, units	Normal Adhesion lb. per 4 sq. in. S. F. Liner	Normal Adhesion lb. per 4 sq. in. D. F. Liner	Flat Crush, p.s.i.
(Starch Adhesive)												
85	A	43.6	13.7	106	134	211	211	248	152	79	66	27.9
107	B	43.2	13.4	108	128	127	222	225	126	71	63	48.9
(Silicate Adhesive)												
106	A	43.1	13.4	108	136	211	208	230	151	67	58	26.4
108	B	43.2	13.4	107	137	129	213	227	134	73	96	57.3

TABLE XVII

THE EFFECT OF THE TYPE OF ADHESIVE ON THE COMPRESSION CHARACTERISTICS OF BOXES

			Average Liner Characteristics			Corrugating Medium		Combined Board	Boxes					
									Top-Load Compression			End-Load Compression		
Run Combination	Flute	Adhesive	Basis Weight, lb.	Caliper, pt.	Bursting Strength, p.s.i.	Type	Basis Weight, lb.	Flat Crush, p.s.i.	Max. Load in Pounds Sustained in Deflection Ranges 0-0.75 in.	Max. Load in Pounds Sustained in Deflection Ranges 0-1.00 in.	Deflection At Max. Load, inch	Max. Load in Pounds Sustained in Deflection Ranges 0-0.50 in.	Max. Load in Pounds Sustained in Deflection Ranges 0-1.00 in.	Deflection At Max. Load, inch
85	A	Starch	43.6	13.7	106	Semichemical	26.8	27.9	865	890	0.68	800	800	0.38
106	A	Silicate	43.1	13.4	108	Semichemical	26.8	26.4	960	960	0.62	795	800	0.46
107	B	Starch	43.2	13.4	108	Semichemical	26.8	48.9	735	735	0.40	810	810	0.23
108	B	Silicate	43.2	13.4	107	Semichemical	26.6	57.3	840	840	0.46	830	830	0.26

TABLE XVIII

THE EFFECT OF THE TYPE OF ADHESIVE ON THE PHYSICAL CHARACTERISTICS OF COMBINED BOARD FABRICATED WITH A STANDARD SEMICHEMICAL CORRUGATING MEDIUM

			Average Liner Characteristics			Combined Board							
Run Combination	Flute	Adhesive	Basis Weight, lb.	Caliper, pt.	Bursting Strength, p.s.i.	Basis Weight, lb.	Caliper, pt.	Bursting Strength, p.s.i.	G. E. Puncture, units	G. E. Stiffness, units	Normal Adhesion, lb. per 4 sq. in. S. F. Liner	Normal Adhesion, lb. per 4 sq. in. D. F. Liner	Flat Crush, p.s.i.
85	A	Starch	43.6	13.7	106	134	211	211	248	152	79	66	27.9
106	A	Silicate	43.1	13.4	108	136	211	208	230	151	67	58	26.4
107	B	Starch	43.2	13.4	108	128	127	222	225	126	71	63	48.9
108	B	Silicate	43.2	13.4	107	137	129	213	227	134	73	96	57.3

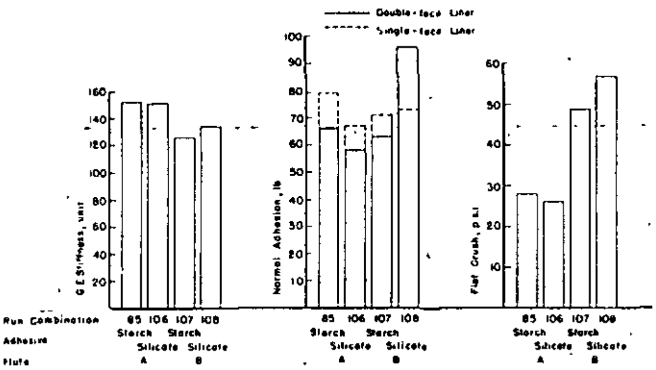


FIGURE 29. G. E. Stiffness, Normal Adhesion, and Flat Crush Test Results of A-flute and B-flute Combined Boards Made with the Same Adhesive

normal adhesion values showed no dependence on the type of flute and, as would be expected, the B-flute flat crush results were considerably higher than A-flute results.

THE EFFECT OF THE TYPE OF ADHESIVE (STARCH VERSUS SILICATE).

Effect on Box Compression

Runs 85, 106, 107, and 108 were fabricated from similar 42-lb. liners and 26-lb. semichemical corrugating medium, the only intentional variables being the flute and the adhesive, a situation which provided an opportunity to study not only the effect of flute construction, A- versus B-, both combined with the same adhesive, but also the effect of the adhesive itself on A- and B-flute board. The top- and end-load box compression test results are presented in Table XVII and illustrated graphically in Figure 30. Examination of these data indicates that the A-flute and B-flute boxes fabricated with silicate adhesive exhibited higher top- and end-load box compression results than those fabricated with starch adhesive. The A- and

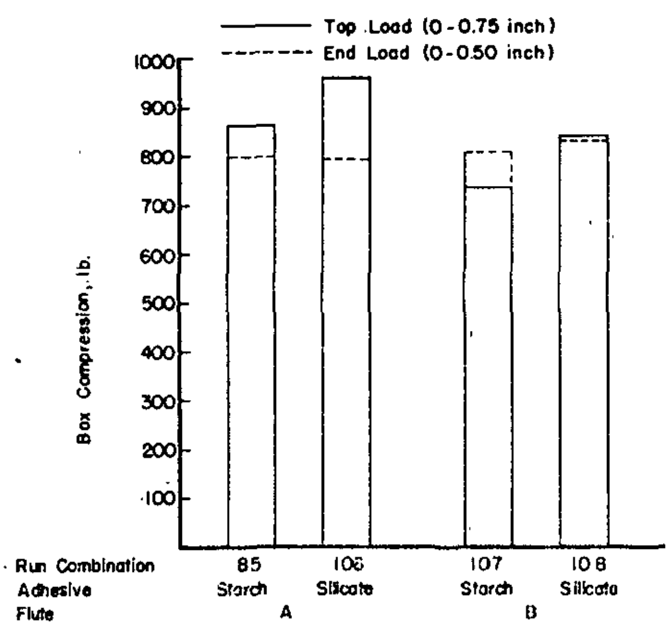


FIGURE 30. Compression Tests on A-flute and B-flute Boxes Made with Different Adhesives

B-flute end-load compression values were approximately the same for starch and silicate adhesives.

Effect on Combined Board Characteristics

The combined board test results are shown in Table XVIII and given graphic presentation in Figures 31 and 32. In Figure 31, the basis weight, caliper, and bursting strength versus G. E. puncture results are shown and

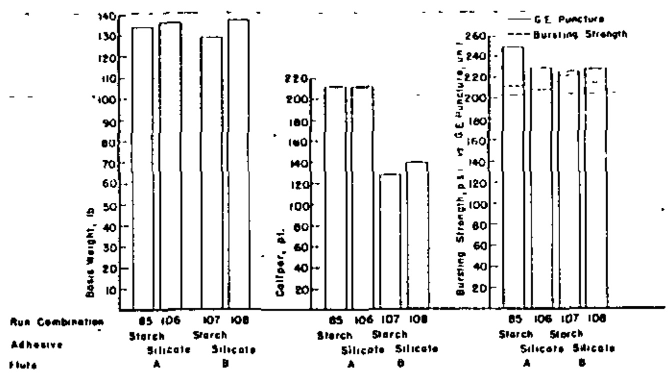


FIGURE 31. Basis Weight, Caliper, Bursting Strength, and G. E. Puncture Test Results of A-flute and B-flute Combined Boards Made with Different Adhesives

exhibit the following trends: The basis weight results were slightly higher for the A- and B-flute boards fabricated with silicate adhesive, whereas the caliper results were approximately the same for both adhesives and flutes. The other tests—bursting strength, G. E. puncture, G. E. stiffness, flat crush, and normal adhesion—did not appear to be affected significantly by the type of adhesive.

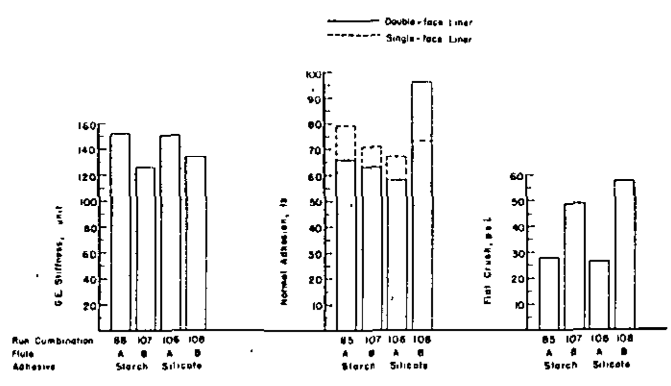


FIGURE 32. G. E. Stiffness, Normal Adhesion, and Flat Crush Test Results of A-flute and B-flute Combined Boards Made with Different Adhesives

THE EFFECT OF THE AMOUNT OF ADHESIVE

Run Combinations 85, 86, and 87 were fabricated with the same 42-lb. liners and a standard 26-lb. semichemical corrugating medium into A-flute board, the only variable being the amount of starch adhesive applied which was varied by changing the clearance between the adhesive pickup and wiper rolls from 0.008 to 0.015 inches. Run Combination 86 was fabricated with a "light" adhesive application (0.008-inch clearance); Run Combination 85

TABLE XIX

THE EFFECT OF THE AMOUNT OF ADHESIVE (STARCH) ON THE COMPRESSION CHARACTERISTICS OF A-FLUTE BOXES FABRICATED WITH A STANDARD SEMICHEMICAL CORRUGATING MEDIUM

	Starch Adhesive Data			Average Liner Characteristics			Combined Board Data			Boxes					
		Adhesive Roll Settings, inch								Top-Load Compression			End-Load Compression		
								Normal Adhesion, lb./4 sq. in.		Max. Load in Pounds Sustained in Deflection Ranges			Max. Load in Pounds Sustained in Deflection Ranges		
Run Combination	Adhesive Application	S.F.	D.F.	Basis Weight, lb.	Caliper, pt.	Bursting Strength, p.s.i.	Flat Crush, p.s.i.	D.F.	S.F.	0-0.75 in.	0-1.00 in.	Deflection At Max. Load, inch	0-0.50 in.	0-1.00 in.	Deflection At Max. Load, inch
86	Light	0.008	0.009	43.6	13.7	106	26.9	60	71	800	800	0.60	800	800	0.44
85	Regular	0.012	0.012	43.6	13.7	106	27.9	66	79	865	890	0.68	800	800	0.38
87	Heavy	0.015	0.015	43.6	13.7	106	27.2	72	88	865	870	0.67	740	740	0.34

TABLE XX

THE EFFECT OF THE AMOUNT OF ADHESIVE (STARCH) ON THE PHYSICAL CHARACTERISTICS OF A-FLUTE COMBINED BOARDS FABRICATED WITH A STANDARD SEMICHEMICAL CORRUGATING MEDIUM

	Starch Adhesive Data			Average Liner Characteristics			Combined Board							
		Adhesive Roll Settings, in.										Normal Adhesion lb./4 sq. in.		
Run Combination	Adhesive Application	S.F.	D.F.	Basis Weight, lb.	Caliper, pt.	Bursting Strength, p.s.i.	Basis Weight, lb.	Caliper, pt.	Bursting Strength, p.s.i.	G. E. Puncture, units	G. E. Stiffness, units	D. F. Liner	S. F. Liner	Flat Crush, p.s.i.
86	Light	0.008	0.009	43.6	13.7	106	132	211	209	231	140	60	71	26.9
85	Regular	0.012	0.012	43.6	13.7	106	134	211	211	248	152	66	79	27.9
87	Heavy	0.015	0.015	43.6	13.7	106	135	210	216	252	166	72	88	27.2

with a "regular" adhesive application (0.012-inch clearance); and Run Combination 87 with a "heavy" adhesive application (0.015-inch clearance).

Effect on Box Compression

The top- and end-load compression test results are shown in Table XIX and illustrated by means of a graph in Figure 33. It may be seen that for "regular" and "heavy" applications of adhesive the top-load box compression test results were higher than for the "light" application. However, the end-load box compression test results were approximately the same for the "regular" adhesive application and the "light" adhesive application, and somewhat lower for the "heavy" application than the "light" application. It appears that the "regular" application results in the best top- and end-load box compression.

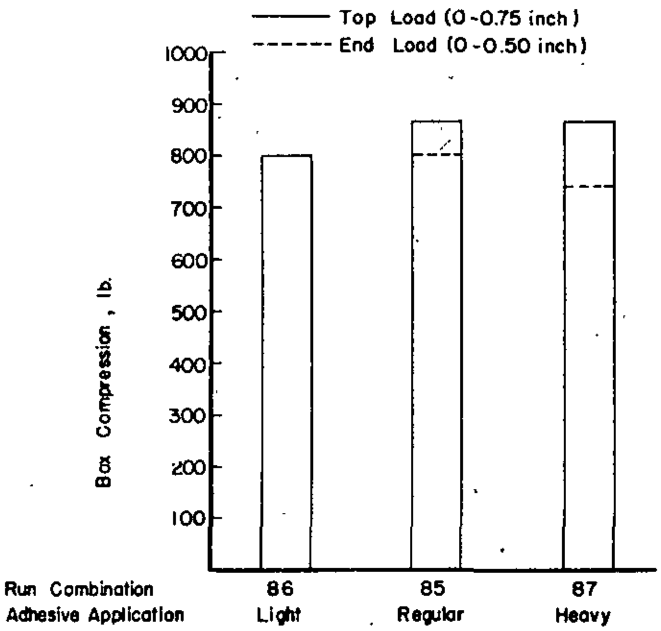


FIGURE 33. Compression Tests on A-flute Boxes Made with Light, Regular, and Heavy Applications of Adhesive

Effect on Combined Board

The combined board test results are given in Table XX and presented graphically in Figures 34 and 35. Figure 34 presents the basis weight, caliper, and bursting strength versus G. E. puncture test results. It may be noted that the basis weight results increased as the amount of adhesive increased as would be expected, and the caliper results remained relatively unchanged. The bursting strength versus G. E. puncture comparison indicates that both tests increased as the amount of adhesive increased. Figure 35 presents the normal adhesion, flat crush, and G. E. stiffness test results. The normal adhesion results are very interesting in that they indicate the adhesion strength of the board is somewhat proportional to the amount of adhesive used. It may be noted that the flat crush test results were not affected by the amount of adhesive but the G. E. stiffness results seem to bear a direct relationship—i.e., the results increased as the amount of adhesive increased.

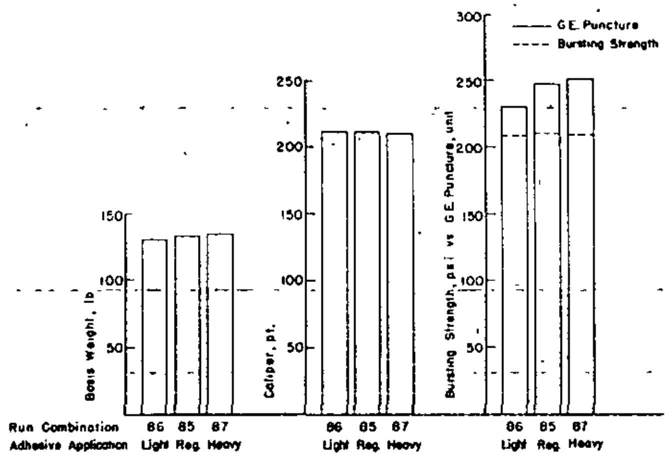


FIGURE 34. Basis Weight, Caliper, Bursting Strength, and G. E Puncture Test Results of A-flute Combined Boards Made with Light, Regular, and Heavy Applications of Adhesive

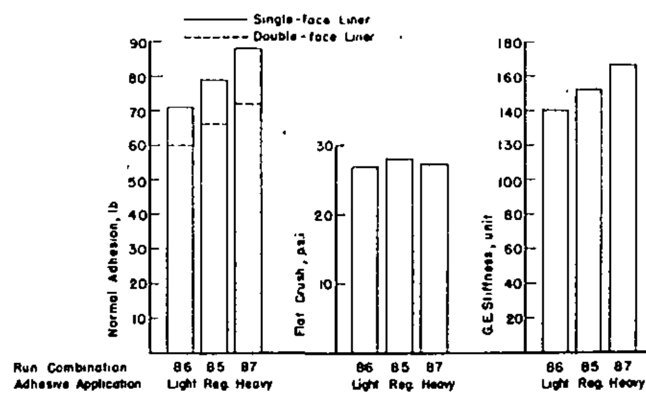


FIGURE 35. Normal Adhesion, Flat Crush, and G. E. Stiffness Test Results of A-flute Combined Boards Made with Light, Regular, and Heavy Applications of Adhesive

STATISTICAL ANALYSIS OF DATA

Relationships Between Various Component, Combined Board, and Box Tests

As was mentioned previously, one of the objectives of this study was to try to illuminate the relationship between (1) the G. E. puncture test and conventional tests on components and combined board and (2) box compression and the G. E. puncture test on combined board. Of interest also was the intercorrelation of tests on combined board and boxes as well as the relationship of conventional component and combined board tests to box compression.

In order to determine these relationships, the data have been divided into two groups. In one group, there are 16 different samples, 14 of which were fabricated with balanced 42-lb. kraft liners and different corrugating mediums, and two of which were fabricated with unbalanced liners (38 and 47 lb.). In the other group, there are 36 different samples, 34 of which were fabricated with balanced liners and two of which were fabricated with unbalanced liners varying in weight from 26 to 90 lb. and corrugating mediums of widely different characteristics.

Before the correlations are considered, it may be well to review briefly what they indicate and how they may be interpreted. 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 it can be applied to only the more obvious correlations. Another method of determining the pattern of the relationship between two tests is to plot the data. Absolute linear correlation exists if, when the plotted values are connected, a straight line results—i.e., all plotted points fall on a straight line. When the plotted points do not form a straight line, the correlation is not absolute. In fact, the more the plotted points deviate from the line, the less the correlation. A third method of determining the correlation is the statistical method by which so-called "correlation coefficients" are calculated. This method of analysis is a determination of simple correlation involving the interrelationship between two different tests. The relationship between two tests 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 closeness of the plotted points about the line of the least square is a measure of the correlation between the two tests in question. It is also 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 defined as

$$R = \sqrt{\frac{[n\Sigma xy - (\Sigma x)\ (\Sigma y)]}{[n\Sigma x^2 - (\Sigma x)^2]\ [n\Sigma y^2 - (\Sigma y)^2]}}$$

where x and y are the two quantities or characteristics, n is the number of items under consideration, and R is the correlation coefficent. The correlation coefficient is an expression of the degree to which two characteristics are related—i.e., it is a measure 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 the 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 inverse correlation.

Intercorrelation of Combined-Board Tests

The correlation coefficients obtained from the intercorrelation of combined board tests are shown in Tables XXI and XXII. The results given in Table XXI are based on 16 samples of combined board fabricated from liners ranging in weight from 38 to 47 lb.; the majority of the samples (16) were fabricated as balanced board using 42-lb. liners while only two were fabricated as unbalanced board using 38 and 47-lb. liners. The correlation coefficients for the relationship of basis weight to the other tests, it may be seen, are +0.80 for bursting strength, +0.91 for G. E. puncture, +0.83 for G. E. stiffness, and +0.92 for flat crush. The magnitude of these coefficients indicates that a relationship between the two tests involved does exist. Generally speaking, these coefficients tell us that the greater the weight, the greater also will be the magnitude of the bursting strength, G. E. puncture, G. E. stiffness, and flat crush tests. The intercorrelation of caliper with the other combined board tests indicates that there is little

TABLE XXI

SIMPLE CORRELATION COEFFICIENTS BETWEEN COMBINED BOARD TESTS

(Sixteen 200-lb. Series A-flute Combinations)

	Caliper	Bursting Strength	G. E. Puncture	G. E. Stiffness	Pin Adhesion S.F.	Pin Adhesion D.F.	Flat Crush
Basis weight	+0.65	+0.80	+0.91	+0.83	+0.21	−0.36	+0.92
Caliper		+0.37	+0.84	+0.84	+0.24	+0.08	+0.79
Bursting strength			+0.71	+0.68	+0.34	−0.29	+0.71
G. E. puncture				+0.98	+0.33	−0.05	+0.98
G. E. stiffness					+0.40	+0.06	+0.95
Pin adhesion, S.F.						+0.04	+0.38
Pin adhesion, D.F.							−0.16

dependence between caliper and bursting strength or pin adhesion but considerable dependence between caliper and G. E. puncture, G. E. stiffness, and flat crush. Bursting strength shows some relationship to G. E. puncture, G. E. stiffness, and flat crush. G. E. puncture is well correlated with G. E. stiffness and with flat crush. G. E. stiffness is also well correlated with flat crush. Pin adhesion does not appear to be well correlated with any of the tests. In summary, it may be stated that the best correlations exist between G. E. puncture and G. E. stiffness and G. E. puncture and flat crush, and the next best between G. E. stiffness and flat crush.

The results shown in Table XXII are based on 36 samples of combined board fabricated in 34 cases as balanced boards with liners ranging in weight from 26 to 90 lb. and in two cases as unbalanced board with 38 and 47-lb. liners. It may be noted from the data given in Tables XXI and XXII that broadening the range of liner weights improved the correlation coefficients for the relationships between basis weight and such tests as caliper, bursting strength, and G. E. puncture and reduced the correlation coefficients between basis weight and such tests as G. E. stiffness and flat crush. This readjustment in relationships when the population is expanded to include a much broader range of liner weights and other properties conforms to expectations in that the physical characteristics of the liners play a more important role and the significance of the corrugating medium is weakened. The correlation coefficients for the relationship of caliper to bursting strength, G. E. puncture, and G. E. stiffness are substantial in magnitude and indicate that an increase in weight would also result in an increase in these tests. Bursting strength appears to be moderately well correlated with G. E. puncture. As might be anticipated, G. E. puncture and G. E. stiffness are closely related. G. E. stiffness and flat crush appear to be correlated moderately.

Relationship of Combined Board and Box Tests

The correlation coefficients for the relationship of four combined board tests—bursting strength, G. E. puncture,

TABLE XXII

SIMPLE CORRELATION COEFFICIENTS BETWEEN COMBINED BOARD TESTS

(36 A-flute Combinations)

	Caliper	Bursting Strength	G. E. Puncture	G. E. Stiffness	Pin Adhesion S.F.	Pin Adhesion D.F.	Flat Crush
Basis weight	+0.93	+0.90	+0.93	+0.78	+0.37	+0.19	+0.39
Caliper		+0.92	+0.88	+0.76	+0.40	+0.41	+0.28
Bursting strength			+0.78	+0.62	+0.38	+0.34	+0.09
G. E. puncture				+0.95	+0.45	+0.24	+0.66
G. E. stiffness					+0.56	+0.30	+0.77
Pin adhesion, S.F.						+0.24	+0.29
Pin adhesion, D.F.							−0.14

TABLE XXIII

CORRELATION COEFFICIENTS BETWEEN COMBINED BOARD TESTS AND BOX COMPRESSION

Combined Board Tests	(36 A-flute Combinations) Top Compression	End Compression	(Sixteen 200-lb. Series A-flute Combinations) Top Compression	End Compression
Bursting strength	+0.87	+0.89	+0.60	+0.51
G.E. puncture	+0.94	+0.94	+0.94	+0.91
G.E. stiffness	+0.90	+0.87	+0.95	+0.95
Flat crush	+0.42	+0.40	+0.80	+0.89

TABLE XXIV

SIMPLE CORRELATION COEFFICIENTS BETWEEN COMPONENT AND COMBINED BOARD TESTS

(Sixteen 200-lb. Series A-flute Combinations)

Component Tests	Combined Board Tests: Bursting Strength	G.E. Puncture	G.E. Stiffness
Liner (S.F. + D.F.)			
Bursting strength	+0.18	+0.02	+0.11
G.E. puncture	+0.01	+0.15	+0.17
Ring compression, in	+0.16	+0.11	+0.16
Ring compression, across	+0.16	+0.13	+0.17
Tensile, in	+0.26	+0.08	+0.15
Tensile, across	+0.15	+0.20	+0.20
Corrugating medium			
Bursting strength	+0.17	+0.63	+0.69
Ring compression, in	+0.25	+0.71	+0.78
Ring compression, across	+0.16	+0.63	+0.71
Tensile, in	+0.24	+0.71	+0.77
Tensile, across	+0.24	+0.71	+0.78
Concora	+0.08	+0.55	+0.66
Single-fluter	+0.16	+0.66	+0.74

TABLE XXV

SIMPLE CORRELATION COEFFICIENTS BETWEEN COMPONENT TESTS AND BOX COMPRESSION
(Sixteen 200-lb. Series A-flute Combinations)

Components Tests	Box Compression	
	Top-load	End-load
Liner (S.F. and D.F.)		
Bursting strength	+0.07	+0.13
G. E. puncture	+0.11	+0.18
Ring compression, in	+0.08	+0.16
Ring compression, across	+0.10	+0.16
Tensile, in	+0.05	+0.14
Tensile, across	+0.11	-0.15
Corrugating medium		
Bursting strength	+0.60	+0.71
Ring compression, in	+0.72	+0.82
Ring compression, across	+0.64	+0.78
Tensile, in	+0.68	+0.79
Tensile, across	+0.71	+0.81
Concora	+0.64	+0.77
Single-fluter	+0.68	+0.81

G. E. stiffness, and flat crush—to top-load and end-load box compression are shown in Table XXIII for populations of 16 samples and 36 samples. It may be noted that for both populations, 16 and 36 samples, the best correlation coefficients are associated with the G. E. puncture and G. E. stiffness tests. The G. E. puncture test or combined board correlated substantially better with top-load and end-load box compression than bursting strength for both populations.

Relationship of Component Tests to Combined Board and Box Tests

The correlation coefficients for the relationships of various liner and corrugating medium tests to combined board and box tests are shown in Tables XXIV and XXV, respectively, for the 16-sample population and in Tables XXVI and XXVII for the 36-sample population. It is readily apparent from an inspection of Table XXIV (16-sample population) that none of the liner tests correlate well with the combined board tests. However, whereas none of the corrugating medium tests correlate well with combined board bursting strength, all of them seem to correlate fairly well with the G. E. puncture and G. E. stiffness tests on combined board. This phenomenon can be explained by the fact that the G. E. puncture and G. E. stiffness tests measure corrugating medium properties which the bursting strength test ignores. Also of interest in Table XXV is the poor correlation between liner tests and box compression for the 16 sample population. This may be explained by the fact that a very narrow range of liner weights was involved. On the other hand, the range of corrugating medium properties, weight included, was rather broad; and it may be noted that the correlation coefficients for the relationships between various corrugating medium tests and box compression were substantially better than they were for the liner relationships.

When the population is expanded to 36 samples, the relationships change considerably as may be seen from the tabulation of correlation coefficients shown in Table XXVI. The improvement in the correlation between the liner tests and combined board tests is readily apparent and results from the fact that the range of liner weights is much greater and naturally affects many of the tests which increase as the weight increases. Combined board bursting strength correlates best with the liner tests followed in order by G. E. puncture and G. E. stiffness. It may be seen in Table XXVII that bursting strength and cross-machine direction liner ring compression exhibit the best correlation coefficients for both top-load and end-load box compression followed very closely by cross-machine direction tensile. None of the corrugating medium tests correlate well with either combined board or box tests. This probably can be traced to the reduced effect of corrugating medium quality on combined board and box tests and the increased and dominant role of the liners when the range of liners weight is greatly enlarged as was the case for this population involving 36 samples.

Multiple Correlations of Component Tests versus Combined Board G. E. Puncture

The theory of multiple correlations has been discussed in previous reports. As a reference, the reader is invited to study Appendix B of a report entitled "Study of Paper Board Quality as Related to Fiber Box Performance Report Number 1 (Baseline Studies 1. The Evaluation of

TABLE XXVI

SIMPLE CORRELATION COEFFICIENTS BETWEEN COMPONENT AND COMBINED BOARD TESTS
(36 A-flute Combinations)

Component Tests	Combined Board Tests		
	Bursting Strength	G.E. Puncture	G.E. Stiffness
Liner (S.F. + D.F.)			
Bursting strength	+0.96	+0.75	+0.62
G.E. puncture	+0.93	+0.75	+0.55
Ring compression, in	+0.95	+0.73	+0.61
Ring compression, across	+0.97	+0.76	+0.61
Tensile, in	+0.88	+0.70	+0.60
Tensile, across	+0.96	+0.77	+0.59
Corrugating medium			
Bursting strength	+0.23	+0.45	+0.52
Ring compression, in	+0.20	+0.51	+0.61
Ring compression, across	+0.24	+0.46	+0.55
Tensile, in	+0.18	+0.45	+0.54
Tensile, across	+0.22	+0.50	+0.58
Concora	+0.17	+0.40	+0.52
Single-fluter	+0.23	+0.47	+0.58

TABLE XXVII

SIMPLE CORRELATION COEFFICIENTS BETWEEN COMPONENT TESTS AND BOX COMPRESSION
(36 A-flute Combinations)

Component Tests	Box Compression Top-load	End-load
Liner (S.F. and D.F.)		
Bursting strength	+0.87	+0.89
G.E. puncture	+0.80	+0.86
Ring compression, in	+0.86	+0.88
Ring compression, across	+0.87	+0.90
Tensile, in	+0.82	+0.83
Tensile, across	+0.84	+0.89
Corrugating medium		
Bursting strength	+0.40	+0.40
Ring compression, in	+0.43	+0.42
Ring compression, across	+0.42	+0.41
Tensile, in	+0.38	+0.38
Tensile, across	+0.43	+0.42
Concora	+0.40	+0.39
Single-fluter	+0.43	+0.43

Current Kraft Liners and Corrugating Mediums, Part II. Combined Boards and Boxes)" dated October, 1946.

The results of correlating various liners and corrugating medium tests versus the G. E. puncture test of the corresponding combined board are shown in Table XXVIII for sixteen samples of 200-pound series A-flute board. An inspection of Table XXVIII reveals that correlating the liner and medium tests resulted in correlation coefficients of only a mediocre quality, thus indicating that the two tests involved in each relationship are not intimately correlated with the G. E. puncture result of combined board.

In Table XXIX the same relationships have been calculated using a population of thirty-six combinations of different series board. The correlation coefficients are somewhat better for the various relationships but this is due to the fact that a broader range of liner and medium characteristics is involved rather than to an improvement in the intimacy of the various correlations. It may be observed in Table XXIX that fair correlations were obtained by relating liner tensile (across) and corrugating medium tensile (across) to combined board G. E. puncture. Correlations of similar magnitude were obtained by relating liner ring compression (in) and corrugating medium ring compression (in) to combined board G. E. puncture. The correlation coefficients were changed only very slightly by substituting the Single-fluter test or Concora medium test for corrugating medium ring compression (in). The results indicate, therefore, that we do not currently have a test or tests for the components which will adequately predict the G. E. puncture of combined board.

TABLE XXVIII

MULTIPLE CORRELATION COEFFICIENTS OF COMPONENT TESTS AND COMBINED BOARD G.E. PUNCTURE
(Sixteen 200-lb. Series A-flute Combinations)

Component Tests Liner	Corrugating Medium	Combined Board G.E. Puncture
Ring compression (across)	Ring compression (across)	+0.64
Ring compression (in)	Ring compression (in)	+0.71
Ring compression (across)	Single-fluter	+0.67
Ring compression (in)	Single-fluter	+0.67
Ring compression (across)	Concora	+0.57
Ring compression (in)	Concora	+0.56
Tensile (across)	Tensile (across)	+0.74
Tensile (in)	Tensile (in)	+0.72
Tensile (across)	Single-fluter	+0.68
Tensile (in)	Single-fluter	+0.66
Tensile (across)	Concora	+0.60
Tensile (in)	Concora	+0.55
G.E. puncture	Single-fluter	+0.67
G.E. puncture	Concora	+0.57

TABLE XXIX

MULTIPLE CORRELATION COEFFICIENTS OF COMPONENT TESTS AND COMBINED BOARD G.E. PUNCTURE
(36 A-flute Combinations)

Component Tests Liner	Corrugating Medium	Combined Board G.E. Puncture
Ring compression (across)	Ring compression (across)	+0.83
Ring compression (in)	Ring compression (in)	+0.85
Ring compression (across)	Single-fluter	+0.84
Ring compression (in)	Single-fluter	+0.83
Ring compression (across)	Concora	+0.82
Ring compression (in)	Concora	+0.81
Tensile (across)	Tensile (across)	+0.86
Tensile (in)	Tensile (in)	+0.81
Tensile (across)	Single-fluter	+0.84
Tensile (in)	Single-fluter	+0.81
Tensile (across)	Concora	+0.83
Tensile (in)	Concora	+0.78
G.E. puncture	Single-fluter	+0.83
G.E. puncture	Concora	+0.81