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THE EFFECT OF SIMULATED HANDLING ON THE COMPRESSION
PERFORMANCE OF CORRUGATED FIBERBOARD
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Bruce W. Crofts

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of the requirements for

M.S. degree in Packaging

S. Paul Singh, Ph.D.

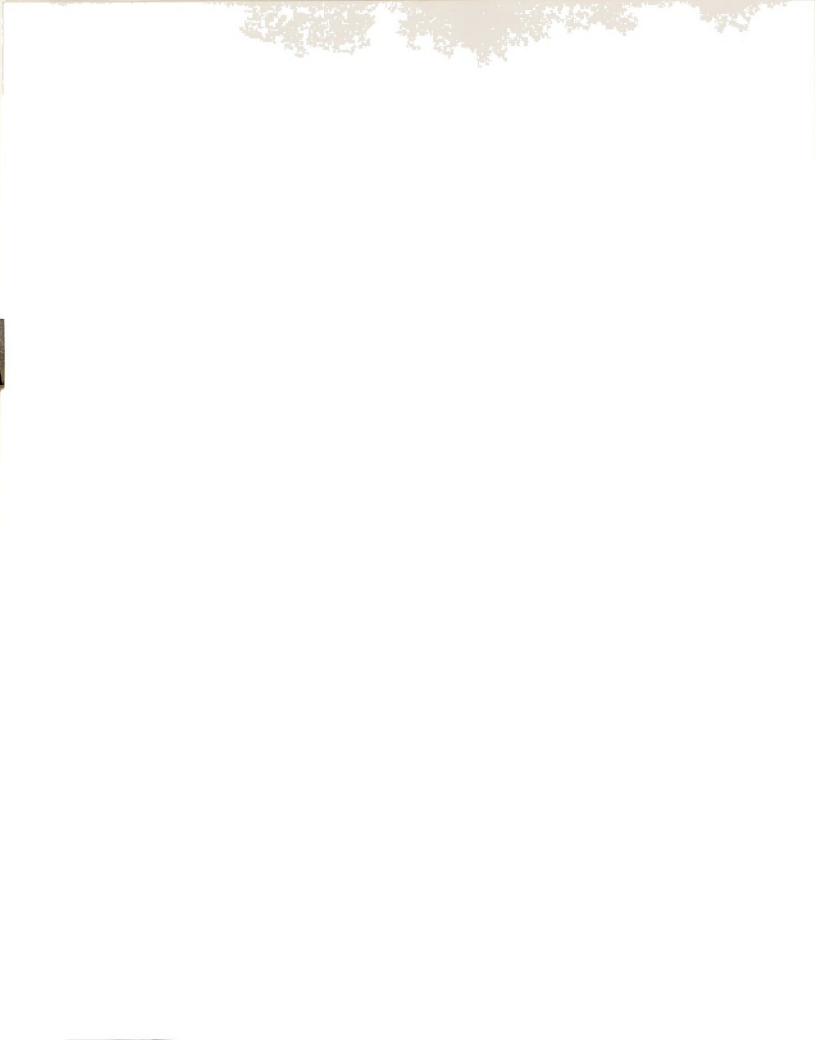
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THE EFFECT OF SIMULATED HANDLING ON THE COMPRESSION
PERFORMANCE OF CORRUGATED FIBERBOARD CONTAINERS

By

Bruce William Crofts

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

School of Packaging

1989

5678699

ABSTRACT

THE EFFECT OF SIMULATED HANDLING ON THE COMPRESSION PERFORMANCE OF CORRUGATED FIBERBOARD CONTAINERS

By

Bruce William Crofts

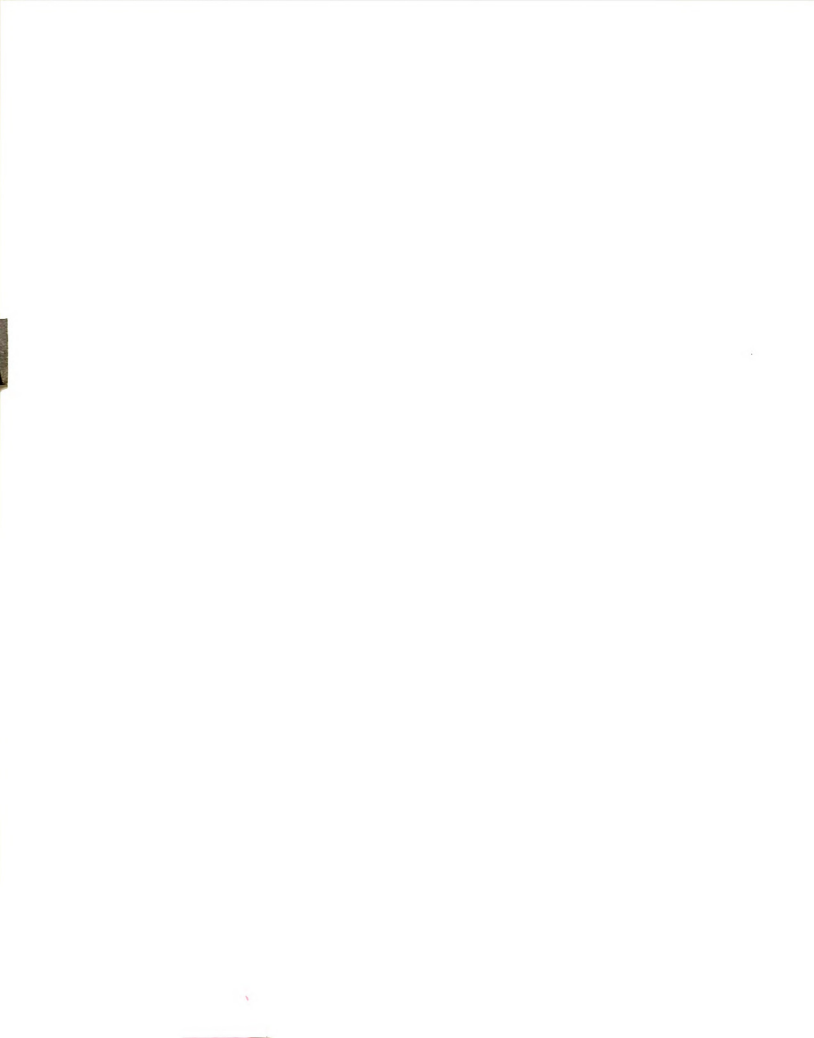
The ability of a corrugated fiberboard box to protect the contents within it is a function of the overall compression strength of the box. The corrugated container industry has been manufacturing corrugated fiberboard using bursting strength and basis weight specifications. These specifications do not accurately predict the ability of a box to meet performance requirements in a normal distribution environment.

This study describes the effect of package weight and the handling environment on the reduction of compression strength of corrugated containers. The mean compression strength and corresponding deflection values for three box sizes were evaluated as a function of package weight and drop height during handling. All tests performed were based on ASTM standards.

The mean overall box compression strength decreased as the package weights increased. The mean overall box compression strength decreased as the drop heights increased. The mean edge crush, flat crush and burst strength values did not decrease as the test conditions became more severe.

DEDICATION

This thesis is dedicated to my parents, Joseph W. Crofts and Hazel M. Crofts, for their support and belief in me. Also, to my loving wife, Janice L. Crofts, for all she has given me, including our son Adam Joseph Crofts.



ACKNOWLEDGEMENTS

I would like to thank my major advisor Dr. S. Paul Singh for his support and guidance through the graduate program. I would also like to express my gratitude to the members of my graduate committee, Dr. Gary Burgess and Dr. George Mase.

I am also indebted to Darren Pepple from Classic Container, Detroit MI, and John Michels from Frito Lay, Inc., Irving TX, for donating testing materials.

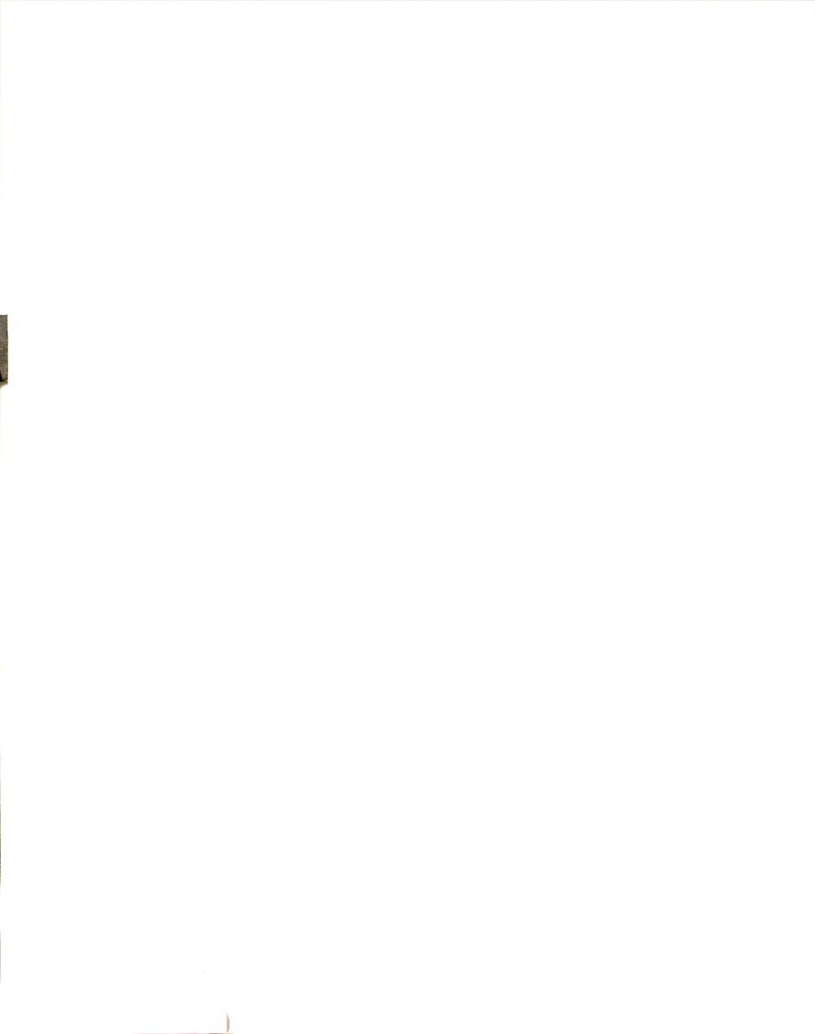


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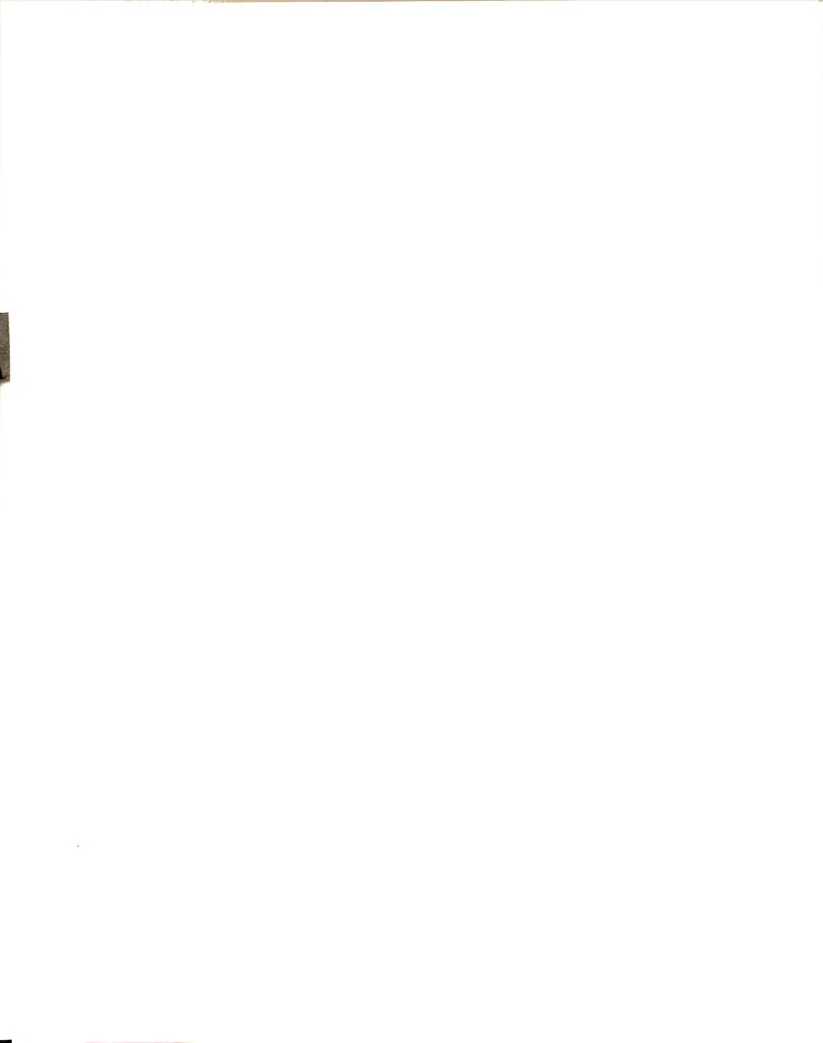
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1.0 INTRODUCTION

One of the primary functions of a package is to offer product protection. The compressive strength of a corrugated container is a means of predicting the performance of that package during stacking. Many studies have been done to develop empirical relationships that will predict the compression strength of corrugated fiberboard boxes. Most of these studies try to relate the compression strength of the box to the material properties of the corrugated fiberboard that was used to fabricate the box. Other factors that influence compression strength are the perimeter of the box (McKee, 1963), fatigue over the expected storage period and the humidity that the box is expected to encounter during distribution (Hanlon, 1984). All these methods use the material properties of the fiberboard used to manufacture the box and the static storage environment. There is a great need to develop an understanding of the effects of handling on compression strength of a regular slotted container (RSC). The compression strength after handling will also be a function of the package weight.

The objectives of this study were:

- 1) To evaluate the change in compression strength of corrugated containers as a function of drop height during handling.
- 2) To evaluate the change in compression strength of corrugated containers as a function of product-package gross weight for given drop heights.



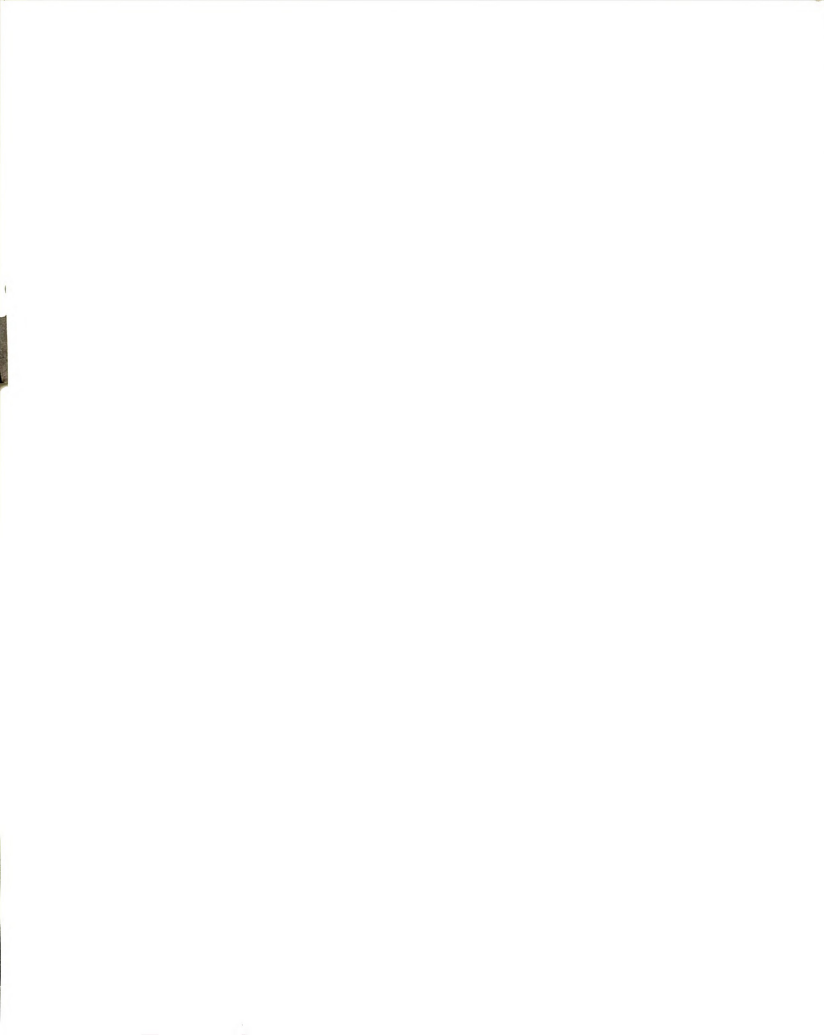
- 3) To evaluate corrugated material performance (edge crush, flat crush and burst strength) for control boxes and those subjected to handling and determine if a correlation exists between material and package performance.
- 4) To test different container systems and see if general patterns exist between material properties and corrugated fiberboard box compression performance after handling.

2.0 LITERATURE REVIEW

The corrugated fiberboard box is the primary package used by American manufacturers to contain and transport their product to the final consumer. The performance requirements for the corrugated fiberboard box are mostly dictated by the railroad and motor carrier industry of the United States. Godshall (1985) stated:

"The corrugated container industry has been making board specifications that have little if any correlation with compression properties. These specifications are those set by the carrier classifications board which, in the absence of other standards for grade classifications, have become the defacto standards for grade classifications of corrugated fiberboard. The corrugating industry in the United States has continued to manufacture corrugated fiberboard using bursting strength and basis weight specifications, as set forth by the carrier industries, because it has been to their economic advantage to support these specifications. They have ignored the findings of the research community and the needs of the shippers for compression strength. However, corrugated users are becoming more knowledgeable about the performance requirements of the transportation environment and are making stronger demands on their suppliers to meet their needs for greater box compressive strength."

Uniform Freight Classification Rule 41 (1978) and National Motor Freight Classification Item 222 (1978) require that single-wall, corrugated fiberboard boxes have a minimum bursting strength ranging from 125 psi. to 350 psi., with required minimum combined weight of facings ranging from 52 lbs. to 180 lbs. allowing for a contents weight of 20 lbs. to 120 lbs. Compression strength is not



mentioned in the standards.

There have been many formulas developed to estimate the compression strength of corrugated fiberboard boxes. McKee (1963) devised a formula that uses the box perimeter, the caliper of the board and the short column crush value to determine compressive strength of the fiberboard box described by,

$$P = 5.87 P_m (hZ)^{1/2} \quad (2-1)$$

where:

P = The maximum top-to-bottom compressive force of an RSC.

P_m = The edgewise compressive strength of the board (lbs/in).

h = The board caliper (inches).

Z = The box perimeter (inches).

This formula applies only to standard conditions (23 degrees C, 50% relative humidity). There are no factors that account for box height, product weight, or the dynamic effects of the distribution environment.

Hanlon (1984) states that a rule of thumb for long-term storage is to use one-fourth of the compressive strength of a corrugated box as a safe load when predicting stacking strength. He also states that a more accurate method would be to calculate the fatigue factor for the length of time in storage. In addition a factor for moisture can be used depending on the climate and the season.

The perimeter of the box, the Mullen burst test, and the type of flute are the primary factors used with his method for predicting the compression strength of the corrugated fiberboard box. Again, there is no consideration given to the dynamic loading that occurs during normal distribution and product handling before a container is usually stored under static conditions. Also, with the recent trends toward just-in-time delivery and lower inventory levels the fatigue factor becomes less of a reality.

Adams (1987) states that the mean top-to-bottom compressive strength of corrugated boxes increased after subjection to vibration. In his study he claims that the height of each support corner becomes more similar after the box has been exposed to resonant vibration. This equating of support heights allows each corner to offer equal strength and he reported an 8 percent increase in top-to-bottom compressive strength.

Singh (1987) investigated the effect of mechanical shocks on the compressive strength of corrugated containers. The results show that as much as 75 % of the original compressive strength can be lost in multiple handling. The more severe Drop Treatment yielded lower compression strength values for the same box style.

Langlois (1989) studied the effect of using a fixed versus floating platen when testing the compression strength of corrugated fiberboard boxes. There was a significant difference in the compression strength of the containers measured using fixed and floating platens. The floating platen gave a compression value 3.6% higher than the fixed platen.

2.1 COMPRESSION STRENGTH TEST METHODS:

The American Society for Testing and Materials (ASTM) (D 685-73) Standard Method of Conditioning Paper and Paper Products for Testing lists two steps in the conditioning process for knocked down shipping containers. The samples must first be preconditioned in an atmosphere of 10 to 35% relative humidity at a temperature of 22 to 40 degrees C for a period of 12 to 16 hours. After this the boxes should be conditioned in an atmosphere of $50 \pm 2.0\%$ R.H. and 23.0 ± 1.0 degrees C for at least 16 hours prior to testing.

The ASTM (D 775-80) Standard Method for Drop Test for Loaded Boxes provides an indication of the ability of a box to withstand the damage caused by the sudden shock of dropping a package. All the surfaces of the box are identified as follows: Top as one, side as two, bottom as three, left side as four, near end as five, far end as six. The manufacturers joint should be identified by the numbers of the two surfaces that form that edge.

The National Safe Transit Association (NSTA) project 1A recommends drop sequences and drop heights to simulate handling. The procedures are basic performance tests for the product and package. Their severity should be increased to adapt to unusual distribution situations. Project 1A requires the test equipment to comply with ASTM D-775 and TAPPI T-801 standards.

The drop heights chosen are as follows:

- (1) Packaged Products less than 61 pounds.
NO ALTERNATIVE
 - 1 Thru 20.99 (lbs) - 30 (in)
 - 21 Thru 40.99 (lbs) - 24 (in)
 - 41 Thru 60.99 (lbs) - 18 (in)

The ASTM standard (D 642-76) is the Standard Method of Compression Testing for Shipping Containers. The method suggests testing containers without contents, sealing the box to avoid distortions that may affect its load-bearing ability, and applying a preload of 50 lb force with the load being applied at a constant rate of 0.5 ± 0.1 in/min.

The ASTM standard (D 1225-66) is the Standard Method for Flat Crush of Corrugated Fiberboard. This method is used to determine the resistance of the flutes in corrugated board to a crushing force applied perpendicular to the surface of the board when tested under prescribed conditions. This test may be used on single-wall or single-face corrugated board. It is not suitable for measuring the crushing resistance of double-wall or triple-wall board. The specimen cutter is used to cut samples without crushing areas at the cut edges to form a circular specimen, either 5 sq. in. or 10 sq. in.

The ASTM standard (D 2808-69) includes Compressive Strength of Corrugated Fiberboard (Short Column Test). This method is used to determine the edgewise compressive strength, parallel to the flutes, of single-wall, double-wall or triple-wall corrugated fiberboard.

The Technical Association of the Pulp and Paper Industry (TAPPI) standard T 810 om-80 is the standard for Bursting Strength of Corrugated Fiberboard. This method describes the procedure for measuring the bursting strength of single-wall and double-wall corrugated and solid fiberboard. Testing of double-wall board is not recommended since it is difficult to get sufficiently simultaneous bursts of the multiple facings.

3.0 MATERIALS AND METHODS

3.1 SAMPLE CONTAINERS:

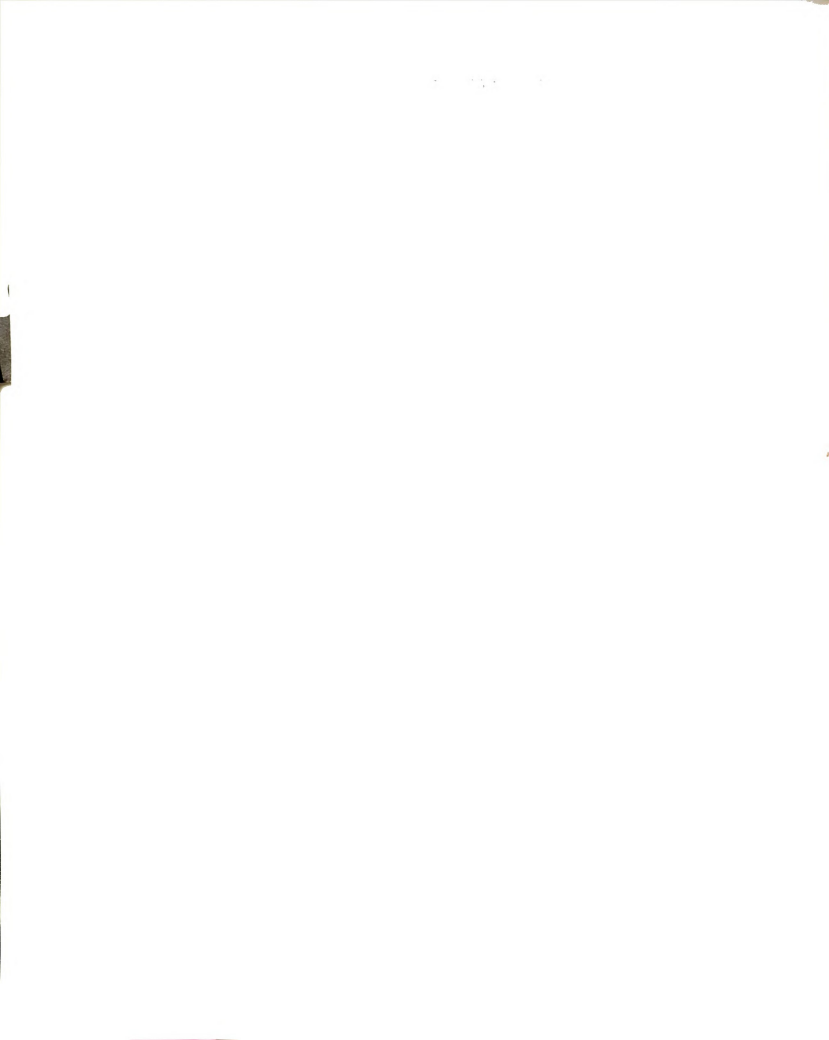
Three sets of regular slotted containers (R.S.C.) were used in this study. Box Types A and B had shortened flaps because they were not taped but tucked during distribution.

Box Type A Specification:

Corrugation	- C flute, double faced, single-wall.
Dimensions	- 20.5" x 16 " x 14" (L x W x D)
Bursting Test	- 200 psi.
Minimum Combined	
Weight of Facings	- 84 lbs. per 1000 square feet.
Size Limit	- 75 inches
Gross Weight Limit	- 65 lbs.
Manufactured by Stone Container Corporation of Detroit, Michigan for Frito Lay, Inc., Texas.	

Box Type B Specification:

Corrugation	- C flute, double faced, single-wall.
Dimensions	- 20.5" x 16" x 8" (L x W x D)
Bursting Test	- 200 psi.
Minimum Combined	
Weight of Facings	- 84 lbs. per 1000 square feet.
Size Limit	- 75 inches.
Gross Weight Limit	- 65 lbs.
Manufactured by Stone Container Corporation of Detroit, Michigan for Frito Lay, Inc.	



Box Type C Specification:

Corrugation	- C flute, double-wall.
Dimensions	- 12" x 12" x 12" (L x W x D)
Bursting Test	- 200 psi.
Minimum Combined	
Weight of Facings	- 92 lbs. per 1000 square feet.
Size Limit	- 75 inches.
Gross Weight Limit	- 65 lbs.
Manufactured by Classic Container Corporation of Detroit, Michigan.	

3.2 CONDITIONING:

Boxes were received knocked-down from Frito Lay and Classic Container. A glued manufacturer's joint (glued by the corrugated box manufacturer) was used on box type A and B. Box type C was stitched with 1/2" metal staples. All the box samples were conditioned at 72 degrees F, at $50.0 \pm 2.0 \% \text{RH}$ for at least 16 hours. Temperature and relative humidity were monitored using a Bendix recording Hygro-thermograph (model 594). After conditioning, empty boxes were sealed top and bottom as outlined in ASTM standard D 642 with 3M brand Scotch Brand Tape - Core Series 2-3300 plastic sealing tape.

TESTING PROCEDURE:3.3 Cushion and Weight Fixture Preparation

Each box type was measured and 2 inch HB-45 Ethafoam (Dow

Chemical Co.) cut to fit the interior (Figures 1, 2 and 3). A 45 degree angle was chosen for the lateral support corners so that a full face cushion would be present on all four lateral sides. This was considered important so as to keep the drop effects as uniform as possible on all four corrugated sides. Concrete bricks were used to increase weight for all three gross weights of box type A (Figure 1). The concrete bricks were also used for the lower weight of box type B (Figure 2). Because of box size restrictions steel weights were used for the two higher gross weights of box type B and both gross weights of box type C (Figure 2, 3). The Ethafoam was cut to provide a tight fit so the weight would not move within the cushion fixture. All the weights were evenly balanced so as not to produce bias results (Figure 1, 2, 3).

3.4 Drop Testing Sequence:

The box faces were marked according to ASTM standard D 775-80 before testing. After they were marked, and packed, each box was sealed with 3M Scotch Brand Tape (core series 2-3300) according to ASTM standard D 642-76.

Every sample was subjected to the following drop sequence:

- | | |
|-------------|----------------------------------|
| First Drop | - Flat (on the bottom face). |
| Second Drop | - Edge (on the 3-6 bottom edge). |
| Third Drop | - Edge (on the 3-4 bottom edge). |
| Fourth Drop | - Flat (on the small 6 face). |
| Fifth Drop | - Flat (on the opposite 5 face). |
| Sixth Drop | - Flat (on the large 4 face). |



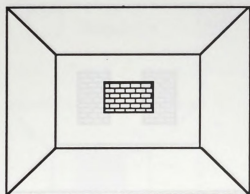
Ethafoam



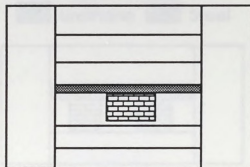
Urethane



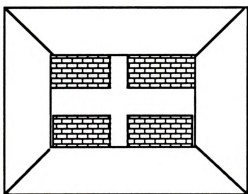
Brick



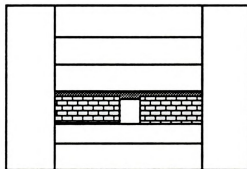
Top View 15.5 lbs.



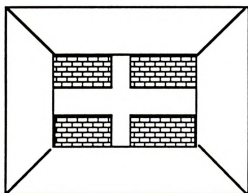
Front View 15.5 lbs



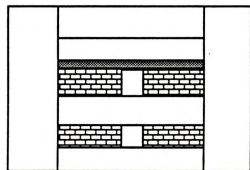
Top View 29.5 lbs



Front View 29.5 lbs

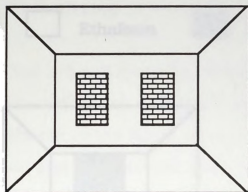


Top View 46 lbs

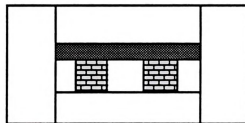
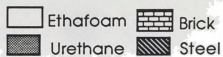


Front View 46 lbs

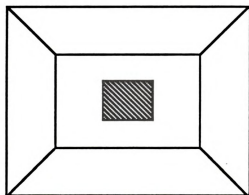
Figure 1
Cushion and Weight placement Box A



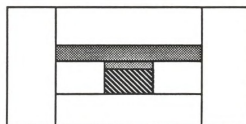
Top View 15.75 lbs



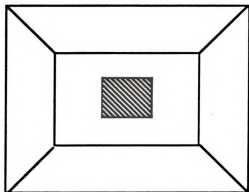
Front View 15.75 lbs



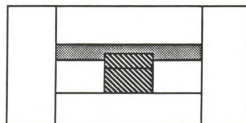
Top View 31.5 lbs



Front View 31.5 lbs



Top View 44.3 lbs



Front View 44.3 lbs

Figure 2
Cushion and Weight placement Box B



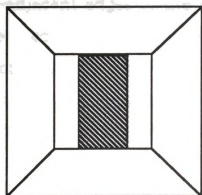
Ethafoam



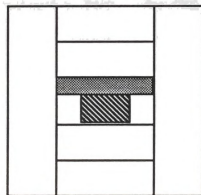
Urethane



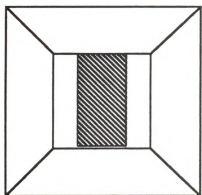
Steel



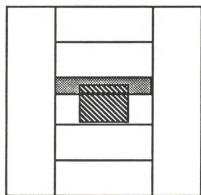
Top View 30 lbs



Front View 30 lbs



Top View 42.5 lbs



Front View 42.5 lbs

Figure 3
Cushion and Weight placement Box C

Seventh Drop - Flat (on the opposite 2 face).

The 3-6 and 3-4 edges were chosen because they were the two non-adjacent edges to the 5-2 manufacture's joint. The flat drops were chosen in the hopes of increasing the consistency between box samples and to note the effect of flute crush on the overall box compression strength. Corner drops were not included so as to minimize the amount of variance between box test samples.

3.5 Drop Test Equipment:

All drop test were done using a Lansmont Corporation Drop Tester (Model No. PDT-56E). All drops were done on a surface that conforms to ASTM standard D 775-80.

3.6 Compression Testing:

After each sample had been through Drop Sequence A the contents were removed and the boxes were resealed. All samples were compression tested using a Lansmont Corporation Compression Tester (Model No. 76-5K). This machine had digital readout of force $\pm 3\%$ accuracy and deflection $\pm 1\%$ linearity. With an after test readout of peak force and corresponding deflection (lbs. & in.) This machine was designed to test in accordance with ASTM D 642 and TAPPI T-804. The compression test speed was 0.5 inches per minute.

3.7 Edge Crush Testing:

The compressive strength of corrugated fiberboard (short

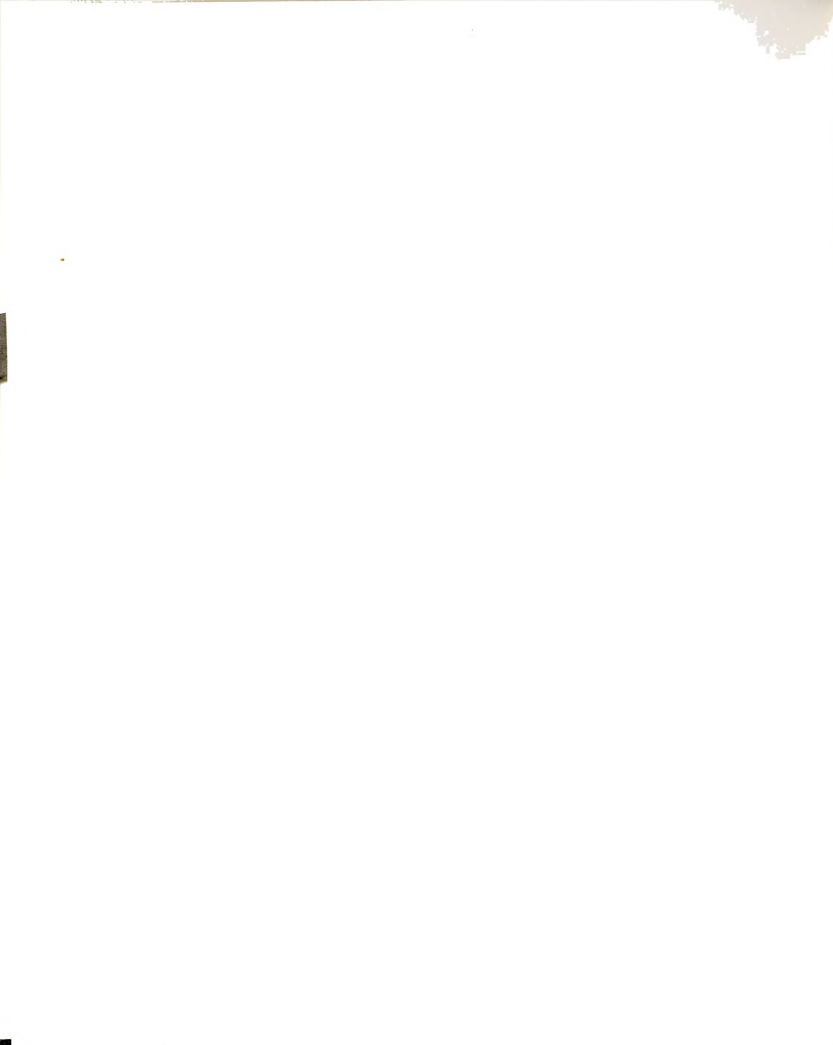
column test) was performed for each grouping of test samples. Specimens were cut and tested in accordance with ASTM standard D 2808-69. Specimens were cut from a new control set, as well as, the control set that had been subjected to the compression test. The only deviation from the ASTM standard was that each specimen was not dipped in molten paraffin to a depth of 1/4 inch on each loading edge. The specimens were tested on a Series 400 Crush Tester (Model No. 17-36) manufactured by Test Machines Incorporated (TMI).

3.8 Flat Crush Testing:

The Flat Crush of corrugated fiberboard test was performed for each grouping of test samples. Specimens were cut and tested in accordance with ASTM standard D 1225-66. Specimens were cut from the same new control set as the edge crush specimens and from the control set that had been subjected to the box compression test. The specimens were tested on a Series 400 Crush Tester (Model No. 17-36) manufactured by Test Machines Inc. (TMI).

3.9 Bursting Strength Testing:

The Bursting Strength of corrugated fiberboard test was performed for each grouping of test samples. Specimens were cut and tested in accordance with TAPPI standard T 810 om-80. Again, specimens were cut from the same new control set as the edge and flat crush specimens and from the control set that had been subjected to the box compression test. The specimens were tested on



a Mullen Tester (Drive No. 5741, Serial No. 65 A 126) manufactured
by B.F. Perkins and Son, Inc.

4.0 DATA AND RESULTS

One hundred twenty corrugated fiberboard boxes were put through the drop sequence to determine the change in compression strength as a function of package weight and drop height during handling. Table 1 shows the experimental design for box types A, B and C. A control set of ten boxes were tested for each box type.

After the boxes were tested specimens were cut from random boxes to evaluate material properties after handling for each group. These were compared against a control set of samples. A total of three hundred specimens were tested for edge crush compressive strength. A total of two hundred twenty specimens were tested each for flat crush and bursting strength. All testing was done at 23 degrees C, and 50 % R.H.

4.1 Box A:

Table 2 contains the average compression strength values for this box for the various weights and drop heights. The individual values for each five samples are listed in Table 16 (Appendix A). Ten samples were compression tested as a control. The mean compression strength value for the control boxes was 805.6 lbs.. As the gross weight increased, the compressive strength decreased. Also, as the drop height increased there was a decrease in the compressive strength. The compressive strength reduced as much as 41% for the package weight of 46 lbs. and a 30 inch drop height. Figure 4 is a graphical representation of the data in Table 2. Based on this data,



TABLE 1

EXPERIMENTAL DESIGN

<u>Package Type</u>	<u>Gross Weight (lbs)</u>	<u>Drop Height (in)</u>
		18
A	15.5	24
		30
		18
A	29.5	24
		30
		18
A	46.0	24
		30
		18
B	15.75	24
		30
		18
B	31.50	24
		30
		18
B	44.30	24
		30
		18
C	30.00	24
		30
		18
C	42.50	24
		30

TABLE 2

COMPRESSION STRENGTH OF BOX A

<u>Drop Height</u> <u>(in)</u>	<u>Gross Weight</u> <u>(lbs)</u>	<u>Mean Compression</u> <u>Strength (lbs)</u>	<u>Std.Dev.</u>	<u>C.O.V.</u>
control	control	805.6	66.170	.082
18	15.5	734.6	25.958	.035
18	29.5	608.6	34.639	.057
18	46.0	523.6	45.416	.087
24	15.5	695.4	73.550	.106
24	29.5	558.2	19.773	.035
24	46.0	497.6	45.863	.092
30	15.5	634.0	83.917	.132
30	29.5	507.6	21.887	.043
30	46.0	472.4	30.051	.064

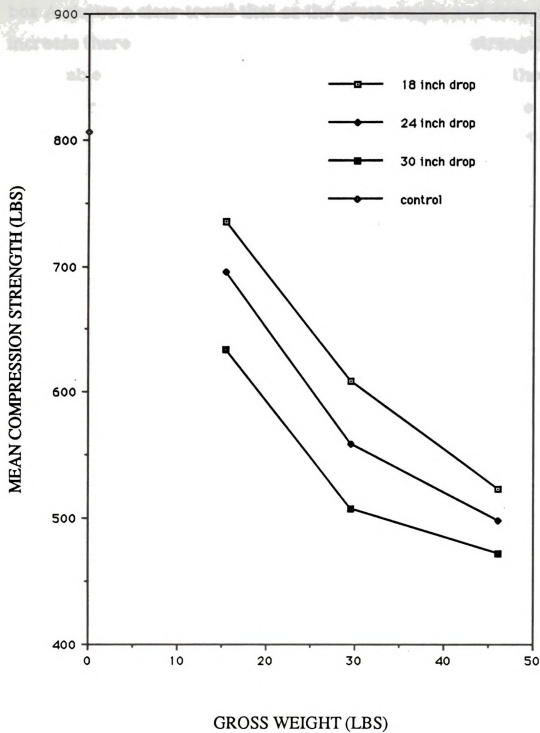


FIGURE 4: COMPRESSION STRENGTH OF BOX A

box A shows a clear trend that as the gross weight and drop height increase there is a decrease in overall box compression strength.

Table 3 contains the deflection results for box A for the same weight and drop height conditions described above. The mean deflection value for the control box was 0.357 inches. The individual values for each five samples are listed in Table 16 (Appendix A). The coefficient of variation (C.O.V.) is also listed for the various deflection values. Due to high values of C.O.V. no trends can be predicted for box A over the various weights and drop heights.

After the boxes were subjected to the drop sequence, specimens were cut from each test group for material tests. These specimens were used to determine the edge crush (short column test) of the corrugated fiberboard subjected to handling. Table 4 contains the mean edge crush results for box A at the various weights and drop heights. The individual values for each five samples are listed in Table 19 (Appendix B).

Specimens were cut from the same boxes to evaluate bursting strength for each of the test groups. The specimens were taken at random from each of the boxes used in the edge crush test. Table 5 contains the mean bursting strength results for box A at the various weights and drop heights. The individual values for each five samples are listed in Table 22 (Appendix C).

Lastly, specimens were cut from the remaining corrugated fiberboard to determine the flat crush values at the various weights and drop heights. Table 6 contains the mean flat crush results for box A at the various weights and drop heights. The individual values for

TABLE 3

DEFLECTION ANALYSIS OF BOX A

Drop Height (in)	Gross Weight (lbs)	Mean Deflection (in)	Std.Dev.	C.O.V.
control	control	.357	.029	.082
18	15.5	.524	.092	.175
18	29.5	.622	.185	.297
18	46.0	.380	.030	.078
24	15.5	.542	.047	.087
24	29.5	.494	.182	.368
24	46.0	.438	.099	.227
30	15.5	.600	.065	.108
30	29.5	.388	.022	.057
30	46.0	.420	.086	.205

TABLE 4

SHORT COLUMN TEST OF BOX A

<u>Drop Height (in)</u>	<u>Gross Weight (lbs)</u>	<u>Mean Load (lbs)</u>	<u>Mean Load Unit Width (lbs/in)</u>	<u>Std.Dev.</u>	<u>C.O.V.</u>
control	control	52.26	26.13	2.13	0.082
control-post	compr.	41.99	20.99	1.87	0.089
18	15.5	45.76	22.88	2.46	0.108
18	29.5	49.03	24.51	1.50	0.061
18	46.0	53.39	26.69	2.12	0.080
24	15.5	51.73	25.86	2.45	0.096
24	29.5	53.42	26.71	2.06	0.077
24	46.0	51.05	25.52	2.71	0.106
30	15.5	52.40	26.20	1.47	0.056
30	29.5	54.70	27.35	1.77	0.065
30	46.0	50.29	25.14	1.39	0.055



TABLE 5

BURSTING STRENGTH OF BOX A

Drop Height (in)	Gross Weight (lbs)	Avg.Burst (psi)	Std.Dev.	C.O.V.
control	control	177.5	17.36	0.098
control-post	compression	140.5	24.84	0.177
18	15.5	169.5	27.06	0.160
18	29.5	161.5	16.13	0.100
18	46.0	174.0	13.93	0.080
24	15.5	166.5	24.80	0.149
24	29.5	165.5	23.92	0.144
24	46.0	176.5	20.01	0.113
30	15.5	156.0	23.85	0.153
30	29.5	151.0	16.70	0.111
30	46.0	173.5	14.15	0.082

TABLE 6

FLAT CRUSH OF BOX A

<u>Drop Height</u> <u>(in)</u>	<u>Gross Weight</u> <u>(lbs)</u>	<u>Mean Load</u> <u>(psi)</u>	<u>Std.Dev.</u>	<u>C.O.V.</u>
control	control	29.61	2.85	0.096
control-post	compression	33.45	2.40	0.072
18	15.5	27.57	5.02	0.182
18	29.5	30.66	5.28	0.172
18	46.0	30.41	5.09	0.167
24	15.5	30.42	4.26	0.140
24	29.5	31.41	4.46	0.142
24	46.0	28.83	4.99	0.173
30	15.5	30.37	5.44	0.179
30	29.5	28.86	4.60	0.159
30	46.0	31.13	3.91	0.126

each five samples are listed in Table 24 (Appendix D).

4.2 Box B:

Table 7 contains the average compression strength results for this box for the various weights and drop heights. The individual values for each five samples are listed in Table 17 (Appendix A). Ten samples were compression tested as a control. The mean compression strength value for the control boxes was 617.1 lbs. As the gross weight increased, the compressive strength decreased. Also, as the drop height increased there was a decrease in the compressive strength. The compressive strength reduced as much as 27.6% for the package weight of 44.3 lbs. and a 30 inch drop height. Figure 5 is a graphical representation of the data in Table 7. Based on this data, box B shows a clear trend that as the gross weight and drop height increase there is a decrease in overall box compression strength.

Table 8 contains the deflection results for box B for the same weight and drop height conditions described above. The individual values for each five samples are listed in Table 17 (Appendix A). Due to high values of C.O.V. no trends can be predicted for box B over the various weights and drop heights.

Table 9 contains the mean edge crush results for box B at the various weights and drop heights. The individual values for each five samples are listed in Table 20 (Appendix B).

Table 10 contains the mean bursting strength results for box B at the various weights and drop heights. The individual values for each five samples are listed in Table 23 (Appendix C).

Table 11 contains the mean flat crush results for box B at the

TABLE 7

COMPRESSION STRENGTH OF BOX B

Drop Height (in)	Gross Weight (lbs)	Mean Compression Strength (lbs)	Std.Dev.	C.O.V.
control	control	617.1	42.326	.069
18	15.75	556.6	13.691	.025
18	31.5	527.2	62.789	.119
18	44.3	479.4	29.214	.061
24	15.75	511.8	48.873	.095
24	31.5	491.2	18.988	.039
24	44.3	459.6	23.320	.051
30	15.75	483.8	29.559	.061
30	31.5	449.2	64.232	.143
30	44.3	447.0	18.044	.040

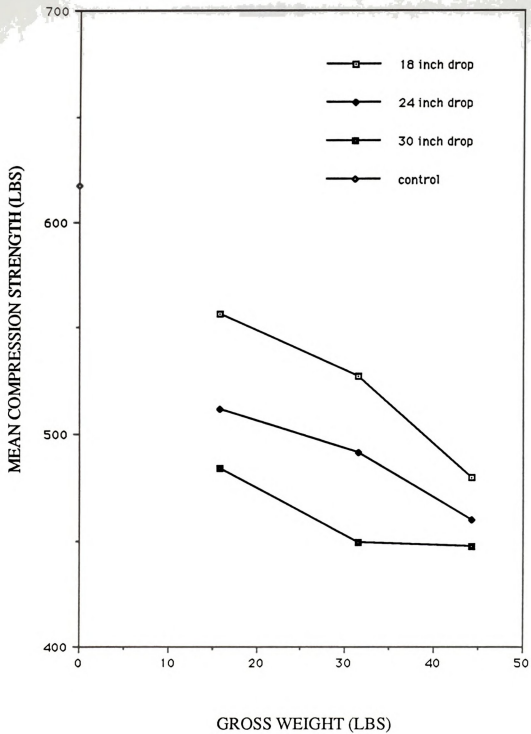


FIGURE 5: COMPRESSION STRENGTH OF BOX B

TABLE 8

DEFLECTION ANALYSIS OF BOX B

Drop Height (in)	Gross Weight (lbs)	Mean Deflection (in)	Std.Dev.	C.O.V.
control	control	.321	.044	.138
18	15.75	.416	.068	.163
18	31.5	.396	.111	.279
18	44.3	.386	.051	.132
24	15.75	.404	.070	.174
24	31.5	.370	.018	.048
24	44.3	.368	.025	.067
30	15.75	.368	.057	.156
30	31.5	.350	.051	.147
30	44.3	.322	.041	.128

TABLE 9

SHORT COLUMN TEST OF BOX B

<u>Drop Height (in)</u>	<u>Gross Weight (lbs)</u>	<u>Mean Load (lbs)</u>	<u>Mean Load Unit Width (lbs/in)</u>	<u>Std.Dev.</u>	<u>C.O.V.</u>
control	control	49.32	24.66	1.72	0.070
control-post	compr.	53.30	26.65	2.33	0.087
18	15.75	55.94	27.97	1.15	0.041
18	31.50	55.75	27.87	1.33	0.048
18	44.30	57.52	28.76	1.34	0.047
24	15.75	54.38	27.19	1.41	0.052
24	31.50	58.89	29.44	1.02	0.035
24	44.30	56.31	28.15	1.04	0.037
30	15.75	54.49	27.24	1.35	0.049
30	31.50	53.83	26.91	1.02	0.038
30	44.30	58.61	29.15	1.23	0.042

TABLE 10

BURSTING STRENGTH OF BOX B

Drop Height (in)	Gross Weight (lbs)	Mean Burst (psi)	Std.Dev.	C.O.V.
control	control	153.5	12.66	0.082
control-post compression		154.0	27.18	0.176
18	15.75	174.0	20.22	0.116
18	31.50	220.5	21.96	0.099
18	44.30	210.5	36.36	0.173
24	15.75	195.5	22.19	0.113
24	31.50	214.0	26.15	0.122
24	44.30	232.0	28.21	0.122
30	15.75	210.5	18.63	0.088
30	31.50	219.0	26.34	0.120
30	44.30	227.0	29.60	0.130

TABLE 11

FLAT CRUSH OF BOX B

Drop Height (in)	Gross Weight (lbs)	Mean Load (psi)	Std.Dev.	C.O.V.
control	control	22.06	4.20	0.190
control-post	compression	27.35	6.52	0.238
18	15.75	24.37	5.07	0.208
18	31.50	22.96	4.83	0.211
18	44.30	25.42	5.64	0.222
24	15.75	24.83	4.18	0.168
24	31.50	23.44	6.19	0.264
24	44.30	23.85	5.13	0.215
30	15.75	22.38	7.28	0.325
30	31.50	23.72	6.05	0.255
30	44.30	20.28	4.48	0.221

various weights and drop heights. The individual values for each five samples are listed in Table 25 (Appendix D).

4.3 Box C:

Table 12 contains the average compression strength results for this box for the various weights and drop heights. The individual values for each five samples are listed in Table 18 (Appendix A). Ten samples were compression tested as a control. The mean compression strength value for the control boxes was 1231.5 lbs. As the gross weight increased, the compressive strength decreased. Also, as the drop height increased there was a decrease in compressive strength. The compressive strength reduced as much as 24.2% for the package weight of 42.5 lbs. and a 30 inch drop height. Figure 6 is a graphical representation of the data in Table 12. Based on this data, box C shows a clear trend that as the gross weight and drop height increase there is a decrease in overall box compression strength.

Table 13 contains the deflection results for box B for the same weight and drop height conditions described above. The individual values for each five samples are listed in Table 18 (Appendix A). Due to high values of C.O.V. no trends can be predicted for box C over the various weights and drop heights.

Table 14 contains the mean edge crush results for box C at the various weights and drop heights. The individual values for each five samples are listed in Table 21 (Appendix B).

Table 15 contains the compression strength reduction results for box A, B and C. There is a decrease in compression strength for all three box types as the weight and drop height were increased.



TABLE 12

COMPRESSION STRENGTH OF BOX C

Drop Height (in)	Gross Weight (lbs)	Mean Compression Strength (lbs)	Std.Dev.	C.O.V.
control	control	1231.5	56.339	.046
18	30	1076.6	113.526	.105
18	42.5	960.8	94.101	.098
24	30	976.4	137.134	.140
24	42.5	944.4	56.602	.060
30	30	948.0	106.401	.112
30	42.5	933.0	64.647	.069

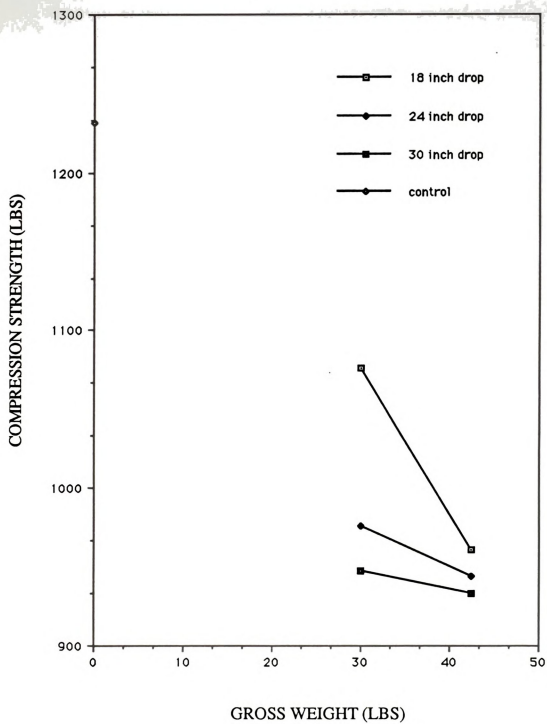


FIGURE 6: COMPRESSION STRENGTH OF BOX C

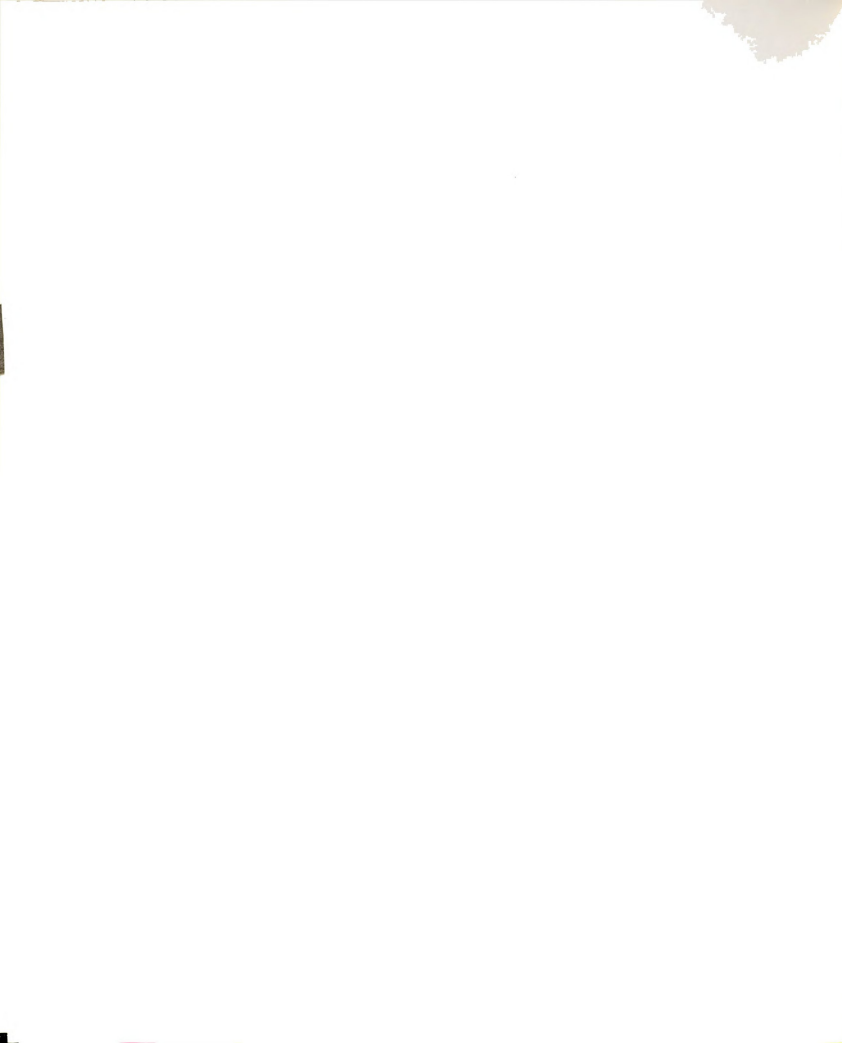


TABLE 13

DEFLECTION ANALYSIS OF BOX C

Drop Height (in)	Gross weight (lbs)	Mean Deflection (in)	Std.Dev.	C.O.V.
control	control	.537	.050	.094
18	30	.588	.083	.142
18	42.5	.558	.064	.115
24	30	.566	.081	.143
24	42.5	.600	.064	.107
30	30	.586	.078	.133
30	42.5	.614	.039	.064

TABLE 14

SHORT COLUMN TEST OF BOX C

<u>Drop Height (in)</u>	<u>Gross Weight (lbs)</u>	<u>Mean Load (lb)</u>	<u>Mean Load Unit Width (lbs/in)</u>	<u>Std.Dev.</u>	<u>C.O.V.</u>
control	control	101.98	50.99	2.29	0.045
control-post	compr.	103.69	51.84	1.32	0.025
18	30.0	105.09	52.54	1.58	0.030
18	42.5	102.03	51.01	1.79	0.035
24	30.0	102.80	51.40	1.52	0.029
24	42.5	107.10	53.55	1.47	0.027
30	30.0	103.06	51.53	1.84	0.036
30	42.5	104.20	52.10	1.58	0.030

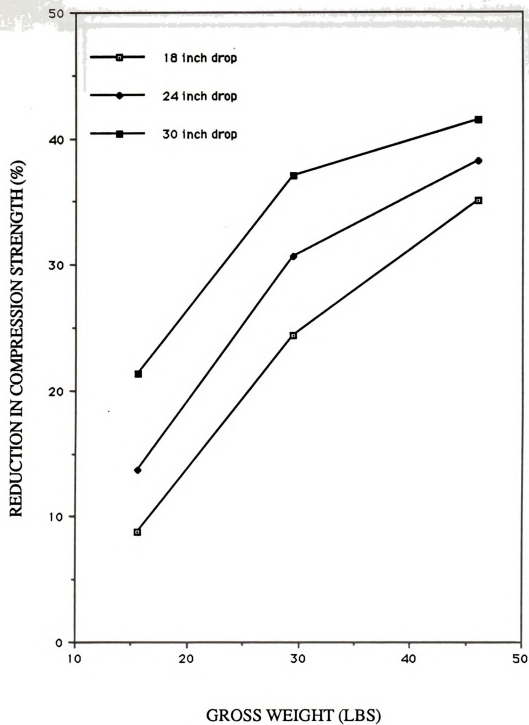


TABLE 15
COMPRESSION REDUCTION

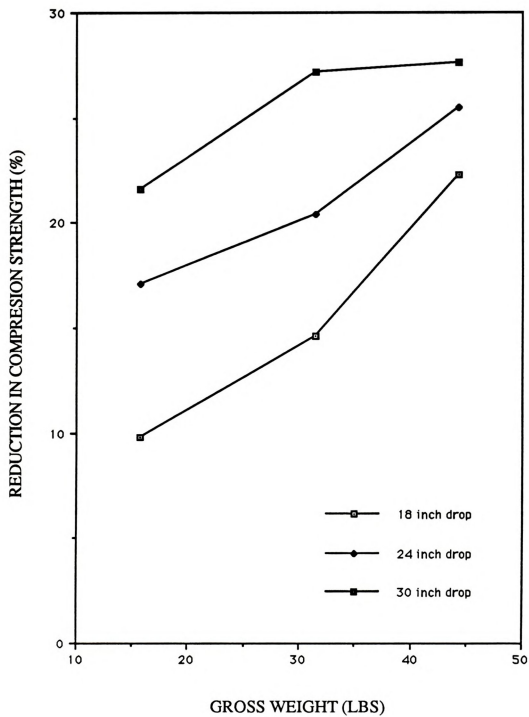
Package Type	Drop Height (in)	Gross Weight (lbs)	Compression Strength Untested (lbs)	% Reduction After Drop Sequence
		15.50	805.6	8.8
A	18	29.50	805.6	24.4
		46.00	805.6	35.0
		15.50	805.6	13.7
A	24	29.50	805.6	30.7
		46.00	805.6	38.2
		15.50	805.6	21.3
A	30	29.50	805.6	37.0
		46.00	805.6	41.4
		15.75	617.1	9.8
B	18	31.50	617.1	14.6
		44.30	617.1	22.3
		15.75	617.1	17.1
B	24	31.50	617.1	20.4
		44.30	617.1	25.5
		15.75	617.1	21.6
B	30	31.50	617.1	27.2
		44.30	617.1	27.6
		30.00	1231.5	12.6
C	18	42.50	1231.5	22.0
		30.00	1231.5	20.7
C	24	42.50	1231.5	23.3
		30.00	1231.5	23.0
C	30	42.50	1231.5	24.2

Figures 7, 8 and 9 are graphical representations of the data in Table

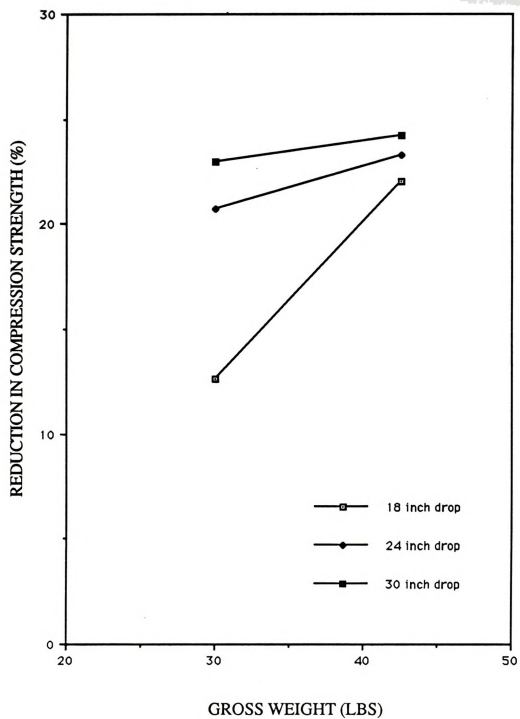
15.



**FIGURE 7: COMPRESSION STRENGTH REDUCTION
OF BOX A**



**FIGURE 8: COMPRESSION STRENGTH REDUCTION
OF BOX B**



**FIGURE 9: COMPRESSION STRENGTH REDUCTION
OF BOX C**

5.0 CONCLUSIONS

Following are the conclusions of this study:

1. The mean overall box compression strength decreased as the drop heights increased for all three box types.
2. The mean overall box compression strength decreased as the gross weights increased for all three box types.
3. The corrugated material properties, namely, edge crush, flat crush and burst strength did not show any significant changes as a result of handling for all three box types.

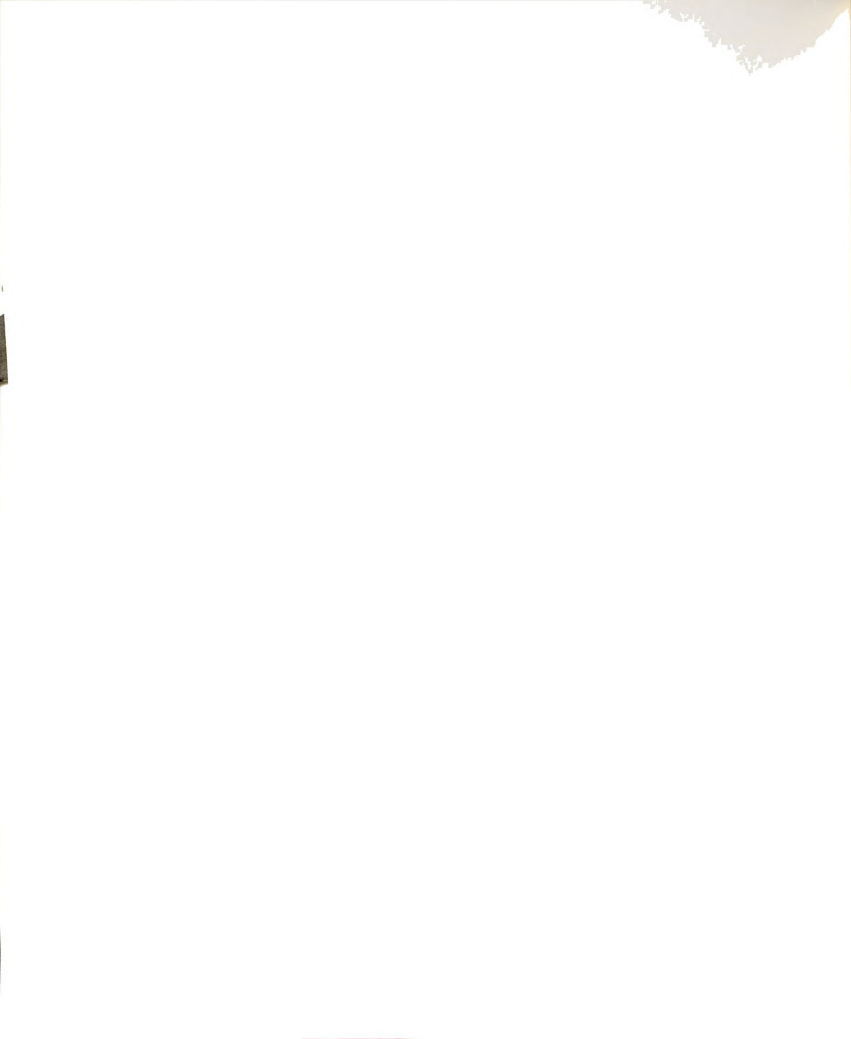
6.0 RECOMMENDATIONS

1. Environmental considerations: All testing was performed at standard conditions ASTM D 685-73, temperature and relative humidity were not evaluated. Testing should be done to see if these trends are the same in severe conditions.
2. Box style variation: All testing was performed on regular slotted containers (R.S.C.). More corrugated box sizes and styles should be tested to see if these trends are valid.

3. Edge crush testing: Because the edge crush values are used to predict box compression strength, materials from the same lot should be tested before and after performance testing.

4. Field environment testing: With recent advances in environmental data recording, an effort should be made to more closely define the hazards of distribution. Accurate handling simulation can only result from an acute understanding of the actual handling environment.

APPENDICES



APPENDIX A

COMPRESSION AND DEFLECTION DATA

TABLE 16

Compression and Deflection Data
BOX A (20.5" x 16" x 14")

Box A Control

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	741	.37
2	779	.35
3	795	.37
4	779	.33
5	779	.33
6	836	.39
7	898	.34
8	944	.42
9	713	.32
10	792	.35
$\bar{X}$	805.600	.357
std.dev.	66.170	.029
c.o.v.	0.082	.082

Box A Drop height = 18 in. ; Gross weight = 15.5 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	718	.52
2	721	.69
3	765	.53
4	703	.43
5	766	.45
$\bar{X}$	734.600	.524
std.dev.	25.960	.092
c.o.v.	0.035	.175

Box A Drop height = 24 in. ; Gross weight = 15.5 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	680	.51
2	688	.48
3	789	.55
4	572	.62
5	748	.55
$\bar{X}$	695.400	.542
std.dev.	73.550	.047
c.o.v.	0.106	.087

Box A Drop height = 30 in. ; Gross weight = 15.5 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	732	.63
2	541	.68
3	535	.63
4	718	.57
5	644	.49
$\bar{X}$	634.000	.600
std.dev.	83.917	.065
c.o.v.	0.132	.108

Box A Drop height = 18 in. ; Gross weight = 29.5 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	636	.61
2	628	.54
3	547	.33
4	638	.86
5	594	.77
$\bar{X}$	608.600	.622
std.dev.	34.639	.185
c.o.v.	0.057	.297



Box A Drop height = 24 in. ; Gross weight = 29.5 lbs.

Test #	Compression Strength (lbs)	Deflection (in)
1	566	.47
2	533	.36
3	589	.85 *
4	562	.41
5	541	.38
$\bar{X}$	558.200	.494 $\frac{w/out}{*}$.405
std.dev.	19.773	.182 .041
c.o.v.	0.035	.368 .102

Box A Drop height = 30 in. ; Gross weight = 29.5 lbs.

Test #	Compression Strength (lbs)	Deflection (in)
1	521	.41
2	519	.38
3	524	.41
4	509	.39
5	465	.35
$\bar{X}$	507.600	.388
std.dev.	21.887	.022
c.o.v.	0.043	.057

Box A Drop height = 18 in. ; Gross weight = 46 lbs.

Test #	Compression Strength (lbs)	Deflection (in)
1	588	.35
2	521	.38
3	477	.39
4	560	.43
5	472	.35
$\bar{X}$	523.600	.380
std.dev.	45.416	.030
c.o.v.	0.087	.078

Box A Drop height = 24 in. ; Gross weight = 46 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	462	.31
2	551	.60
3	556	.38
4	466	.41
5	453	.49
$\bar{X}$	497.600	.438
std.dev.	45.863	.099
c.o.v.	0.092	.227

Box A Drop height = 30 in. ; Gross weight = 46 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	445	.37
2	503	.40
3	495	.59
4	428	.38
5	491	.36
$\bar{X}$	472.400	.420
std.dev.	30.051	.086
c.o.v.	0.064	.205

TABLE 17

Compression and Deflection Data
BOX B (20.5" x 16" x 8")

Box B Control

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	677	.32
2	531	.26
3	672	.34
4	572	.27
5	654	.27
6	600	.39
7	622	.38
8	613	.35
9	606	.34
10	624	.29
$\bar{X}$	617.100	.321
std.dev.	42.326	.044
c.o.v.	0.069	.138

Box B Drop height = 18 in. ; Gross weight = 15.75 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	536	.35
2	551	.47
3	575	.49
4	553	.32
5	568	.45
$\bar{X}$	556.600	.416
std.dev.	13.691	.068
c.o.v.	0.025	.163

Box B Drop height = 24 in. ; Gross weight = 15.75 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	506	.49
2	607	.35
3	483	.49
4	472	.35
5	491	.34
$\bar{X}$	511.800	.404
std.dev.	48.873	.070
c.o.v.	0.095	.174

Box B Drop height = 30 in. ; Gross weight = 15.75 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	519	.28
2	504	.36
3	498	.36
4	456	.38
5	442	.46
$\bar{X}$	483.800	.368
std.dev.	29.559	.057
c.o.v.	0.061	.156

Box B Drop height = 18 in. ; Gross weight = 31.5 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	477	.41
2	469	.27
3	545	.59
4	641	.40
5	504	.31
$\bar{X}$	527.200	.396
std.dev.	62.789	.111
c.o.v.	0.119	.279

Box B Drop height = 24 in. ; Gross weight = 31.5 lbs.

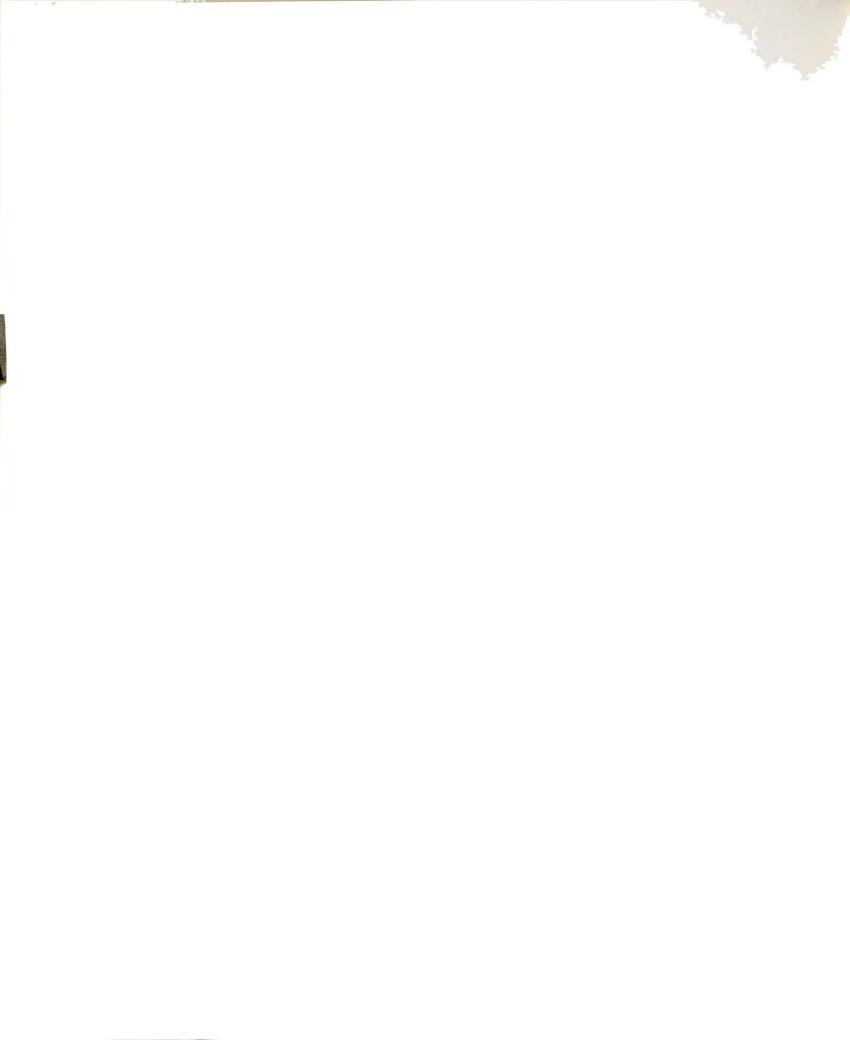
<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	494	.35
2	527	.35
3	475	.39
4	480	.39
5	480	.37
$\bar{X}$	502.400	.370
std.dev.	18.988	.018
c.o.v.	0.039	.048

Box B Drop height = 30 in. ; Gross weight = 31.5 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	336	.35
2	441	.44
3	533	.34
4	465	.28
5	471	.34
$\bar{X}$	449.200	.350
std.dev.	64.232	.051
c.o.v.	0.143	.147

Box B Drop height = 18 in. ; Gross weight = 44.3 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	462	.33
2	512	.36
3	431	.48
4	494	.37
5	498	.39
$\bar{X}$	479.400	.386
std.dev.	29.214	.051
c.o.v.	0.061	.132



Box B Drop height = 24 in. ; Gross weight = 44.3 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	486	.35
2	459	.38
3	481	.34
4	421	.36
5	451	.41
$\bar{X}$	459.600	.368
std.dev.	23.320	.025
c.o.v.	0.051	.067

Box B Drop height = 30 in. ; Gross weight = 44.3 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	454	.33
2	436	.31
3	472	.37
4	419	.25
5	454	.35
$\bar{X}$	447.000	.322
std.dev.	18.044	.041
c.o.v.	0.040	.128

TABLE 18

Compression and Deflection Data
 BOX C (12" x 12" X 12") double-wall

Box C Control

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	1192	.47
2	1326	.55
3	1170	.53
4	1174	.53
5	1176	.51
6	1197	.48
7	1236	.64
8	1256	.60
9	1267	.50
10	1321	.56
$\bar{X}$	1231.500	.537
std.dev.	56.339	.050
c.o.v.	0.046	.094

Box C Drop height = 18 in. ; Gross weight = 30 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	1160	.62
2	1245	.72
3	948	.54
4	965	.47
5	1065	.59
$\bar{X}$	1076.600	.588
std.dev.	113.526	.083
c.o.v.	0.105	.142

Box C Drop height = 24 in. ; Gross weight = 30 lbs.

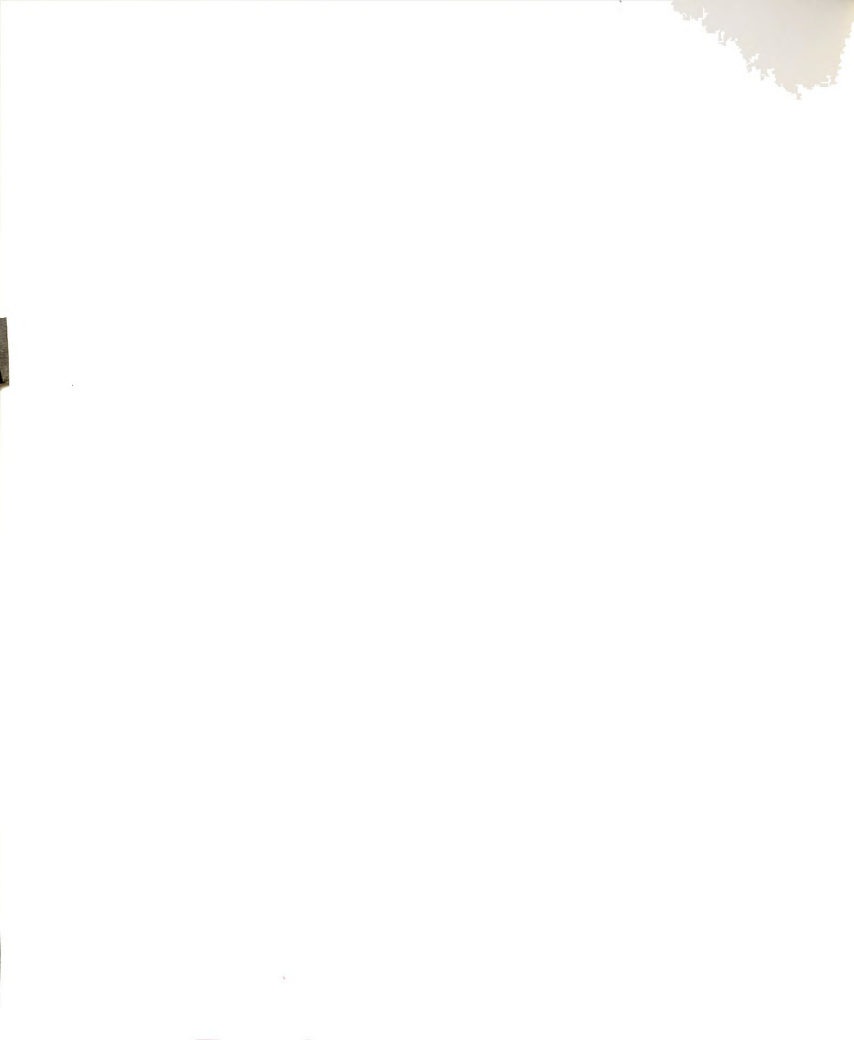
<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	1109	.56
2	780	.50
3	866	.47
4	1136	.70
5	991	.60
$\bar{X}$	976.400	.566
std.dev.	137.134	.081
c.o.v.	0.140	.143

Box C Drop height = 30 in. ; Gross weight = 30 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	1006	.64
2	903	.53
3	791	.48
4	1110	.70
5	930	.58
$\bar{X}$	948.000	.586
std.dev.	106.401	.078
c.o.v.	0.112	.133

Box C Drop height = 18 in. ; Gross weight = 42.5 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	956	.53
2	919	.60
3	1020	.55
4	815	.46
5	1094	.65
$\bar{X}$	960.800	.558
std.dev.	94.101	.064
c.o.v.	0.098	.115

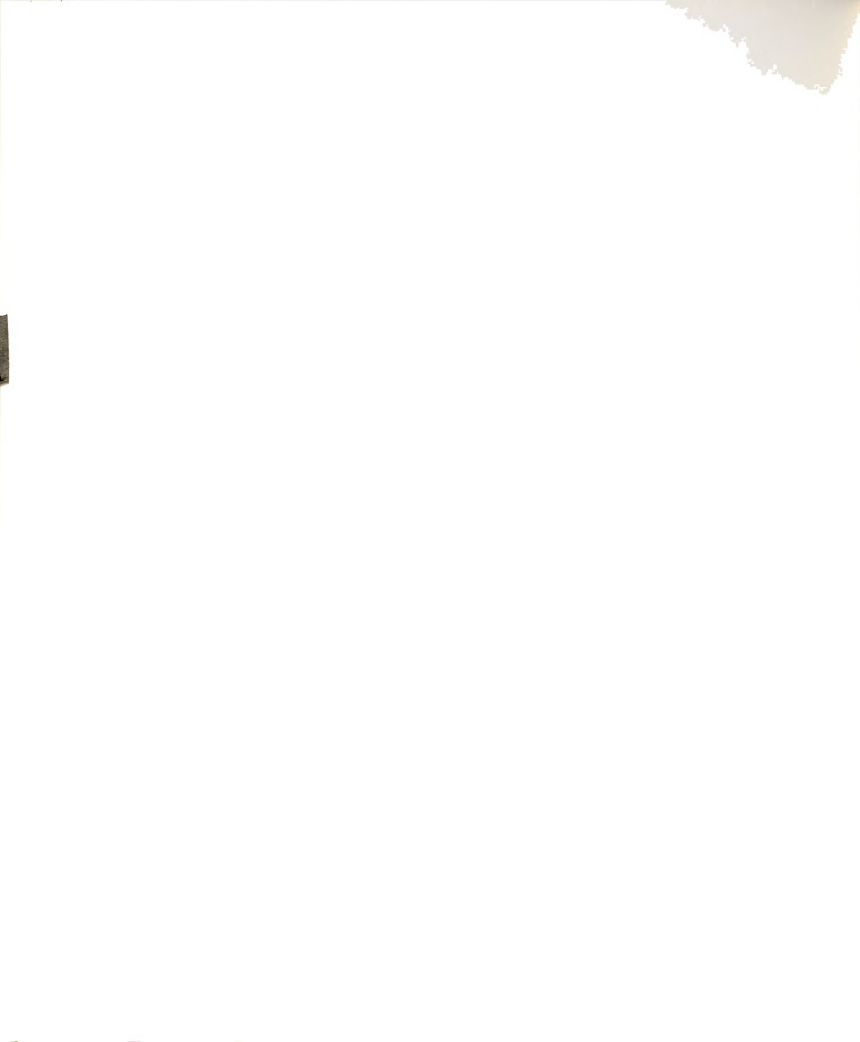


Box C Drop height = 24 in. ; Gross weight = 42.5 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	980	.65
2	1030	.67
3	876	.49
4	944	.57
5	892	.62
$\bar{X}$	944.400	.600
std.dev.	56.602	.064
c.o.v.	0.060	.107

Box C Drop height = 30 in. ; Gross weight = 42.5 lbs.

<u>Test #</u>	<u>Compression Strength (lbs)</u>	<u>Deflection (in)</u>
1	935	.55
2	826	.64
3	1000	.59
4	906	.63
5	998	.66
$\bar{X}$	933.000	.614
std.dev.	64.647	.039
c.o.v.	0.069	.064



APPENDIX B

COMPRESSIVE STRENGTH OF CORRUGATED FIBERBOARD
SHORT COLUMN TEST DATA

TABLE 19

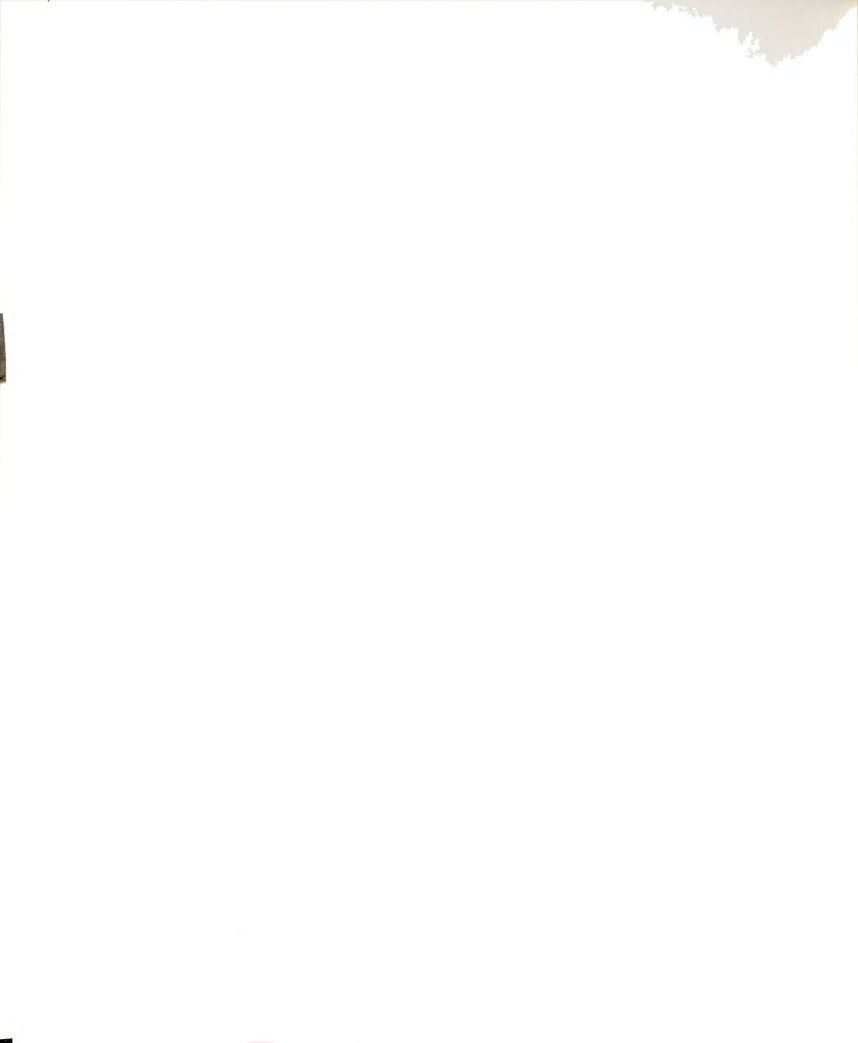
Edge Crush Data
BOX A (20.5" x 16" x 14")

Box A Control

<u>Test #</u>	<u>Load at Fail (lbs)</u>	<u>Test #</u>	<u>Load at Fail (lbs)</u>
1	51.9	6	60.4
2	45.9	7	48.9
3	47.9	8	55.9
4	56.0	9	52.6
5	48.7	10	54.4
$\bar{X}$	52.260	std.dev.	4.263
c.o.v.	0.082		

Box A Control - Post Compression Test

<u>Test #</u>	<u>Load at Fail (lbs)</u>	<u>Test #</u>	<u>Load at Fail (lbs)</u>
1	39.3	6	46.1
2	40.8	7	44.6
3	40.3	8	47.5
4	47.2	9	37.6
5	38.2	10	38.3
$\bar{X}$	41.990	std.dev.	3.741
c.o.v.	0.089		



Box A Drop Height = 18 in. ; Gross Weight = 15.5 lbs.

Test #	Load at Fail (lbs)	Test #	Load at Fail(lbs)
--------	--------------------	--------	-------------------

1	46.9	6	48.3
2	51.4	7	36.9
3	50.1	8	44.9
4	46.6	9	52.2
5	40.3	10	40.0

$\bar{X}$	45.760	std.dev.	4.927
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c.o.v.	0.108
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Box A Drop Height = 24 in. ; Gross Weight = 15.5 lbs.

Test #	Load at Fail (lbs)	Test #	Load at Fail(lbs)
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1	48.3	6	44.7
2	60.8	7	59.8
3	52.0	8	50.3
4	49.9	9	49.0
5	47.6	10	54.9

$\bar{X}$	51.730	std.dev.	4.990
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c.o.v.	0.096
--------	-------

Box A Drop Height = 30 in. ; Gross Weight = 15.5 lbs.

Test #	Load at Fail (lbs)	Test #	Load at Fail(lbs)
--------	--------------------	--------	-------------------

1	54.9	6	56.0
2	50.5	7	50.5
3	53.0	8	55.8
4	56.0	9	48.7
5	50.4	10	48.2

$\bar{X}$	52.400	std.dev.	2.940
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c.o.v.	0.056
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Box A Drop Height = 18 in. ; Gross Weight = 29.5 lbs.

Test #	Load at Fail (lbs)	Test #	Load at Fail(lbs)
1	48.6	6	46.3
2	47.2	7	53.3
3	49.4	8	43.4
4	47.6	9	49.3
5	53.5	10	51.7
$\bar{X}$	49.030	std.dev.	3.00
C.O.V.	0.061		

Box A Drop Height = 24 in. ; Gross Weight = 29.5 lbs.

Test #	Load at Fail (lbs)	Test #	Load at Fail(lbs)
1	58.7	6	51.9
2	52.9	7	55.6
3	49.2	8	59.7
4	51.0	9	48.6
5	48.4	10	58.2
$\bar{X}$	53.420	std.dev.	4.12
C.O.V.	0.077		

Box A Drop Height = 30 in. ; Gross Weight = 29.5 lbs.

Test #	Load at Fail (lbs)	Test #	Load at Fail(lbs)
1	58.0	6	57.7
2	54.6	7	57.6
3	49.7	8	51.1
4	52.6	9	57.2
5	59.2	10	49.3
$\bar{X}$	54.700	std.dev.	3.55
C.O.V.	0.065		



Box A Drop Height = 18 in. ; Gross Weight = 46 lbs.

Test #	Load at Fail (lbs)	Test #	Load at Fail (lbs)
1	56.1	6	46.7
2	58.5	7	48.4
3	48.3	8	56.3
Box 4B Control 4	56.9	9	49.9
5	57.1	10	55.7
$\bar{X}$	53.390	std.dev.	4.25
c.o.v.	0.080		

Box A Drop Height = 24 in. ; Gross Weight = 46 lbs.

Test #	Load at Fail (lbs)	Test #	Load at Fail (lbs)
1	57.8	6	47.6
2	46.2	7	44.8
3	47.0	8	55.2
4	60.9	9	53.7
5	52.2	10	45.1
$\bar{X}$	51.050	std.dev.	5.426
c.o.v.	0.106		

Box A Drop Height = 30 in. ; Gross Weight = 46 lbs.

Test #	Load at Fail (lbs)	Test #	Load at Fail (lbs)
1	49.3	6	50.5
2	56.0	7	51.4
3	46.0	8	49.5
4	48.1	9	53.7
5	50.7	10	47.7
$\bar{X}$	50.290	std.dev.	2.78
c.o.v.	0.055		

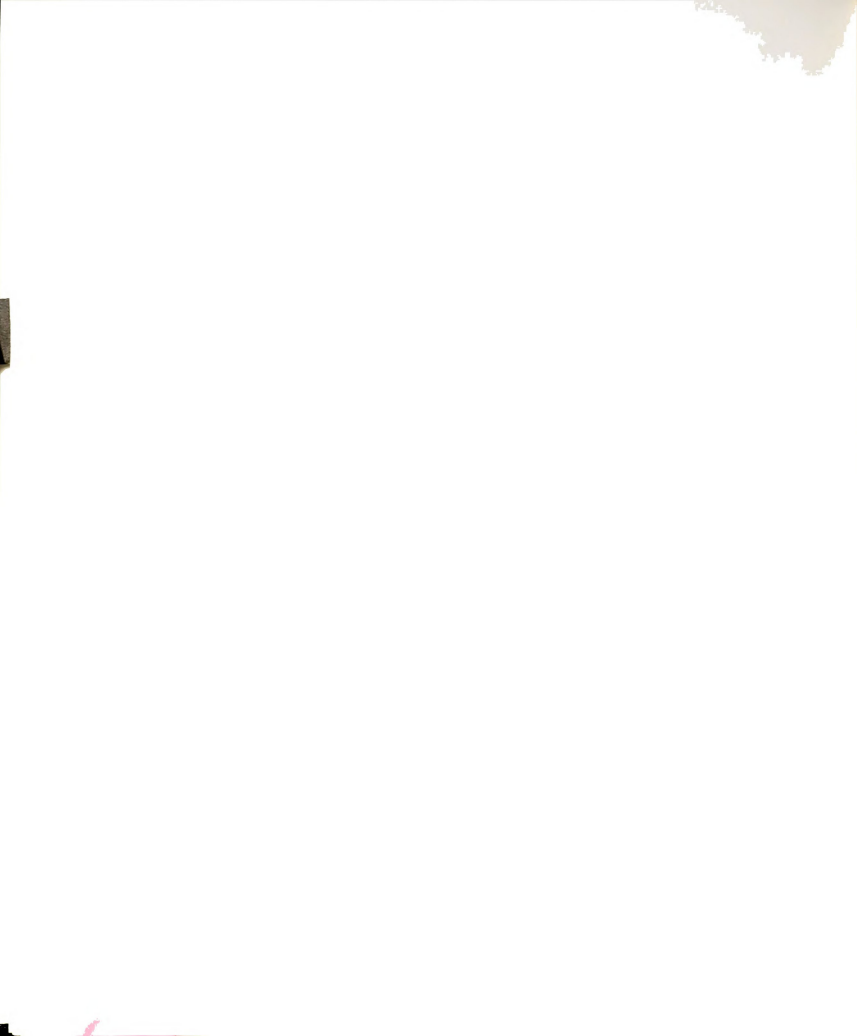


TABLE 20

Edge Crush Data

BOX # 2 (20.5" x 16" x 8")

Box B Control

<u>Test #</u>	<u>Load at Fail (lbs)</u>	<u>Test #</u>	<u>Load at Fail(lbs)</u>
1	50.6	6	50.3
2	47.6	7	46.8
3	45.4	8	54.1
4	46.6	9	56.1
5	50.2	10	45.5
$\bar{X}$	49.320	std.dev.	3.447
c.o.v.	0.070		

Box B Control - Post Compression Test

<u>Test #</u>	<u>Load at Fail (lbs)</u>	<u>Test #</u>	<u>Load at Fail(lbs)</u>
1	53.3	6	57.4
2	57.4	7	58.3
3	50.5	8	44.4
4	47.9	9	56.1
5	58.0	10	49.7
$\bar{X}$	53.300	std.dev.	4.666
c.o.v.	0.087		

Box B Drop Height = 18 in. ; Gross Weight = 15.75 lbs.

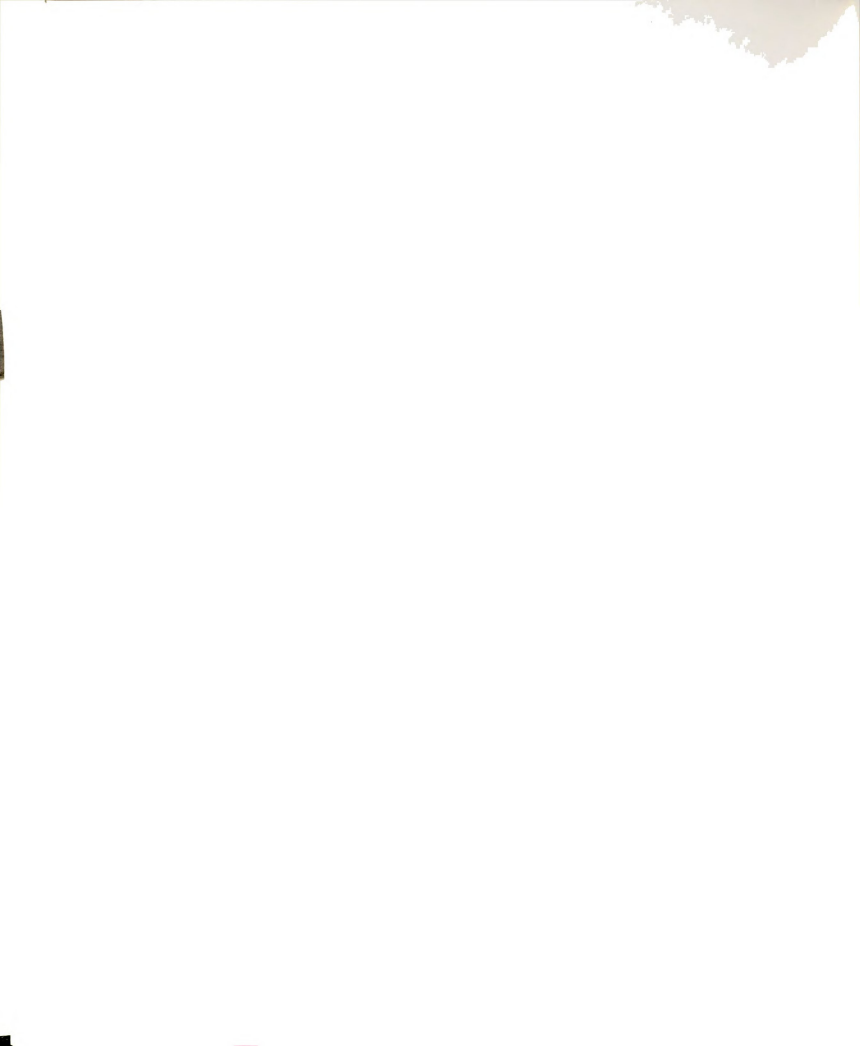
<u>Test #</u>	<u>Load at Fail (lbs)</u>	<u>Test #</u>	<u>Load at Fail(lbs)</u>
1	58.2	6	54.3
2	56.0	7	57.6
3	53.7	8	55.1
4	51.3	9	55.9
5	59.1	10	58.2
$\bar{X}$	55.94	std.dev.	2.300
c.o.v.	0.041		

Box B Drop Height = 24 in. ; Gross Weight = 15.75 lbs.

<u>Test #</u>	<u>Load at Fail (lbs)</u>	<u>Test #</u>	<u>Load at Fail(lbs)</u>
1	51.0	6	55.2
2	52.5	7	56.2
3	53.9	8	58.1
4	59.9	9	53.5
5	52.9	10	50.9
$\bar{X}$	54.380	std.dev.	2.820
c.o.v.	0.052		

Box B Drop Height = 30 in. ; Gross Weight = 15.75 lbs.

<u>Test #</u>	<u>Load at Fail (lbs)</u>	<u>Test #</u>	<u>Load at Fail(lbs)</u>
1	59.1	6	53.6
2	52.7	7	57.8
3	53.0	8	53.2
4	52.8	9	49.8
5	56.1	10	56.8
$\bar{X}$	54.49	std.dev.	2.699
c.o.v.	0.049		



Box B Drop Height = 18 in. ; Gross Weight = 31.5 lbs.

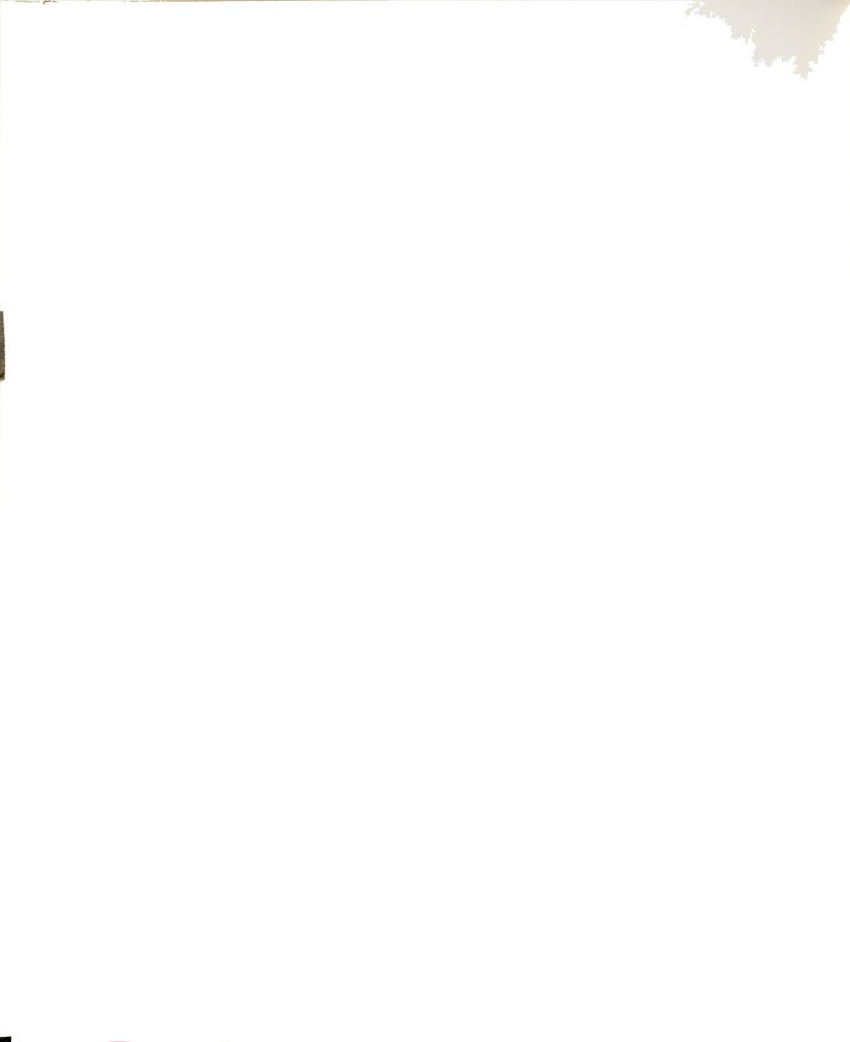
<u>Test #</u>	<u>Load at Fail (lbs)</u>	<u>Test #</u>	<u>Load at Fail(lbs)</u>
1	56.2	6	54.6
2	54.1	7	54.2
3	56.8	8	52.3
4	58.2	9	52.3
5	57.6	10	61.2
$\bar{X}$	55.750	std.dev.	2.659
c.o.v.	0.048		

Box B Drop Height = 24 in. ; Gross Weight = 31.5 lbs.

<u>Test #</u>	<u>Load at Fail (lbs)</u>	<u>Test #</u>	<u>Load at Fail(lbs)</u>
1	59.8	6	61.3
2	60.4	7	59.6
3	55.7	8	61.4
4	56.5	9	56.1
5	57.9	10	60.2
$\bar{X}$	58.890	std.dev.	2.052
c.o.v.	0.035		

Box B Drop Height = 30 in. ; Gross Weight = 31.5 lbs.

<u>Test #</u>	<u>Load at Fail (lbs)</u>	<u>Test #</u>	<u>Load at Fail(lbs)</u>
1	55.5	6	51.3
2	55.0	7	51.8
3	56.3	8	51.2
4	54.4	9	56.6
5	54.7	10	51.5
$\bar{X}$	53.83	std.dev.	2.046
c.o.v.	0.038		



Box B Drop Height = 18 in. ; Gross Weight = 44.3 lbs.

Test #	Load at Fail (lbs)	Test #	Load at Fail(lbs)
1	57.9	6	57.6
2	56.5	7	59.9
3	57.7	8	60.2
4	57.5	9	55.8
5	51.0	10	61.1
$\bar{X}$	57.520	std.dev.	2.690
C.o.v.	0.047		

Box B Drop Height = 24 in. ; Gross Weight = 44.3 lbs.

Test #	Load at Fail (lbs)	Test #	Load at Fail(lbs)
1	56.0	6	56.8
2	55.6	7	55.4
3	58.4	8	56.2
4	56.5	9	54.3
5	52.9	10	61.0
$\bar{X}$	56.310	std.dev.	2.092
C.o.v.	0.037		

Box B Drop Height = 30 in. ; Gross Weight = 44.3 lbs.

Test #	Load at Fail (lbs)	Test #	Load at Fail(lbs)
1	57.2	6	61.4
2	56.7	7	61.7
3	59.0	8	61.9
4	54.0	9	58.1
5	56.5	10	59.6
$\bar{X}$	58.610	std.dev.	2.468
C.o.v.	0.042		

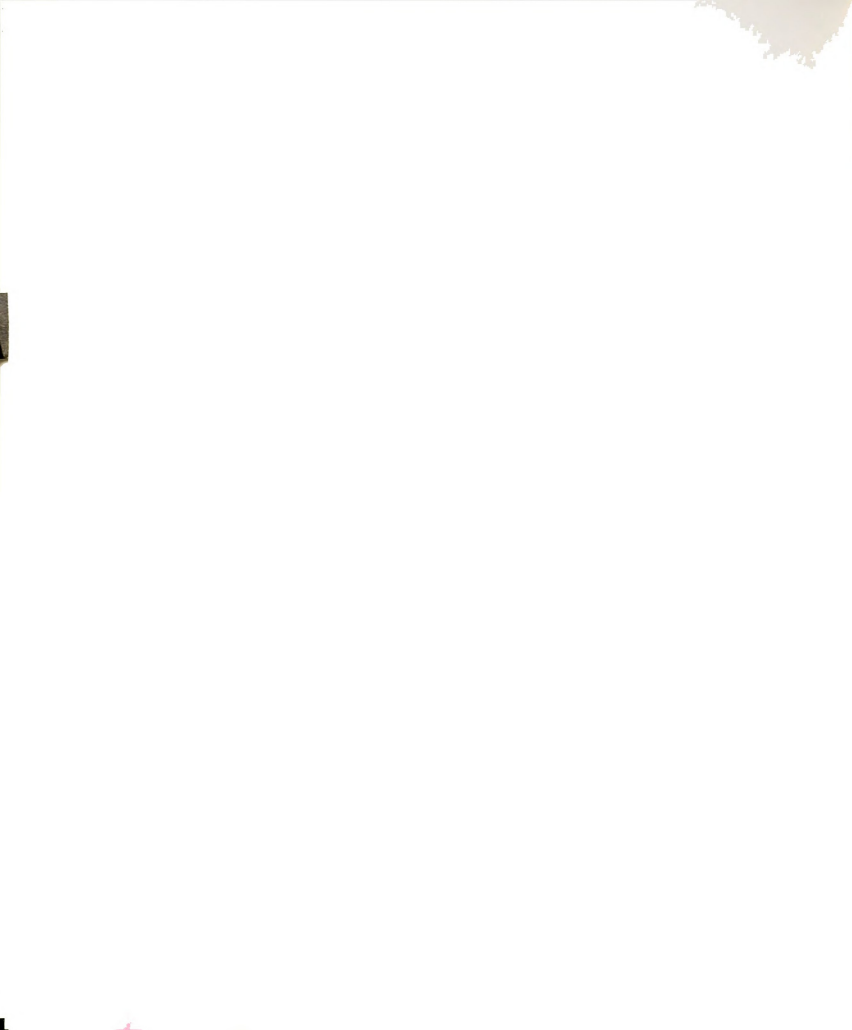


TABLE 21

Edge Crush Data

BOX C double-wall (12" x 12" x 12")

Box C Control

<u>Test #</u>	<u>Load at Fail (lbs)</u>	<u>Test #</u>	<u>Load at Fail (lbs)</u>
1	101.1	6	101.3
2	108.3	7	96.2
3	103.4	8	110.1
4	95.2	9	104.2
5	102.2	10	97.8
$\bar{X}$	101.980	std.dev.	4.593
c.o.v.	0.045		

Box C Control - Post Compression Test

<u>Test #</u>	<u>Load at Fail (lbs)</u>	<u>Test #</u>	<u>Load at Fail (lbs)</u>
1	104.4	6	105.1
2	102.8	7	108.9
3	107.1	8	100.4
4	104.1	9	101.7
5	101.5	10	100.9
$\bar{X}$	103.690	std.dev.	2.638
c.o.v.	0.025		

Box C Drop Height = 18 in. ; Gross Weight = 30 lbs.

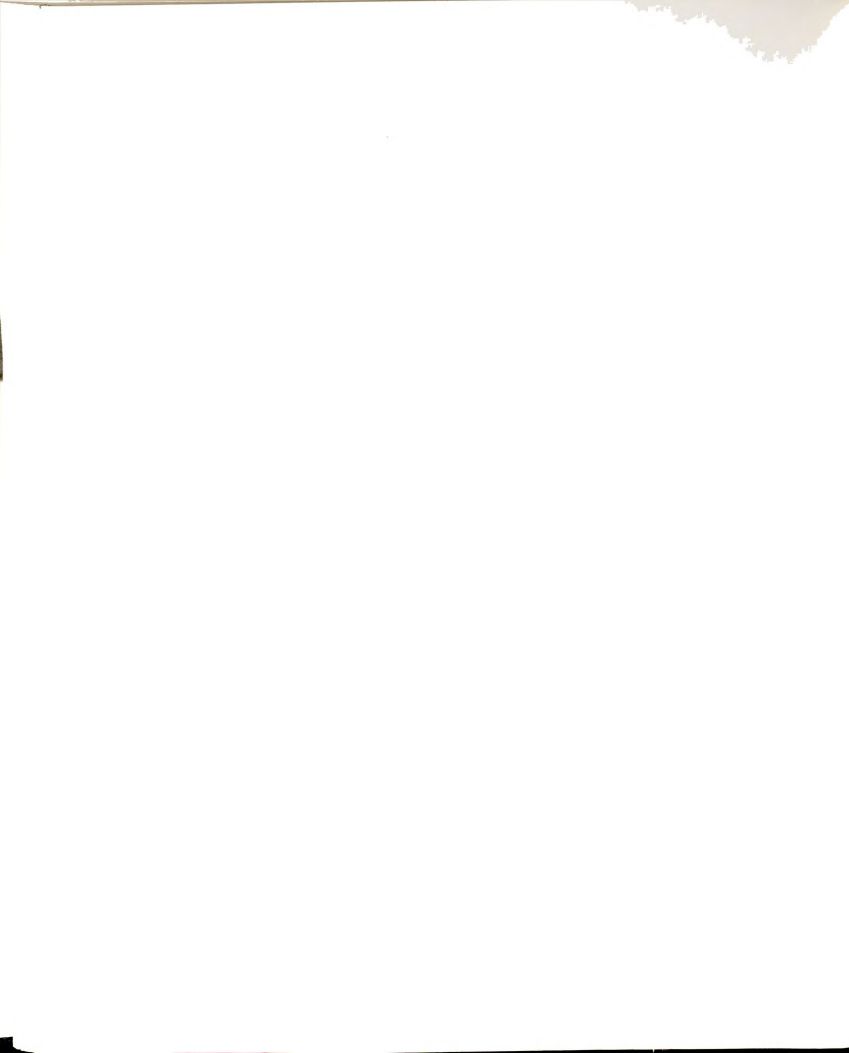
Test #	Load at Fail (lbs)	Test #	Load at Fail (lbs)
1	100.7	6	110.1
2	105.6	7	101.8
3	105.3	8	107.9
4	109.6	9	104.3
5	101.2	10	104.4
$\bar{X}$	105.090	std.dev.	3.162
c.o.v.	0.030		

Box C Drop Height = 24 in. ; Gross Weight = 30 lbs.

Test #	Load at Fail (lbs)	Test #	Load at Fail (lbs)
1	101.5	6	101.8
2	105.3	7	102.4
3	103.6	8	105.0
4	102.2	9	99.4
5	97.7	10	109.1
$\bar{X}$	102.800	std.dev.	3.036
c.o.v.	0.029		

Box C Drop Height = 30 in. ; Gross Weight = 30 lbs.

Test #	Load at Fail (lbs)	Test #	Load at Fail (lbs)
1	97.2	6	109.2
2	105.7	7	97.6
3	101.8	8	100.3
4	106.4	9	105.5
5	104.2	10	102.7
$\bar{X}$	103.060	std.dev.	3.695
c.o.v.	0.036		



Box C Drop Height = 18 in. ; Gross Weight = 42.5 lbs.

Test # Load at Fail (lbs) Test # Load at Fail (lbs)

1	104.5	6	99.4
2	100.3	7	96.7
3	101.5	8	97.2
4	101.8	9	106.7
5	107.7	10	104.5

$\bar{X}$ 102.030 std.dev. 3.580

c.o.v. 0.035

Box C Drop Height = 24 in. ; Gross Weight = 42.5 lbs.

Test # Load at Fail (lbs) Test # Load at Fail (lbs)

1	101.6	6	102.2
2	109.2	7	105.2
3	110.3	8	108.3
4	109.0	9	108.9
5	106.8	10	109.5

$\bar{X}$ 107.100 std.dev. 2.944

c.o.v. 0.027

Box C Drop Height = 30 in. ; Gross Weight = 42.5 lbs.

Test # Load at Fail (lbs) Test # Load at Fail (lbs)

1	103.4	6	100.0
2	102.9	7	108.9
3	102.3	8	107.3
4	103.7	9	99.9
5	109.3	10	104.3

$\bar{X}$ 104.200 std.dev. 3.163

c.o.v. 0.030

APPENDIX C

BURSTING STRENGTH OF CORRUGATED BOARD DATA

TABLE 22

Burst Strength Data

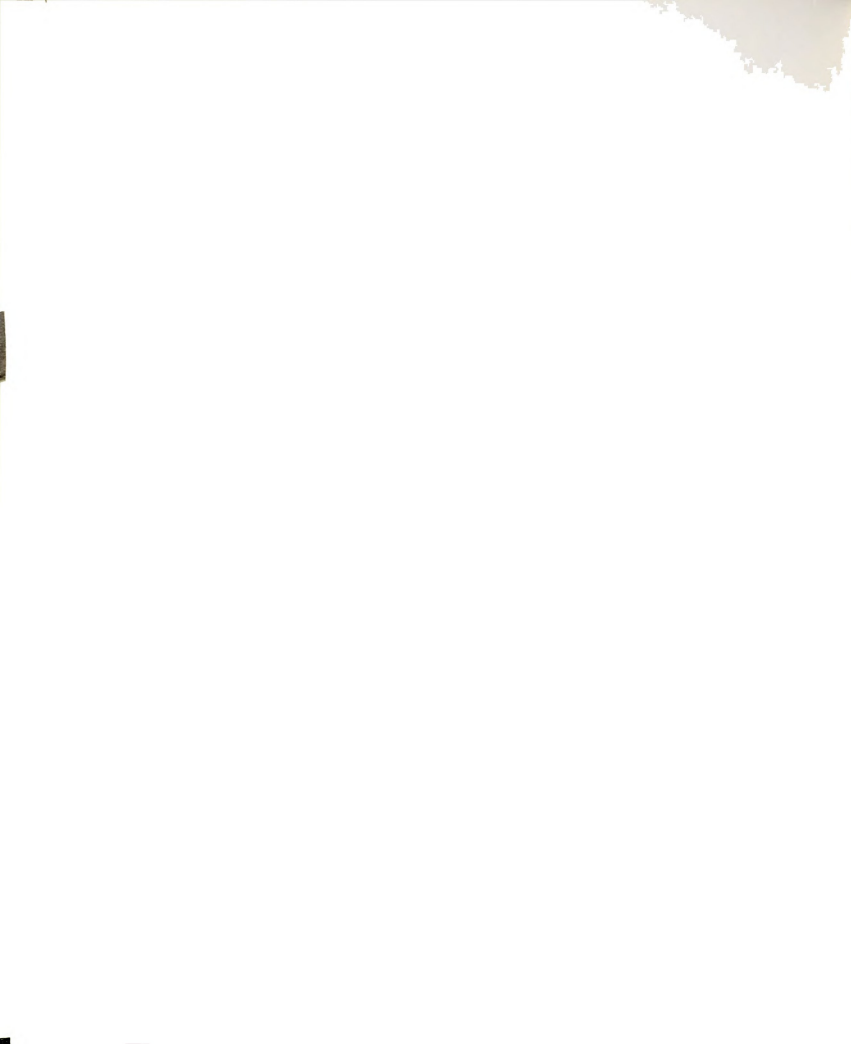
BOX A (20.5" x 16" x 14")

Box A Control

<u>Test #</u>	<u>Burst Strength (lbs/sq.in.)</u>	<u>Test #</u>	<u>Burst Strength (lbs/sq.in.)</u>
1	170	6	160
2	180	7	180
3	160	8	210
4	205	9	160
5	185	10	165
$\bar{X}$	177.500	std.dev.	17.356
c.o.v.	0.098		

Box A Control - Post Compression Test

<u>Test #</u>	<u>Burst Strength (lbs/sq.in.)</u>	<u>Test</u>	<u>Burst Strength (lbs/sq.in.)</u>
1	105	6	145
2	135	7	155
3	185	8	110
4	165	9	130
5	115	10	160
$\bar{X}$	140.500	std.dev.	24.844
c.o.v.	0.177		



Box A Drop Height = 18 in. ; Gross Weight = 15.5 lbs.

Burst Strength		Burst Strength	
Test #	(lbs/sq.in.)	Test #	(lbs/sq.in.)
1	130	6	205
2	155	7	195
3	205	8	150
4	130	9	190
5	170	10	165
$\bar{X}$	169.500	std.dev.	27.06
c.o.v.	0.160		

Box A Drop Height = 24 in. ; Gross Weight = 15.5 lbs.

Burst Strength		Burst Strength	
Test #	(lbs/sq.in.)	Test #	(lbs/sq.in.)
1	155	6	180
2	170	7	170
3	220	8	185
4	170	9	135
5	130	10	150
$\bar{X}$	166.500	std.dev.	24.80
c.o.v.	0.149		

Box A Drop Height = 30 in. ; Gross Weight = 15.5 lbs.

Burst Strength		Burst Strength	
Test #	(lbs/sq.in.)	Test #	(lbs/sq.in.)
1	175	6	130
2	145	7	170
3	140	8	190
4	155	9	195
5	135	10	125
$\bar{X}$	156.000	std.dev.	23.85
c.o.v.	0.153		

Box A Drop Height = 18 in. ; Gross Weight = 29.5 lbs.

Burst Strength		Burst Strength	
Test #	(lbs/sq.in.)	Test #	(lbs/sq.in.)
1	175	6	155
2	160	7	185
3	155	8	170
4	175	9	140
5	130	10	170
$\bar{X}$	161.500	std.dev.	16.13
c.o.v.	0.100		

Box A Drop Height = 24 in. ; Gross Weight = 29.5 lbs.

Burst Strength		Burst Strength	
Test #	(lbs/sq.in.)	Test #	(lbs/sq.in.)
1	130	6	190
2	185	7	155
3	185	8	150
4	180	9	195
5	125	10	160
$\bar{X}$	165.500	std.dev.	23.92
c.o.v.	0.144		

Box A Drop Height = 30 in. ; Gross Weight = 29.5 lbs.

Burst Strength		Burst Strength	
Test #	(lbs/sq.in.)	Test #	(lbs/sq.in.)
1	125	6	125
2	175	7	170
3	165	8	165
4	145	9	145
5	150	10	145
$\bar{X}$	151.000	std.dev.	16.70
c.o.v.	0.111		



Box A Drop Height = 18 in. ; Gross Weight = 46 lbs.

Burst Strength		Burst Strength	
Test #	(lbs/sq.in.)	Test #	(lbs/sq.in.)
1	190	6	175
2	180	7	200
3	155	8	160
4	170	9	155
5	180	10	175
$\bar{X}$	174.000	std.dev.	13.93
c.o.v.	0.080		

Box A Drop Height = 24 in. ; Gross Weight = 46 lbs.

Burst Strength		Burst Strength	
Test #	(lbs/sq.in.)	Test #	(lbs/sq.in.)
1	195	6	180
2	190	7	200
3	145	8	195
4	190	9	160
5	165	10	145
$\bar{X}$	176.500	std.dev.	20.01
c.o.v.	0.113		

Box A Drop Height = 30 in. ; Gross Weight = 46 lbs.

Burst Strength		Burst Strength	
Test #	(lbs/sq.in.)	Test #	(lbs/sq.in.)
1	190	6	180
2	180	7	175
3	145	8	185
4	170	9	150
5	185	10	175
$\bar{X}$	173.500	std.dev.	14.15
c.o.v.	0.082		



TABLE 23

Burst Strength Data

BOX B (20.5" x 16" x 8")

Box B Control

<u>Test #</u>	<u>Burst Strength (lbs/sq.in.)</u>	<u>Test #</u>	<u>Burst Strength (lbs/sq.in.)</u>
1	145	6	150
2	165	7	155
3	160	8	165
4	135	9	170
5	130	10	160
$\bar{X}$	153.500	std.dev.	12.659
c.o.v.	0.082		

Box B Control - Post Compression Test

<u>Test #</u>	<u>Burst Strength (lbs/sq.in.)</u>	<u>Test #</u>	<u>Burst Strength (lbs/sq.in.)</u>
1	140	6	115
2	185	7	125
3	180	8	180
4	115	9	185
5	160	10	155
$\bar{X}$	154.000	std.dev.	27.184
c.o.v.	0.176		

1000 1000 1000 1000

Box B Drop Height = 18 in. ; Gross Weight = 15.75 lbs.

Burst Strength		Burst Strength	
Test #	(lbs/sq.in.)	Test #	(lbs/sq.in.)
1	175	6	165
2	195	7	195
3	140	8	165
4	180	9	190
5	140	10	195
$\bar{X}$	174.000	std.dev.	20.224
c.o.v.	0.116		

Box B Drop Height = 24 in. ; Gross Weight = 15.75 lbs.

Burst Strength		Burst Strength	
Test #	(lbs/sq.in.)	Test #	(lbs/sq.in.)
1	230	6	160
2	220	7	195
3	215	8	200
4	175	9	190
5	205	10	165
$\bar{X}$	195.500	std.dev.	22.187
c.o.v.	0.113		

Box B Drop Height = 30 in. ; Gross Weight = 15.75 lbs.

Burst Strength		Burst Strength	
Test #	(lbs/sq.in.)	Test #	(lbs/sq.in.)
1	210	6	235
2	210	7	210
3	180	8	215
4	205	9	220
5	240	10	180
$\bar{X}$	210.500	std.dev.	18.635
c.o.v.	0.088		

Box B Drop Height = 18 in. ; Gross Weight = 31.5 lbs.

Burst Strength		Burst Strength	
Test #	(lbs/sq.in.)	Test #	(lbs/sq.in.)
1	230	6	185
2	250	7	205
3	225	8	225
4	190	9	210
5	230	10	255
$\bar{X}$	220.500	std.dev.	21.960
c.o.v.	0.099		

Box B Drop Height = 24 in. ; Gross Weight = 31.5 lbs.

Burst Strength		Burst Strength	
Test #	(lbs/sq.in.)	Test #	(lbs/sq.in.)
1	235	6	220
2	165	7	195
3	225	8	220
4	255	9	225
5	175	10	225
$\bar{X}$	214.000	std.dev.	26.153
c.o.v.	0.122		

Box B Drop Height = 30 in. ; Gross Weight = 31.5 lbs.

Burst Strength		Burst Strength	
Test #	(lbs/sq.in.)	Test #	(lbs/sq.in.)
1	255	6	165
2	210	7	215
3	240	8	235
4	195	9	200
5	225	10	250
$\bar{X}$	219.000	std.dev.	26.344
c.o.v.	0.120		

Box B Drop Height = 18 in. ; Gross Weight = 44.3 lbs.

<u>Test #</u>	<u>Burst Strength (lbs/sq.in.)</u>	<u>Test #</u>	<u>Burst Strength (lbs/sq.in.)</u>
1	155	6	230
2	220	7	200
3	245	8	225
4	160	9	250
5	165	10	255
$\bar{X}$	210.500	std.dev.	36.363
c.o.v.	0.173		

Box B Drop Height = 24 in. ; Gross Weight = 44.3 lbs.

<u>Test #</u>	<u>Burst Strength (lbs/sq.in.)</u>	<u>Test #</u>	<u>Burst Strength (lbs/sq.in.)</u>
1	205	6	260
2	240	7	200
3	200	8	205
4	230	9	285
5	235	10	260
$\bar{X}$	232.000	std.dev.	28.213
c.o.v.	0.122		

Box B Drop Height = 30 in. ; Gross Weight = 44.3 lbs.

<u>Test #</u>	<u>Burst Strength (lbs/sq.in.)</u>	<u>Test #</u>	<u>Burst Strength (lbs/sq.in.)</u>
1	230	6	180
2	240	7	225
3	245	8	245
4	175	9	265
5	205	10	260
$\bar{X}$	227.000	std.dev.	29.597
c.o.v.	0.130		

APPENDIX D

FLAT CRUSH OF CORRUGATED FIBERBOARD DATA

TABLE 24

Flat Crush Data

BOX A (20.5" x 16" x 14")

Box A Control

Test #	Load at Fail (lbs/sq.in.)	Test #	Load at Fail (lbs/sq.in.)
1	28.95	6	31.52
2	25.94	7	29.95
3	26.79	8	33.21
4	27.84	9	34.31
5	31.64	10	25.94
$\bar{X}$	29.609	std.dev.	2.853
c.o.v.	0.096		

Box A Control - Post Compression Test

Test #	Load at Fail (lbs/sq.in.)	Test #	Load at Fail (lbs/sq.in.)
1	34.18	6	28.85
2	33.21	7	35.12
3	36.10	8	32.83
4	35.43	9	33.59
5	35.78	10	29.40
$\bar{X}$	33.449	std.dev.	2.402
c.o.v.	0.072		

Box A Drop Height = 18 in. ; Gross Weight = 15.5 lbs.

Test #	Load at Fail (lbs/sq.in.)	Test #	Load at Fail (lbs/sq.in.)
1	33.75	6	21.42
2	22.35	7	33.13
3	35.70	8	30.14
4	28.03	9	23.43
5	23.31	10	24.46
$\bar{X}$	27.572	std.dev.	5.020
c.o.v.	0.182		

Box A Drop Height = 24 in. ; Gross Weight = 15.5 lbs.

Test #	Load at Fail (lbs/sq.in.)	Test #	Load at Fail (lbs/sq.in.)
1	32.29	6	34.63
2	36.08	7	34.22
3	29.63	8	31.93
4	21.90	9	30.06
5	29.10	10	24.35
$\bar{X}$	30.419	std.dev.	4.265
c.o.v.	0.140		

Box A Drop Height = 30 in. ; Gross Weight = 15.5 lbs.

Test #	Load at Fail (lbs/sq.in.)	Test #	Load at Fail (lbs/sq.in.)
1	35.84	6	25.36
2	24.54	7	28.62
3	20.87	8	33.52
4	28.42	9	38.19
5	36.42	10	31.96
$\bar{X}$	30.374	std.dev.	5.444
c.o.v.	0.179		



Box A Drop Height = 18 in. ; Gross Weight = 29.5 lbs.

Test #	Load at Fail (lbs/sq.in.)	Test #	Load at Fail (lbs/sq.in.)
1	35.09	6	35.47
2	22.85	7	22.87
3	35.55	8	32.59
4	30.40	9	23.05
5	33.49	10	35.23
$\bar{X}$	30.659	std.dev.	5.282
c.o.v.	0.172		

Box A Drop Height = 24 in. ; Gross Weight = 29.5 lbs.

Test #	Load at Fail (lbs/sq.in.)	Test #	Load at Fail (lbs/sq.in.)
1	29.94	6	35.03
2	31.71	7	23.91
3	35.56	8	34.19
4	35.69	9	32.30
5	22.49	10	33.32
$\bar{X}$	31.414	std.dev.	4.460
c.o.v.	0.142		

Box A Drop Height = 30 in. ; Gross Weight = 29.5 lbs

Test #	Load at Fail (lbs/sq.in.)	Test #	Load at Fail (lbs/sq.in.)
1	35.26	6	28.30
2	24.47	7	30.91
3	22.61	8	25.28
4	35.17	9	33.34
5	23.06	10	30.17
$\bar{X}$	28.857	std.dev.	4.603
c.o.v.	0.159		



Box A Drop Height = 18 in. ; Gross Weight = 46 lbs.

<u>Test #</u>	<u>Load at Fail (lbs/sq.in.)</u>	<u>Test #</u>	<u>Load at Fail (lbs/sq.in.)</u>
1	35.80	6	30.38
2	35.65	7	28.74
3	33.47	8	23.73
4	36.36	9	23.74
5	33.33	10	22.86
$\bar{X}$	30.406	std.dev.	5.086
c.o.v.	0.167		

Box A Drop Height = 24 in. ; Gross Weight = 46 lbs.

<u>Test #</u>	<u>Load at Fail (lbs/sq.in.)</u>	<u>Test #</u>	<u>Load at Fail (lbs/sq.in.)</u>
1	31.70	6	24.18
2	23.00	7	33.53
3	30.79	8	32.44
4	33.53	9	34.79
5	22.50	10	21.88
$\bar{X}$	28.834	std.dev.	4.988
c.o.v.	0.173		

Box A Drop Height = 30 in. ; Gross Weight = 46 lbs.

<u>Test #</u>	<u>Load at Fail (lbs/sq.in.)</u>	<u>Test #</u>	<u>Load at Fail (lbs/sq.in.)</u>
1	25.44	6	30.88
2	34.58	7	25.43
3	37.32	8	33.00
4	35.00	9	32.92
5	27.78	10	28.91
$\bar{X}$	31.126	std.dev.	3.911
c.o.v.	0.126		



TABLE 25

Flat Crush Data

BOX B (20.5" x 16" x 8")

Box B Control

<u>Test #</u>	<u>Load at Fail (lbs/sq.in.)</u>	<u>Test #</u>	<u>Load at Fail (lbs/sq.in.)</u>
1	25.63	6	18.74
2	27.38	7	23.00
3	16.76	8	15.04
4	20.69	9	20.33
5	25.89	10	27.19
$\bar{X}$	22.065	std.dev.	4.197
c.o.v.	0.190		

Box B Control - Post Compression Test

<u>Test #</u>	<u>Load at Fail (lbs/sq.in.)</u>	<u>Test #</u>	<u>Load at Fail (lbs/sq.in.)</u>
1	26.07	6	33.76
2	23.10	7	19.83
3	35.86	8	34.35
4	21.85	9	18.13
5	35.46	10	25.14
$\bar{X}$	27.355	std.dev.	6.517
c.o.v.	0.238		

Box B Drop Height = 18 in. ; Gross Weight = 15.75 lbs.

Load at Fail		Load at Fail	
Test #	(lbs/sq.in.)	Test #	(lbs/sq.in.)
1	19.88	6	24.50
2	15.53	7	23.71
3	27.88	8	32.90
4	20.35	9	31.67
5	22.36	10	24.90
$\bar{X}$	24.368	std.dev.	5.075
c.o.v.	0.208		

Box B Drop Height = 24 in. ; Gross Weight = 15.75 lbs.

Load at Fail		Load at Fail	
Test #	(lbs/sq.in.)	Test #	(lbs/sq.in.)
1	21.51	6	25.23
2	25.75	7	23.81
3	34.83	8	22.81
4	19.00	9	21.66
5	28.57	10	25.06
$\bar{X}$	24.828	std.dev.	4.184
c.o.v.	0.168		

Box B Drop Height = 30 in. ; Gross Weight = 15.75 lbs.

Load at Fail		Load at Fail	
Test #	(lbs/sq.in.)	Test #	(lbs/sq.in.)
1	14.75	6	30.59
2	33.48	7	24.70
3	21.71	8	17.09
4	15.69	9	15.87
5	33.56	10	16.40
$\bar{X}$	22.384	std.dev.	7.284
c.o.v.	0.325		



Box B Drop Height = 18 in. ; Gross Weight = 31.5 lbs.

Test #	Load at Fail (lbs/sq.in.)	Test #	Load at Fail (lbs/sq.in.)
1	16.64	6	34.15
2	27.62	7	23.40
3	22.86	8	16.84
4	22.13	9	20.80
5	23.87	10	21.25
$\bar{X}$	22.956	std.dev.	4.834
c.o.v.	0.211		

Box B Drop Height = 24 in. ; Gross Weight = 31.5 lbs.

Test #	Load at Fail (lbs/sq.in.)	Test #	Load at Fail (lbs/sq.in.)
1	22.85	6	18.65
2	34.67	7	23.25
3	26.02	8	18.43
4	19.96	9	16.80
5	19.06	10	34.71
$\bar{X}$	23.440	std.dev.	6.194
c.o.v.	0.264		

Box B Drop Height = 30 in. ; Gross Weight = 31.5 lbs.

Test #	Load at Fail (lbs/sq.in.)	Test #	Load at Fail (lbs/sq.in.)
1	22.76	6	29.60
2	28.41	7	27.09
3	35.96	8	16.47
4	20.25	9	19.24
5	21.23	10	16.24
$\bar{X}$	23.725	std.dev.	6.046
c.o.v.	0.255		

Box B Drop Height = 18 in. ; Gross Weight = 44.3 lbs.

Test #	Load at Fail (lbs/sq.in.)	Test #	Load at Fail (lbs/sq.in.)
1	18.08	6	19.93
2	23.89	7	34.81
3	36.52	8	22.84
4	27.33	9	23.19
5	23.53	10	24.11
$\bar{X}$	25.423	std.dev.	5.642
c.o.v.	0.222		

Box B Drop Height = 24 in. ; Gross Weight = 44.3 lbs.

Test #	Load at Fail (lbs/sq.in.)	Test #	Load at Fail (lbs/sq.in.)
1	27.12	6	20.16
2	24.19	7	30.47
3	16.53	8	34.16
4	24.19	9	21.85
5	19.92	10	19.87
$\bar{X}$	23.846	std.dev.	5.134
c.o.v.	0.215		

Box B Drop Height = 30 in. ; Gross Weight = 44.3 lbs.

Test #	Load at Fail (lbs/sq.in.)	Test #	Load at Fail (lbs/sq.in.)
1	18.02	6	24.20
2	16.22	7	25.74
3	15.74	8	18.52
4	29.43	9	20.08
5	19.69	10	15.20
$\bar{X}$	20.284	std.dev.	4.476
c.o.v.	0.221		



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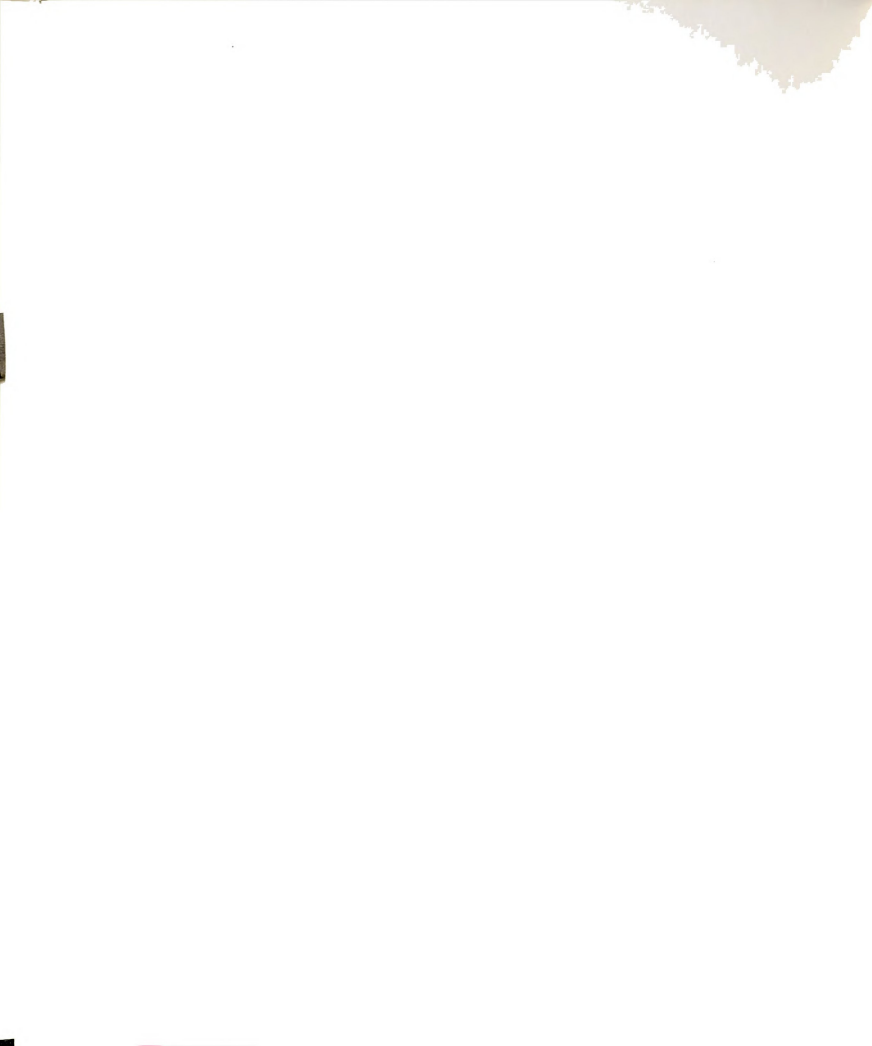
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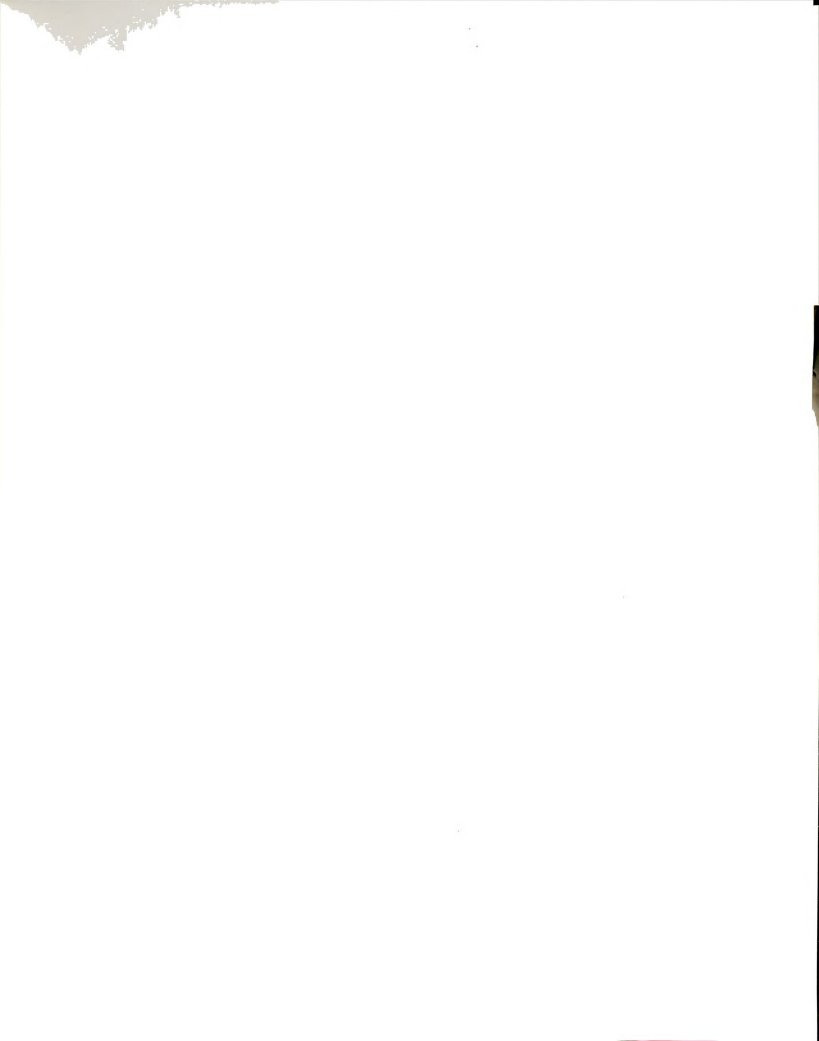
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