This is to certify that the

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CORRUGATED CASE LINE DAMAGE ASSESMENT

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CORRUGATED CASE LINE DAMAGE ASSESSMENT

By

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ABSTRACT

CORRUGATED CASE LINE DAMAGE ASSESSMENT

By

Jill Jeannette Warnick

This study investigated the percent reduction in compression strength of RSC style single-wall corrugated containers handled on an automated packaging line. The study was sponsored by Clorox Company and examined box performance on the gallon size HDPE plastic bleach bottle line. Box compression strength was measured for samples obtained from four packaging line locations and compared to new knock-down boxes received from the corrugated supplier. Also the effect of drop loading the six bottles in to the corrugated shipper from approximately 11.5 inches using a drop case packer was evaluated.

The results of the research study show that corrugated boxes lose approximately 10% of the compression strength when handled on an automatic packaging line. Also the automatic drop loading case packers do not produce significant damage as compared to other line equipment.

ACKNOWLEDGMENTS

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1.0 INTRODUCTION

Corrugated board serves a multitude of purposes in today's packaging industry. Serving as a cushioning medium, slip sheet, or most commonly as a shipping container, the packaging industry relies heavily on the protective aspects of corrugated board. In 1903 the first corrugated box was approved as an alternate to wooden crates for use as a shipping container in the United States. It was not until the end of World Word II, that the majority of all shipments were packaged in corrugated fiberboard boxes (Hanlon, 1992). In 1994 the amount of corrugated fiberboard manufactured and shipped was approximately $21 billion. This amounts to an average increase of 4.9% between the years of 1989 and 1994, and is a greater increase than any other paperboard or molded pulp product used for packaging in the last few years (Rauch Associates, 1994).

Since its introduction, corrugated board has been the subject of many scientific studies to improve its effectiveness in the transportation, handling, and storage environments. Whether the studies are related to the process of bonding the liners and medium, container design, or environmental factors encountered during transportation and storage, these factors, individually and in combination, play a role in the overall box compression strength and ultimate performance. Studies of material properties, the box-making process, design criteria and compression reduction relative to the transportation and storage environments has been studied in detail (Maltenfort, 1989).

An area that has not received previous attention is the performance of corrugated boxes during the box-filling process which has some affect on overall box compression strength. This study evaluates the percentage of compression loss related to corrugated box handling in an automated packaging facility by examining compression values of corrugated containers sampled at different locations on a packaging line. This paper reviews various factors that play a role in determining overall box compression strength and loss pertaining to the automated handling environment.

1.1 Corrugated Board Components

The basis of corrugated board is a combination of flat sheets of paper (liners) glued to a central, fluted component (medium) as shown in Figure 1. The liners are primarily the load-carrying member of a corrugated structure with the medium functioning as a divider to hold the liners apart.

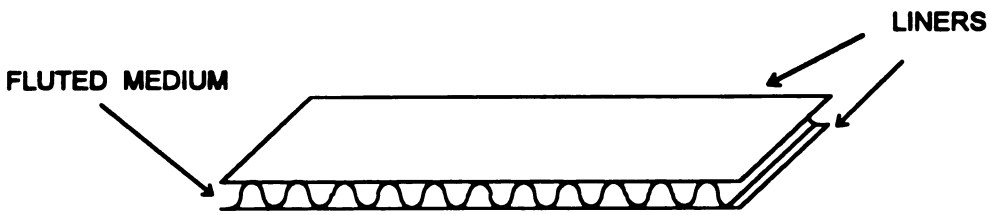


Figure 1

PAPER CORRUGATED STRUCTURE

The combination produces a three layered structure that is much stronger than the individual components based on the basic architectural structures of the column and arch (Abbott, 1989). The arch provides structural resistance to lateral forces in the handling environment and the column offers the structure the ability to act as a vertical load bearing member (Kellicut, 1960). There are several material properties related to the liners and medium that play a role in providing compression strength. The following characteristics describe the contribution liners and mediums make to the strength of the corrugated container:

- raw material composition
- paper making process
- basis weight

1.1.1 Liners

Liners (or linerboards) are generally made of softwood fibers using the kraft pulping process. Softwood fibers are sourced from evergreen trees and may vary in length between two to four millimeters (Abbott, 1989). The length of the fiber provides good strength which contributes to the overall box compression strength. The kraft pulping process is a chemical process that produces a strong, unbleached paper. By comparison, mechanical pulping processes are less expensive but have a tendency to destroy the fiber, resulting in lower strength properties.

Linerboard is specified by basis weight that corresponds to the weight of paper per 1,000 square feet (MSF) and relates to caliper and stiffness. Heavier basis weights that are thicker and stiffer produce stronger corrugated board. The basis weight of a commonly used linerboard is 69 pounds/MSF (Boonyasarn, et al, 1992).

Corrugated linerboards are generally made using the Fourdrinier process containing a blend of recycle and virgin fibers. As the paper is formed, the fibers have a tendency to align with the direction of movement of the process, or machine direction (MD). The screen carrying the web of paper is mechanically shaken from side to side to allow for more alignment in the cross direction (CD). The result is increased fiber to fiber bonding and stronger paper. By comparison, linerboard made by the Cylinder machines align fibers more uniformly in the machine direction. Effectively, liners produced on the Fourdrinier machine will have a similar modulus of elasticity in the MD and CD. Liners produced on a cylinder machine will have a higher modulus of elasticity in the MD than in the CD.

The development of High Performance Liners (HPL) has changed the assumption that increasing basis weight will produce linerboard with higher strength. The HPL manufacturing process aligns the fibers more uniformly in the MD and CD than the Fourdrinier or Cylinder process. The result is greater strength at a reduced basis weight. Compared to the commonly used liner (69 pounds/MSF) HPL linerboard with comparable strength properties will typically have a basis weight of 58 pounds/MSF.

1.1.2 Corrugated Mediums

Corrugated mediums are made of hardwood fibers which are much shorter than softwood fibers. Hardwood fibers range from one half to one millimeter in length (Abbott, 1989). The fibers in the corrugated medium contribute to overall container strength in two major ways as shown in Figure 2. Fibers aligned in the cross direction contribute to column compression and fibers aligned in the machine direction contribute to flat crush (Maltenfort, 1989). Flat crush is the resistance of the flutes to a force applied parallel to the surface of the combined board verses compression strength that refers to the resistance of the flutes to a vertical (column) compression force. Mediums are commonly produced in 26 pounds/MSF with a nominal thickness of 9 points (0.009 inches). Mediums generally contain a higher amount of recycled content than linerboards.

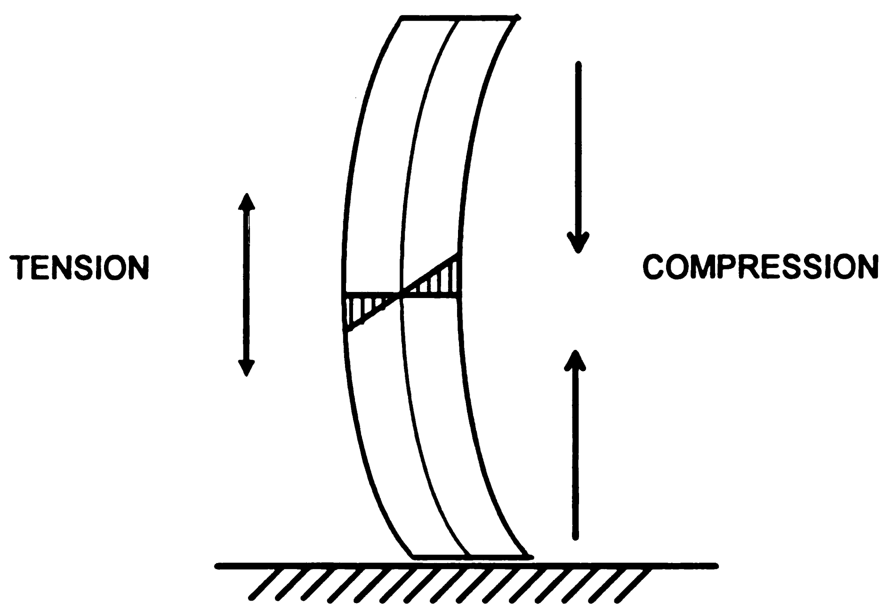


Figure 2

STRESSES IN A COMPRESSED CORRUGATED PANEL

1.2 Corrugated Board Component Properties

While the overall top to bottom compression strength is an important factor to the user, the quality of the liners and the medium are important factors at paper converting and box plants. Parameters related to the quality of the liners and the medium that are important to vertical compression strength are basis weight and modulus of elasticity.

1.2.1 Basis Weight

Increasing basis weights, and subsequently caliper, produces a container with greater top to bottom compression strength. Studies indicate that placement of materials of differing basis weights will play a role in the ultimate strength, which is evaluated by observing the mode of failure of a corrugated structure (Maltenfort, 1989). A corrugated structure bends under a load until it begins to buckle. The bending generates compression stresses on the inside liner while creating tension on the outside liner (Figure 3). To maximize compression resistance the heavier liner is often placed on the inside.

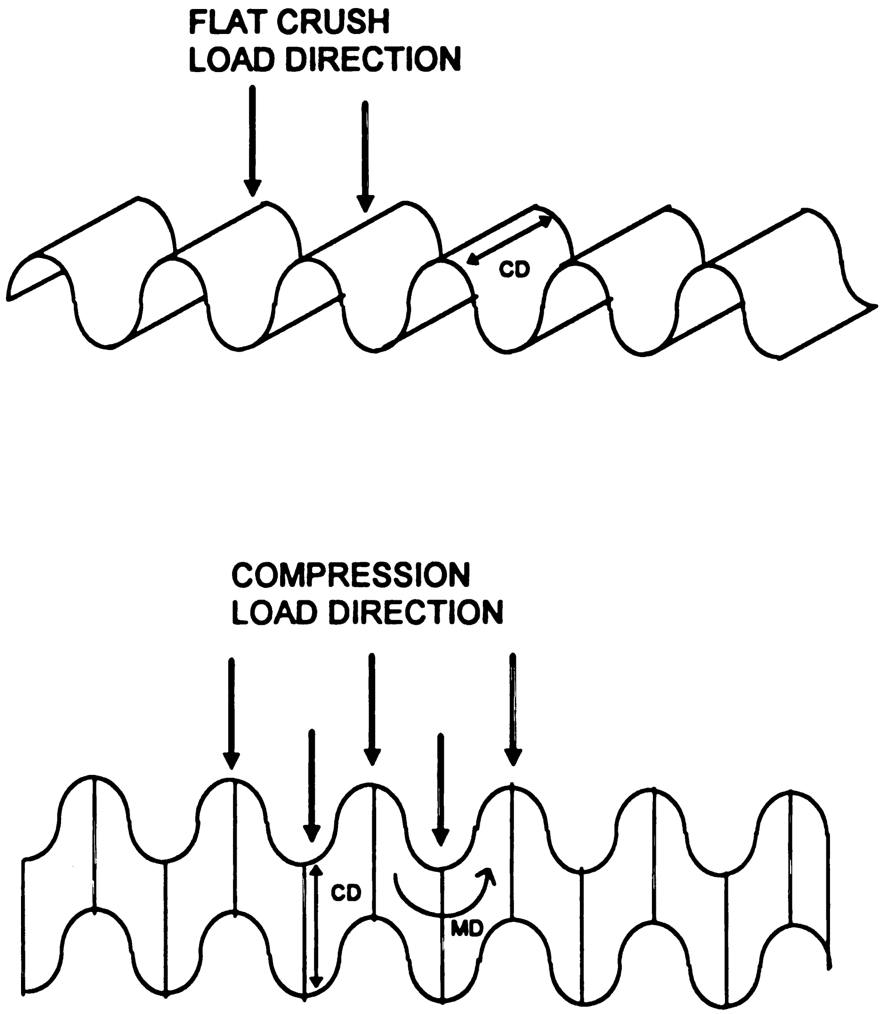


Figure 3

CONTRIBUTION OF MEDIUMS

1.2.2 Modulus of Elasticity

Modulus of elasticity is indicated by the slope of the straight-line portion of a tensile test curve. The modulus of elasticity is calculated by dividing a stress value (selected from the straight line portion) by the corresponding strain value.

An increase in the stiffness of the linerboard contributes to the resistance of the combined corrugated material to failure. Therefore, the higher the modulus of elasticity, the greater the resistance to vertical compressive forces. The stiffness of the liners directly affects the stiffness of the combined board, and ultimately the top to bottom compression strength (Kellicut, 1959).

1.3 Combined Board Properties

The materials that are combined to produce corrugated board can be modified to produce containers with different top to bottom compression strengths. The basis of sound corrugated board is related to the stiffness of the combined material. Stiffness can be modified by altering combined caliper. Factors that influence combined corrugated board properties include:

- combined caliper
- adhesives

- converting processes

A variety of laboratory tests can be conducted on a sample piece of combined board to give an indication of the quality related to the combining and converting processes (McKee, et al, 1989). The most important of these tests include the Mullen Burst test and edge wise compression.

1.3.1 Combined Caliper

The combined thickness of liners and medium is referred to as combined caliper. Combined caliper is modified by specifying different basis weights and/or by specifying different flute structures. The flute size and basis weight of the components affects the degree of stiffness of combined components (Kellicut, 1959). Stiffness can be increased by using liners with a higher modulus of elasticity, heavier basis weight liners or larger flutes. Maximizing the caliper is a step towards optimizing container compression strength. The three most common flutes are A, B, and C. The dimensions of each flute are shown below:

FLUTE	HEIGHT (in)	FLUTES /LINEAR FOOT
A	3/16	36
B	3/32	50
C	9/64	42

The progression from best to worst in vertical compression strength is from A to C to B.

1.3.2 Adhesives

The combining stage is where the medium and the liners are joined to produce the columnar structure. Inadequate gluing, or faulty adhesion can result in significant losses of compression strength. Faulty gluing equipment, adhesive properties, or high moisture content of the board can result in glue skips. Glue skips refer to inadequate gluing in the combining operation resulting in reduction in compression strength (Koning & Moody, 1989).

With the exception of poor fabrication, "adhesives appear to have greater influence on the physical properties of corrugated board than any other factor" (Bristow, 1989). Faulty bonds can reduce compression strength by as much as 50%. A good bond depends on sufficient adhesives being applied at the tip of the flutes to form small fillets between the corrugated medium and the liners (Kellicut, 1959).

1.3.3 Converting Processes

The US Institute of Paper Science and Technology had recently examined the quantitative effects of a number of operations at a box conversion plant (Batelka, 1994). This study specifically examined the quantitative effects of the converting operations by studying crushing, single facing cured bond strength, leaning flutes, and variations in flute height. The study concluded that lower single-face pin adhesion bond strength, a greater percentage of high/low flutes, and crushing of the combined board, can reduce the average edge crush test by as much as 13.0%. The cause of these variations had been attributed to material properties and manufacturing conditions.

1.3.4 Mullen Burst Value

In the past, corrugated board was specified based on Mullen Burst Strength values and combined basis weights of liners and medium. The Mullen Burst Strength value indicates the amount of force required to burst one circular square inch of corrugated board. This means of specifying corrugated board dates back to 1903 when use of corrugated fiberboard boxes was approved as a legal freight classified package (Hanlon, 1992). The Mullen Burst Strength value becomes important when the contents of the package are of a nature (dense, angular products) that may potentially puncture the walls of the box. The Mullen Burst does not give an indication of the top to bottom compression strength which is often a more important consideration.

1.3.5 Edge Crush Test

In 1992 the Fiber Box Association and the Association of Independent Corrugated Converters introduced a rule as an alternate to Rule 41/Item 222. The Alternate Rule 41/Item 222, or Edge Crush Test (ECT), highlights the important contribution of the corrugating medium to the strength of the corrugated structure (Kroeschell, 1992).

The ECT is a measure of the columnar strength of a sample of corrugated board. The mode of failure observed in the edgewise compression test is similar to the type of failure seen in the top-load compression tests (McKee, et al, 1989). It is now recognized as the most important test of vertical box compression strength.

This change to the ruling has renewed an interest in studying the factors that affect overall box compression strength. The introduction of high performance liners has been instrumental to this change.

1.4 Corrugated Box Performance

Corrugated box performance is primarily dependent on the quality of the materials and quality of fabrication at box making facilities. Factors that can be modified to increase performance primarily depend on flexural stiffness of the corrugated material. Attaining optimal container performance is based on the following factors:

- flute type
- recycle content
- load distribution
- environmental factors

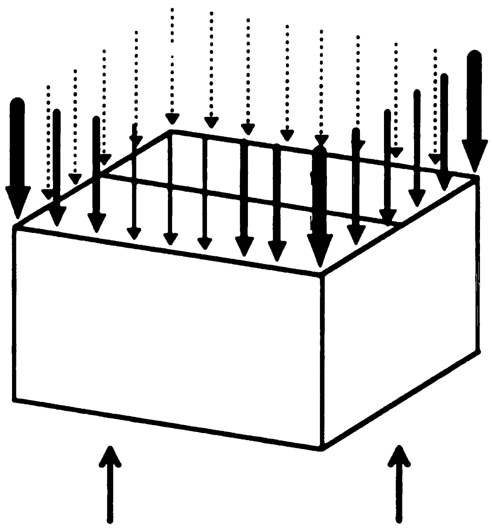
1.4.1 Flute Type

The importance of flexural stiffness to top-load box compression strength becomes apparent when evaluating containers fabricated of the same components in A, B, and C-flute. Edgewise compression testing of these materials show little difference, however, top-to-bottom compression values of containers of the same size are considerably different. This difference can be attributed to the difference in flexural stiffness which is related to the difference in combined board thickness. The container constructed of A-flute has the highest compression value, the container constructed of C-flute has the next highest value, and the container constructed of B-flute shows the lowest compression value.

1.4.2 Load Distribution

Flexural stiffness is the capacity of a piece of corrugated board to resist bending. The importance of flexural stiffness is evident when evaluating the mode of failure in corrugated containers. Experiments of box failure show that panels will buckle in the center at a load lower than the load at failure. As the load is applied the initially flat panel bends, creating uneven strain on the liners. The inside liner experiences an increase in compression while the outside liner experiences tension. The panel becomes unstable and begins to buckle before failure is achieved.

The vertical edges of the container support most of the load (64%), with the center part of the panels carrying the remainder of the load as show in Figure 4 (Maltenfort, 1989). As compared to the central region of the panels, the combined board at the vertical edges are more uniformly stressed in edgewise compression. The vertical edges carry more load per inch than the board at the center of the panel, however it is the bending characteristics of



COMPRESSION LOAD

Figure 4

LOAD DISTRIBUTION ON CORRUGATED CONTAINER the combined board that dictate the load-carrying capacity of the central region of each panel.

The contribution of the center part of the panel is directly related to the flexural stiffness. Flexural stiffness can be improved by using liners with a high modulus of elasticity in tension and compression and high caliper. It is important that the combined caliper be as uniform as possible. Variation in combined caliper due to processes such as printing, can decrease the caliper, thereby lowering the potential flexural stiffness (Nordman, et al, 1978).

Corrugated box performance in a pallet stack is related to stress distribution. Shifting load from the corners to the sides of the container, as in an interlocking pallet load reduces the static compressive strength (Kutt & Mithel, 1989). This is evidenced in compression studies of pallet sized loads. A change from a column to interlock pattern results in compression loss of 45%, and a one inch overhang reduces compression strength by 32% in C-flute corrugated boxes (Rha, 1996).

Column stacking boxes takes advantage of the greatest strength of the container. The corners are the strongest members, so by aligning the weakest members (panels) and by aligning the strongest members the greatest strength can be achieved. This alignment creates a situation of even deflection and consequently the boxes will fail at higher loads. Column stack configurations typically show as much as 29% greater stacking strength than interlocked stacks.

1.4.3 Recycle Content

The use of recycled fiber in the past few years has generated great interest. Until recently recycled fiber was considered to be a major influence on compression values. The common perception was that an increase in recycled content would cause a reduction in box compression strength. Various recent studies have shown that cyclic humidity can produce higher compression strength reductions than continuous exposure at a higher humidity. This has been supported by the fact that during cyclic humidity there is continuous expansion and contraction of the paper structure making the glue bonds weaker and damaging the corrugated structure (Laufenberg and Leake, 1992).

These studies also show that recycled paperboard and high-yield paperboard have more tendency to deform under cyclic humidity conditions than does virgin paperboard. However, at constant conditions at high relative humidity, there is no significant difference between virgin and recycled or high-yield pulp paperboards (Soderberg, 1992). Another report concludes that boxes constructed of 100% recycle liners perform similar to virgin kraft under cycling humidity and temperature conditions. The results show that under cycling humidity and temperature, all box combinations fail within the same time period (Laufenberg & Leake, 1992).

In a recent study corrugated board performance with differing amounts of recycled content was evaluated for corrugated material properties and overall box compression strength. The results of this study show that the paper making process, in addition to the presence of recycled fiber, greatly affects the strength of the board. This is because newer technologies process the fibers with less damage to the fiber structure. The result is stronger bonding forces, and effectively higher compression values (Singh, et al, 1995).

1.5.4 Environmental Influences

Other external factors to consider are environmental influences, especially cyclic conditions. Humidity is recognized as the major factor since the moisture content is directly related to compression values. Cyclic humidity further degrades performance (Laufenberg and Leake, 1992). Another study shows that early failure of containers exposed to cyclic conditions is related to changes in moisture content (Boonyasarn et al, 1992). This study determined that exposure to a variety of cyclic conditions resulted in an uptake of moisture and reduction of compression strength.

Studying the effects of cyclic environments related to box life span indicate that containers experiencing greater changes in moisture have a reduced life span. The study shows that as the container takes on moisture, the paper expands affecting the box height. The box height undergoes a change when it is exposed to high humidity. To determine the difference, containers were evaluated at static loading conditions and results show that there is a greater change in height for boxes experiencing two cycle changes per day than there is for boxes experiencing one or one half cycles per day (Leake & Wojcik, 1992).

1.5 Study Objectives

This study was initiated by the Clorox Company to determine the strength reduction in corrugated boxes when they are handled in an automated packaging line. Specifically the study had the following two objectives:

- Determine the percent reduction in compression strength of single-wall corrugated boxes at various stages in the packaging line.
- Determine if the automatic drop loading case packers produce the largest damage to the compression strength of corrugated boxes.

2.0 EXPERIMENTAL DESIGN

The containers used in this study were modified RSC's, constructed of single-wall C-Flute corrugated material. The material combination had an ECT value of 55 lbs/in. The boxes measured 19-1/4" x 12-13/16" x 12-3/8". These containers were automatically erected, loaded, and sealed at a rate of 30 cases/ minute. The samples were evaluated for the Clorox plant in Chicago that blow molds the gallon plastic bottles, fills them with Clorox bleach, case packs, and palletizes the load for shipment. This plant operation runs all three shifts.

Thirty corrugated box samples were randomly selected at four locations on the packaging line as shown in Table 1. These various locations were selected by Clorox and MSU as potential areas that may attribute to the largest degradation in compression strength performance of corrugated containers. The packaging line equipment specifications are shown in Table 2. The corrugated containers are supplied knock-down and palletized to the Clorox facility by Clorox corrugated suppliers.

Table 1: SAMPLE LOCATIONS

SAMPLE	DESCRIPTION
A	Control, Knockdowns from supplier
B	Sample Location #1; cases erected, bottom flaps glued
C	Sample Location #2; after loading bottles
D	Sample Location #3; post closing & gluing, prior to up conveyor
E	Sample Location #4; after palletizing & unitizing

Table 2: PACKAGING LINE EQUIPMENT

EQUIPMENT	MANUFACTURER	MODEL #	MAX RATED SPEED (CASES/MIN)	TYPICAL OPERATING SPEED (CASES/MIN)
Case Erector	McDowell	201	30	26-27
Case Packer	Harkness	825	on demand	26-27
Case Gluing	Nordson	2302	on pressure	26-27
Case Sealing	Nordson	2302	30	26-27
Palletizer	Columbia	510	45	30

The boxes were fed in a magazine and automatically erected by the case erector. The case erector also applies glue on the bottom flaps and seals the base of the container. Along side to this line (Figure 5), the blow molding machine manufactures the gallon size HDPE bottles. These bottles are filled on a rotary filler, capped and labeled. The two lines merge at the case packer, where six gallon bottles are drop packed into the corrugated case. The case packer drops the bottle approximately 11.5 inch into the box.

The cases are then subjected to a side tilt on a power conveyor, to inspect for any leaks in the bottles. This operation results in substantial flexing of the side wall of the corrugated shippers. After inspection the boxes enter a case sealer where the top flaps are glued shut. The cases are then bar-coded, and travel across the building on an overhead conveyor to the warehouse. The filled cases are then automatically palletized and stretch wrapped. Photographs showing sections of different line equipment at the Clorox facility are presented in the Appendix section of this thesis.

The thirty samples selected at the various locations were then transported to the School of Packaging the same day. These were then conditioned for 24 hours. The cases were erected, glued and tested for

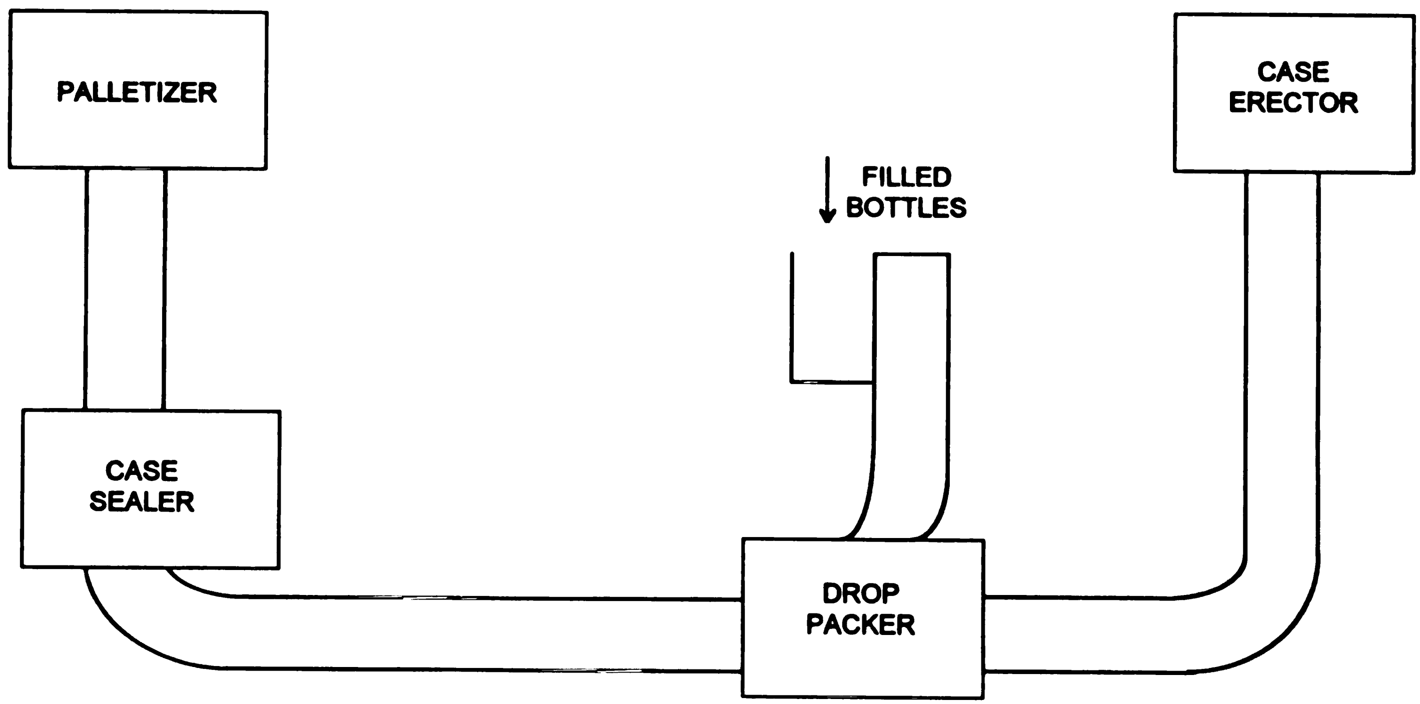


Figure 5

PACKAGING LINE LAYOUT

compression strength.

2.1 Conditioning of Test Samples

The knock-down containers were conditioned according to ASTM D 4332 at 72°F and 50% Relative Humidity for at least 24 hours prior to testing. After conditioning, the boxes were sealed both top and bottom using hot melt glue adhesive similar to that used at the Clorox facility.

2.2 Testing Procedure

The boxes were tested for compression strength according to ASTM D 642. The cases were tested using a Lansmont Corporation Compression Tester (Model No. 76-5K). A fixed platen was used, and the load was applied at a rate of 0.5 inch/minute. The test equipment has a digital readout of force with a ±1% linearity and is in accordance with ASTM D-642 and TAPPI T-804 test methods. The maximum compression strength at failure and the corresponding deflection was measured.

3.0 DATA ANALYSIS AND RESULTS

A total of 165 empty corrugated containers were tested to determine the reduction in compression strength of corrugated containers at various locations for the Clorox automated packaging facility. Maximum compression and deflection values of corrugated boxes tested are listed in Tables A1 - A6 in the Appendix section.

Thirty knockdown samples (Sample A) were erected, glued and compression tested as a control, to determine average compression values of knockdown boxes that have not been handled by the automated line equipment. The individual values for each empty container tested are listed in the Appendix, Table A1. The mean compression value for the control samples was found to be 1322 lbs. Table 3 shows the average percent reduction in compression strength of corrugated containers sampled from Locations 1,2,3, and 4 on the automated packaging handling line.

Table 3: AVERAGE PERCENT REDUCTION IN COMPRESSION STRENGTH

SAMPLE	AVERAGE COMPRESSION STRENGTH (lbs)	PERCENT REDUCTION (%)
A	1322	-
B	1146	13.3
C	1203	9.0
D	1187	10.2
E	1213	8.2

Table 3 shows the average percent reduction in compression of boxes relative to the control, Sample A. This data was analyzed to determine the distribution and variation of compression strength values for each of the four locations studied.

Figures 6-10 are histograms that represent the distribution of compression strength values for the corrugated containers tested as control and at the various line locations. This provides a measurement of the variation of the process conditions of each location pertaining to box compression strength.

The average compression strength after the boxes were erected and bottom flaps glued was found to be 1146 lbs. This represents a 13.3% reduction in compression strength. The average compression strength of the boxes after drop loading the bottles in the case was found to be 1203 lbs. This represents a 9.0% reduction in compression strength as compared to the control. Similarly the average compression strength of the boxes after closing and gluing the top flaps was found to be 1187 lbs. and represents a 10.2% reduction in compression strength. Lastly the average compression strength after the boxes are unitized and palletized was found to be 1213 lbs. showing an 8.2% reduction in

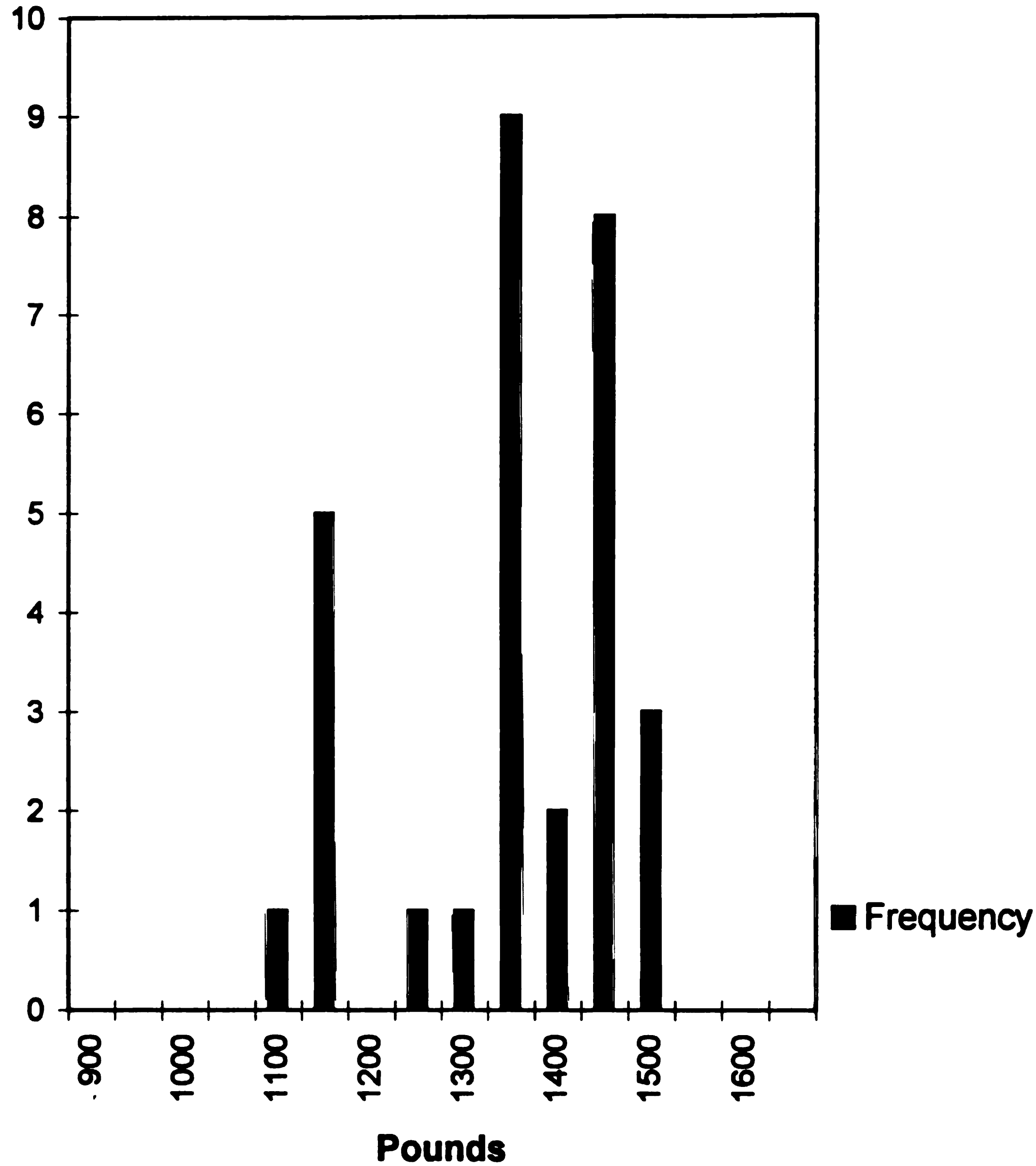


Figure 6

HISTOGRAM OF COMPRESSION
STRENGTH VALUES, SAMPLE A

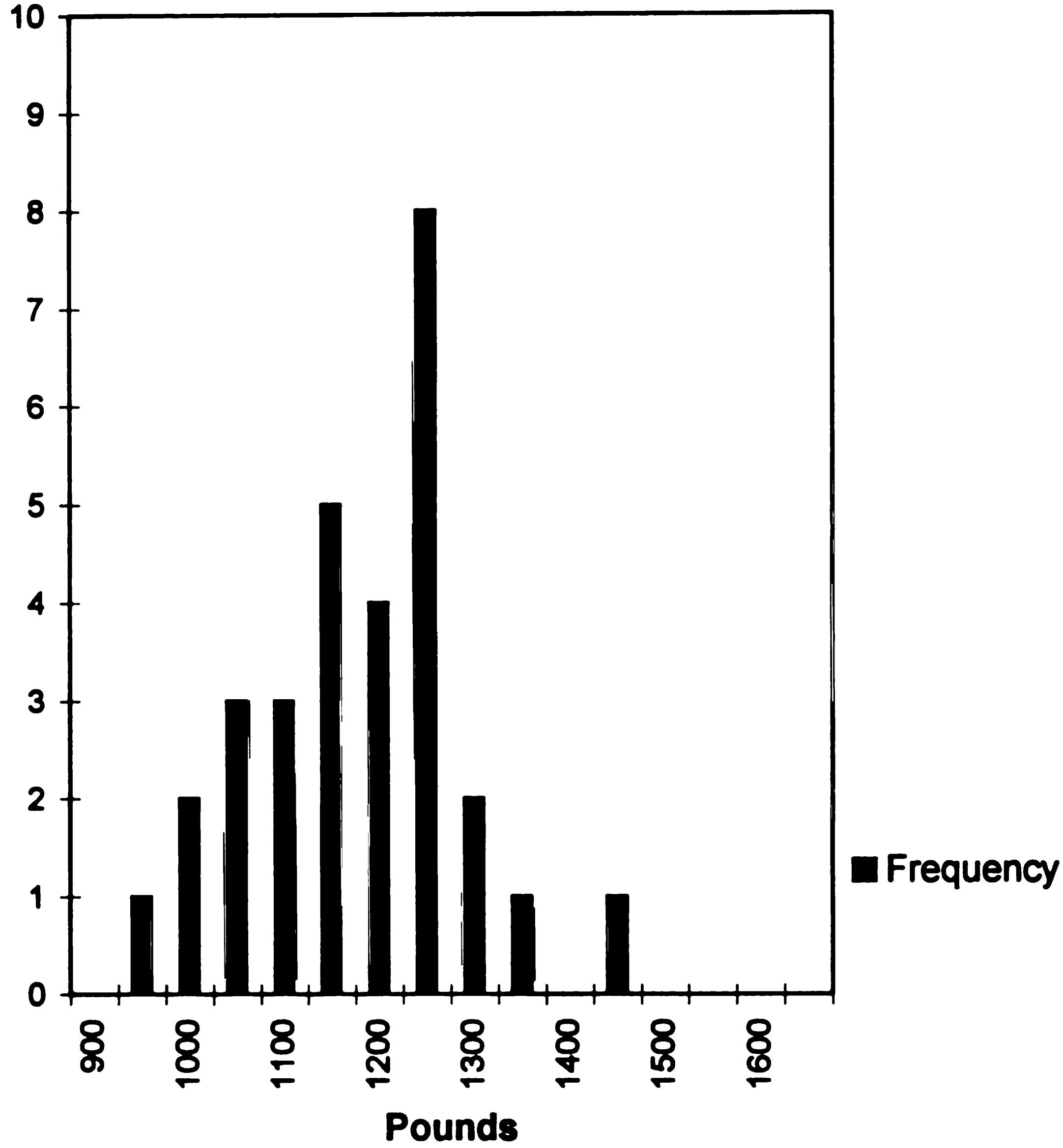


Figure 7

HISTOGRAM OF COMPRESSION STRENGTH VALUES, SAMPLE B

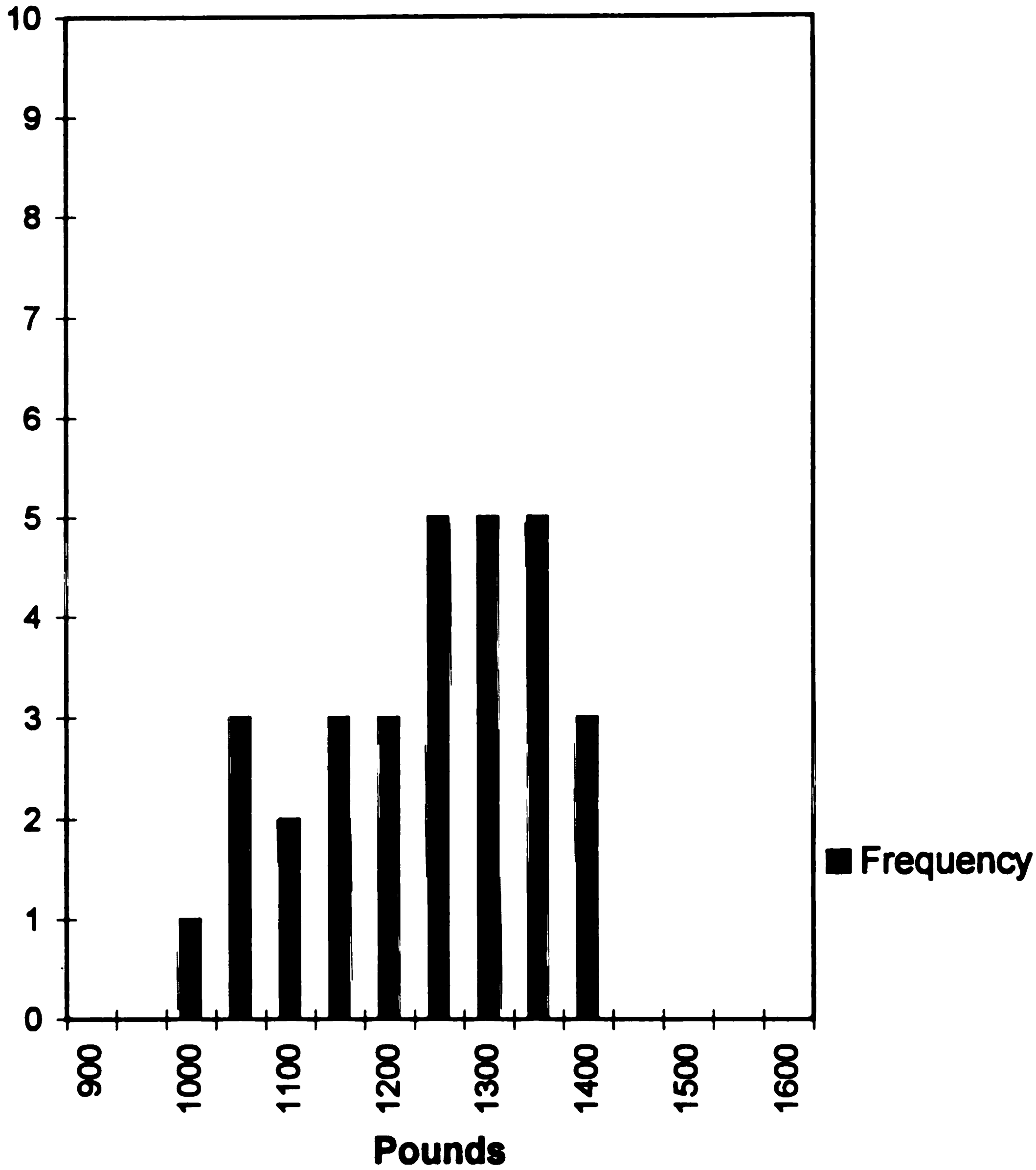


Figure 8

HISTOGRAM OF COMPRESSION STRENGTH VALUES, SAMPLE C

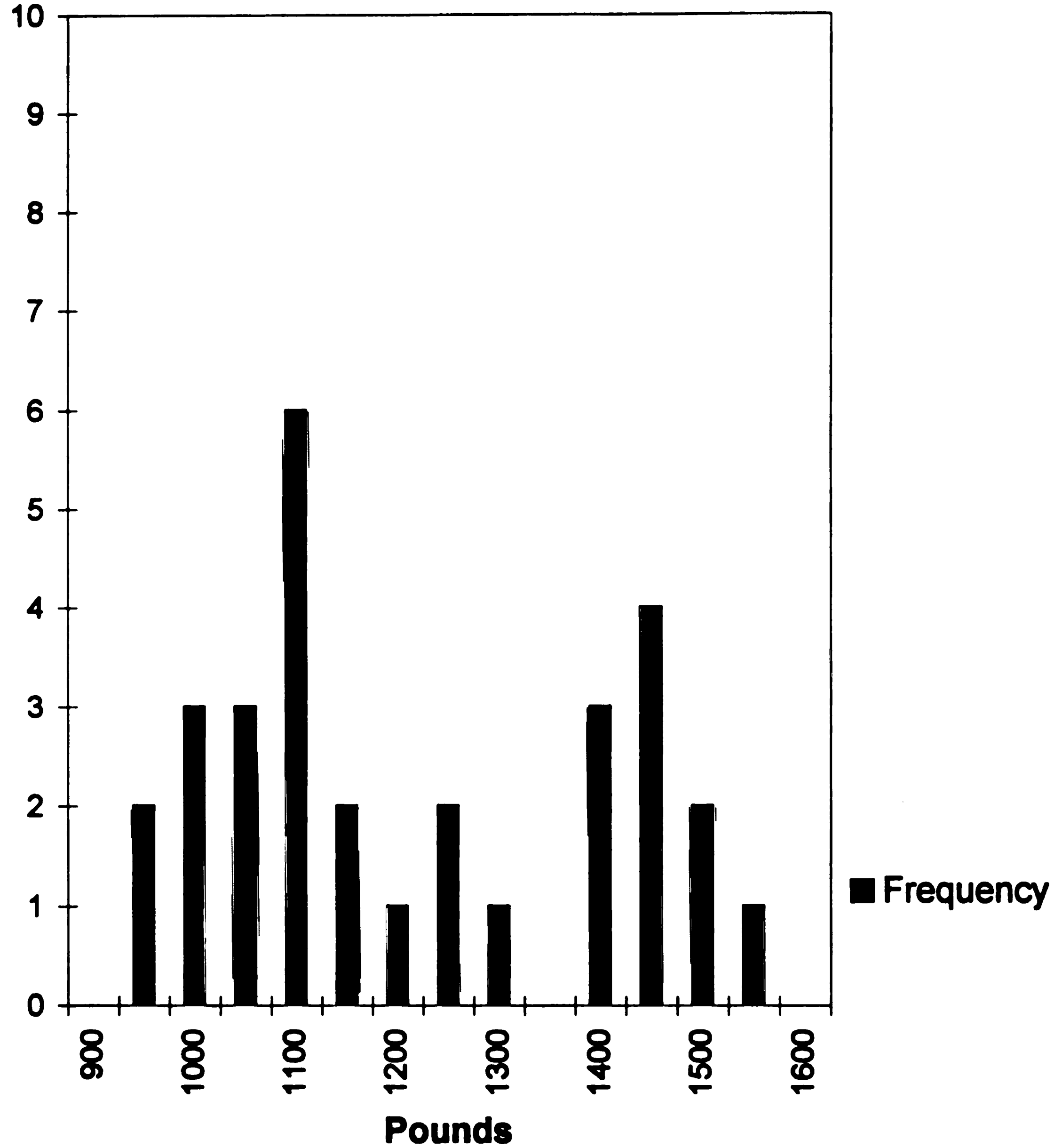


Figure 9

HISTOGRAM OF COMPRESSION
STRENGTH VALUES, SAMPLE D

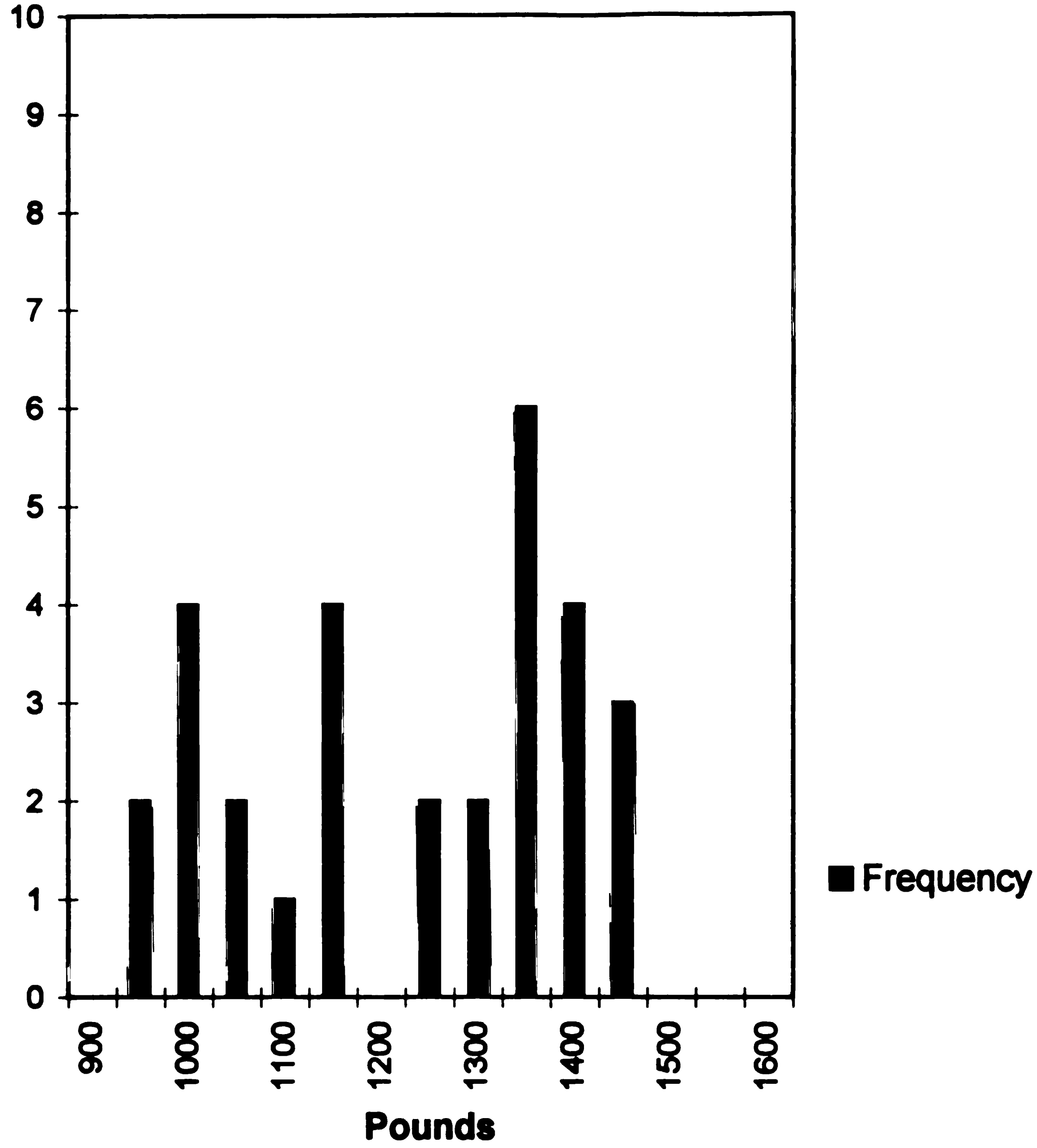


Figure 10

HISTOGRAM OF COMPRESSION STRENGTH VALUES, SAMPLE E compression strength as compared to the control.

Initially, a two-tail t-test was performed to compare the significant difference between the control samples and the four line locations with a 99.5% confidence level (alpha = 0.05). Tables 4 and 5 show the results of the t-tests.

The results in Table 4 show that there is a significant difference between the control samples (A) and each of the locations on the packaging line. Table 6 shows that there is no significant difference between the strength of corrugated boxes among each adjacent location on the packaging line.

The results of the two tail t-test are further supported from the results of the Kolmogorov-Smirnov Two Sample Test, Maximum Difference for Pairs. This test indicates the significance of compression value comparisons between each adjacent location. Table 6 summarizes the results by showing that there is a significant difference in compression values between the control samples (A) and samples tested at the first location (Sample B). However, there is no significant reduction of compression strength along remaining line locations.

Table 4: t-STATISTIC BETWEEN CONTROL AND VARIOUS LINE LOCATIONS

COMPARISON	VARIABLE 1			VARIABLE 2					
VARIABLE 1 VS VARIABLE 2	Mean	SD	Observations	Mean	SD	Observations	T-Stat	df	DIFFERENCE
A vs B	1322.4	122	30	1155.3	116	30	5.44	58	Significant
A vs C	1322.4	122	30	1210.8	113	30	3.68	58	Significant
A vs D	1322.4	122	30	1193.8	192	30	3.10	58	Significant
A vs E	1322.4	122	30	1204.7	168	30	3.10	58	Significant

*Significant at 99.5% confidence level.

Table 5: t-STATISTIC COMPARISON BETWEEN ADJACENT LINE LOCATIONS

COMPARISON	VARIABLE 1			VARIABLE 2					
VARIABLE 1 VS VARIABLE 2	Mean	SD	Observations	Mean	SD	Observations	T-Stat	df	DIFFERENCE
B vs C	1155.3	116	30	1210.8	113	30	-1.88	58	Not Significant
C vs D	1210.8	113	30	1193.8	192	30	0.42	58	Not Significant
D vs E	1193.8	192	30	1204.7	168	30	-0.23	58	Not Significant

*Significant at 99.5% confidence level.

Table 6: RESULTS OF KOLMOGOROV-SMIRNOV TWO SAMPLE TEST, MAXIMUM DIFFERENCE FOR PAIRS

SAMPLE	A	B	C	D	E
A	0.0				
B	0.667	0.0			
C	0.500	0.333	0.0		
D	0.433	0.300	0.300	0.0	
E	0.333	0.400	0.233	0.200	0.0

The data collected for various locations has also been presented in the form of statistical box plots. Figure 12 shows the box plots that indicate the variances for each location. The diagram illustrates the shift in the mean and the change in variance at each line location, indicating that there is a significant difference between the control (A) and samples selected at the case erector (Sample B). Again, there is not a significant difference between the remaining adjacent line locations (B-C, C-D, D-E).

If a continued damaging effect was caused at each line location, the samples tested at location E would show the lowest compression strength values. However, the results from this study show that the last location (palletized boxes) actually showed the least reduction in strength. However, the variation in the average compression strength values found in this study are within the range of typical variability in compression strength values of corrugated containers.

In addition, the results of this study show that drop loading of bottles in corrugated containers is not the single most strength reduction factor on this type of automated packaging line. This is attributed to the fact that drop loading can cause some damage to the bottom flaps, however the vertical compression strength is predominately a function of the side faces of the boxes alone. The palletization process involves sliding the boxes laterally,

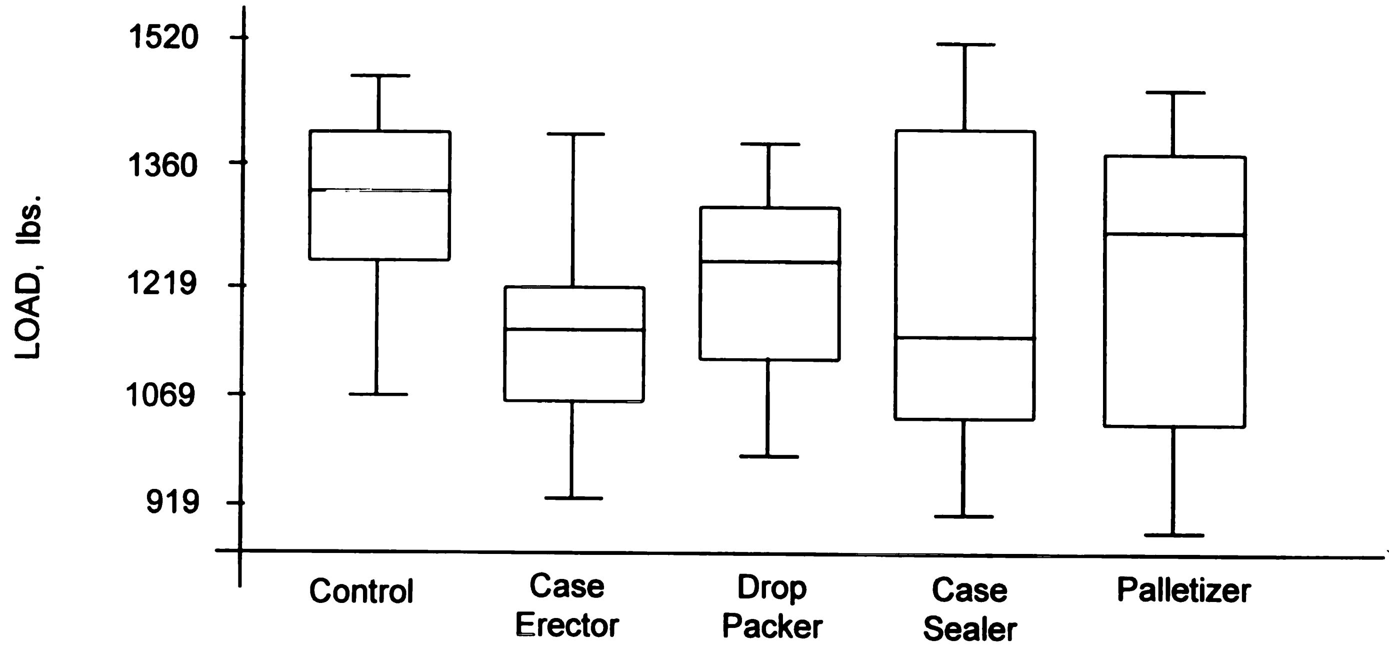


Figure 11

STATISTICAL BOX PLOT

resulting in some side squeeze when the stretch wrap is applied. This however does not produce significant damage as compared to any other line equipment tested.

An important observation of this study is that drop loading case packers do not produce the most significant damage to the boxes as compared to other line equipment.

4.0 CONCLUSIONS

The results of this study show that the automated packaging line results in average compression strength reduction of approximately 10% in C-flute single-wall regular slotted corrugated containers. No individual line equipment tested produced the most contributing damage to the boxes. Also the drop loading case packers are not a significant factor in strength reduction to corrugated boxes on the packaging line.

There is no significant variation in the compression strength values among adjacent equipment locations on the packaging line. Most of the damage is attributed to erecting and set-up of boxes and the travel along the conveying system.

5.0 RECOMMENDATIONS

Based on the results of the study several areas of future investigation are needed. The effect of line equipment on corrugated containers made of different flute sizes needs to be studied. Similarly different styles of box configurations need to be investigated. A general comparison between drop case packers and wrap-around case packers to evaluate strength reductions would also provide important information. This would assist in the choice between these two types of line equipment. Drop case packers while, cheaper, are often thought to produce more damage to corrugated cases, whereas wrap-around case packers, which are expensive, and require die cut boxes, are considered to be gentle.

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APPENDIX

Table A-1: RAW DATA, SAMPLE A

SAMPLE	LOAD (POUNDS)	DEFLECTION (INCHES)	SAMPLE	LOAD (POUNDS)	DEFLECTION (INCHES)
1	1350	0.70	16	1485	0.68
2	1321	0.62	17	1468	0.75
3	1138	0.59	18	1447	0.63
4	1429	0.68	19	1424	0.78
5	1476	0.91	20	1124	0.67
6	1304	0.63	21	1342	0.66
7	1425	0.65	22	1342	0.64
8	1341	0.74	23	1071	0.57
9	1335	0.81	24	1120	0.62
10	1257	0.82	25	1103	0.64
11	1432	0.75	26	1303	0.63
12	1245	1.07	27	1314	0.64
13	1406	0.67	28	1359	0.63
14	1361	0.66	29	1414	0.64
15	1408	0.78	30	1129	0.62

Table A-2: RAW DATA, SAMPLE B

SAMPLE	LOAD (POUNDS)	DEFLECTION (INCHES)	SAMPLE	LOAD (POUNDS)	DEFLECTION (INCHES)
1	1435	0.65	16	1020	0.64
2	1124	0.55	17	1271	0.71
3	1113	0.64	18	1170	0.66
4	1127	0.84	19	1295	0.69
5	1065	0.66	20	1242	0.74
6	1063	0.64	21	1239	0.68
7	957	0.66	22	1217	0.68
8	1129	0.59	23	1176	0.68
9	982	0.52	24	1230	0.69
10	1312	0.81	25	1220	0.62
11	1244	0.68	26	948	0.51
12	1150	0.79	27	1006	0.53
13	1239	0.63	28	1188	0.75
14	1015	0.59	29	1173	0.64
15	1071	0.61	30	1238	0.76

Table A-3: RAW DATA, SAMPLE C

SAMPLE	LOAD (POUNDS)	DEFLECTION (INCHES)	SAMPLE	LOAD (POUNDS)	DEFLECTION (INCHES)
1	1321	0.79	16	1368	0.72
2	1326	0.81	17	1092	0.64
3	1230	0.83	18	1392	0.76
4	1368	0.82	19	1248	0.72
5	1242	0.71	20	1267	0.80
6	1103	0.67	21	1126	0.61
7	1118	0.63	22	1253	0.76
8	1156	0.68	23	1280	0.69
9	995	0.57	24	1306	0.74
10	1295	0.68	25	1195	0.86
11	1151	0.65	26	1253	0.70
12	1048	0.60	27	1315	0.86
13	1224	0.66	28	1223	0.65
14	1023	0.64	29	1309	0.67
15	1035	0.62	30	1062	0.62

Table A-4: RAW DATA, SAMPLE D

SAMPLE	LOAD (POUNDS)	DEFLECTION (INCHES)	SAMPLE	LOAD (POUNDS)	DEFLECTION (INCHES)
1	1180	0.54	16	1068	0.52
2	1409	0.65	17	1379	0.74
3	1520	0.74	18	935	0.49
4	1403	0.55	19	1100	0.58
5	1035	0.47	20	1059	0.46
6	1397	0.68	21	980	0.49
7	1459	0.71	22	1056	0.55
8	1015	0.48	23	1147	0.52
9	1206	0.58	24	1057	0.53
10	1427	0.69	25	1023	0.51
11	1445	0.69	26	1295	0.60
12	1486	0.84	27	1118	0.58
13	1250	0.57	28	930	0.48
14	1398	0.64	29	979	0.51
15	1091	0.56	30	968	0.53

Table A-5: RAW DATA, SAMPLE E

SAMPLE	LOAD (POUNDS)	DEFLECTION (INCHES)	SAMPLE	LOAD (POUNDS)	DEFLECTION (INCHES)
1	1027	0.48	16	1401	0.63
2	968	0.48	17	1323	0.62
3	1120	0.54	18	1359	0.67
4	989	0.47	19	1276	0.55
5	1086	0.53	20	1239	0.61
6	1027	0.49	21	1374	0.68
7	995	0.52	22	1389	0.53
8	947	0.51	23	1401	0.63
9	1215	0.58	24	1292	0.54
10	1118	0.55	25	1395	0.58
11	968	0.48	26	1332	0.51
12	1103	0.49	27	1329	0.59
13	1320	0.56	28	919	0.58
14	1127	0.63	29	1442	0.51
15	1312	0.54	30	1347	0.52

Table A-6: MAXIMUM, MINIMUM, AVERAGE , MEAN and STANDARD DEVIATION

LOCATION	MAXIMUM FORCE (lbs)	MINIMUM FORCE (lbs)	MEAN	STANDARD DEVIATION
A	1485	1071	1322	122
B	1435	948	1155	116
C	1392	995	1210	113
D	1520	930	1193	192
E	1442	919	1205	168