This is to certify that the

thesis entitled

LOSS IN COMPRESSION STRENGTH
OF CORRUGATED CONTAINERS DUE TO OFFSET
AND ITS EFFECT ON STABILITY OF PALLETIZED LOADS

presented by

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has been accepted towards fulfillment
of the requirements for

MASTER degree in PACKAGING

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Date JANUARY 31, 1996

LOSS IN COMPRESSION STRENGTH OF CORRUGATED CONTAINERS DUE TO OFFSET AND ITS EFFECT ON STABILITY OF PALLETIZED LOADS

By

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A THESIS

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

MASTER OF SCIENCE

School of Packaging

1996

ABSTRACT

LOSS IN COMPRESSION STRENGTH OF CORRUGATED CONTAINERS DUE TO OFFSET AND ITS EFFECT ON STABILITY OF PALLETIZED LOADS

By

Sang-Yoon (Jim) Rha

This study investigated the effect of lateral offset on the compression strength of single wall corrugated containers. Tests were conducted to evaluate stack stability in normal and tropical climatic conditions for different offsets. The results show that between 20% to 64% of the stacking strength is lost due to the presence of offset. This loss is further increased due to exposure to higher humidity environments. The data also showed that the initial 5% reduction in offset area resulted in the highest reduction in compression strength. Additional amount of offset reduced the compression strength but at a lower rate. The results also showed that offset contributed to a higher degree of strength reduction than exposure to high humidity for 48 hours.

The results also showed that the stability of stacked palletized loads is greatly affected by the amount of shift of the center of gravity of the individual unit loads and the quality of the pallet.

I would like to dedicate this thesis to my parents for their love and belief.

ACKNOWLEDGEMENT

I would like to first express my sincere thanks to my major professor, Dr. S. Paul Singh, and to other members of my graduate committee, Dr. Gary Burgess and Dr. George E. Mase. Their assistance throughout my research and analysis is gratefully acknowledged.

I would also like to thank Stone Container, Laimbeer Packaging Company and Ross Products for the materials and supplies and the funding which made this research possible.

I would like to thank all the faculty and staff of the School of Packaging and all those who helped me in during the course of my graduate studies. I would like to extend my special thanks to my colleagues with whom I worked on various projects.

Finally, I am especially thankful to my father, Jin-Koo Rha, and my mother, Kyung-Joo Lee for their everlasting intellectual and financial support throughout the program. I like to thank my sister, brother-in-law, and my close relatives for their guidance and support.

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1.0 Introduction

Long term stability of stacked pallet loads is one of the important requirements for warehouse and distribution package systems. A lack of complete information about the strength of a product/package system in a stacked configuration can result in leaning stacks that could eventually fall. Such scenarios though rare can result in excessive product damage and possibility of serious human injury. In many cases, packaging professionals often use computer software programs to optimize packages in trailers and warehouses. Most such tools often provide good information on cube utilization and different methodologies to arrange packages. However, these models do not account for factors such as inferior quality pallets, partially damaged packages, localized offset in the palletized load, uneven floor surface, and irregularity in the geometry of the package due to fabrication. All these factors can collectively produce an accelerated phenomenon that would cause packages in stacked pallets to yield and result in a catastrophic situation.

The purpose of this study was to investigate the effect of offset in single wall corrugated containers to see how a loss in compression strength could affect the load bearing capacity of stacked packages. This provided a better understanding of the package performance at the micro level. The effect of humidity and degree of offset was evaluated. The stability of palletized loads was studied at the macro level as well. This consisted of stacking the pallets at varying degrees of offset that would result in the center of gravity of the top loaded pallets to shift sideways and result in a tipping scenario.

In order to accomplish the objectives of this study, two different kinds of experiments were conducted. Each individual experiment is discussed in detail and is identified as 'Experiment 1' and 'Experiment 2'. The first experiment evaluates the package performance at the micro level and the second at the macro level. Detailed information on test procedures used and data collected is provided in Chapter 3 and 4 of this thesis.

The primary objectives of this study are listed below.

1. Determine the loss in compression strength as a function of offset and exposure to humidity in three different sizes of single wall regular slotted containers.
2. Evaluate the effect of lateral offset to the center of gravity of stacked palletized loads on their vertical stability.
3. Perform actual simulations of palletized load offset scenarios that would cause stacked pallets to become unstable and fall.

2.0 Literature Review

Warehouse costs are minimized by using full cubic capacity of the storage space and maintaining a fast change in stock cycle time. Of particular importance is the long term stability of stacked palletized loads. The bottom box or container in the stack must carry the residual load of the packages above it for the full storage time without collapse or excessive bulge to the box or container itself. However, not fully understanding the capability of the package system's strength in the stack, full cubic utilization of the warehouse to achieve cost minimization could lead to leaning stacks that would potentially collapse. This could produce secondary damage as once a stack starts to collapse it would propagate to adjacent columns and would produce a "Dominos Effect".

Today, corrugated containers are used to package a majority of products in the United States and account for over 90% of industrial and consumer goods (Fiedler, 1995). The design requirements critical for one type of packaging application may not be suitable for another application since factors such as storage time, humidity, stacking pattern, package weight, transportation all contribute to the overall performance of the package. It is therefore necessary to evaluate the effect of these various factors on the total package performance.

The load bearing ability of a box is related to the strength of the vertical panels in compression. The dominant influence on compression strength is corner rigidity since buckling of corrugated sides can take place at relatively low loads. The box is weakest in the center panels and strongest at the corner. The greatest stacking strength is obtained by arranging the stack so that the strongest areas match together and the weakest areas also align. This provides a uniform deflection along the horizontal edges of each panel. This is ideally achieved by column stacking the boxes directly above one another. When interlock stacking is used, the strong stiff corners of one panel match the weaker areas in those panels in adjoining layers both above and below. This creates uneven deflection along the horizontal edges of the panel causing excessive panel bulge and consequently box failure at lower loads than those for column stacking. Column stacking is said to show as much as 29% greater stacking strength than an interlocked stack (Wright, et al, 1992).

The compression strength of a box depends on various factors such as board properties, construction, style, as well as its size and shape. The compression strength measured during laboratory testing generally determines a load at which the box collapses. This value is considerably higher than actual conditions since it does not account for creep (long term storage) or effects of the climatic environment. Thus a safety factor is generally used in real life applications. The safety factor will depend on the effect of moisture, the storage time, effect of stacking, the handling methods and distance and type of transportation (Wright et.

al., 1992).

The McKee formula, developed by McKee, Gander and Wachutta (1963) at the Institute of Paper Chemistry, provides corrugated box designers with an empirical formula for predicting top-to-bottom compression strength (CS) of corrugated boxes using the following equation:

$$CS = 5.8745\ Pm\ h^{0.5076}\ z^{0.4924}$$

where Pm is column crush in lb./in., h is caliper of board in inches, and z is box perimeter in inches. This formula applies only to standard conditions (73 °F, 50 %RH) and RSC style boxes of a uniform shape where the depth of the box is at least 1/7 of the box perimeter. There is no factor to account for the effect of both climatic, storage, and shipping environments. (McKee et al., 1963).

Another method to predict compression strength of corrugated shippers uses the Mullen Burst Test. It determines the compression strength based on the perimeter of the box, burst strength value, and type of flute (Hanlon, 1985). However, the above method also does not account for the effects of creep and humidity.

A recent study done at the Institute of Paper Chemistry uses a better representation of compression performance by actually testing the entire pallet load and evaluating the relative contribution of each component in terms of total package strength (box and its contents). They express the total load supported by each package in terms of the number of layers in the stack above the bottom box. It also shows the contribution of internal cell partitions and inserts and column or interlocking stacking pattern on the total load support strength. The results showed that to have a better stack alignment a smaller cell size is required (SPI, 1993). However, the report does not investigate the effect of reused wooden warehouse pallets. Pallets with broken deck boards, wide voids between deck boards, and varying stacking patterns that have overhang, will all result in causing instability in stacked palletized loads. Under these circumstances, the potential stacking strength is also reduced. In addition, the ratio of the height of the stack to the size of the pallet also affects stacking performance. Increase in stack height will reduce the stability of the stack and result in an increase in leaning.

Many studies have been done to investigate the effect of humidity on corrugated box performance. Maltenfort (1989) documents various studies that have studied this interaction. However though all studies show a reduction in compression strength on exposure to humidity, different levels of reduction were found among various investigators. This is attributed to the variation in the corrugated board manufacturing process, the consistency of the quality of paper used for the medium and liner, and the adhesive used to bond the different layers of paper to form the corrugated board. The results from various studies show that tear strength and puncture strength on combined board are known to decrease and the stretch on liners increase on exposure to higher humidities. The porosity of paper decreases at higher humidities since the paper becomes saturated quicker. Packaging fresh produce that is often wet or allowing boxes to sweat during storage can have disastrous effects on stacking performance due to absorption of moisture in the board.

Ievans (1973) developed an empirical factor to account for the effect of humidity on compression strength of corrugated boxes at different humidities. The first section of his paper shows how moisture content affects compression strength. He also investigated the effect of cycling certain range of humidities throughout some period of time and its influence on the stacking strength. Since the moisture content of the outside boxes in a pallet is higher than that of the inside boxes in a pallet load, a floating platen compression tester was used to seek out the weaker members of the box, a situation similar to that expected in the warehouse. By this reasoning the report goes on to say that in an interlocking stacking pattern, the stronger boxes in the center of the arrangement would contribute to the entire stacking strength and increase the safe stacking period. In conclusion, the box collapsed almost immediately at the critical moisture content and the rate at which the failure occurred depended on the contents of the box, as well as on the limits of the high and low extremes in cyclic humidity. In column stacking, the reduction in compression strength by changing the relative humidity from 50 %RH to 85 %RH was found to be 26.7%. (Ievans, 1973).

Beardsell (1960) cited a Refrigeration Research Foundation Scientific Advisory Council study that found that in general, the paper fibers soften as they increase in length, and thereby lose strength with gain in moisture. The continued expansion and contraction of paper fibers caused by cyclic humidity can weaken the fibers to the extent of structural failure. Also, the quantity of moisture available to the fibers on the outside of the stack is different from that within the stack, more often in tightly stacked packages. There will appear a differential gradient of strength across the containers. He concluded that this strain could play a role in pallet load failing due to lack of uniformity. Beardsell (1960) goes on to state that stresses and strains on packages caused by external atmospheric conditions and by internal reactions of the contents of the container are a prime source of problem in the warehouse.

Typical compression failures reported by Kellicutt (1963) state that the size and shape of the box not only determines how it will fail in compression but also the maximum load it will attain. For shallow boxes that are compressed in the top-to-bottom direction, failure results almost entirely by crushing along the top and bottom horizontal score lines. As box height increases, compressive failure results from a combination of crushing along the score lines and buckling of the side panels of the box. Increase in length and width of the box will generally increase the compression strength. However, increase in depth of the box generally reduces the compression strength. Finally, after reaching a specific height, the failure is almost entirely due to the result of buckling.

Kellicutt further investigated the effect of bearing surface, length of time the box supports a specific dead load, and stacking alignment factors. The compression strength decreased about 23% in perfectly aligned three high stack of boxes as compared for a single high B-flute box. This lower strength occurred because the top surface of the top box in the stack and the bottom surface of the bottom box in the stack were the only surfaces bearing on the flat parallel platens of the testing machine. The other top and bottom surfaces of the boxes in the stack were making a contact on the uneven top or bottom surfaces of the adjacent boxes. Misalignment in the stack reduced the strength more because the four vertical edges were misaligned and they are the stiffest parts of a box. Edges that did not bear directly on top of each other but bore some place on the bridge of the panel between two of them caused a reduction in stacking strength. When comparing the stacking pattern, the interlocking stack showed 32% less compressive strength as compared to the column stack.

Maltenfort (1988) also investigated similar performance of corrugated containers as a function of stacking patterns. His results show that from changing the 3 tier column stacked load to the 3 tier interlockingly stacked load, a 45% reduction in stacking strength occurred. In terms of inspecting the importance of the supporting area of the load, a 1 inch overhang in all four sides of the pallet resulted in a 32% reduction in compression strength, in a 3 tier column stack of corrugated boxes.

3.0 Experimental Design

In order to accomplish the objectives of this study, two different experiments were conducted. Each individual experiments was identified as 'Experiment 1' and 'Experiment 2'. The respective test materials and methods used for each experiment are discussed in this chapter.

3.1 EXPERIMENT 1:

Materials:

In 'Experiment 1,' three different sizes of C-flute corrugated board boxes were tested. Boxes were taped with "3M Brand Packaging Tape". The box specifications for the three sizes is listed below in Table 1.

Table 1. Box Specification of Experiment 1

Box Type	Sizes of RSC Boxes (inches)	Burst Strength
A	12 ½ X 9 ½ X 5 3/4	275 lb/sq. in.
B	12 ½ X 12 ½ X 12 ½	275 lb/sq. in.
C	21 1/4 X 19 X 13 1/4	275 lb/sq. in.

Conditioning and Test Methods:

All samples were conditioned using the American Society for Testing and Materials Standard (D 4332) - "Standard Practice for Conditioning Containers, Packages, or Packaging Components for Testing". Two simulated warehouse atmospheric conditions were selected for this study: Normal (23.0 ± 1.0 °C @ 50 ± 2.0 %RH) and Tropical (40 ± 2.0 °C @ 85 ± 5.0 %RH). Standard conditions were measured and monitored using a Hygro-thermograph (Model number 594) recording instrument, which records both relative humidity and air temperature. The sample boxes were conditioned for 48 hours at the tropical atmosphere in the environmental chamber before being tested.

The ASTM D 642 test method was used for compression testing of the corrugated boxes after they were subjected to conditioning. The test recommends to use a compression tester that has a fixed platen and applies a load at a constant rate of 0.5 in./ min. A preload of 50 lbs. was used for zero deflection.

All samples were compression tested using a Lansmont Corporation Compression Tester (Model No. 76-5K). This machine provides a digital readout of force to within ± 3% accuracy and deflection reading to within ± 1% linearity. Both the maximum force at failure and corresponding deflection were measured for all the box types and offsets used in this study.

Procedures:

Ten sample boxes of each size were tested for compression strength using a compression tester described above. These samples were conditioned at normal conditions as described in the previous section. These boxes were stacked in pairs and the total compression strength of a two high stack with perfectly aligned edges and corners was measured. This data was used as the ideal strength of a perfectly aligned stack condition and represented the "control" value. This test setup is shown in Figure 1. All subsequent test data was compared to this value.

A second set of ten sample boxes were subjected to conditioning at the tropical conditions. These boxes were also tested in the perfectly aligned condition.

The next phase of the tests consisted of initiating a "lateral offset" among a pair of stacked boxes. This is shown in Figure 2. Three different amounts of lateral offsets were evaluated. These were represented by the percent area of contact between the lower and upper box. The three levels were 95%, 90% and 85% contact area. The distance of lateral offset was determined that would provide the above required percent area of contact. These values are shown in Table 2.

Table 2. Displacements for Lateral Offset in Experiment 1

Box type	95 % of Contact in Base Area	90 % of Contact in Base Area	85 % of Contact in Base Area
	Lateral Offset in Inches	Lateral Offset in Inches	Lateral Offset in Inches
A	0.475 "	0.950 "	1.425 "
B	0.625 "	1.250 "	1.875 "
C	0.950 "	1.900 "	2.850 "

The third phase of this experiment consisted of initiating a "diagonal offset" among a pair of stacked boxes. This is shown in Figure 3. Three different amounts of diagonal offsets were also evaluated. These were represented by the percent area of contact between the lower and upper box. The three levels were 95%, 90%

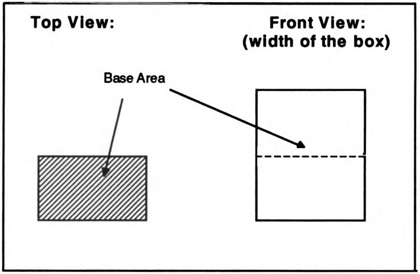

Figure 1. Test Set-up for Experiment 1
(Control)

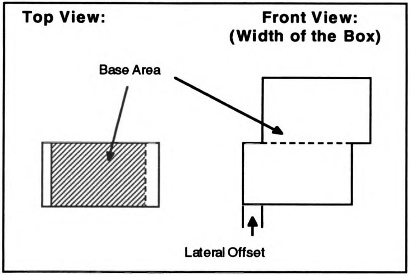

Figure 2. Test Set-up for Experiment 1
(Lateral Offset)

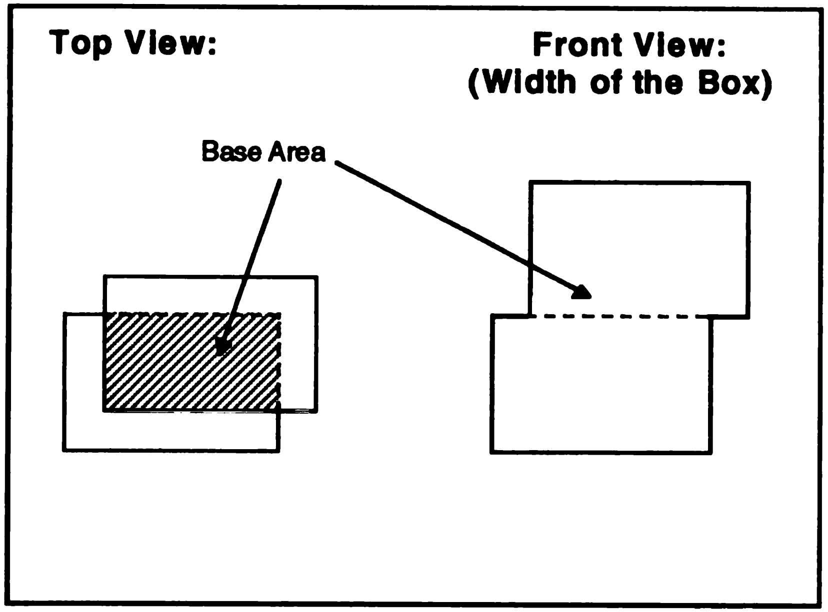

Figure 3. Test Set-up for Experiment 1
(Diagonal Offset)

and 85% contact area. The distance of offset was determined that would provide the above required percent area of contact. These values are shown in Table 3.

Table 3. Displacements for Diagonal Offset in Experiment 1

Box type	95 % of Contact in Base Area	90 % of Contact in Base Area	85 % of Contact in Base Area
	Diagonal Offset in Inches	Diagonal Offset in Inches	Diagonal Offset in Inches
A	0.273 "	0.554 "	0.842 "
B	0.317 "	0.641 "	0.976 "
C	0.508 "	1.029 "	1.566 "

The data was collected for stacked boxes after conditioning at both normal and tropical conditions. A total of 380 boxes were tested for all different sizes and test conditions.

3.2 EXPERIMENT 2:

Materials:

In 'Experiment 2' the offset to stacked palletized load was studied to determine the overall stability. The palletized loads were staged at the Michigan State University Salvage Yard so that any tipped pallet load does not cause potential injury. A 48" X 40" wood stringer GMA style pallet was used. The load consisted of plastic cans with aluminum tops that were packaged in corrugated trays measuring 16.5" X 11" X 2.75". The can was a 212 X 304 style two piece (Aluminum top / Plastic body) can. The palletized load weighed 2070 lbs. A fork truck was used to stack the palletized loads in the staging area. The palletized loads were marked along the deckboard to determine the amount of offset between stacked pallets.

Procedure:

This test was performed to determine the stability of the actually stacked pallet loads as a function of lateral offset. The instability of the stack of pallet loads was created by shifting the center of gravity of the pallets (Figure 4) stacked on top of the bottom pallet.

The different pallet stack configurations are shown in Figure 5. The test was started with a perfectly aligned pallet stack as shown in Option 1. This is the condition of perfect stability where the center of gravity of all pallets pass through the same straight line. The view of pallets shown are along the 40 inch dimension. The Option 2 shifts the top two pallets collectively sideways. This lateral shift was performed in 6 inch increments. Theoretically this lateral shift could be done to maximum offset of 20 inches. However this assumes a very good quality pallet base. In a real situation a wood pallet would crack before this condition due to concentrated load on the bottom deckboards. Similarly two additional conditions were studied as shown in Option 3 and Option 4.

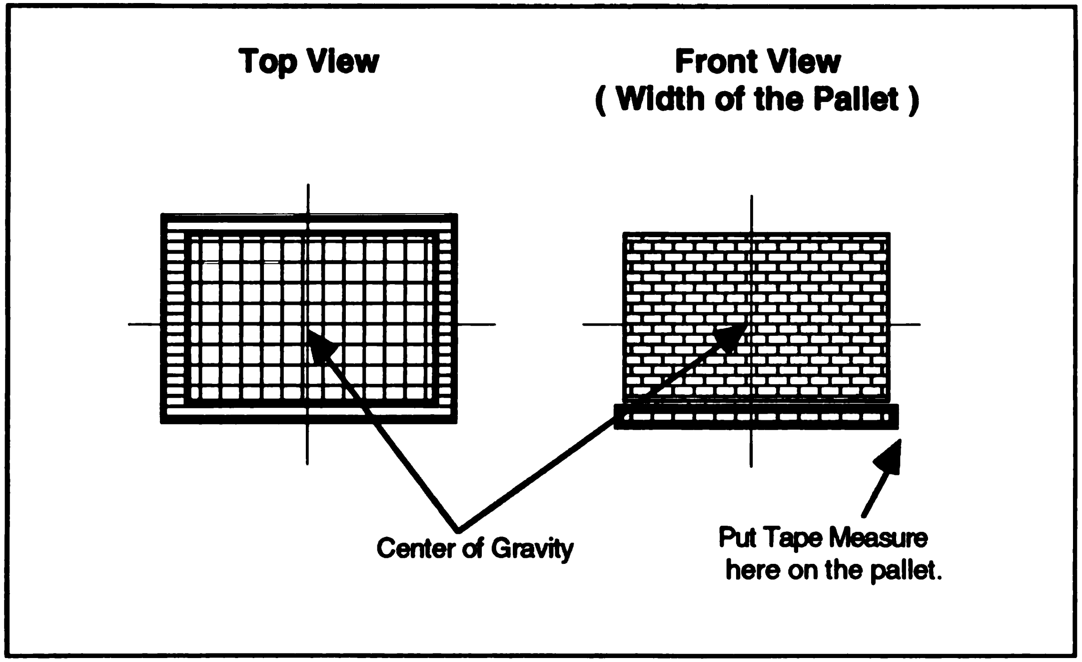

Figure 4. Sample Set-up Discription for Experiment 2

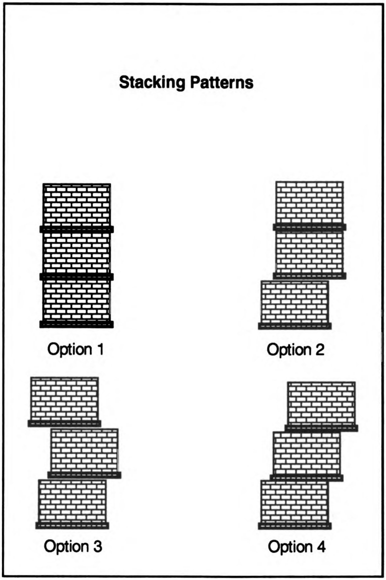

Figure 5. Stacking Patterns Developed for Experiment 2.

4.0 Data and Results

Two different experiments on structural stability were performed. The data collected and the results of these experiments is discussed in this chapter.

4.1 Experiment 1:

The raw data for all the compression tests on the corrugated containers for the various conditions performed in Experiment 1 are listed in Table A1 to A14 (Appendix A). The data is shown in both English and Metric units. These tables summarize peak compression strengths and corresponding deflections of lateral and diagonal box offset in the three different sizes of boxes tested. The percent reduction of compression strength was calculated as follows:

$$\% \text{ Reduction in CS} = \frac{\text{Ave. CS of Control Samples} - \text{Ave. CS at a Specific Condition}}{\text{Ave. CS of Control Samples}} \times 100$$

The average percent reduction in compression strength in the three box sizes on exposure to the tropical storage condition as compared to normal storage condition was 16%, 19%, and 24% respectively for Type A, Type B, and Type C boxes. This is also shown in Table 4 and 5. The larger size boxes showed a

Table 4. Percent Reduction in Compression Strength of Double Stacked Boxes as a Function of Humidity (English Units)

Box Size	Climatic Storage Condition		Percent Reduction in Compression Strength
	Normal (73°F @ 50%RH)	Tropical (104°F @ 85%RH)	
Type A	633 lb. (0.50 in.)	530 lb. (0.45 in.)	16 %
Type B	737 lb. (.68 in.)	598 lb. (0.39 in.)	19 %
Type C	736 lb. (0.79 in.)	557 lb. (0.68 in.)	24 %

Table 5. Percent Reduction in Compression Strength of Double Stacked Boxes as a Function of Humidity (Metric Units)

Box Size	Climatic Storage Condition		Percent Reduction In Strength
	Normal (23°C @ 50%RH)	Tropical (40°C @ 85%RH)	
Type A	287 kg. (1.28 cm.)	240 kg. (1.14 cm.)	16 %
Type B	334 kg. (1.74 cm.)	271 kg. (1.00 cm.)	19 %
Type C	334 kg. (2.01 cm.)	253 kg. (1.72 cm.)	24 %

greater reduction in compression strength on exposure to humidity.

Tables 6 and 7 show the percent reduction in compression strength of corrugated boxes as a function of the Lateral Offset at Normal Climatic Conditions for the three types of boxes tested. The data shows that the 95% contact area offset, resulted in between 20% to 27% reduction in compression strength compared to the control samples. Subsequent reduction in contact area to 90% and 85% showed further reduction in compression strength by as much as 47%. It is clear from comparing data between Tables 4(5) and 6(7) that even a 5% reduction in contact area caused by lateral offset shows a greater reduction in compression strength than boxes exposed to tropical climatic conditioning.

Tables 8 and 9 show the percent reduction in compression strength of corrugated boxes as a function of the Lateral Offset at Tropical Climatic Conditions for the three types of boxes tested. The data shows that the 95% contact area offset, resulted in between 42% to 43% reduction in compression strength compared to the control samples. Subsequent reduction in contact area to 90% and 85% showed further reduction in compression strength by as much as 64%.

Tables 10 and 11 show the percent reduction in compression strength of corrugated boxes as a function of the Diagonal Offset at Normal Climatic Conditions for the three types of boxes tested. The data shows that the 95% contact area offset, resulted in between 26% to 33% reduction in compression strength compared to the control samples. Subsequent reduction in contact area to 90% and 85% showed further reduction in compression strength by as much as 52%.

Table 6. Percent Reduction in Compression Strength as a Function of Lateral Offset at Normal Climatic Condition (English Units)

Box Size	Compression Strength in Lateral Offset				Percent Reduction in Compression Strength		
	100 % Contact in Base Area	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area
Type **A**	633 lb. (0.50 in.)	505 lb. (0.75 in.)	370 lb. (0.54 in.)	368 lb. (0.43 in.)	**20 %**	**42 %**	**42 %**
Type **B**	737 lb. (.68 in.)	534 lb. (0.83 in.)	465 lb. (0.74 in.)	388 lb. (0.59 in.)	**27 %**	**37 %**	**47 %**
Type **C**	736 lb. (0.79 in.)	538 lb. (1.00 in.)	485 lb. (0.72 in.)	443 lb. (0.67 in.)	**27 %**	**34 %**	**40 %**

Table 7. Percent Reduction in Compression Strength as a Function of Lateral Offset at Normal Climatic Condition (Metric Units)

Box Size	Lateral Offset in Area				Percent Reduction in Compression Strength		
	100 % Contact in Base Area	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area
Type **A**	287 kg. (1.28 cm)	229 kg. (1.91 cm)	168 kg. (1.37 cm)	167 kg. (1.09 cm)	**20 %**	**42 %**	**42 %**
Type **B**	334 kg. (1.74 cm)	242 kg. (2.11 cm)	211 kg. (1.88 cm)	176 kg. (1.50 cm)	**27 %**	**37 %**	**47 %**
Type **C**	334 kg. (2.01 cm)	244 kg. (2.54 cm)	220 kg. (1.83 cm)	201 kg. (1.70 cm)	**27 %**	**34 %**	**40 %**

Table 8. Percent Reduction in Compression Strength as a Function of Lateral Offset at Tropical Climatic Condition (English Units)

Box Size	Lateral Offset in Area				Percent Reduction in Compression Strength		
	100 % Contact in Base Area	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area
Type **A**	633 lb. (0.50 in.)	370 lb. (0.75 in.)	293 lb. (0.67 in.)	271 lb. (0.46 in.)	**42 %**	**54 %**	**57 %**
Type **B**	737 lb. (.68 in.)	417 lb. (0.67 in.)	375 lb. (0.47 in.)	267 lb. (0.35 in.)	**43 %**	**49 %**	**64 %**
Type **C**	736 lb. (0.79 in.)	421 lb. (0.77 in.)	373 lb. (0.54 in.)	317 lb. (0.48 in.)	**43 %**	**49 %**	**57 %**

Table 9. Percent Reduction in Compression Strength as a Function of Lateral Offset at Tropical Climatic Condition (Metric Units)

Box Size	**Lateral Offset in Area**				**Percent Reduction in Compression Strength**		
	100 % Contact in Base Area	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area
Type **A**	287 kg. (1.28 cm)	168 kg. (1.91 cm)	133 kg. (1.70 cm)	123 kg. (1.17 cm)	**42 %**	**54 %**	**57 %**
Type **B**	334 kg. (1.74 cm)	189 kg. (1.70 cm)	170 kg. (1.19 cm)	121 kg. (0.89 cm)	**43 %**	**49 %**	**64 %**
Type **C**	334 kg. (2.01 cm)	191 kg. (1.96 cm)	169 kg. (1.37 cm)	144 kg. (1.22 cm)	**43 %**	**49 %**	**57 %**

Table 10. Percent Reduction in Compression Strength as a Function of Diagonal Offset at Normal Climatic Condition (English Units)

Box Size	Diagonal Offset in Area				Percent Reduction In Compression Strength		
	100 % Contact in Base Area	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area
Type **A**	633 lb. (0.50 in.)	470 lb. (0.54 in.)	379 lb. (0.72 in.)	344 lb. (1.03 in.)	**26 %**	**40 %**	**46 %**
Type **B**	737 lb. (.68 in.)	492 lb. (0.59 in.)	359 lb. (0.87 in.)	351 lb. (1.15 in.)	**33 %**	**51 %**	**52 %**
Type **C**	736 lb. (0.79 in.)	538 lb. (1.08 in.)	456 lb. (1.53 in.)	425 lb. (2.02 in.)	**27 %**	**38 %**	**42 %**

Table 11. Percent Reduction in Compression Strength as a Function of Diagonal Offset at Normal Climatic Condition (Metric Units)

Box Size	Diagonal Offset in Area				Percent Reduction in Compression Strength		
	100 % Contact in Base Area	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area
Type **A**	287 kg. (1.28 cm)	213 kg. (1.37 cm)	172 kg. (1.83 cm)	156 kg. (2.62 cm)	**26 %**	**40 %**	**46 %**
Type **B**	334 kg. (1.74 cm)	223 kg. (1.50 cm)	163 kg. (2.21 cm)	159 kg. (2.92 cm)	**33 %**	**51 %**	**52 %**
Type **C**	334 kg. (2.01 cm)	244 kg. (2.74 cm)	207 kg. (3.89 cm)	193 kg. (5.13 cm)	**27 %**	**38 %**	**42 %**

It is clear from comparing data between Tables 4(5) and 10(11) that even a 5% reduction in contact area caused by diagonal offset shows a greater reduction in compression strength than boxes exposed to tropical climatic conditioning. Also the diagonal offset generally produced a greater reduction than lateral offset.

Tables 12 and 13 show the percent reduction in compression strength of corrugated boxes as a function of the Lateral Offset at Tropical Climatic Conditions for the three types of boxes tested. The data shows that the 95% contact area offset, resulted in between 42% to 46% reduction in compression strength compared to the control samples. Subsequent reduction in contact area to 90% and 85% showed further reduction in compression strength by as much as 60%.

Tables 14 and 15 show the average percent reduction for both lateral and diagonal offset at normal and tropical climatic conditions respectively.

4.2 Experiment 2:

The degree of instability of stacked pallet loads was evaluated. Various conditions of lateral offset were staged using a fork truck to validate the model developed by the Consortium of Distribution Packaging at Michigan State University (Burgess, 1995). Table 16 shows these various conditions and also identifies if the overall system is stable or unstable. These were experimentally verified and some of these conditions are shown in the various photographs in Appendix B.

Some of the drawbacks of the theoretical model that was evaluated are briefly discussed. The model assumes a good homogeneous weight distribution on

Table 12. Percent Reduction in Compression Strength as a Function of Diagonal Offset at Tropical Climatic Condition (English Units)

Box Size	Diagonal Offset in Area				Percent Reduction in Compression Strength		
	100 % Contact in Base Area	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area
Type **A**	633 lb. (0.50 in.)	364 lb. (0.58 in.)	317 lb. (0.73 in.)	273 lb. (0.99 in.)	**42 %**	**50 %**	**57 %**
Type **B**	737 lb. (.68 in.)	412 lb. (0.57 in.)	287 lb. (0.79 in.)	298 lb. (1.25 in.)	**44 %**	**61 %**	**60 %**
Type **C**	736 lb. (0.79 in.)	401 lb. (0.90 in.)	364 lb. (1.32 in.)	344 lb. (2.08 in.)	**46 %**	**51 %**	**53 %**

Table 13. Percent Reduction in Compression Strength as a Function of Diagonal Offset at Tropical Climatic Condition (Metric Units)

Box Size	**Diagonal Offset in Area**				**Percent Reduction in Compression Strength**		
	100 % Contact in Base Area	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area
Type **A**	287 kg. (1.28 cm)	165 kg. (1.47 cm)	144 kg. (1.85 cm)	124 kg. (2.51 cm)	**42 %**	**50 %**	**57 %**
Type **B**	334 kg. (1.74 cm)	187 kg. (1.45 cm)	130 kg. (2.01 cm)	135 kg. (3.18 cm)	**44 %**	**61 %**	**60 %**
Type **C**	334 kg. (2.01 cm)	182 kg. (2.29 cm)	165 kg. (3.35 cm)	156 kg. (5.28 cm)	**46 %**	**51 %**	**53 %**

Table 14. Average Percent Reduction at Normal Climatic Conditions for Lateral and Diagonal Offset

Box Type	Percent Reduction in Compression Strength due to Lateral Offset			Percent Reduction in Compression Strength due to Diagonal Offset		
	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area
Type **A**	**20 %**	**42 %**	**42 %**	**26%**	**40 %**	**46 %**
Type **B**	**27 %**	**37 %**	**47 %**	**33 %**	**51 %**	**52 %**
Type **C**	**27 %**	**34 %**	**40 %**	**27 %**	**38 %**	**42 %**

Table 15. Average Percent Reduction at Tropical Climatic Conditions for Lateral and Diagonal Offset

Box Type	Percent Reduction in Compression Strength due to Lateral Offset			Percent Reduction in Compression Strength due to Diagonal Offset		
	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area	95 % Contact in Base Area	90 % Contact in Base Area	85 % Contact in Base Area
Type **A**	**42 %**	**54 %**	**57 %**	**42 %**	**50 %**	**57 %**
Type **B**	**43 %**	**49 %**	**64 %**	**44 %**	**61 %**	**60 %**
Type **C**	**43 %**	**49 %**	**57 %**	**46 %**	**51 %**	**53 %**

Table 16. Center of Gravity Prediction and Stability in a Stack

Stack Pattern	Combined CG of Top and Middle Samples by Mathematical Solution	Stability
Option 1 with No Displacement	Vertically aligned with the CG of bottom pallet load	Stable
Option 2 with 6" Displacement	6" laterally to the right of the CG of bottom pallet load	Stable
Option 3 with 6" Displacement at Middle & 4" Displacement at Top	4" laterally to the right of the CG of bottom pallet load	Stable
Option 4 with 6" Displacement at Middle & 4" Displacement at Top	8" laterally to the right of the CG of bottom pallet load	Stable
Option 4 with 6" Displacement at Middle & 8" Displacement at Top	10" laterally to the right of the CG of bottom pallet load	*Unstable

* Both the top and middle samples tumbled down to cause stack failure.

the loaded pallet. This may not be true in real life loads that are stagger layered. Also the model assumes a good quality and strong pallet (high bending stiffness). In most applications this may not be true especially with reused wooden pallets where load concentration on the deckboard members will cause them to fail before the theoretical model. Uneven floor surface, partially damaged packages in the pallet load, type of load restraining method (shrink wrap, stretch wrap, banding, etc.) all will cause the load to become unstable before that predicted by the model.

5.0 Conclusions

On the basis of this study, the following conclusions were reached:

1. The results show that both lateral and diagonal offset caused a greater percent reduction in compression strength as compared to humidity. The percent reduction in compression strength was found to be between 20% and 52% at normal conditions and between 42% to 64% at tropical conditions.

2. The results from the stability of stacked pallet loads experiment showed that the various factors that could cause accelerated instability in the stack are: quality of the pallet, condition of packages, load restraining method, center of gravity, non-homogeneous loads, and uneven floor surface.

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Appendix A

Raw Data Results
and Illustration of
Experiment 1

Figure A-1. Picture of Type A, B, and C Boxes
in Experiment 1

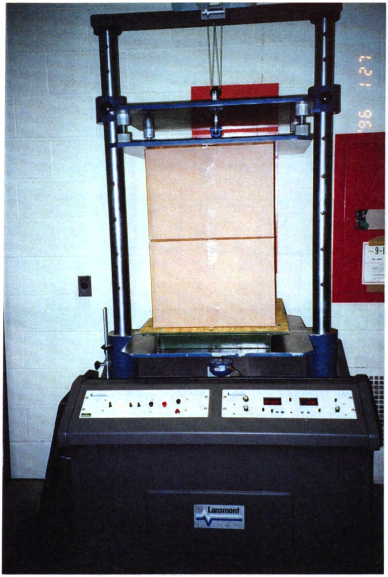

Figure A-2. Picture of Perfect Alignment Testing in Experiment 1

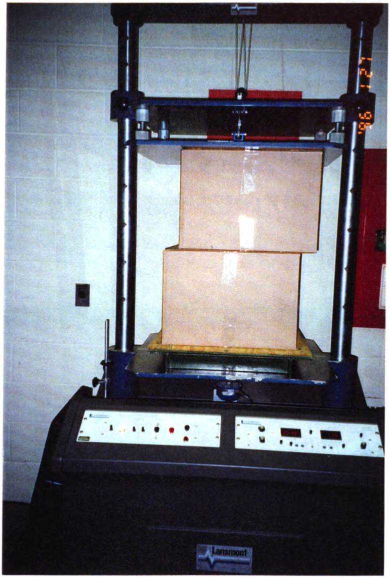

Figure A-3. Picture of Lateral Offset Testing in Experiment 1

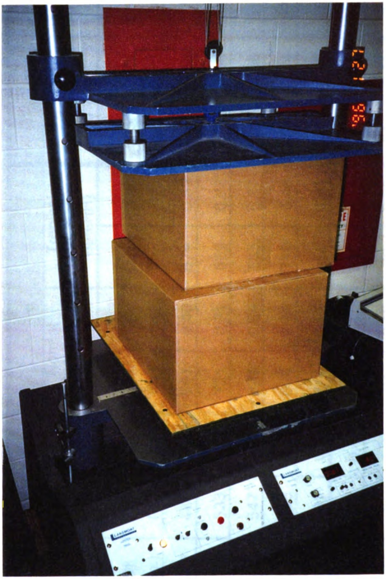

Figure A-4. Picture of Diagonal Offset Testing in Experiment 1

Table A-1. Compression Strength of Control Data which is in Perfect Alignment

(English Units)

Box Type	Type A				Type B				Type C			
Atm. Condition	Normal (73°C @ 50%RH)		Tropical (104°C @ 85%RH)		Normal (73°C @ 50%RH)		Tropical (104°C @ 85%RH)		Normal (73°C @ 50%RH)		Tropical (104°C @ 85%RH)	
# of Samples	C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)
1	636	0.47	480	0.41	741	0.49	574	0.39	627	0.62	577	0.72
2	604	0.58	533	0.47	751	0.71	582	0.33	715	0.88	655	0.60
3	584	0.45	547	0.41	621	0.84	535	0.37	853	0.86	516	0.89
4	648	0.52	506	0.44	826	0.71	710	0.46	757	0.84	577	0.53
5	694	0.49	585	0.51	744	0.67	588	0.41	730	0.75	460	0.64
Ave.	633	0.50	530	0.45	737	0.68	598	0.39	736	0.79	557	0.68
Std.Dev.	42	0.05	40	0.04	74	0.13	66	0.05	81	0.11	73	0.14

C.S. : Compression Strength

Df. : Deflection

Table A-2. Compression Strength of Control Data which is in Perfect Alignment

(Metric Units)

Box Type	Type A				Type B				Type C			
Atm. Condition	Normal (23°C @ 50%RH)		Tropical (40°C @ 85%RH)		Normal (23°C @ 50%RH)		Tropical (40°C @ 85%RH)		Normal (23°C @ 50%RH)		Tropical (40°C @ 85%RH)	
# of Samples	C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)
1	288	1.19	218	1.04	336	1.24	260	0.99	284	1.57	262	1.83
2	274	1.47	242	1.19	341	1.80	264	0.84	324	2.24	297	1.52
3	265	1.14	248	1.04	282	2.13	243	0.94	387	2.18	234	2.26
4	294	1.32	230	1.12	375	1.80	322	1.17	343	2.13	262	1.35
5	315	1.24	265	1.30	337	1.70	267	1.04	331	1.91	209	1.63
Ave.	287	1.28	240	1.14	334	1.74	271	1.00	334	2.01	253	1.72
Std.Dev.	19	0.13	18	0.11	33	0.32	30	0.12	37	0.27	33	0.35

C.S. : Compression Strength

Df. : Deflection

Table A-3. Compression Strength Test of Lateral Off-Set in Type A Box (English Units)

Conditioning	Sample #	Type A					
		5 % Area Reduction		10 % Area Reduction		15 % Area Reduction	
		C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)
Ambient	1	428	0.80	408	0.60	320	0.38
Ambient	2	518	0.90	368	0.55	395	0.55
Ambient	3	492	0.79	302	0.36	388	0.43
Ambient	4	545	0.61	370	0.65	342	0.34
Ambient	5	542	0.66	408	0.56	397	0.44
	Ave.	505	0.75	370	0.54	368	0.43
	Std.Dev.	49	0.12	44	0.11	35	0.08
		C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)
High Humidity	1	375	0.72	293	1.13	302	0.42
High Humidity	2	359	0.76	280	0.33	260	0.43
High Humidity	3	375	0.73	271	1.06	245	0.44
High Humidity	4	384	0.75	293	0.32	302	0.39
High Humidity	5	357	0.80	322	0.52	247	0.63
	Ave.	370	0.75	293	0.67	271	0.46
	Std.Dev.	11	0.03	20	0.40	29	0.10

C.S. : Compression Strength Df. : Deflection

Table A-4. Compression Strength Test of Lateral Off-Set in Type A Box (Metric Units)

Conditioning	Sample #	Type A					
		5 % Area Reduction		10 % Area Reduction		15 % Area Reduction	
		C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)
Ambient	1	194	2.03	185	1.52	145	0.97
Ambient	2	235	2.29	167	1.40	179	1.40
Ambient	3	223	2.01	137	0.91	176	1.09
Ambient	4	247	1.55	168	1.65	155	0.86
Ambient	5	246	1.68	185	1.42	180	1.12
	Ave.	229	1.91	168	1.37	167	1.09
	Std.Dev.	22	0.30	20	0.28	16	0.20
		C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)
High Humidity	1	170	1.83	133	2.87	137	1.07
High Humidity	2	163	1.93	127	0.84	118	1.09
High Humidity	3	170	1.85	123	2.69	111	1.12
High Humidity	4	174	1.91	133	0.81	137	0.99
High Humidity	5	162	2.03	146	1.32	112	1.60
	Ave.	168	1.91	133	1.70	123	1.17
	Std.Dev.	5	0.08	9	1.02	13	0.25

C.S. : Compression Strength   Df. : Deflection

Table A-5. Compression Strength Test of Lateral Off-Set in Type B Box (English Units)

Conditioning	Sample #	Type B					
		5 % Area Reduction		10 % Area Reduction		15 % Area Reduction	
		C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)
Ambient	1	534	0.98	465	0.50	366	0.73
Ambient	2	538	0.99	507	0.92	364	0.43
Ambient	3	593	0.56	500	1.06	403	0.36
Ambient	4	485	0.57	410	0.50	448	0.55
Ambient	5	520	1.03	448	0.73	362	0.90
	Ave.	534	0.83	465	0.74	388	0.59
	Std.Dev.	40	0.24	40	0.25	37	0.22
		C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)
High Humidity	1	448	0.60	366	0.49	265	0.23
High Humidity	2	366	0.38	386	0.37	218	0.55
High Humidity	3	375	0.56	401	0.43	260	0.37
High Humidity	4	463	0.98	421	0.85	269	0.35
High Humidity	5	430	0.82	304	0.23	324	0.25
	Ave.	417	0.67	375	0.47	267	0.35
	Std.Dev.	44	0.23	44	0.23	37	0.13

C.S. : Compression Strength   Df. : Deflection

Table A-6. Compression Strength Test of Lateral Off-Set in Type B Box (Metric Units)

Conditioning	Sample #	Type B					
		5 % Area Reduction		10 % Area Reduction		15 % Area Reduction	
		C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)
Ambient	1	242	2.49	211	1.27	166	1.85
Ambient	2	244	2.51	230	2.34	165	1.09
Ambient	3	269	1.42	227	2.69	183	0.91
Ambient	4	220	1.45	186	1.27	203	1.40
Ambient	5	236	2.62	203	1.85	164	2.29
	Ave.	242	2.11	211	1.88	176	1.50
	Std.Dev.	18	0.61	18	0.64	17	0.56
		C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)
High Humidity	1	203	1.52	166	1.24	120	0.58
High Humidity	2	166	0.97	175	0.94	99	1.40
High Humidity	3	170	1.42	182	1.09	118	0.94
High Humidity	4	210	2.49	191	2.16	122	0.89
High Humidity	5	195	2.08	138	0.58	147	0.64
	Ave.	189	1.70	170	1.19	121	0.89
	Std.Dev.	20	0.58	20	0.58	17	0.33

C.S. : Compression Strength

Df. : Deflection

Table A-7. Compression Strength Test of Lateral Off-Set in Type C Box (English Units)

Conditioning	Sample #	Type C					
		5 % Area Reduction		10 % Area Reduction		15 % Area Reduction	
		C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)
Ambient	1	569	1.15	527	0.74	419	0.53
Ambient	2	505	0.80	467	0.70	478	0.88
Ambient	3	500	0.72	525	0.83	487	0.75
Ambient	4	571	1.57	456	0.66	379	0.57
Ambient	5	549	0.77	441	0.65	448	0.64
	Ave.	538	1.00	485	0.72	443	0.67
	Std.Dev.	33	0.36	40	0.07	44	0.14
		C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)
High Humidity	1	428	0.71	375	0.54	282	0.58
High Humidity	2	452	0.63	388	0.53	342	0.62
High Humidity	3	412	1.37	406	0.61	311	0.36
High Humidity	4	456	0.69	342	0.33	342	0.46
High Humidity	5	355	0.46	353	0.67	306	0.37
	Ave.	421	0.77	373	0.54	317	0.48
	Std.Dev.	42	0.35	26	0.13	24	0.12

C.S. : Compression Strength　　　Df. : Deflection

Table A-8. Compression Strength Test of Lateral Off-Set in Type C Box (Metric Units)

Conditioning	Sample #	Type C					
		5 % Area Reduction		10 % Area Reduction		15 % Area Reduction	
		C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)
Ambient	1	258	2.92	239	1.88	190	1.35
Ambient	2	229	2.03	212	1.78	217	2.24
Ambient	3	227	1.83	238	2.11	221	1.91
Ambient	4	259	3.99	207	1.68	172	1.45
Ambient	5	249	1.96	200	1.65	203	1.63
	Ave.	244	2.54	220	1.83	201	1.70
	Std.Dev.	15	0.91	18	0.18	20	0.36
		C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)
High Humidity	1	194	1.80	170	1.37	128	1.47
High Humidity	2	205	1.60	176	1.35	155	1.57
High Humidity	3	187	3.48	184	1.55	141	0.91
High Humidity	4	207	1.75	155	0.84	155	1.17
High Humidity	5	161	1.17	160	1.70	139	0.94
	Ave.	191	1.96	169	1.37	144	1.22
	Std.Dev.	19	0.89	12	0.33	11	0.30

C.S. : Compression Strength

Df. : Deflection

Table A-9. Compression Strength Test of Diagonal Off-Set in Type A Box (English Units)

Conditioning	Sample #	Type A					
		5 % Area Reduction		10 % Area Reduction		15 % Area Reduction	
		C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)
Ambient	1	452	0.58	421	0.77	351	0.98
Ambient	2	470	0.44	377	0.74	320	1.13
Ambient	3	522	0.61	399	0.77	353	1.11
Ambient	4	448	0.56	324	0.63	342	0.99
Ambient	5	461	0.53	370	0.71	353	0.94
	Ave.	470	0.54	379	0.72	344	1.03
	Std.Dev.	31	0.07	35	0.06	13	0.08
		C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)
High Humidity	1	408	0.64	276	0.92	227	0.85
High Humidity	2	313	0.61	364	0.71	298	1.01
High Humidity	3	384	0.60	311	0.73	278	1.01
High Humidity	4	340	0.49	324	0.73	298	0.98
High Humidity	5	377	0.57	313	0.56	269	1.09
	Ave.	364	0.58	317	0.73	273	0.99
	Std.Dev.	37	0.06	33	0.13	29	0.09

C.S. : Compression Strength   Df. : Deflection

Table A-10. Compression Strength Test of Diagonal Off-Set in Type A Box (Metric Units)

Conditioning	Sample #	Type A					
		5 % Area Reduction		10 % Area Reduction		15 % Area Reduction	
		C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)
Ambient	1	205	1.47	191	1.96	159	2.49
Ambient	2	213	1.12	171	1.88	145	2.87
Ambient	3	237	1.55	181	1.96	160	2.82
Ambient	4	203	1.42	147	1.60	155	2.51
Ambient	5	209	1.35	168	1.80	160	2.39
	Ave.	213	1.37	172	1.83	156	2.62
	Std.Dev.	14	0.18	16	0.15	6	0.20
		C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)
High Humidity	1	185	1.63	125	2.34	103	2.16
High Humidity	2	142	1.55	165	1.80	135	2.57
High Humidity	3	174	1.52	141	1.85	126	2.57
High Humidity	4	154	1.24	147	1.85	135	2.49
High Humidity	5	171	1.45	142	1.42	122	2.77
	Ave.	165	1.47	144	1.85	124	2.51
	Std.Dev.	17	0.15	15	0.33	13	0.23

C.S. : Compression Strength

Df. : Deflection

Table A-11. Compression Strength Test of Diagonal Off-Set in Type B Box (English Units)

Conditioning	Sample #	Type B					
		5 % Area Reduction		10 % Area Reduction		15 % Area Reduction	
		C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)
Ambient	1	465	0.41	403	1.00	395	1.31
Ambient	2	503	0.56	373	1.04	373	1.21
Ambient	3	518	0.77	322	0.76	355	1.08
Ambient	4	507	0.48	346	0.76	293	0.96
Ambient	5	465	0.75	355	0.81	335	1.20
	Ave.	492	0.59	359	0.87	351	1.15
	Std.Dev.	24	0.16	31	0.14	37	0.13
		C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)
High Humidity	1	478	0.73	254	0.77	317	1.51
High Humidity	2	315	0.35	315	0.90	289	0.92
High Humidity	3	470	0.67	304	0.86	273	1.04
High Humidity	4	408	0.53	265	0.66	309	1.30
High Humidity	5	390	0.55	298	0.74	302	1.49
	Ave.	412	0.57	287	0.79	298	1.25
	Std.Dev.	66	0.15	26	0.10	18	0.26

C.S. : Compression Strength   Df. : Deflection

Table A-12. Compression Strength Test of Diagonal Off-Set in Type B Box (Metric Units)

Conditioning	Sample #	Type B					
		5 % Area Reduction		10 % Area Reduction		15 % Area Reduction	
		C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)
Ambient	1	211	1.04	183	2.54	179	3.33
Ambient	2	228	1.42	169	2.64	169	3.07
Ambient	3	235	1.96	146	1.93	161	2.74
Ambient	4	230	1.22	157	1.93	133	2.44
Ambient	5	211	1.91	161	2.06	152	3.05
	Ave.	223	1.50	163	2.21	159	2.92
	Std.Dev.	11	0.41	14	0.36	17	0.33
		C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)
High Humidity	1	217	1.85	115	1.96	144	3.84
High Humidity	2	143	0.89	143	2.29	131	2.34
High Humidity	3	213	1.70	138	2.18	124	2.64
High Humidity	4	185	1.35	120	1.68	140	3.30
High Humidity	5	177	1.40	135	1.88	137	3.78
	Ave.	187	1.45	130	2.01	135	3.18
	Std.Dev.	30	0.38	12	0.25	8	0.66

C.S. : Compression Strength　　　　Df. : Deflection

Table A-13. Compression Strength Test of Diagonal Off-Set in Type C Box (English Unit)

Conditioning	Sample #	Type C					
		5 % Area Reduction		10 % Area Reduction		15 % Area Reduction	
		C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)
Ambient	1	538	1.16	472	1.61	388	2.03
Ambient	2	549	0.92	439	1.42	439	1.99
Ambient	3	549	1.01	485	1.65	456	2.11
Ambient	4	509	1.17	459	1.53	377	1.83
Ambient	5	540	1.15	430	1.45	465	2.14
	Ave.	538	1.08	456	1.53	425	2.02
	Std.Dev.	18	0.11	22	0.10	40	0.12
		C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)	C.S. (lb.)	Df. (in.)
High Humidity	1	386	1.11	381	1.36	333	1.72
High Humidity	2	397	0.67	381	1.24	384	2.24
High Humidity	3	414	1.00	317	1.44	351	2.54
High Humidity	4	437	0.72	370	1.35	342	2.11
High Humidity	5	375	0.99	362	1.23	311	1.80
	Ave.	401	0.90	364	1.32	344	2.08
	Std.Dev.	24	0.19	26	0.09	26	0.33

C.S. : Compression Strength Df. : Deflection

Table A-14. Compression Strength Test of Diagonal Off-Set in Type C Box (Metric Units)

Conditioning	Sample #	Type C					
		5 % Area Reduction		10 % Area Reduction		15 % Area Reduction	
		C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)
Ambient	1	244	2.95	214	4.09	176	5.16
Ambient	2	249	2.34	199	3.61	199	5.05
Ambient	3	249	2.57	220	4.19	207	5.36
Ambient	4	231	2.97	208	3.89	171	4.65
Ambient	5	245	2.92	195	3.68	211	5.44
	Ave.	244	2.74	207	3.89	193	5.13
	Std.Dev.	8	0.28	10	0.25	18	0.30
		C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)	C.S. (kg.)	Df. (cm.)
High Humidity	1	175	2.82	173	3.45	151	4.37
High Humidity	2	180	1.70	173	3.15	174	5.69
High Humidity	3	188	2.54	144	3.66	159	6.45
High Humidity	4	198	1.83	168	3.43	155	5.36
High Humidity	5	170	2.51	164	3.12	141	4.57
	Ave.	182	2.29	165	3.35	156	5.28
	Std.Dev.	11	0.48	12	0.23	12	0.84

C.S. : Compression Strength Df. : Deflection

Appendix B

Illustration

of

Experiment 2

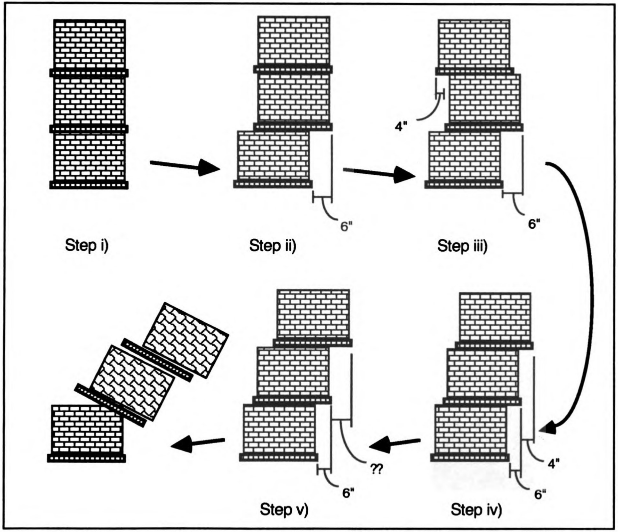

Figure B-1. Illustration of Procedures in Experiment 2

Figure B-2. Picture of Similac Product/ Tray Sample
in Experiment 2

Figure B-3. Picture of Experiment 2, Option 1

Figure B-4. Picture of Experiment 2, Option 2

Figure B-5. Picture of Experiment 2, Option 3

Figure B-6. Picture of Experiment 2, Option 4

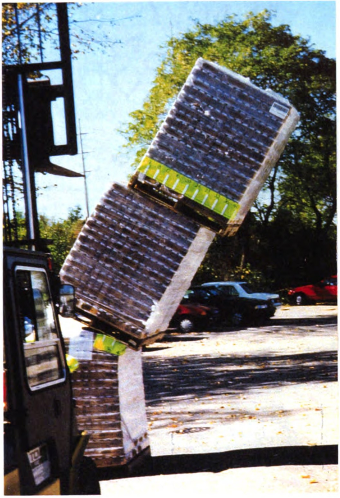

Figure B-7. Picture of Experiment 2,
Collapsing of the Stacked Structure

Figure B-8. Picture of Experiment 2,
Collapsed Structure