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Interactive effects of palletizing factors on fiberboard packaging strength

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INTERACTIVE EFFECTS OF PALLETIZING FACTORS ON FIBERBOARD PACKAGING STRENGTH

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by

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ABSTRACT

INTERACTIVE EFFECTS OF PALLETIZING FACTORS ON FIBERBOARD PACKAGING STRENGTH

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Experiments were carried out to determine the interactive effects of pallet gaps, overhang, and interlock stacking on the ultimate vertical compression strength of 10" x 6" x 6" B-flute corrugated fiberboard boxes. The experiments used a 30" x 30" Lansmont compression tester to simulate real forces that packages encounter in storage. Ultimate compression strength (point at which failure occurs) as well as deflection were measured and compared to computed value.

It was found that compression strength decreased as pallet gap size, overhang, and type of stacking became more severe. Overhang seemed to be the most influential strength-reducing factor. Individual effects of pallet gaps, pallet overhang and interlock stacking were initially determined. These effects were multiplied together to estimate the stacking strength of all possible combinations. Results showed that the effects cannot be directly calculated by multiplication. Measured values were found to be 7% to 16% higher than calculated by direct multiplication. The results of this study have considerable relevance to the ultimate performance of corrugated fiberboard boxes. The choice of using gapped pallets, overhang, and interlock stacking of boxes has to be made based on space efficiency versus loss of stacking strength.

ACKNOWLEDGMENTS

I would like to thank my graduate advisor, Dr. Jorge A. Marcondes, for his guidance throughout my course of studies at San Jose State University. His knowledge, practical advice, and encouragement made it possible for me to complete this research. I would also like to thank Dr. Lucy McProud for her precise guidance and assistance in this research. I would like to thank Dr. Albert Elboudwarej for his commitment and help.

I would like to extend my gratitude to THARCO of San Lorenzo, California, for providing the materials and facilities and Darwin Drew who ensured that everything that was needed for this research was available and functioning properly.

Finally, I would like to thank my wife, Lisa DiSalvo and son, Domenic DiSalvo for their continuous support throughout out my studies at San Jose State University.

PREFACE

The following is a publication style thesis. Chapter 1 and 3 are written according to guidelines outlined in the *Publication Manual of the American Psychological Association*, 4th edition, and 1994. The second chapter is written in journal format and will be submitted to *Packaging Technology and Science*.

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List of Acronyms, Abbreviations, and Variables

ASTM = American Society for Testing and Materials

C = Calculated

IL = Interlock Stacking

M = Measured

OH = Pallet Overhang

PG = Pallet Gaps

R = Correlation Coefficient

RSC = Regular Slotted Container

TAPPI = Technical Association of the Pulp and Paper Industries

CHAPTER 1

INTRODUCTION AND REVIEW OF LITERATURE

Introduction

The corrugated fiberboard container, or to be more precise the box, has become so interwoven in today's society that the general public does not realize the immense impact it has had on the packaging industry in the last 100 years. From the first patent awarded to Albert L. Jones in 1871 through the landmark Pridham Decision in 1914 (Maltenfort, 1988) to the current status, where over 90 % of all products in the United States are shipped in boxes, the corrugated industry has become the largest segment ($19 billion per year) of the entire packing industry (CPC, 1999). The reasons why corrugated boxes have had such phenomenal growth are based on their performance characteristics. Boxes offer strength and versatility that no other package can match. While the primary function is to provide adequate protection for the product inside, corrugated boxes also provide exterior advertisement and product recognition, and serve as a point of purchase display. When properly designed structurally, corrugated boxes are able to withstand the rigors of the distribution environment, and yet they are versatile enough to be cut and folded into an infinite variety of shapes and sizes, with direct-printed, high-resolution graphics (CPC, 1999).

Although the corrugated box's versatility has had a large impact on its growth, the main reason for its staying power is its strength. As with most containers the objective of a corrugated box is to deliver to the customer a product that is in an acceptable, damage free condition. This protection must be provided throughout the distribution system that often includes transportation and storage in unitized loads. These loads are most commonly unitized on pallets, a platform that can be picked up by the tines of a forklift truck (Soroka, 1995). When palletized loads enter the distribution system many hazards are encountered that can adversely affect the condition of a product. Among these hazards, high compressive loads can cause the most severe damage. Despite a box's simple appearance it is a complex engineering structure that provides protection to the product (Maltenfort, 1988) during high compressive loadings. Therefore, the main measurement of a box's performance is the ultimate compression strength.

The compression strength of a box is generally measured using a compression testing machine that applies a load in the vertical direction at a specific speed, from top to bottom, and measures the force the box is able to withstand. The failure point is defined as the compression strength of the box. There are several factors encountered in the distribution environment which reduce the compression strength of the box, and they can be classified into environmental factors and palletizing factors. The environmental factors include humidity, temperature, and stacking duration and the palletizing factors consist of pallet gaps, pallet overhang, and stack interlocking. These palletizing factors were the objects of this study.

Objectives

The objective of this study was to examine the strength reducing effects on corrugated fiberboard boxes of three palletizing factors, when encountered not only alone, but also in combination with each other. These factors are pallet gaps, pallet overhang, and stack interlocking.

Significance of the Study

Driven by customer requirements, the complexity of the design and manufacture of corrugated containers have increased dramatically in recent years. Box designs have evolved during this decade into high-tech, multi-functional containers. The demand for these innovative designs and cost reductions require validation of the actual strength of primary, secondary and shipping containers. Today, corrugated boxes are designed by fully evaluating the hazards of the distribution environment and reproducing or simulating those conditions in a controlled test environment. For boxes, special attention is given to factors that will affect the strength of the box. From this data the required strength is determined and the material that will provide the box with the appropriate ultimate compression strength is chosen. These procedures are based on research that dates back more than 50 years. The problem that exists is that research has concentrated on how each strength-reducing factor, as an entity in itself, affects the compression strength, but the literature shows no comprehensive study on the interaction between these factors. The industry has thus assumed that each factor is simply added to the next to find the final strength or stacking strength of the box.

It is important to know how the relationships of different combinations of these factors contribute to reducing the compression strength of a corrugated box, so that accurate design considerations can be taken into account and proper protection can be provided. By more accurately predicting the compression strength of a box, designers can meet the needs of the products and distribution systems by providing the correct level of protection. By providing more protection than what is actually needed, the designer can avoid product damage that could inflict serious economic losses, not only in the loss of products but the replacement cost of these products. By providing less protection (elimination of a container that provides overprotection) the designer will use less material in construction, therefore less waste will be generated. The entire system can be optimized in a way that the overall cost is minimized (the overall cost includes cost of packaging, cost of damages, among other factors). All of these advantages will lead to less cost and less resource depletion.

Review of Literature

At the beginning of the century almost all shipments of goods packed in corrugated boxes were floor loaded, one at a time in boxcars and trucks. In today's modern warehousing and distribution systems, goods are loaded on pallets at the end of the manufacturing line and are transported as pallet loads as far as possible through the entire system. This has changed the role of the box from merely containing the product to one of protecting the contents from compressive loads. Containment continues to be important but stacking strength is now one of the key elements looked for in boxes.

Knowing what will adversely affect the compression strength of a box can help in the proper design of the container. It also provides companies the ability to effectively reduce cost, ship new products to market faster and with more confidence, and minimize the impact of the container on the environment. In loading filled corrugated boxes on a pallet it is important to realize that the majority of the strength is concentrated near the corners (about 2/3 to 3/4) (Maltenfort, 1988). A study by Maskell showed that the corners of a corrugated fiberboard box contribute 60-70% of its strength (Maskell, 1986). The greatest reason for a box failing on a pallet is the violation of this concept.

Before proceeding, the difference between compression strength and stacking strength should be examined. Compression strength is the result of lab tests at specified conditions. Determination of compression strength is performed using a compression tester consisting of a lower and upper platen. The box specimen to be tested is placed on the lower platen which is connected to a load cell. The upper platen is then lowered, applying load at a constant rate until the box collapses. The failing point (maximum force sustained before collapsing) is known as the compression strength of the box. Stacking strength is used to describe the performance of a box taking into account strength reduction factors that are encountered in the distribution environment (Marcondes, 1999). These factors significantly lower the ability of a corrugated fiberboard box in sustaining top to bottom forces. In this study, three factors (pallet gaps, pallet overhang, and interlock stacking), are discussed in depth.

Pallet Gaps

Pallet gaps are the spaces that occur between the top platform slats of a pallet (see Figure 1). The box, when palletized, must bridge these gaps and as a result the amount of support is reduced, which reduces the strength. Pallet gaps are necessary to both reduce the weight of the pallet (important because cost of shipments is potentially based on weight) and to reduce the amount of material used in pallet construction. A few of the many pallet styles, which have various sizes of gaps, are shown in Figure 1.1.

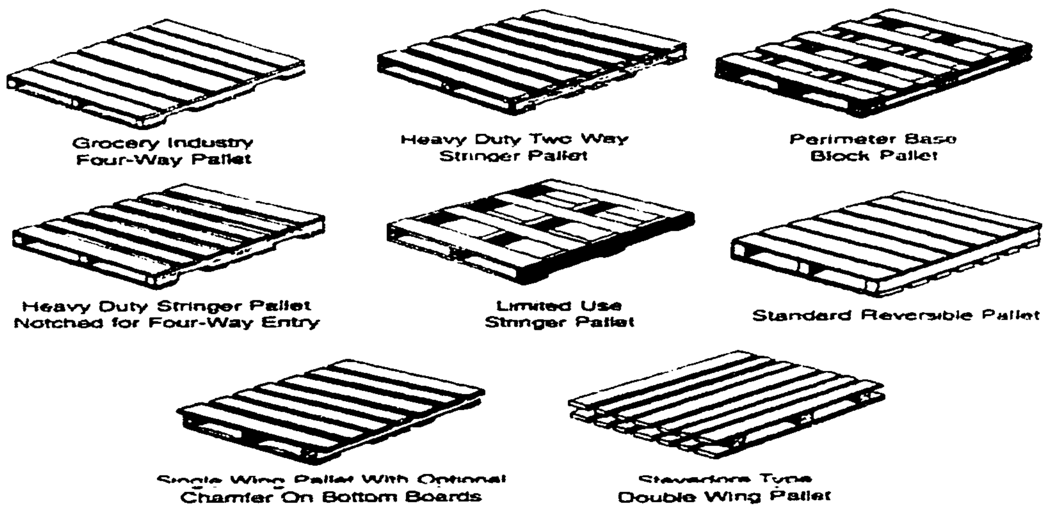

Figure 1.1-Various Pallet Types (National Wood Pallet and Container Association, 1999)

One study by Ievans has shown container panels that must bridge pallet gaps have a significant reduction in the compression strength of the box (Ievans, 1975). In this study, it was found that gap width must become approximately 30% of the bridging panel length before a significant reduction of compression strength occurred. With a gap of 33% of panel length, an 8% reduction in strength was observed. And with a gap of 47% a 15% reduction in strength occurred.

Another study by Monaghan and Marcondes found that the compression strength of fiberboard boxes decreased as the gap size increased. In fact the box compression strength decreased exponentially as the gap sized increased. Also developed was an exponential decay function for pallet gaps (Monaghan & Marcondes, 1992).

In attempting to compare these two studies vast differences were observed. One of the main factors is the time between the studies. Ievans' was done twenty years earlier and since that time materials and manufacturing techniques have dramatically changed. Also the manufacturing technology between the two studies has advanced over twenty years therefore methods and accuracies have changed dramatically. It is therefore unrealistic to compare the studies to gain any meaningful insight.

Pallet Overhang

Pallet overhang is used to improve warehouse space and pallet utilization. Warehouse storage costs money and, the larger the number of products on a pallet, the more cost effective is the storage and transport. It also occurs unintentionally, when palletizing practices are neglected and when horizontal dynamic forces cause packages to lose alignment in the vertical direction. Pallet overhang results when one box panel overhangs the pallet and thus the load must be borne only by the remaining two corners. A package with pallet overhang on one side is shown in Figure 1.2.

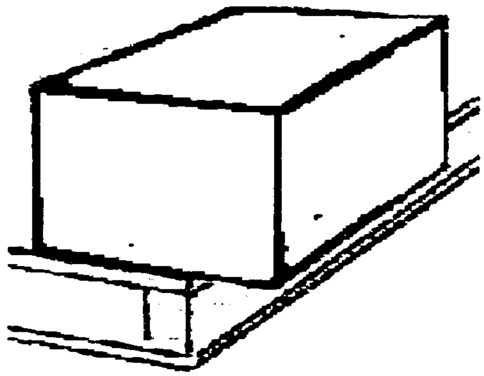

Figure 1.2-Pallet Overhang (Clarke & Marcondes, 1998)

Ievans found that pallet overhang produced by strength losses varied greatly depending on the box geometry and other variables such as board grade and flute type which were implied, but could not be proven without extensive additional work. Ievans developed a new concept called “overhang loss factor” (OLF) which is defined as the ratio of percent strength loss divided by the percent of overhung perimeter. Theoretically this ratio is expected to reach one, thus a box with half of its perimeter overhung would be half of its original compression strength. Ievans covered this by testing boxes overhung by half their length. However, for a lesser overhang it was discovered that this ratio became smaller than one, indicating that overhanging box members make some residual contribution to compression strength (such as the strength contribution of box corners). Ievans also found that an overhanging stack of boxes suffers strength losses from two sources. First, there is the approximate 10% loss due to vertical stacking. Then there is the overhang strength loss. The latter was found to be approximately the same as that for single boxes (Ievans, 1975).

Monaghan and Marcondes found that there was a large reduction in compression strength for small overhangs (which may be explained by the contribution of corners to box strength) and that the reduction of strength increased linearly as the overhang became more severe. Also found was that the effect of overhang does not follow McKee's model (contradicting Ievans argument that the loss in strength is proportional to the perimeter in overhang).

Stack Interlocking

Interlock stacking patterns are popular because they make unitized loads more stable than loads where vertical alignment patterns are used. When interlocking is used, each layer is arranged in opposing directions to the layer below. However, not all corners are aligned; in fact it is possible for three or all four corners to rest on the side panels of the box below. A case where only one corner is aligned vertically is shown in Figure 1.3.

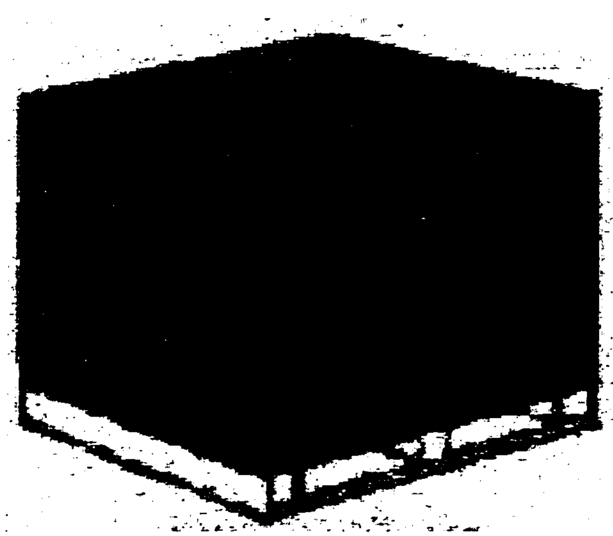

Figure 1.3-Stack Interlocking (Clarke & Marcondes, 1998)

Numerous studies have shown that interlocking stacking reduces the stacking strength of boxes. Kellicutt found that, for A flute boxes, an 18% strength loss occurred when the box was in a vertical stacked arrangement and that a 55% loss occurred when the stacking was in an interlocking pattern (Kellicutt, 1963). This loss was not fully accounted for or explained in his study. In another study, Hillenius determined a 49% strength loss for A-flute container in an interlocking stacking arrangement, but for vertical-aligned stacks losses ranged from 13% for a single stack down to 5% for multiple stacks while palletized (Hillenius, 1970). Hillenius attributed the resulting strength losses to the difference in alignment of both the corners and sidewalls of the boxes.

Ievans found that interlocking of containers reduced the stacking strength by approximately 45% when compared to vertical column stacking. However, Ievans also noted that interlock stacking is much less affected by pallet overhang. In comparison, when vertically aligned columns had a one inch overhang the strength reduction was 32% versus the same overhang for interlock stacking resulting in an 8% strength reduction (Ievans, 1975). Of course the interlock stack arrangement had a lower compression strength initially. In a more current study by Carstens and Mina, it was found that the strength reduction can be as much as 45% (Carstens & Mina, 1988).

Estimation of Compression Strength

Throughout the development of the corrugated fiberboard container much research has been directed at developing an empirical formula based on a container's dimensions and construction to determine exactly how high it can be stacked. To date several formulas exist, but only to estimate the compression strength of a container. With these formulas, a compression strength is calculated, based on the physical properties of the corrugated board and box dimensions, then each expected condition or strength reducing factor is added to determine the final stacking strength. As shown previously, the effect of each of these factors has been widely explored and documented throughout the corrugated industry. Tables and formulas determining the amount of reduction for each of these factors can be found readily in design texts. The most popular and widely used today is the McKee formula that was developed by the Institute of Paper Chemistry under the leadership of R.C. McKee. The McKee formula predicts the compression strength of a box based on the Edge Crush Test of the corrugated material, the thickness of the corrugated material, and the perimeter of the box (Maltenfort, 1988).

Another study in 1964 by Buchanan, Draper and Teague developed a compression strength formula based on Edge Crush Test and bending stiffness of the corrugated board. This method or equation is not readily used in industry (Maltenfort, 1988).

As with all compression estimation formulas, the equations are no better than the data used to calculate the results. The manufacture of and materials used have changed dramatically over the past 35 years since McKee's study was completed, some changes in the calculations should be expected. Thus, specifically, the McKee formula developed in 1963, in some cases underpredicts the strength of the box (Maltenfort, 1988). For a quick estimate though, it is very useful but to obtain more accurate results an actual compression test is preferred.

CHAPTER 2

JOURNAL ARTICLE

Authors Title Page

INTERACTIVE EFFECTS OF PALLETIZING FACTORS ON FIBERBOARD PACKAGING STRENGTH

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ABSTRACT

Experiments were carried out to determine the interactive effects of pallet gaps, overhang, and interlock stacking on the ultimate vertical compression strength of 10" x 6" x 6" B-flute corrugated fiberboard boxes. The experiments used a 30" x 30" Lansmont compression tester to simulate real forces that packages encounter in storage. Ultimate compression strength (point at which failure occurs) as well as deflection were measured and compared to computed value.

It was found that compression strength decreased as pallet gap size, overhang, and type of stacking became more severe. Overhang seemed to be the most influential strength-reducing factor. Individual effects of pallet gaps, pallet overhang and interlock stacking were initially determined. These effects were multiplied together to estimate the stacking strength of all possible combinations. Results showed that the effects cannot be directly calculated by multiplication. Measured values were found to be 7% to 16% higher than calculated by direct multiplication. The results of this study have considerable relevance to the ultimate performance of corrugated fiberboard boxes. The choice of using gapped pallets, overhang, and interlock stacking of boxes has to be made based on space efficiency versus loss of stacking strength.

Keywords: boxes, pallet gaps, pallet overhang, interlock stacking

Running headline: Strength reduction of palletizing factors on boxes

INTRODUCTION

At the beginning of the century almost all shipments of goods packed in corrugated boxes were floor loaded, one at a time in boxcars and trucks. But in today's market, mostly driven by customer requirements, the complexity of the design and manufacture of corrugated containers have increased dramatically. From modern warehousing and distribution systems, to the ability to be direct printed with high-resolution graphics[1], box designs have evolved into high-tech, multi-functional containers. The demand for these innovative designs require validation of the actual strength of primary, secondary and shipping containers. Today, corrugated boxes are designed by fully evaluating the hazards of the distribution cycle and reproducing or simulating those conditions in a controlled test environment. For boxes, special attention is given to factors that will affect their compression strength.

The main measurement of a box's performance is the ultimate compression strength and is generally measured using a compression testing machine which applies a load in the vertical direction at a specific speed, from top to bottom, and measures the force the box is able to withstand. The compression strength of the box is defined as the force withstood by the box just before it fails. There are several factors encountered in the distribution environment which reduce the compression strength of the box, and they can be classified into environmental factors and palletizing factors. The environmental factors include humidity, temperature and stacking duration and the palletizing factors consist of pallet gaps, pallet overhang, and stack interlocking. These palletizing factors were the objects of this study.

The focus to date has been on how each strength reducing factor, as an entity in itself, affects the compression strength. The industry has thus assumed that each factor is simply added to the next to find the final strength or stacking strength of the box. Since these factors occur simultaneously, it is important to know what different combinations of these factors contribute to reducing the compression strength of a corrugated box, so that accurate design considerations can be taken into account and proper protection can be provided. By more accurately predicting the compression strength of a box, designers can meet the needs of the products and distribution systems by providing appropriate protection. By providing the needed protection, the designer can avoid product damage which could inflict serious economic losses, not only in the loss of products but the replacement cost of these products. These will lead to less cost and less resource depletion.

The objective of this study was to examine the strength reducing effects on corrugated fiberboard boxes of three palletizing factors when encountered not only alone, but in combination with each other. These factors are pallet gaps, pallet overhang, and stack interlocking.

BACKGROUND

Knowing what will adversely affect the compression strength of a box can help in the proper design of the container. It also provides companies the ability to effectively reduce cost, ship new products to market faster and with more confidence, and minimize the impact of the container on the environment. In today's world of modern warehousing and distribution systems, goods are loaded on pallets at the end of the manufacturing line and transported as pallet loads as far as possible through the entire system. In loading filled corrugated boxes on a pallet it is important to realize that 60%-70% of the strength of the box is concentrated near the corners[2]. The greatest reason for a box failing on a pallet is the disregard of this concept.

Pallet gaps are the spaces that occur between the top platform slats of a pallet. The box, when palletized, must bridge these gaps and as a result the amount of support is reduced, which reduces the stacking strength. In today's modern distribution systems there are many types of pallets, each having its own special purpose. Accompanying these different pallets are various sized gaps. It is important to know how a corrugated box will perform when it encounters these different size gaps.

When a container must bridge these gaps a significant reduction in compression strength occurs[3]. In fact some studies showed that the box stacking strength decreased exponentially as the gap sized increased[4].

Pallet overhang is used to improve warehouse space and pallet utilization. Warehouse storage costs money and, the larger the number of products on a pallet, the more cost effective is the storage and transport. Pallet overhang results when one box panel overhangs the pallet and thus the load must be borne by the two corners.

Studies have found that pallet overhang produced strength loss that varied greatly depending on the box geometry and other variables such as board grade and flute size[3]. Also discovered was that there is a large reduction in compression strength for small overhangs and that the reduction of strength increased linearly as the overhang became more severe[4].

Interlock stacking patterns are popular because they are more stable than vertical patterns. In this arrangement, each layer is arranged in opposing directions to the layer below. However, the corners are not aligned, in fact it is possible for three or all four corners to rest on the side panels of the box below.

Numerous studies have shown that interlocking stacking reduces the stacking strength of boxes. One study showed for A flute boxes a 55% loss when the stacking was in an interlocking pattern[5]. In another study, an interlock stacking pattern produced a 49% strength loss for A-flute containers[6]. A third study found that interlocking of containers reduced the stacking strength by approximately 45% when compared to vertical column stacking. However, also noted was that the effect of interlock stacking is much less when pallet overhang is present[3]. And finally, another study found that the strength reduction can be as much as 45%[7].

Throughout the development of the corrugated fiberboard container much research has been directed at developing an empirical formula based on a container's dimensions and construction, to determine exactly how high it can be stacked. To date several formulas exist, but they only estimate the strength of a container. With these formulas, compression strength is calculated based on the physical properties of the corrugated board and box dimensions, then each expected condition or strength reducing factor is added to determine the final stacking strength. As shown previously the effect of each of these factors has been widely explored and documented throughout the corrugated industry. Tables and formulas determining the amount of reduction for each of these factors can be found readily in design texts. The most popular and widely used today is the McKee formula which was developed by the Institute of Paper Chemistry under the leadership of R.C. McKee. The McKee formula predicts the compression strength of a box based on the Edge Crush Test of the corrugated material, the thickness of the corrugated material, and the perimeter of the box[8].

As with all compression estimation formulas, the equations are no better than the data used to calculate the results. The manufacturing and materials used have changed since this research was carried out which leads to some changes in calculations . Thus specifically for the McKee formula, since it was developed in 1963, it in some cases underpredicts the strength of the box[8]. For a quick estimate though, it is very useful, but to get accurate results, an actual compression test is preferred.

EXPERIMENTAL DESIGN

The corrugated fiberboard boxes used in this study were 10" x 6" x 6" B-flute, produced by THARCO of San Lorenzo, California. Each box was stored knocked down flat until time of testing, when it was closed using hot glue. The boxes contained no printing except the Box Manufacturer Certificate which indicated an edge crush test of 32 pounds per inch.

Each factor (pallet gaps, pallet overhang, and interlock stacking) varied at 4 levels. There were 64 possible combinations for the three different strength reduction factors (see Tables 1-4). The positions for pallet gaps and pallet overhang were: (i) no factor; (ii) 5% of the area of bottom panel; (iii) 15% of the area of bottom panel and; (iv) 25% of the area of bottom panel. The positions of interlock stacking were: (i) no interlock; (ii) edge of middle roll tray aligned with edge of test specimen; (iii) edge of middle roll tray off set 10% of area of top panel and; (iv) edge of roll tray offset by 20% of area of the top panel. These positions are shown in Figure 1. In accordance with ASTM D 642, five repetitions for each condition were performed with an initial preload of 50 pounds. A load was applied with a continuous motion of 0.5 inches per minute until failure was reached[9]. Maximum load and maximum deformation was recorded after each test.

Pallet gaps and pallet overhang were simulated with wooded boards. Each board was 1.5" thick and cut to the appropriate width. A fixture was constructed from three roll end trays (see Figure 2) to produce the affect of interlock stacking. The roll trays were attached side to side by tape. These trays were constructed of B-flute with 275 p.s.i. burst strength material to ensure that the box would fail prior to fixture. The trays had the bottom panel removed and had the dimensions of 10" x 6" x 2". Templates were constructed to give accurate and repeatable measurements for each of the conditions tested.

All testing was done using a Lansmont PCT-5000, S/N 11545-296694, compression tester with a fixed platen following ASTM D-642 [9]. An example of a compression test is shown in Figure 3. The Lansmont Tester was calibrated on May 13, 1998, and has an accuracy of ± 5%. Temperature and humidity were measured on a HT-2106 Hydro -Thermometer.

Once all testing was complete, the data were organized and statistical analysis was performed. The effect of each single factor was determined; as was the effect of these factor combined. The results of the combination of two and three strength reduction factors were plotted against the multiplication of applicable single factors. A formula for predicting the actual strength reduction was then derived for each combination. The relationship was then obtained using a best-fit regression line.

DATA AND RESULTS

Each strength reduction factor, when tested alone, showed almost a linear progression of strength reduction as the condition became more severe. Pallet gaps showed the least reduction in strength with a range of 7.7% to 12.9 %. Pallet overhang showed the middle amount of a strength reduction of 30.5% to 42.1%. Interlock stacking showed the worst strength reduction with a range of 42.0% to 48.7%. The results of each strength reduction factor were used to calculate the multiple effect of these factors. For the combination of two factors, the single factor results were multiplied together and compared against the measured value for the same conditions. The two results were then plotted as shown in Figures 4, 5, 6, and 7.

Analysis was performed on the data obtained from Figures 4, 5, 6, and 7 by using a best fit linear regression line and correlation coefficient. For the combination of pallet gaps and overhang, the equation for the best-fit linear regression line is shown in Figure 1. Pallet overhang showed the strongest linear correlation coefficient (R) of 0.97. The equations for all the best-fit line are indicated in each figure. For the combination of pallet gaps and interlock stacking, neither factor had a strong correlation coefficient. For the combination of pallet overhang and interlock stacking, overhang once again had a stronger correlation with an R value of 0.64. When all three of the factors were compared, pallet overhang showed the strongest correlation with a R value of 0.90. This data indicated that pallet overhang is more severe than other strength reducing factors in reducing box stacking strength.

DISCUSSION

As expected when each factor was tested separately, as each of the factors increased, the severity of the strength reduction also increased. When combinations of two factors were tested and compared with the calculated value (using the test for each factor separately) the results showed that the results for the measured seemed to be less than the calculated values. In fact for each combination of two factors, the measured value seemed to be an average of 11% less severe than the calculated value. This indicates that there are other factors involved and that individual factors do not have a multiplying effect. Also indicated by the data is that the severity of pallet overhang has a very strong correlation with the reduction in strength of a box. When combined with one or the other two factors, it dictates the reduction in strength. One can deduce that pallet overhang is therefore the most serious threat to a box's strength. The combination of pallet gaps and interlock stacking, the two less dominating factors, showed very little correlation and tended to be concentrated in the range of 35% to 50% strength reduction. It might be beneficial to do further research in this area to see if a single reduction factor can be allocated when these two factors exists in combination.

The limitations of this study are that the tests were conducted on only one box size and one flute size. Hence, generalization or inference of the effect of other materials and sizes might not be valid. Also the pallet gaps were tested only with the gap being across the center of the width of the box; thus different locations of the gap might produce different effect on the box.

CONCLUSIONS

Results of these experiments confirmed that the palletizing factors do have a statistically significant effect on the stacking strength of a corrugated box. Also discovered was that pallet overhang was by far the most dominant strength reducing factor when in combination with other factors and dictated the pattern and order of decreasing strength. The individual effects of pallet gaps, pallet overhang and interlock stacking that were initially determined were then multiplied together to estimate the stacking strength of all possible combinations and compared to measured values. Results showed that the effects cannot be directly calculated by multiplication. Measured values were found to be 7% to 16% higher than those calculated by direct multiplication.

Since these factors are common in today's modern distribution systems, these results can be used as a model for the determination of compression strength and design of corrugated boxes. In particular, the formulas derived from the combination of factors can be used as an aid in predicting the stacking strength of a corrugated fiberboard box.

ACKNOWLEDGMENT

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Titles of tables

Titles of figures

Pallet Gaps = 0%

	Percent Area						Offset		
	PG			OH			IL		
Treatment	5%	15%	25%	5%	15%	25%	0%	10%	20%
49									
50				OH					
51					OH				
52						OH			
53							IL		
54								IL	
55									IL
56				OH			IL		
57				OH				IL	
58				OH					IL
59					OH		IL		
60					OH			IL	
61					OH				IL
62						OH	IL		
63						OH		IL	
64						OH			IL

PG = Pallet Gaps, OH = Overhang, IL = Interlocking

Pallet Gaps = 5%

	Percent Area						Offset		
	PG			**OH**			**IL**		
Treatment	**5%**	**15%**	**25%**	**5%**	**15%**	**25%**	**0%**	**10%**	**20%**
1	PG								
2	PG			OH					
3	PG				OH				
4	PG					OH			
5	PG						IL		
6	PG							IL	
7	PG								IL
8	PG			OH			IL		
9	PG			OH				IL	
10	PG			OH					IL
11	PG				OH		IL		
12	PG				OH			IL	
13	PG				OH				IL
14	PG					OH	IL		
15	PG					OH		IL	
16	PG					OH			IL

PG = Pallet Gaps, OH = Overhang, IL = Interlocking

Pallet Gaps = 15%

	Percent Area						Offset		
	PG			**OH**			**IL**		
Treatment	**5%**	**15%**	**25%**	**5%**	**15%**	**25%**	**0%**	**10%**	**20%**
17		PG							
18		PG		OH					
19		PG			OH				
20		PG				OH			
21		PG					IL		
22		PG						IL	
23		PG							IL
24		PG		OH			IL		
25		PG		OH				IL	
26		PG		OH					IL
27		PG			OH		IL		
28		PG			OH			IL	
29		PG			OH				IL
30		PG				OH	IL		
31		PG				OH		IL	
32		PG				OH			IL

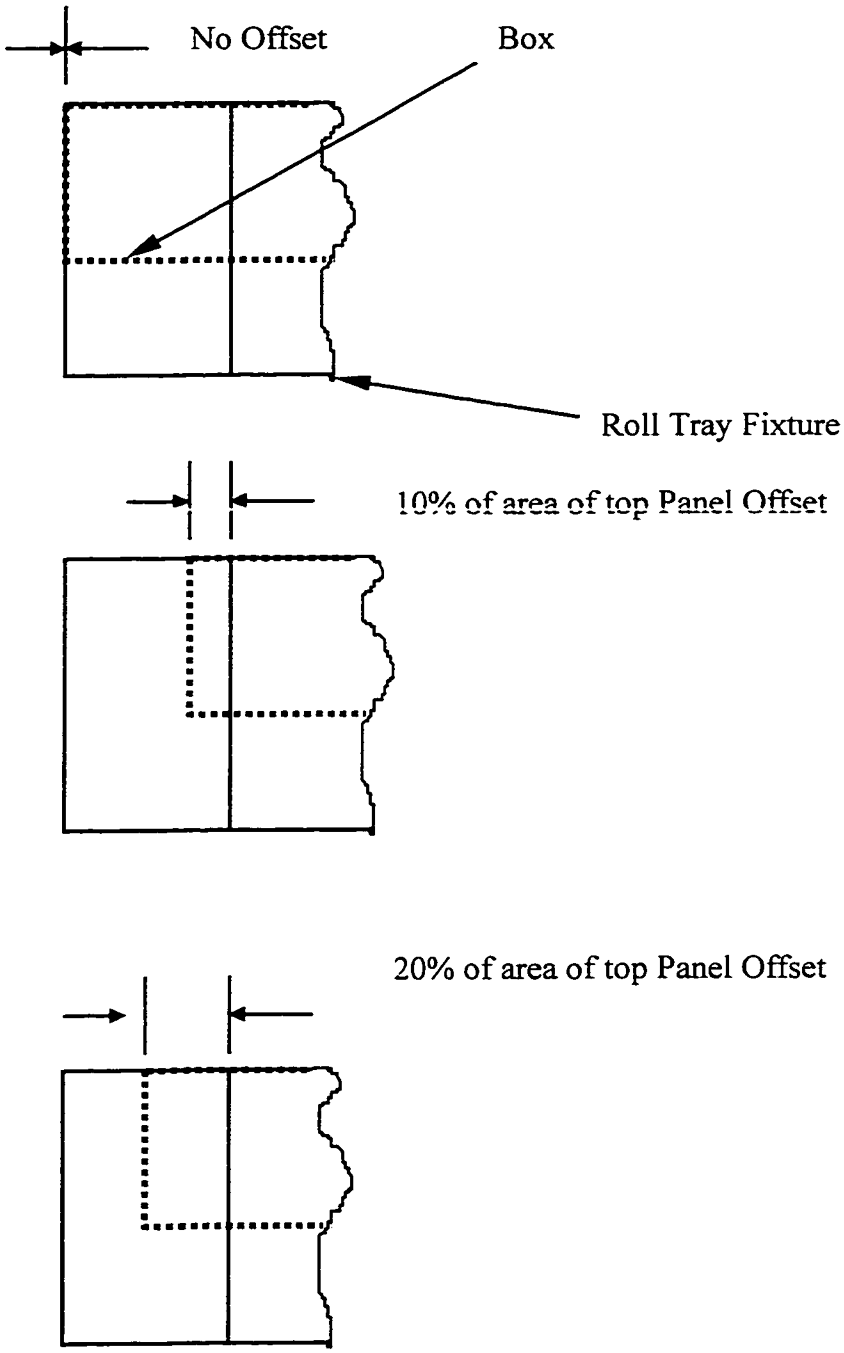
PG = Pallet Gaps, OH = Overhang, IL = Interlocking

Pallet Gaps = 25%

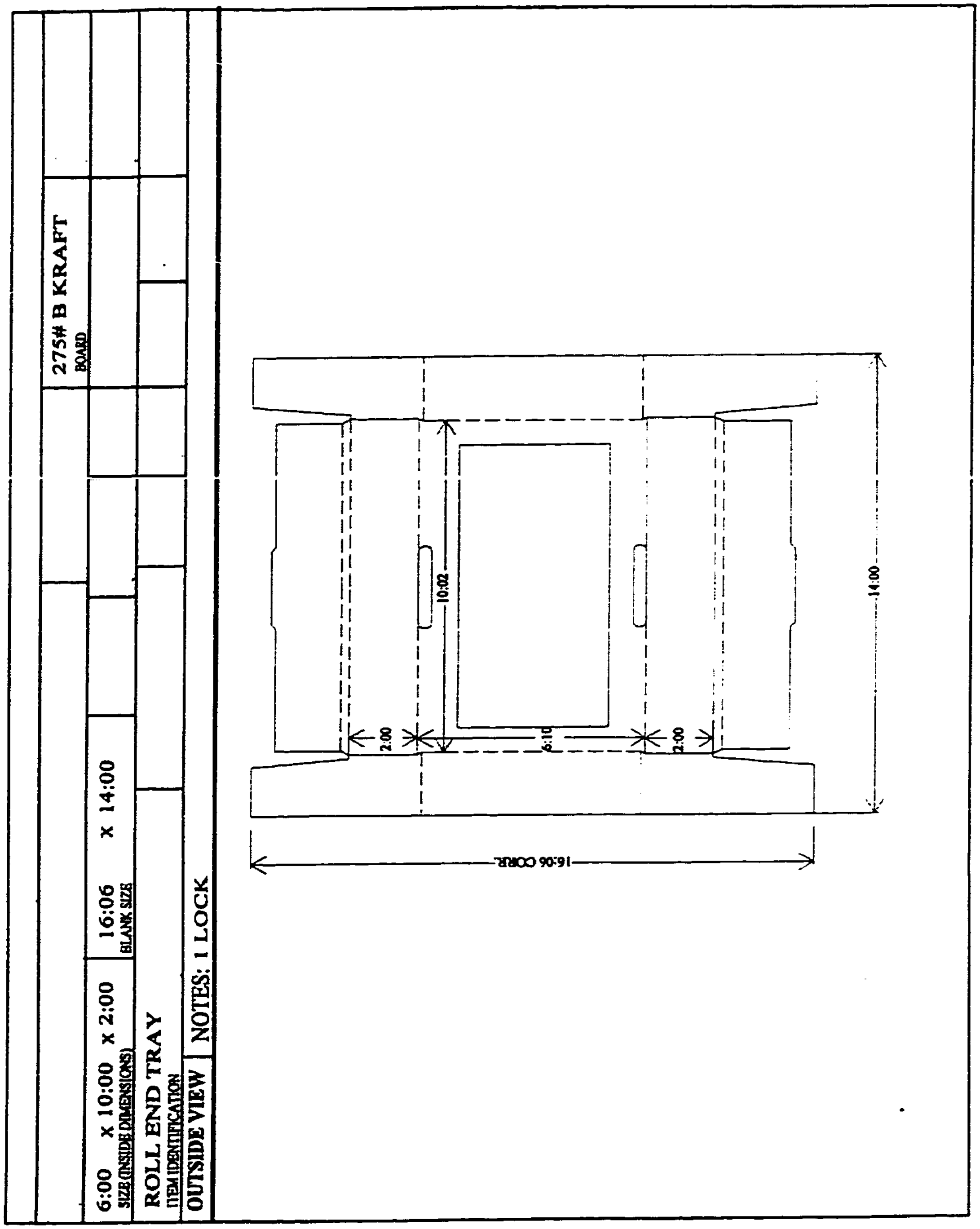
	Percent Area						Offset		
	PG			**OH**			**IL**		
Treatment	**5%**	**15%**	**25%**	**5%**	**15%**	**25%**	**0%**	**10%**	**20%**
33			PG						
34			PG	OH					
35			PG		OH				
36			PG			OH			
37			PG				IL		
38			PG					IL	
39			PG						IL
40			PG	OH			IL		
41			PG	OH				IL	
42			PG	OH					IL
43			PG		OH		IL		
44			PG		OH			IL	
45			PG		OH				IL
46			PG			OH	IL		
47			PG			OH		IL	
48			PG			OH			IL

PG = Pallet Gaps, OH = Overhang, IL = Interlocking

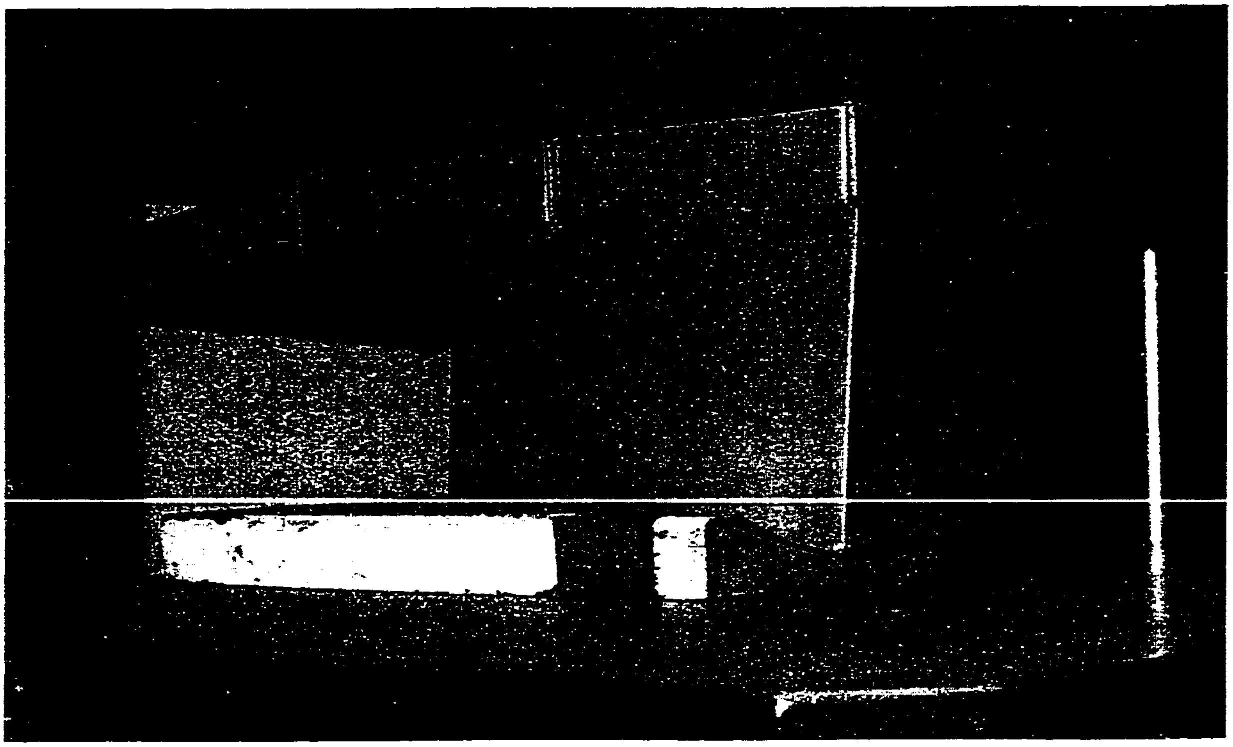
Interlock Stacking Positions



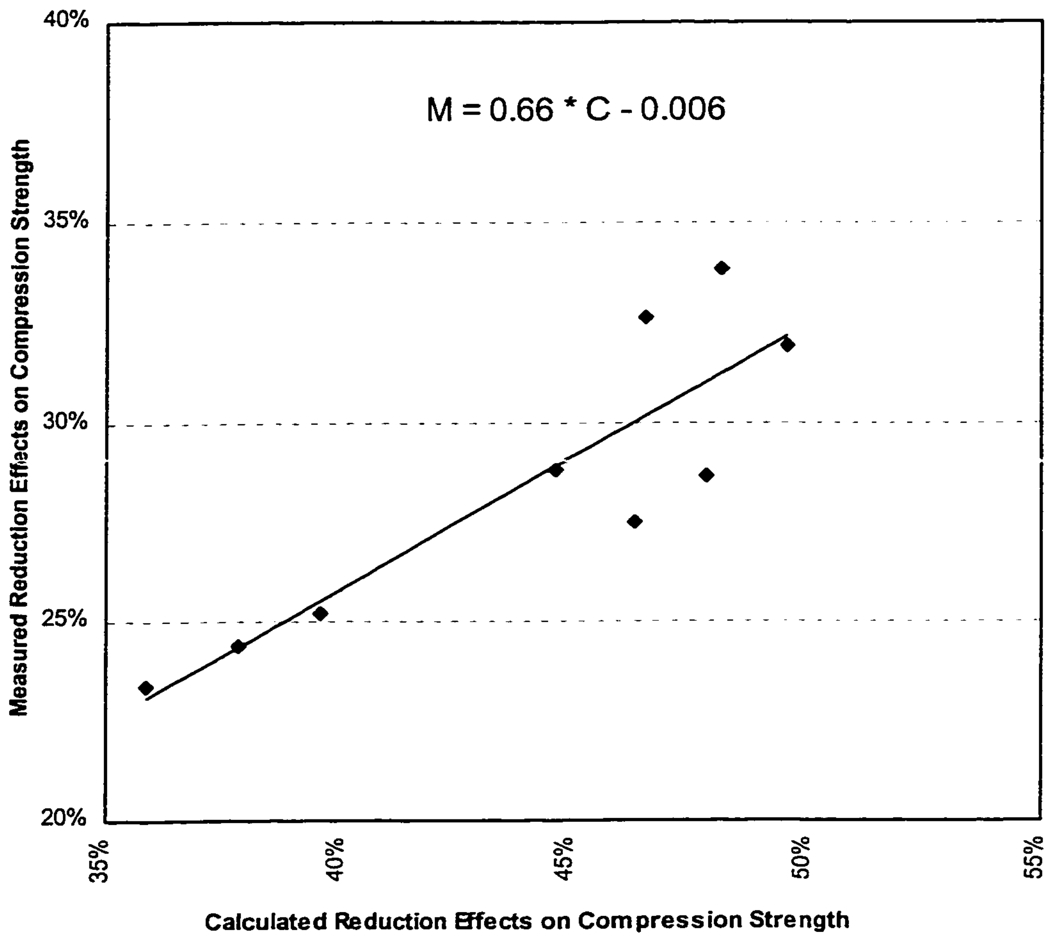
Design of Roll Tray



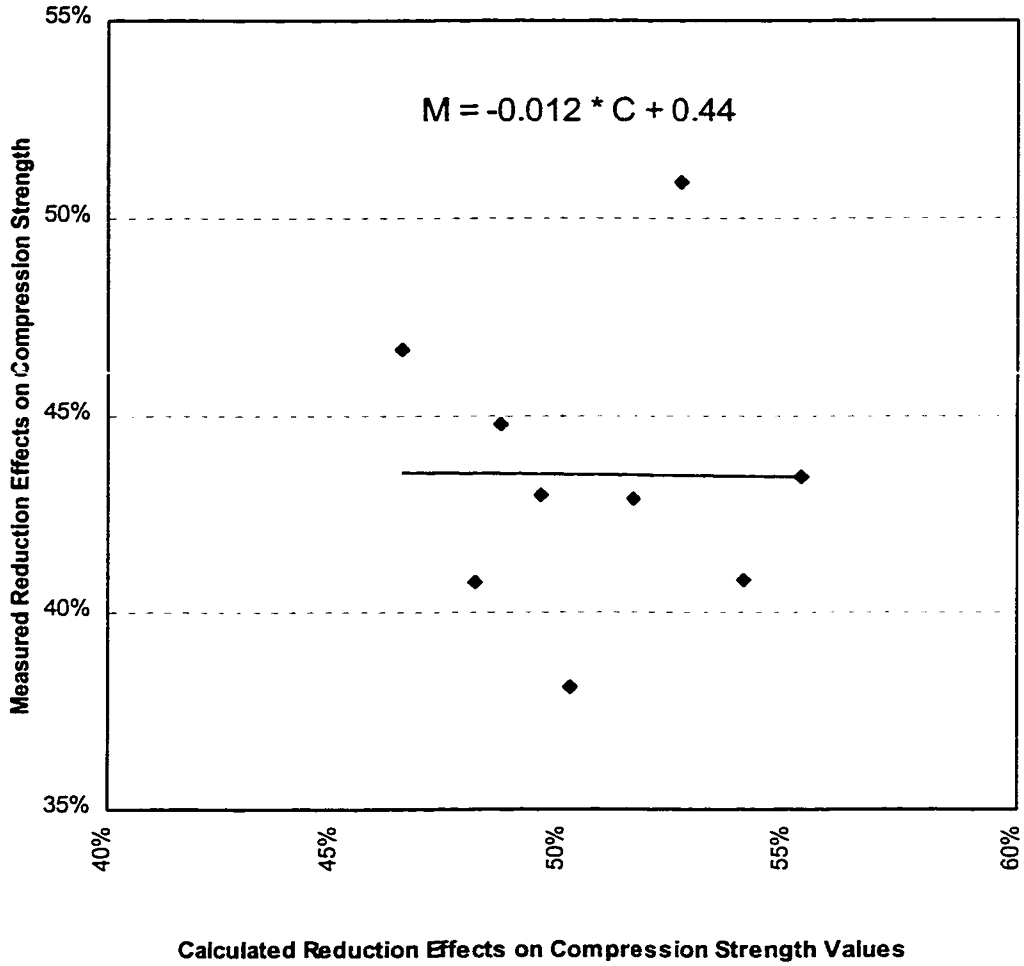
Simulation of All Three Strength Reduction Factors



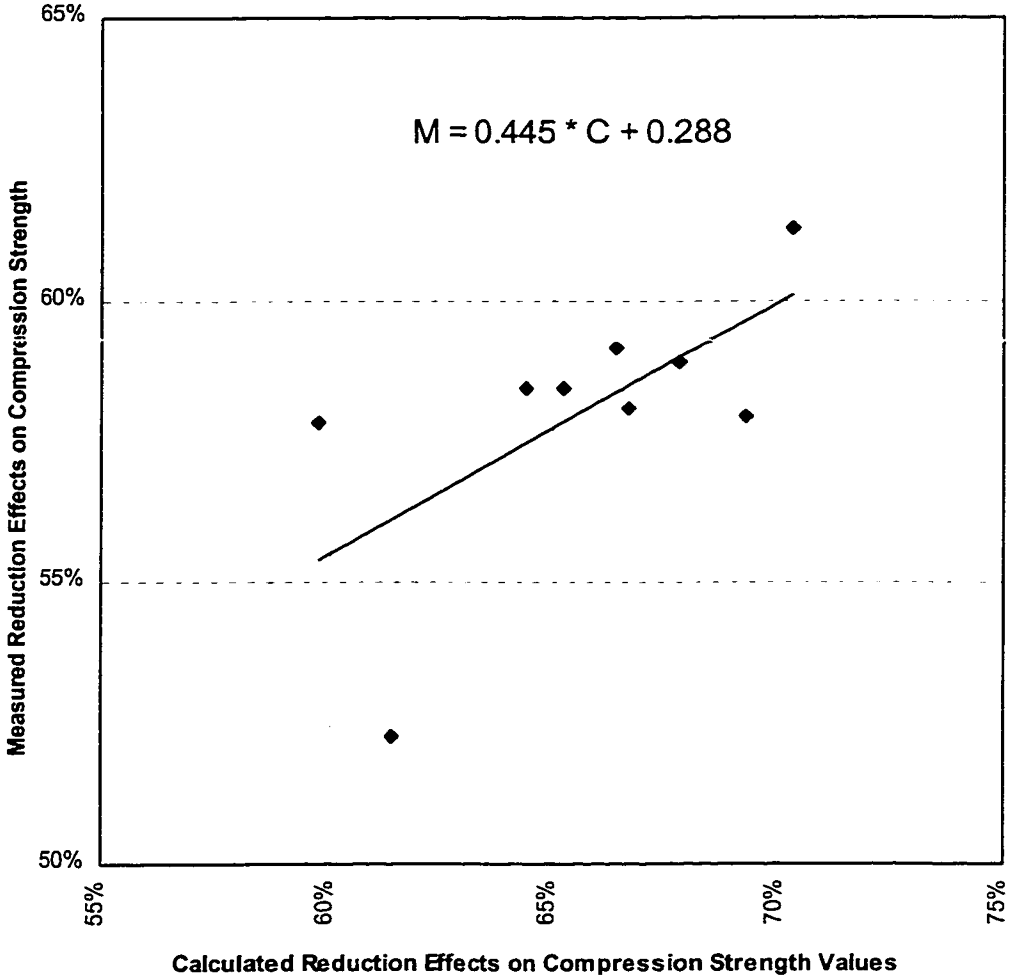
Combinations of Pallet Gaps and Pallet Overhang: Measured Versus Calculated



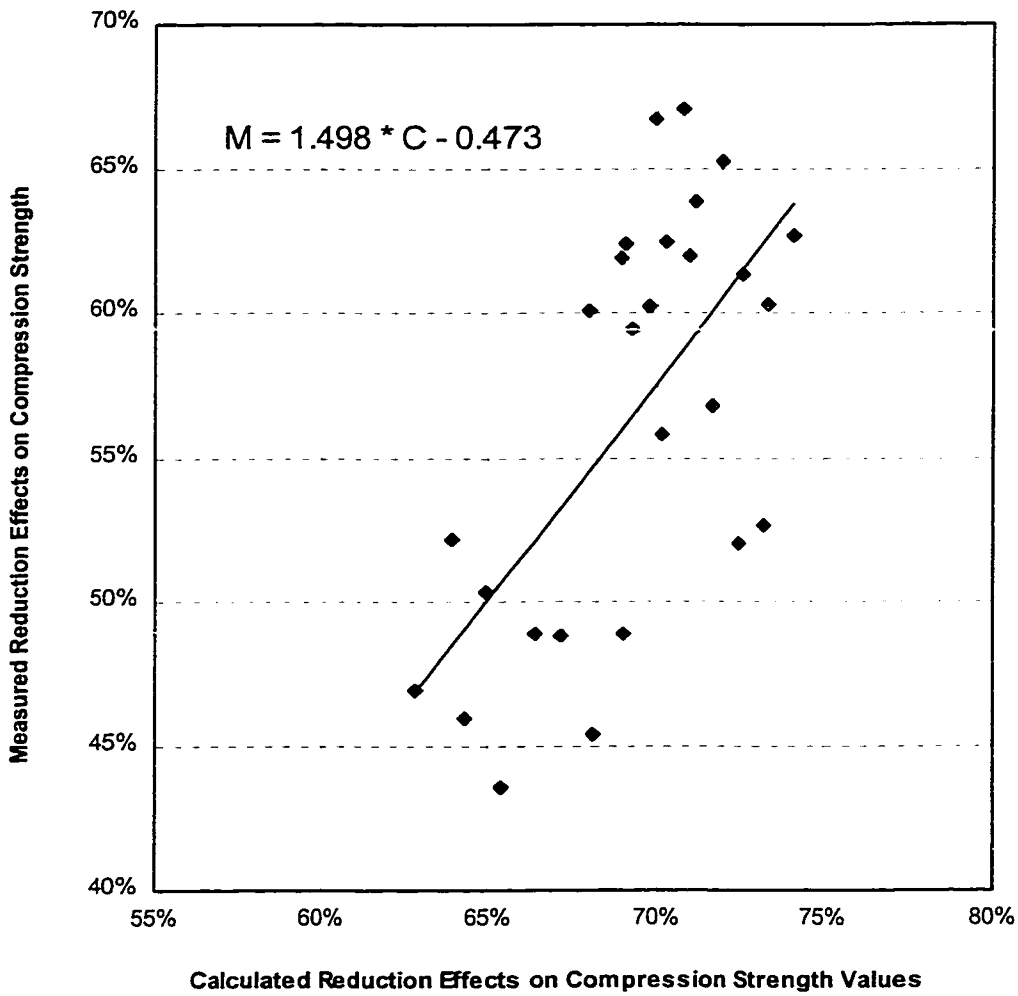
Combinations of Pallet Gaps and Interlock Stacking: Measured Versus Calculated



Combinations of Overhang and Interlock Stacking: Measured Versus Calculated



Combinations of Pallet Gaps, Overhang, and Interlock Stacking: Measured Versus Calculated



CHAPTER 3

SUMMARY AND RECOMMENDATIONS

Summary

The interactive effects of three strength reducing factors encountered in the distribution system were investigated for a 10" x 6" x 6" B-fluted regular slotted container. This style and flute were chosen because of their immense popularity in the distribution system today. The test was conducted at THARCO located in San Lorenzo, California using a Lansmont PCT-5000, S/N 11545-296694, compression tester with a fixed platen (See Appendix B). The Lansmont Tester was calibrated on May 13, 1998, and has an accuracy of $\pm$ 5%.

The boxes were tested by varying the combination of pallet gaps, overhang, and stack interlocking and by adjusting the percent area of contact of the bottom surface of the box from 5 % to 15 % and finally 25 % for pallet gaps and pallet overhang and one of three positions of stack interlocking (See Appendix D) . There are 64 (4^3) possible combinations that occur between these three variables. Five repetitions of each combination were tested . These combinations are presented in appendix A.

Pallet gaps were simulated through the use of wooden boards placed beneath the center and perpendicular to the longest side panel. Pallet overhang was simulated again with wooden boards and placed beneath the end and perpendicular to the longest side panel (See appendix B). A fixture was constructed of three, 275 p.s.i. Kraft, B flute corrugated rolling trays attached together. These trays were used to simulate the edges of the top boxes in an interlocking stack pattern (See appendix C). This material was chosen because it has a higher compression strength than B flute RSC, thus the specimen would fail first. The location of the positions correspond to the percent area of offset and is shown in appendix D. Since the effect of humidity was not in question, the samples were not preconditioned, but used immediately from warehouse storage. For the two days of testing the humidity was monitored and never reached over 50% RH and was never under 35% RH. Also the temperature range was between 20^{o} C and 26^{o} C. In appendix F, Figure F.1 shows the temperature and humidity readings recorded during the experiment. The results of the compression test were then corrected according to the factors in Table F.1 (Maltenfort, 1988). This was necessary to normalize all results to an equivalent humidity of 50%.

Results revealed that the strength of the corrugated RSC varied with the different combinations of palletizing strength reduction factors. When taken alone interlock stacking had the greatest measured reduction in strength of 48.7% at its worst case scenario. Pallet gaps had the least measured reduction in strength of 7.7% at the least worst case scenario. When two factors were tested together the combination of pallet gaps and pallet overhang produced the lowest measured strength reduction at about 23% and the combination of overhang and interlock stacking produced the greatest measured strength reduction at 62%. The combination of all three produced a strength reduction range of 44% to 68%. The combination of pallet gaps and interlock stacking produced interesting results that were not consistent with the remaining combinations. When each measured value was compared with the calculated value (single factor results multiplied together) the lines generally ran parallel, but with the combination of pallet gaps and interlock stacking the measured line was horizontal when ordered by increasing severity of pallet gaps. Also a pattern developed where the pallet gap order of increasing strength reduction occurred in the order of 15 % then 25% and finally the worst was 5%. There is obviously some kind of interaction due to the construction of the corrugated RSC and the forces that are being applied that produces this result. This same interaction to some extent can be found in the measured values for the combination of all three factors. By far the controlling factor is pallet overhang.

Analysis was performed on the data gathered to derive formulas for predicting the reduction in strength for a given combination by using best-fit regression lines. There was a strong positive correlation between the severity of the strength reduction factor and the measured reduction in strength of the corrugated box when the factors were taken alone. The correlation coefficients (R) ranged from 0.93 to 0.99. When analysis was performed on the two combination scenarios a positive correlation was found only when pallet overhang was involved. For the combination of pallet gaps and overhang, overhang had a value of R=0.97, and for the combination of overhang and interlock stacking, overhang had a value of R=0.64. There was no correlation for the Pallet gaps and interlock stacking combination. When all three factors were combined only overhang had a strong correlation at R= 0.90 versus R= 0.08 for pallet gaps and R= -0.24 for interlocking. From this, we can deduce that pallet overhang has the most influence in determining the loss in strength even thought it was found to cause the second highest reduction in strength.

Recommendation

Since pallet gaps, pallet overhang and interlock stacking are very prevalent in today's modern distribution systems, these results can be used as a model for box stacking strength estimation and design of the optimum packaging. In particular, the derived formulas can be used as an aid in predicting the stacking strength of a corrugated box when these factors are known to exist.

Further studies are necessary to determine if the formulas derived in this study are still applicable to other size boxes and other configurations. Also needing further investigation is the effect of pallet gaps at locations other than across the center of the width of the box (as used in this study). Different placement of pallet gaps might produce different results.

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APPENDICES

APPENDIX A

TESTS COMBINATIONS

Figure A.1 to A.4 show the 64 combinations that were tested in this study.

	Percent Area						Offset		
	PG			**OH**			**IL**		
Treatment	**5%**	**15%**	**25%**	**5%**	**15%**	**25%**	**0%**	**10%**	**20%**
49									
50				OH					
51					OH				
52						OH			
53							IL		
54								IL	
55									IL
56				OH			IL		
57				OH				IL	
58				OH					IL
59					OH		IL		
60					OH			IL	
61					OH				IL
62						OH	IL		
63						OH		IL	
64						OH			IL

Table A.1 Pallet Gaps = 0%
PG = Pallet Gaps, OH = Overhang, IL = Interlocking

	Percent Area						Offset		
	PG			**OH**			**IL**		
Treatment	**5%**	**15%**	**25%**	**5%**	**15%**	**25%**	**0%**	**10%**	**20%**
1	PG								
2	PG			OH					
3	PG				OH				
4	PG					OH			
5	PG						IL		
6	PG							IL	
7	PG								IL
8	PG			OH			IL		
9	PG			OH				IL	
10	PG			OH					IL
11	PG				OH		IL		
12	PG				OH			IL	
13	PG				OH				IL
14	PG					OH	IL		
15	PG					OH		IL	
16	PG					OH			IL

Table A.2 Pallet Gaps = 5%
PG = Pallet Gaps, OH = Overhang, IL = Interlocking

	Percent Area						Offset		
	PG			OH			IL		
Treatment	5%	15%	25%	5%	15%	25%	0%	10%	20%
17		PG							
18		PG		OH					
19		PG			OH				
20		PG				OH			
21		PG					IL		
22		PG						IL	
23		PG							IL
24		PG		OH			IL		
25		PG		OH				IL	
26		PG		OH					IL
27		PG			OH		IL		
28		PG			OH			IL	
29		PG			OH				IL
30		PG				OH	IL		
31		PG				OH		IL	
32		PG				OH			IL

Table A.3 Pallet Gaps = 15%
PG = Pallet Gaps, OH = Overhang, IL = Interlocking

	Percent Area						Offset		
	PG			**OH**			**IL**		
Treatment	**5%**	**15%**	**25%**	**5%**	**15%**	**25%**	**0%**	**10%**	**20%**
33			PG						
34			PG	OH					
35			PG		OH				
36			PG			OH			
37			PG				IL		
38			PG					IL	
39			PG						IL
40			PG	OH			IL		
41			PG	OH				IL	
42			PG	OH					IL
43			PG		OH		IL		
44			PG		OH			IL	
45			PG		OH				IL
46			PG			OH	IL		
47			PG			OH		IL	
48			PG			OH			IL

Table A.4 Pallet Gaps = 25%
PG = Pallet Gaps, OH = Overhang, IL = Interlocking

APPENDIX B

TEST SETTING

Figures B.1 and B.2 show the Lansmont Compression tester used and the actual testing for the various strength reduction factors.

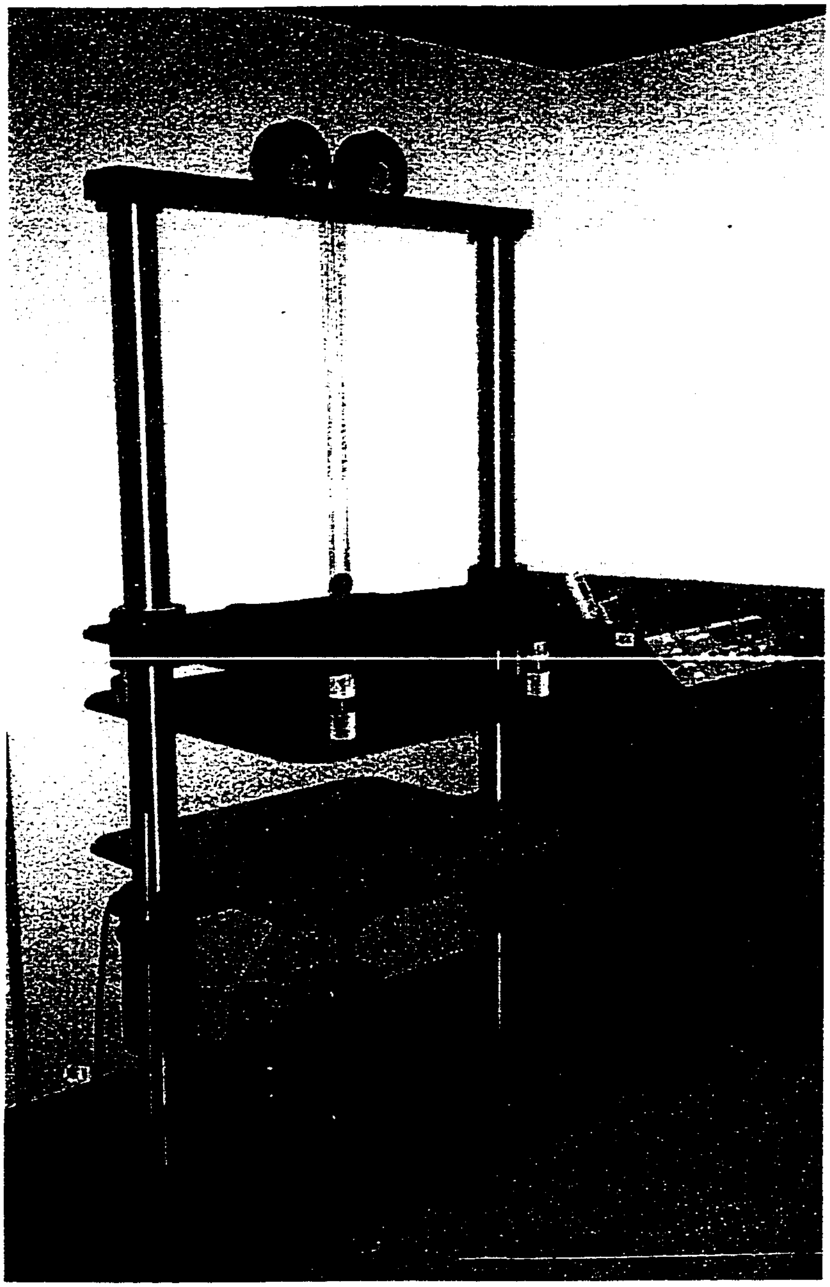

Figure B.1 Lansmont PCT-5000 Compression Tester

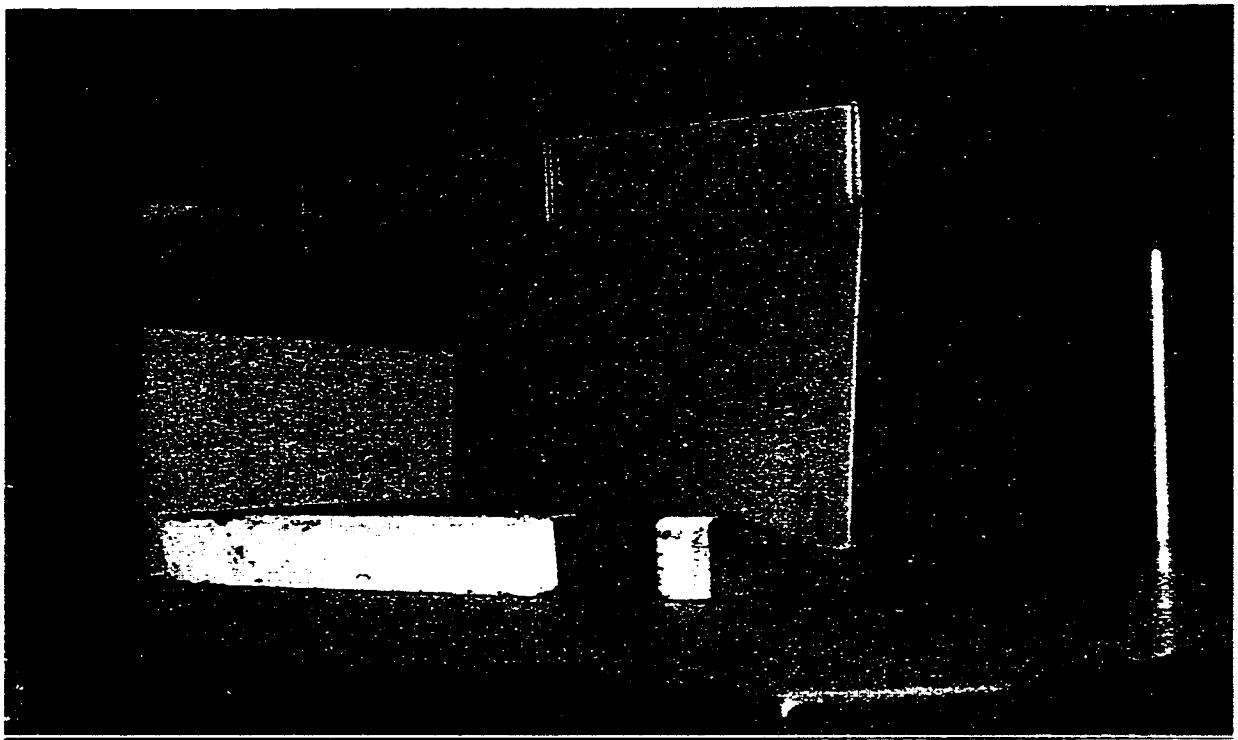

Figure B.2 Simulation of All Three Strength Reduction Factors

APPENDIX C

ROLL TRAY FOR INTERLOCK SIMULATION

Figure C.1 shows the design of one of the three roll trays used for the simulation of interlock stacking.

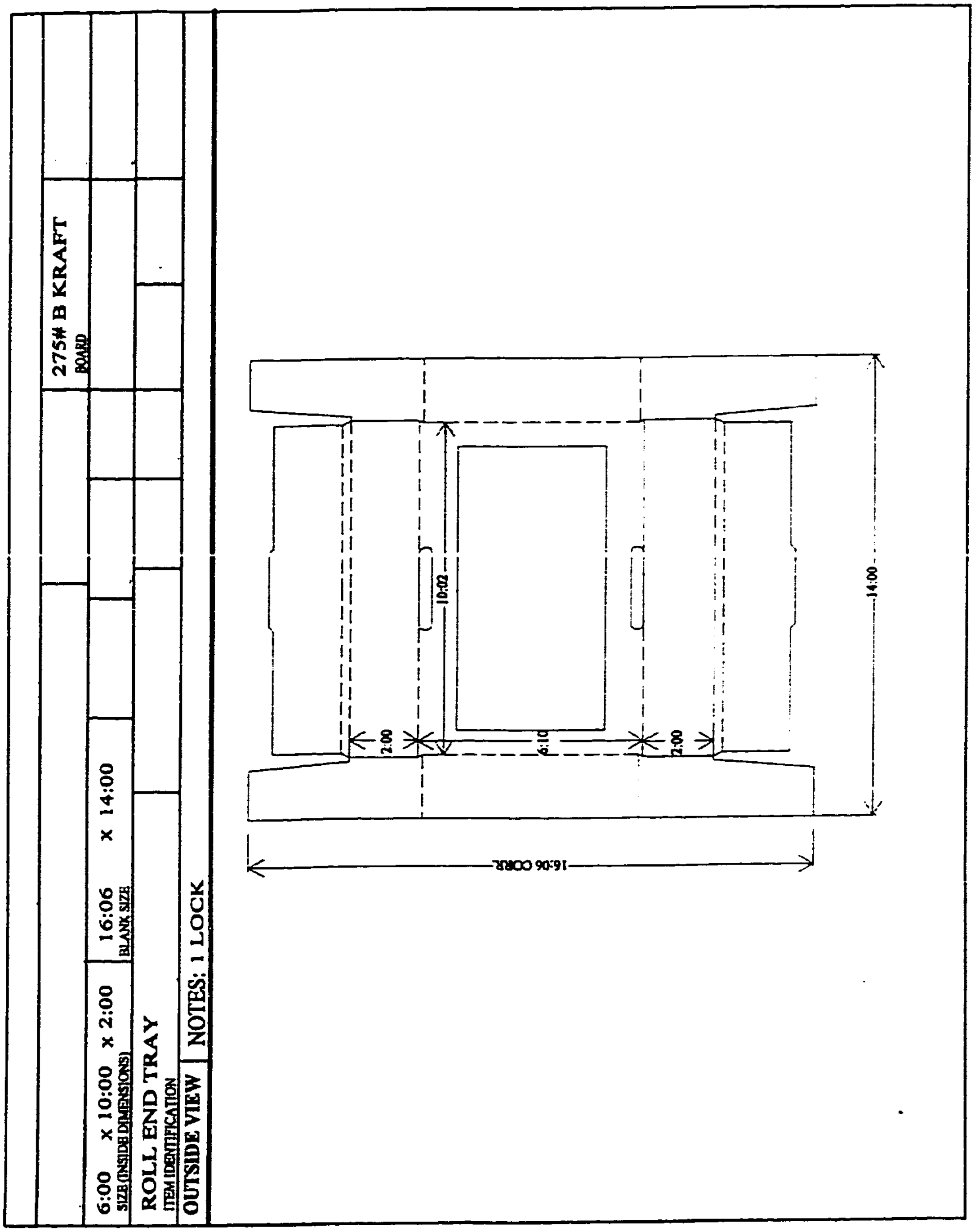

Figure C.1 Design of Roll Tray

APPENDIX D

INTERLOCK STACKING OFFSET POSITIONS

Figure D.1 shows the placement of the interlock fixture

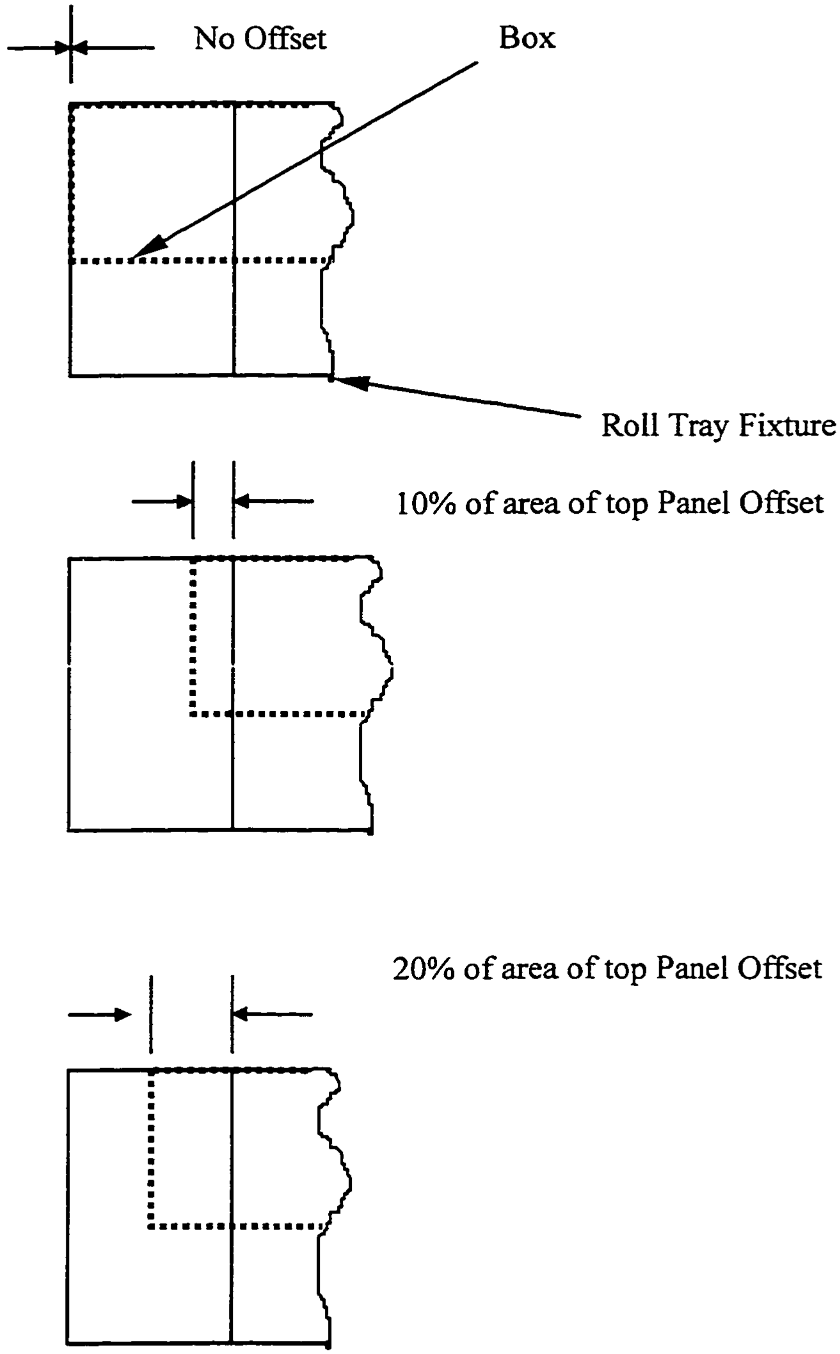

Figure D.1 Interlock Stacking Positions

APPENDIX E

SUMMARY OF STUDY RESULTS

Figures E.1 to E.7 show the comparison of calculated and measured values of the three palletizing factors. Table E.1 shows the results of Figure E.7 in tabular form.

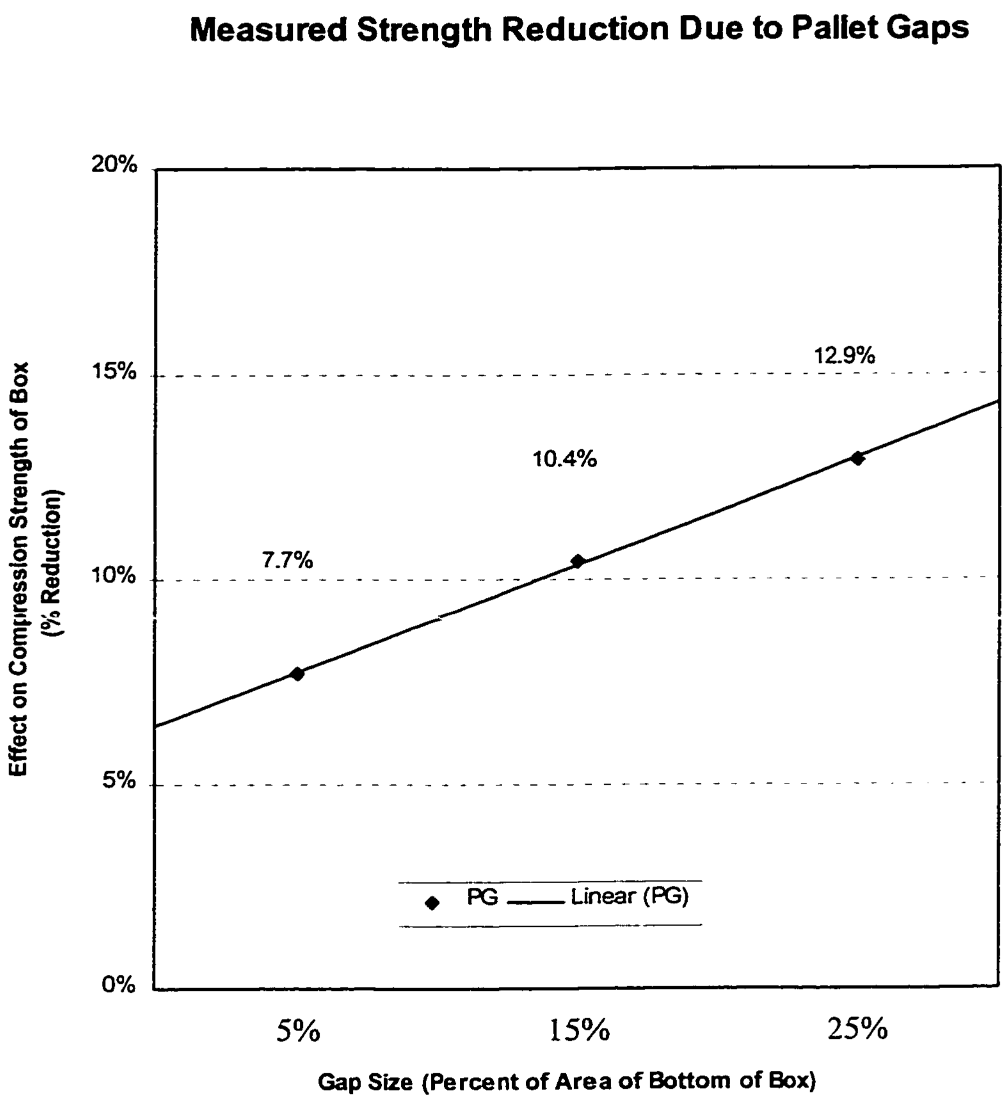

Figure E.1 Effects of Pallet Gaps

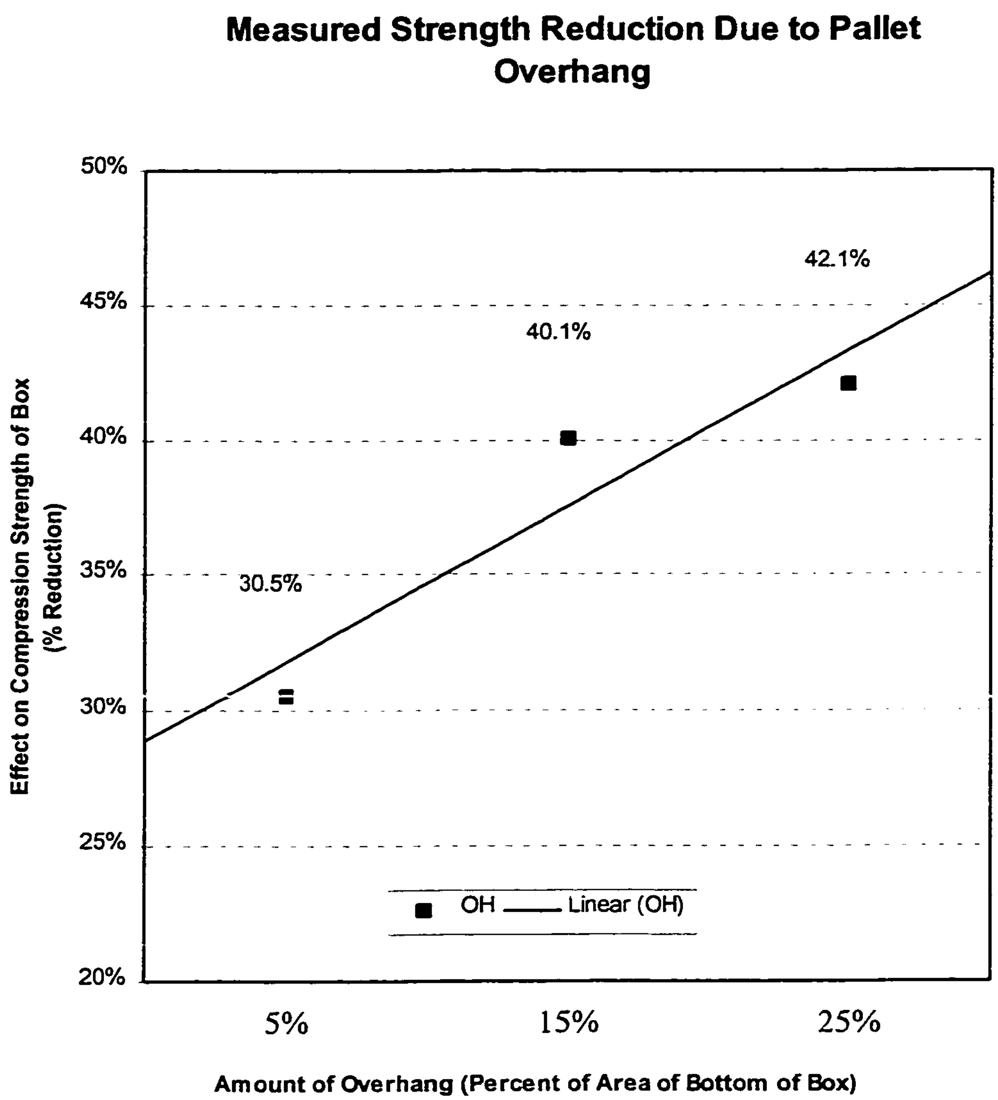

Figure E.2 Effects of Pallet Overhang

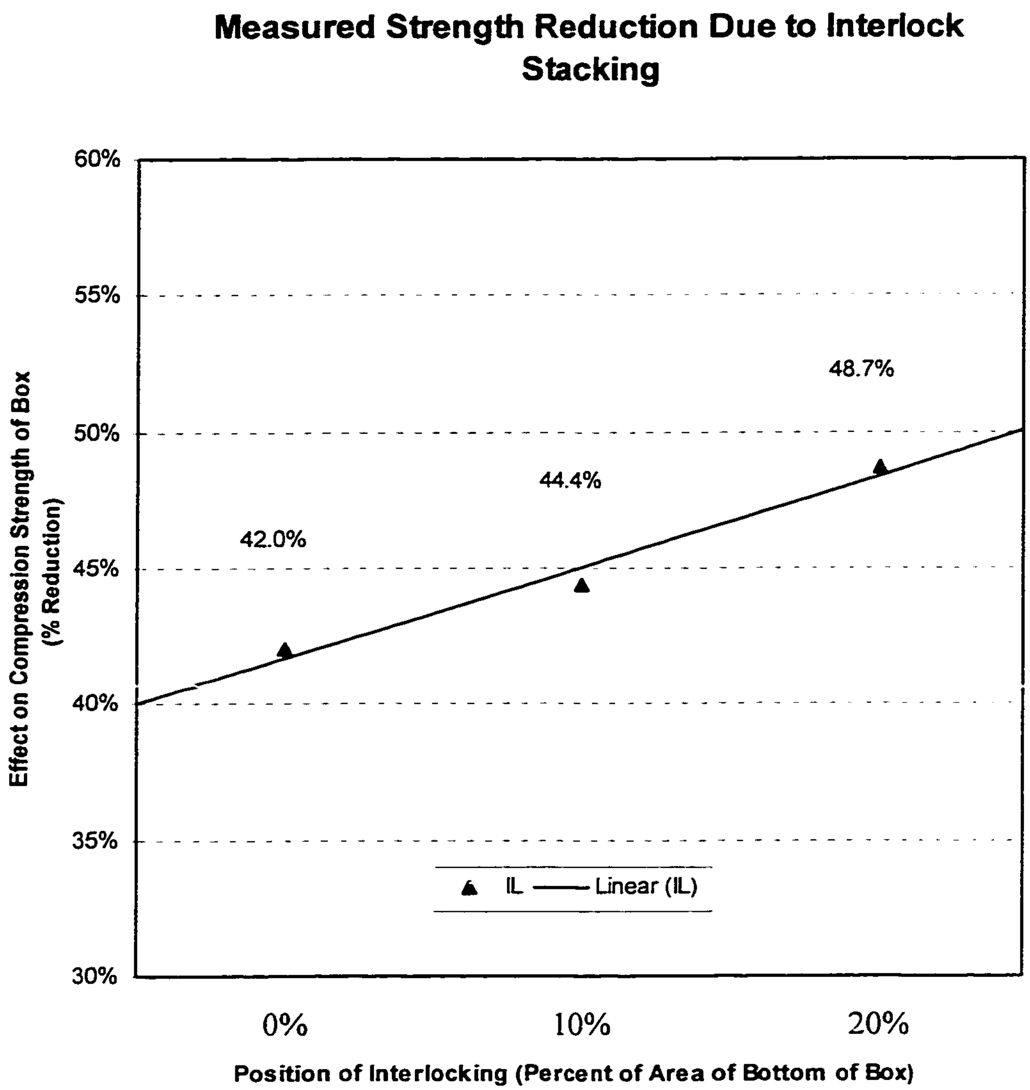

Figure E.3 Effects of Interlock Stacking

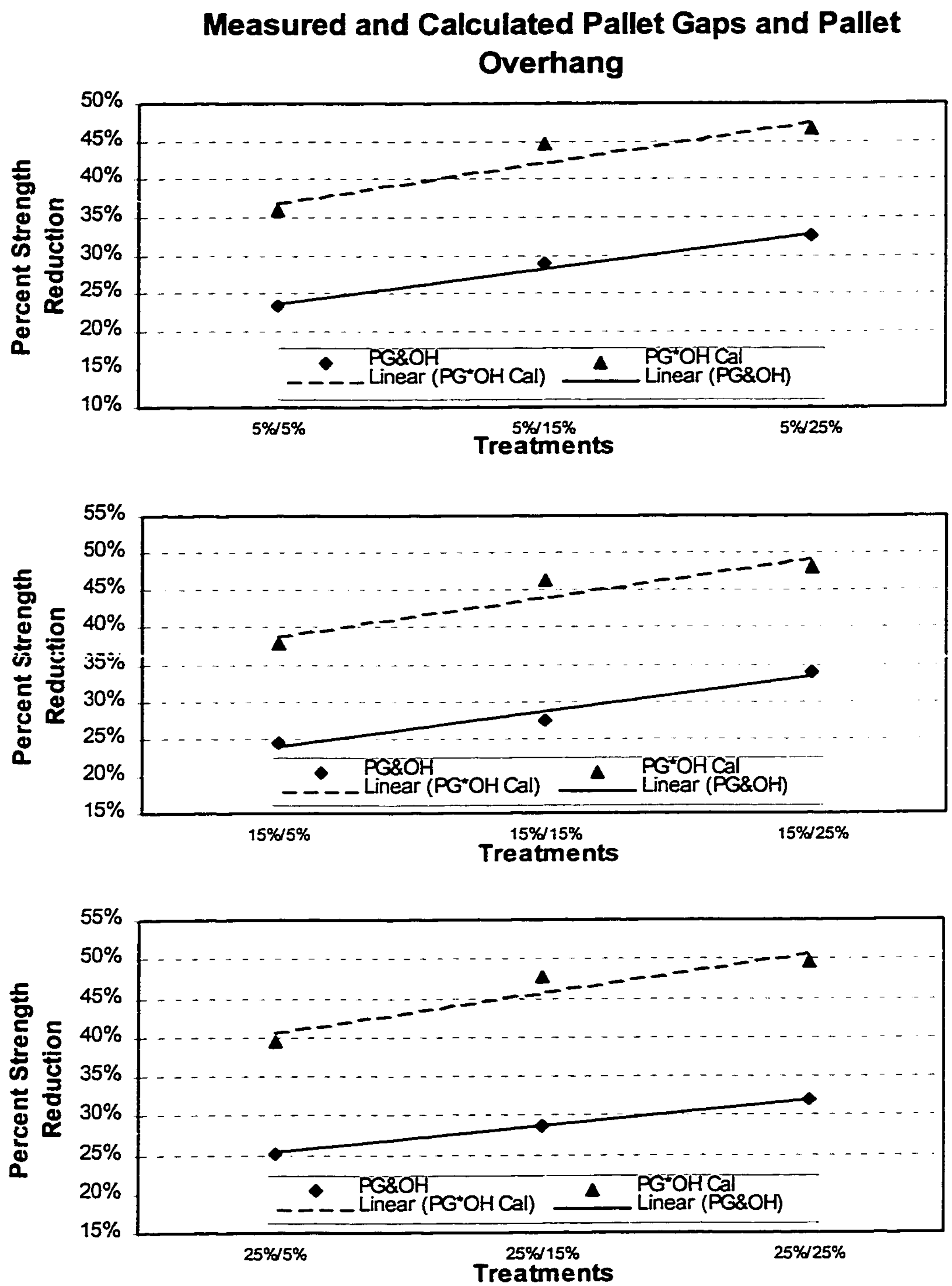

Figure E.4 Combination Pallet Gaps and Pallet Overhang: Measured and Calculated

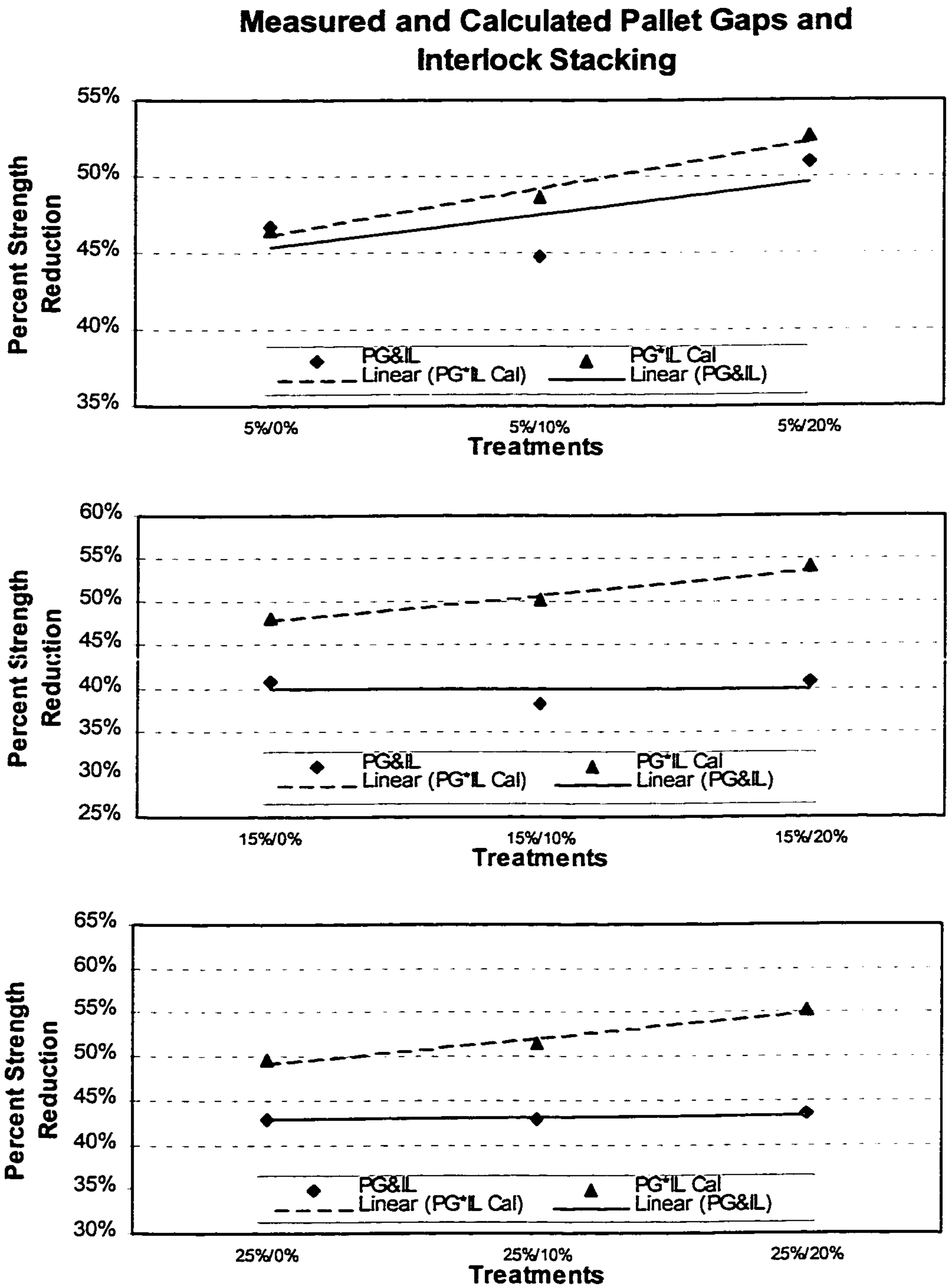

Figure E.5 Combination Pallet Gaps and Interlock Stacking: Measured and Calculated

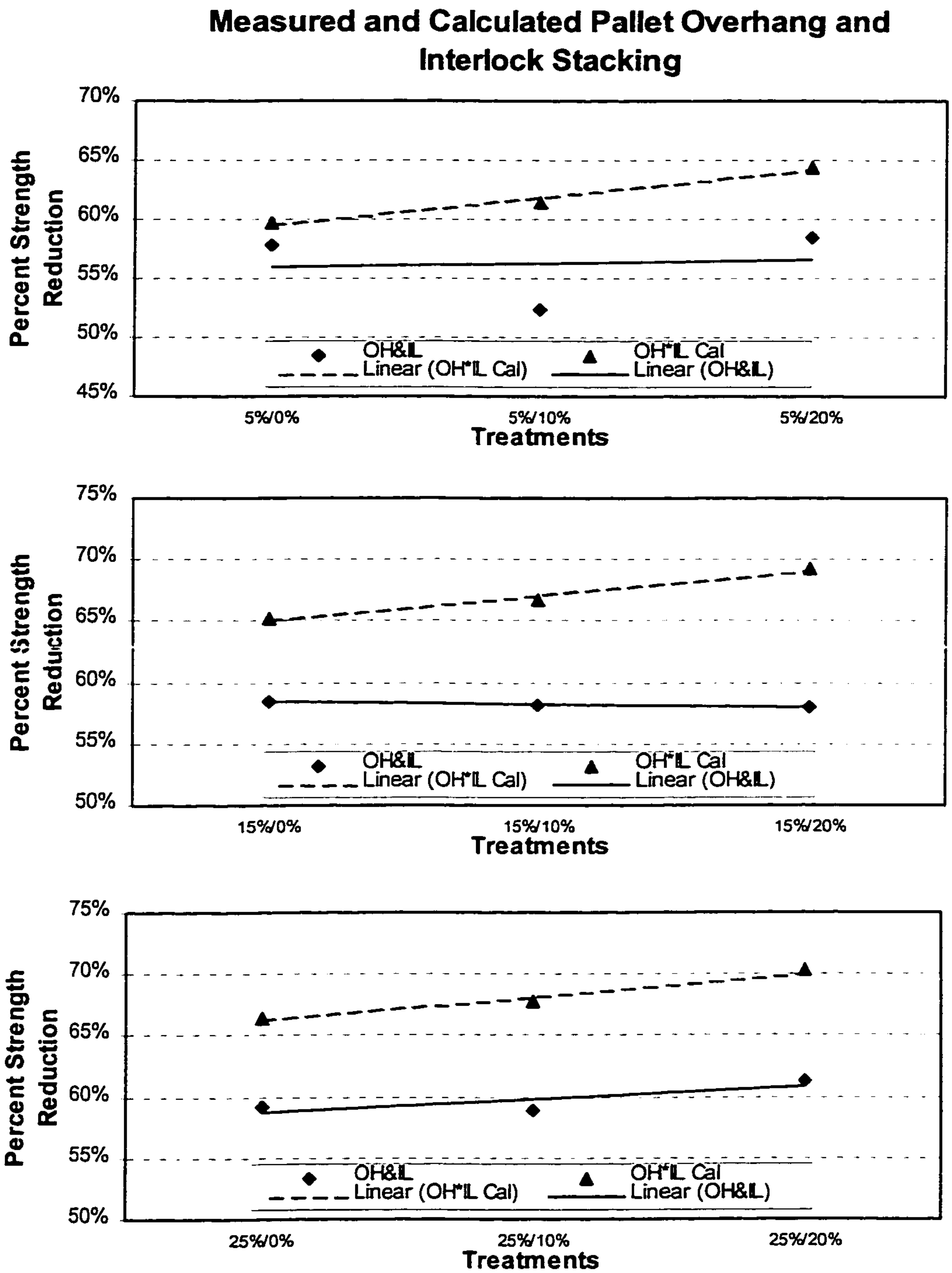

Figure E.6 Combination Pallet Overhang and Interlock Stacking: Measured and Calculated

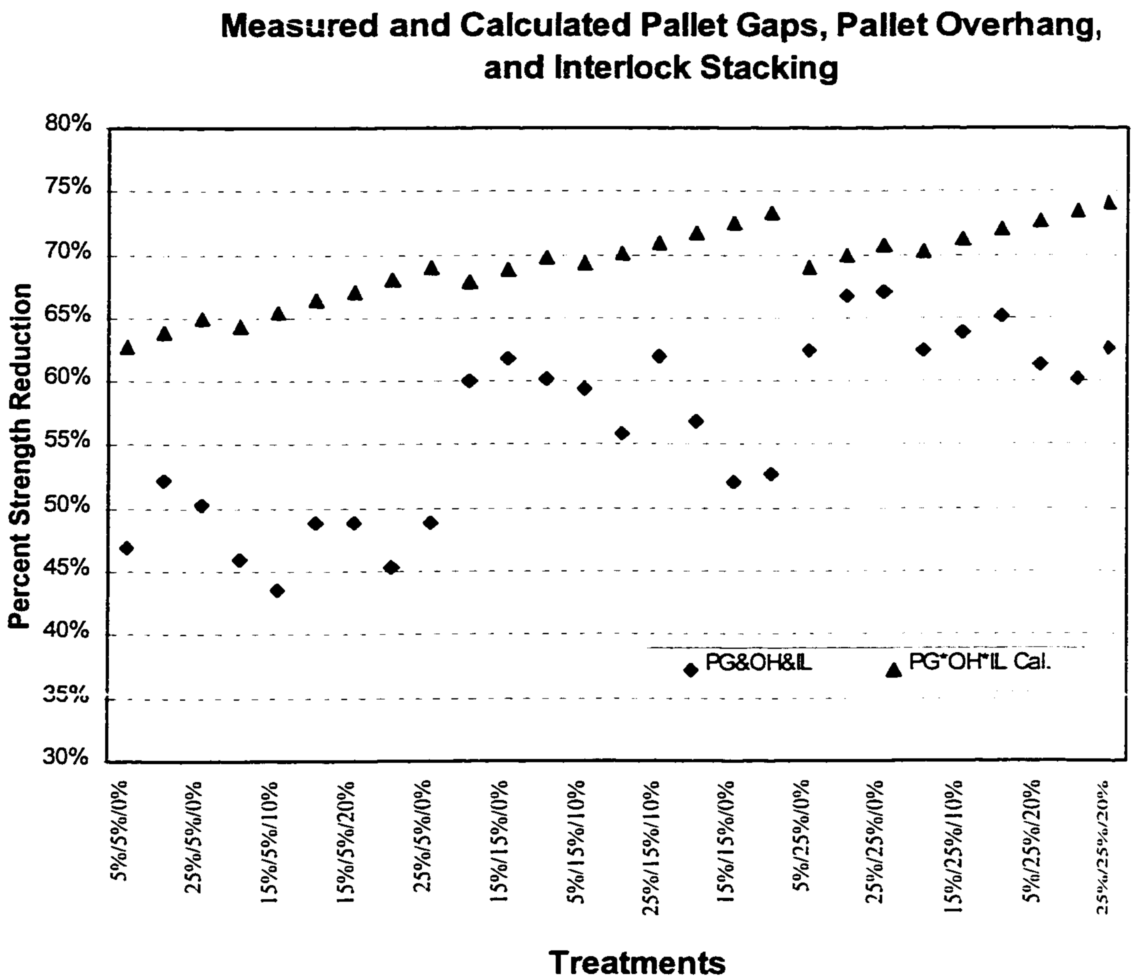

Figure E.7 Combination Pallet Gaps Pallet Overhang and Interlock Stacking: Measured and Calculated

OH	IL	PG	OH&IL&PG	OH*IL*PG Cal.
5%	0%	5%	46.90%	62.83%
5%	0%	15%	52.15%	63.94%
5%	0%	25%	50.33%	64.94%
5%	10%	5%	45.93%	64.33%
5%	10%	15%	43.56%	65.40%
5%	10%	25%	48.90%	66.36%
5%	20%	5%	48.78%	67.11%
5%	20%	15%	45.39%	68.09%
5%	20%	25%	48.89%	68.97%
15%	0%	5%	60.09%	67.92%
15%	0%	15%	61.87%	68.88%
15%	0%	25%	60.22%	69.74%
15%	10%	5%	59.45%	69.22%
15%	10%	15%	55.84%	70.14%
15%	10%	25%	61.98%	70.97%
15%	20%	5%	56.80%	71.62%
15%	20%	15%	52.01%	72.47%
15%	20%	25%	52.69%	73.23%
25%	0%	5%	62.39%	69.00%
25%	0%	15%	66.69%	69.93%
25%	0%	25%	67.09%	70.76%
25%	10%	5%	62.45%	70.26%
25%	10%	15%	63.86%	71.15%
25%	10%	25%	65.22%	71.95%
25%	20%	5%	61.34%	72.57%
25%	20%	15%	60.27%	73.39%
25%	20%	25%	62.64%	74.13%

Table E.1 Combination Pallet Gaps Pallet Overhang and Interlock Stacking: Measured and Calculated

APPENDIX F

Temperature and Humidity

Figure F.1 shows the temperature and humidity during the compression testing. Table F.1 is correction factors used to normalize the results to an equivalent humidity of 50%.

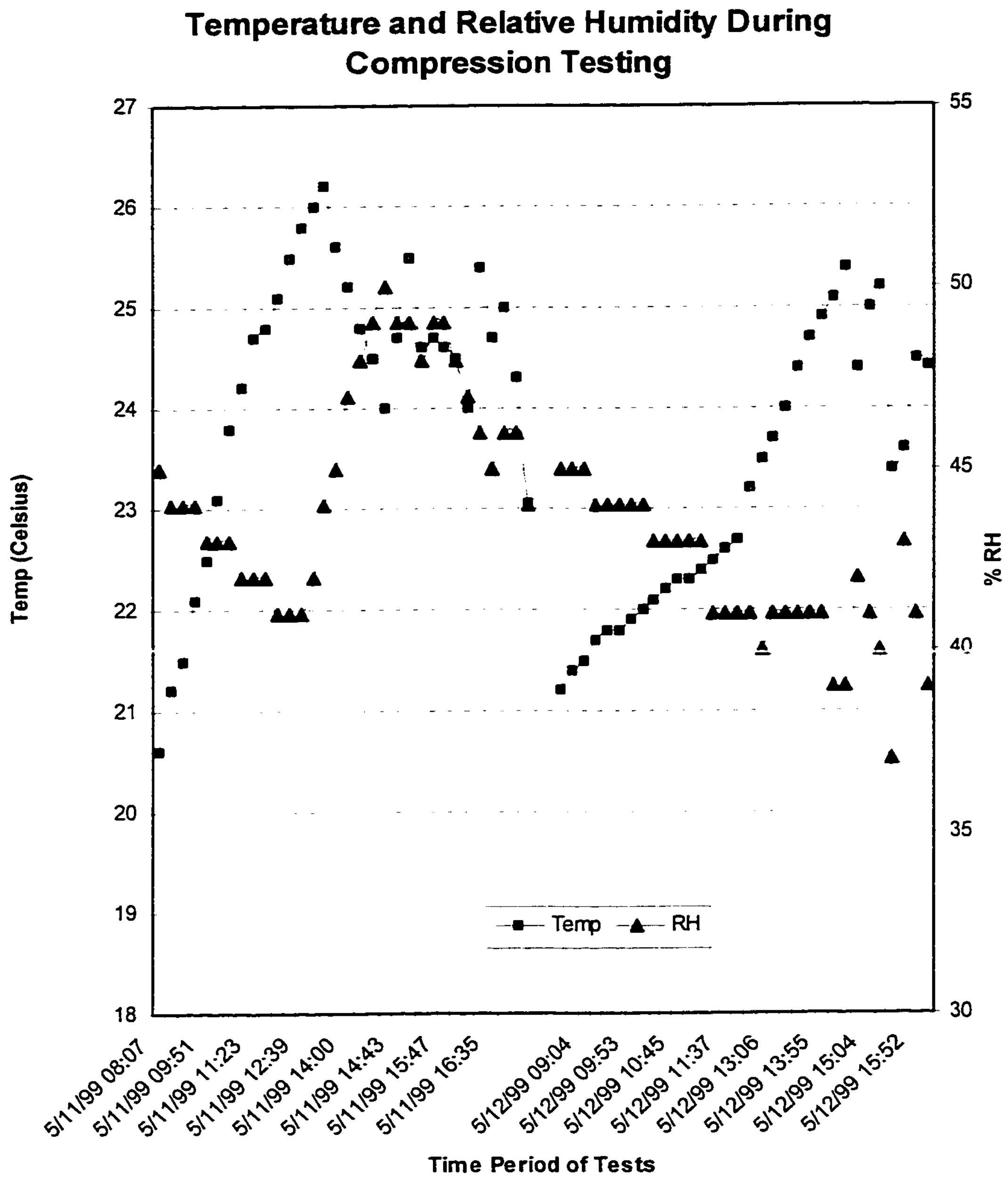

Figure F.1 Temperature and Humidity During Compression Testing

Average Room Relative Humidity	Correction Factor to correct to 50% Relative Humidity
35%	0.924
36%	0.929
37%	0.933
38%	0.938
39%	0.943
40%	0.947
41%	0.952
42%	0.957
43%	0.962
44%	0.967
45%	0.972
46%	0.977
47%	0.983
48%	0.989
49%	0.994
50%	1.000
51%	1.007

Table F.1 Correction Factors used to normalize to an equivalent humidity of 50%

(Maltenfort, 1988)