Effect of Palletized Box Offset on Compression Strength of Unitized and Stacked Empty Corrugated Fiberboard Boxes

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ABSTRACT: The purpose of this study was to evaluate the effect of pallet type, tie-sheet and stack configuration on compression strength of a palletized load of boxes. Four boxes made from similar board grade and different dimensions were selected for this study. The column stack configuration which represented the control was compared with the 3 stack configurations either on a CHEP® or GMA pallet. The unitized load either had a tie-sheet in between layers or no tie-sheet between layers of boxes on the respective pallets, for compression strength comparison with the control unitized load represented by a column stack configuration. This is the first of a series of two papers.

1.0 INTRODUCTION

THE compression strength of corrugated fiberboard shipping containers is affected by various factors including temperature, moisture content, humidity, flute size and the basis weight of linerboard and medium of a corrugated container. These factors can contribute towards the natural variation in board characteristics eventually affecting the variation in box compression strength of two identical boxes.

Corrugated shipping containers containing goods are typically stacked on a pallet that are unitized using a stretch wrap film or banding for distribution and storage in a warehouse. Stack configurations, to make a unitized load of the shipping containers on a pallet, typically depend on their size and dimensions. The two commonly practiced stack configuration in the packaging industry are ‘column’ and ‘interlocked’.

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Stacking operations in a manufacturing plant can be either automated or manual depending on the volume of the production. Irrespective of the method of stacking a common issue that is generally faced is that a unitized load may not be completely situated on top of the pallet deck boards. Sometimes the bottom layer of boxes overhangs slightly off the pallet. The magnitude of this overhang may compromise the load bearing strength of the bottom layer, eventually causing pallet instability.

To address this issue a study was performed where the effect of various magnitudes of overhang and stack configurations was evaluated [1]. It was discovered that the percent strength loss for a palletized box compression strength varied considerably depending on the box geometry and possibly by board grade and flute size [1]. This study showed that the percent loss in palletized box compression strength as an effect of overhang can range between 23–49% depending on the magnitude and direction (length, width or adjacent panel) of overhang [1]. Similarly, palletized box compression strength was also observed to be affected by the stacking configuration of the unitized load of boxes [1]. It was ascertained that there was a 45% loss in palletized box compression strength compared to an interlocked configuration [1]. These losses in palletized box compression strength can drastically affect pallet stability during distribution, handling or storage in a warehouse.

A research study was conducted where three palletized loads of two-piece plastic cans were stacked in various staggered positions to evaluate the effect of off-set on stack stability [2]. It was discovered that a 153 mm (6 in) pallet offset in the middle pallet and a 204 mm (8 in) pallet offset on the top pallet made the 3 high palletized load unstable resulting to a tip-over of the top two stacked pallet loads [2]. This can have very detrimental reparations in a warehouse environment where workers carry out their daily operations. This makes it necessary to ascertain the effect of overhang and stack configurations on palletized box compression strength to assess pallet stability during transportation and handling. Therefore, the focus of this study was to evaluate the effect of pallet type, tie-sheet and stack configuration on compression strength of a palletized load of boxes with different dimensions.

In 1975, Phil M. Ziegler, sent results of findings of a major research study conducted by the Container Corporation of America to all designers of corrugated packaging on behalf of the Technical Services of the Container Divisions. The report stated various factors that resulted in loss in top-to-bottom box compression strength due to pallet overhang, box misalignment and interlocking. It also stated that *"Without*

exception our customers underestimate the deterioration in top to bottom compression of containers when they are improperly handled and stacked in the distribution system" [3]. The study further concluded that as much as 29% loss in compression strength is due to misalignment vertically and a 45% loss of compression is due to an interlocking pattern on a three high pallet unit. Data and test details on this extensive testing done on empty boxes was discussed by Ievans [3].

The results from this study were further presented in a Fibre Box Association document called "*CORRU~FACTS*" that summarized "corrugated facts for users of corrugated packaging" [4]. This document summarized the results of the study as:

1. Pallet Overhang can reduce top to bottom compression up to 32%.
2. Wooden pallets can reduce top to bottom compression up to 32%.
3. Interlocked patterns can reduce top to bottom compression up to 55%.

In addition, this document stated that to provide load stability of stacked corrugated boxes in transit a shipper had four options. These were reported as:

1. Use of anti-skid treatment on the flaps of the containers to increase the coefficient of friction.
2. Spot-gluing the tiers of a pallet load
3. Use of a plastic or corrugated shroud.
4. Use of a Master Pack

It also concluded that "whenever possible make sure that you utilize 'vertical (columnar) stacking rather than interlocked stacking' ".

The test methods that have been widely accepted and used globally to test empty box compression strength for over forty years are ASTM D642 "Standard Test Method for Determining Compressive Resistance of Shipping Containers, Components and Unit Loads" [5] or its International Standards Organization (ISO) equivalent ISO 12048 "Packaging—Complete, Filled Transport Packages—Compression and Stacking Test Using a Compression Tester" [6].

It has been a standard practice for corrugated fiberboard boxes to be tested with no contents (empty) to compare their expected performance in actual conditions after they are filled and stacked in warehouses. The test methodology was originally developed by the paper industry

through Technical Association of Pulp and Paper Industries (TAPPI). TAPPI standard T804 was the original standard for "Compression Testing of Fiberboard Containers" [7]. The authors caution readers of this paper that while this has been the most used and internationally accepted test method to measure strength of a fiberboard box, testing of filled containers typically have a significantly different performance. Bulk liquids and bulk granular products when filled in a corrugated fiberboard boxes cause them to bulge and most likely loose strength, whereas semi-rigid and rigid contents tend to enhance overall package (box and contents) strength.

Box compression strength can be measured by using either a floating platen or a fixed platen on a compression testing machine [8]. A past study has shown that there was no significant differences in single box compression strength between the two methods of compression testing for several types of boxes [8]. This was more than likely because the natural variation in the compression strength of two identical boxes masked the difference between the two test methods. However, corrugated board and box manufacturing processes have improved considerably over the years in order to reduce the natural variation in box compression strength.

2.0 MATERIALS AND METHODS

Four corrugated fiberboard regular slotted containers (FEFCO 0201) of varying dimensions and made from the same board grade (ECT of 5.71 Kgf/cm) were selected for this study (Table 1). The test samples were obtained from three different suppliers in Michigan. These boxes were erected, closed without any contents and sealed using hot melt glue, and pre-conditioned at 23°C (73°F) and 50% RH (standard conditions) for at least 72 hours prior to compression testing.

This study selected two types of standard wooden pallets measuring 1219 × 1016 × 127 mm (48 × 40 × 5 in). The first type of pallet was in conformance to the requirements of the Grocery Manufacturers Association (GMA). The second type of pallet was manufactured per the specifications of the Commonwealth Handling Equipment Pool organization (CHEP®). CHEP® is the world's largest container and pallet leasing company and issues, collects, repairs and reissues about 300 million pallets and containers to assist manufacturers, distributors and retailers to transport their products safely and efficiently [9]. GMA pallets are amongst the most commonly used pallet styles in North America

Table 1. Sample Box Specifications.

Type	ECT (Kgf/cm)	Length (m)	Width (m)	Height (m)	Fiberboard Box Supplier
Box 1	5.71	0.48	0.38	0.25	Coastal Container, MI
Box 2	5.71	0.48	0.33	0.15	Coastal Container, MI
Box 3	5.71	0.38	0.25	0.25	South Haven Packaging, MI
Box 4	5.71	0.41	0.30	0.25	Michcor Container, MI

and accounts for 30% of all new wood pallets produced in the United States [9]. ISO also recognizes the GMA pallet footprint as one of its six standard sizes. The major application of these pallets is for grocery distribution in North America. The CHEP® pallet has a larger top deck surface coverage than the GMA pallet.

The study was designed to determine the effect of pallet type, tie-sheet and stack configuration on the compression strength of a unitized load. The four stack configurations considered for this study were column stack (control), interlocked, overhang and interlocked overhang stack as shown in Figures 2–5. Four corrugated fiberboard regular slotted containers (FEFCO 0201) of varying dimensions were selected to capture the deviation contributed by the different box sizes towards the palletized box compression strength.

The unitized load compression strength was performed on all four stack configurations with a tie-sheet between each layer and repeated without tie-sheet between the layers. Three replicates were performed for each test set up. The experimental design for this study is shown in Table 2. The column stack configuration which represented the control was compared with the 3 stack configurations with either tie-sheet in between layers or no tie-sheet between layers. Compression testing was done in accordance with ASTM D642 on a box compression tester (Lansmont, Monterey, CA) under standard conditions.

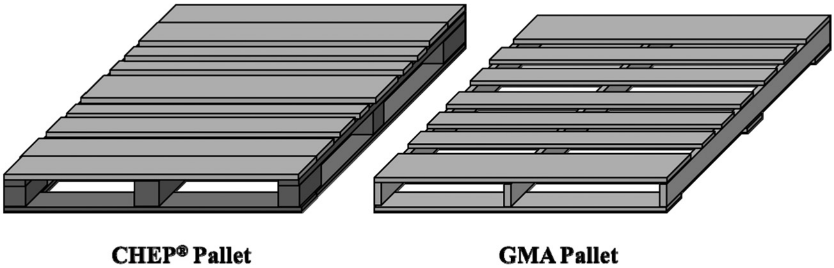

Figure 1. *Pallet types used in study.*

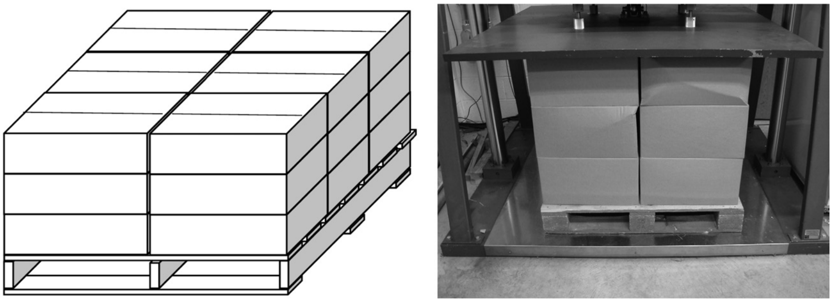

Figure 2. *Palletized box stack configuration for control—column pattern.*

3.0 RESULTS AND DISCUSSION

Palletized box compression strength of the column stack configuration (control) was observed to have the highest compression strength compared to the three-stack configurations on CHEP® or GMA pallets, with or without tie-sheet between layers for all box dimensions.

Column stack configuration of palletized boxes was expected to have the highest compression strength as they perfectly aligned along the edges and corners, therefore providing the maximum compressive resistance during vertical top to bottom compression testing (Tables 3–6).

The interlocked stack configuration showed lower palletized compression strength than the column stack overhang stack configuration (Tables 3–6). This trend was observed on both types of pallets with or without ties sheet between layers. This shows that an interlocked stacking pattern has a larger effect on reducing overall unitized load box compression strength rather than a column stack with a 25.4 mm overhang as shown in Figure 3. An interlocked pattern provides a more stable configuration however, as the boxes are not aligned along the edges and corners between layers therefore the load bearing area pro-

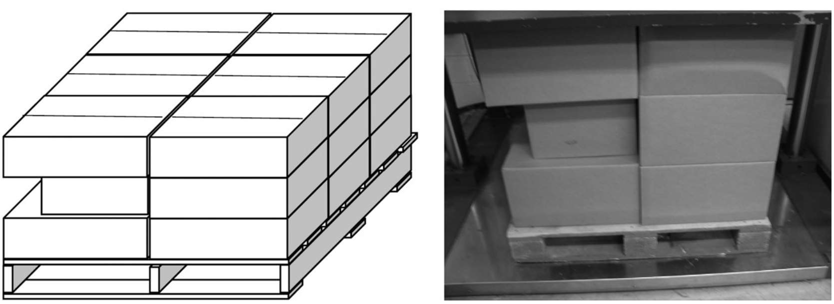

Figure 3. *Palletized box stack configuration for interlocked pattern.*

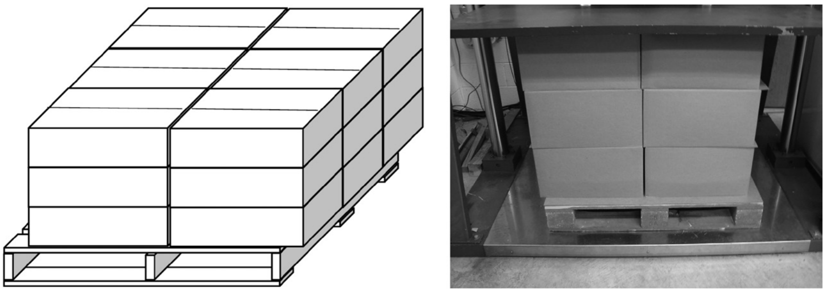

Figure 4. *Palletized box stack configuration for overhang pattern.*

vides lesser compressive resistance compared to a column stack configuration.

From the results shown in Tables 3–6, it is evident that an overhang of 25.4 mm is not a large enough magnitude to compromise palletized box compression strength compared to an interlocked pattern. However, when an interlocked stack configuration is combined with an overhang of 25.4 mm (Figure 3), the results indicate that there was a greater reduction of palletized box compression strength for all combinations of pallets and tie-sheets (Tables 3–6). This explains that the effect of an interlocked stack pattern is considerably magnified by an overhang of 25.4 mm while measuring palletized box compression strength compared to a column stacked pattern with a 25.4 mm overhang.

Overall the CHEP® pallets provided a higher palletized box compression strength than boxes placed on a GMA pallet. The spacing between the top deckboards on a CHEP® pallet is relatively less compared to standard GMA pallets. Therefore the bottom layer (load bearing layer) without tie-sheet on a CHEP® pallet is not damaged considerably during compression testing, thus enabling the bottom layer to provide higher compressive resistance compared to a bottom layer on GMA Pallet.

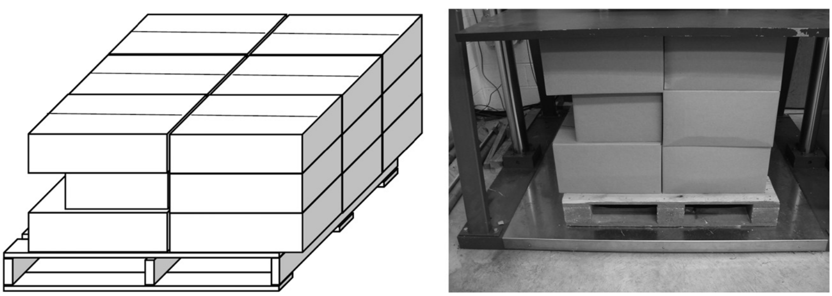

Figure 5. *Palletized box stack configuration for interlocked overhang pattern.*

Table 2. Experimental Design for Different Test Treatments.

Type of Box	Pallet Type	Stack Configuration					
Box 1	CHEP®	Tie-sheet	Control	Interlocked	Overhang	Interlocked Overhang
Box 1	CHEP®	No Tie-sheet	Control	Interlocked	Overhang	Interlocked Overhang
Box 1	GMA	Tie-sheet	Control	Interlocked	Overhang	Interlocked Overhang
Box 1	GMA	No Tie-sheet	Control	Interlocked	Overhang	Interlocked Overhang
Box 2	CHEP®	Tie-sheet	Control	Interlocked	Overhang	Interlocked Overhang
Box 2	CHEP®	No Tie-sheet	Control	Interlocked	Overhang	Interlocked Overhang
Box 2	GMA	Tie-sheet	Control	Interlocked	Overhang	Interlocked Overhang
Box 2	GMA	No Tie-sheet	Control	Interlocked	Overhang	Interlocked Overhang
Box 3	CHEP®	Tie-sheet	Control	Interlocked	Overhang	Interlocked Overhang
Box 3	CHEP®	No Tie-sheet	Control	Interlocked	Overhang	Interlocked Overhang
Box 3	GMA	Tie-sheet	Control	Interlocked	Overhang	Interlocked Overhang
Box 3	GMA	No Tie-sheet	Control	Interlocked	Overhang	Interlocked Overhang
Box 4	CHEP®	Tie-sheet	Control	Interlocked	Overhang	Interlocked Overhang
Box 4	CHEP®	No Tie-sheet	Control	Interlocked	Overhang	Interlocked Overhang
Box 4	GMA	Tie-sheet	Control	Interlocked	Overhang	Interlocked Overhang
Box 4	GMA	No Tie-sheet	Control	Interlocked	Overhang	Interlocked Overhang

The palletized box compression strength of boxes between respective stack configurations on CHEP® and GMA pallets with or without tie-sheets between layers was compared. It was observed that tie-sheets between layers had a positive effect on the palletized box compression strength. The data in Tables 3 and 4 indicate that the load bearing layer is able to sustain higher compressive resistance when a tie-sheet is placed between the bottom layer and the top deck for both CHEP® and GMA pallet.

This is more evident when the percent loss in palletized box compression strength data shown in Tables 7 and 8 are compared between the CHEP® pallets with tie-sheet and without tie-sheet between layers. It was observed that the percent reduction in box compression strength

Table 3. Palletized Box Compression Strength on CHEP® with Tie-sheet.

	Control (Kg)	Interlocked (Kg)	Overhang (Kg)	Interlocked Overhang (Kg)
Box 1	1124	933 ± 60.7	1 097 ± 29.0	858 ± 3.2
Box 2	1195	1028 ± 38.3	1258 ± 79.9	997 ± 86.6
Box 3	613	588 ± 10.4	574 ± 43.0	498 ± 13.4
Box 4	963	661 ± 100.3	934 ± 58.1	753 ± 7.4

Table 4. Palletized Box Compression Strength CHEP® with No Tie-sheet.

	Control (Kg)	Interlocked (Kg)	Overhang (Kg)	Interlocked Overhang (Kg)
Box 1	1050	773 ± 37.1	1126 ± 53.1	764 ± 9.5
Box 2	1100	827 ± 24.1	1204 ± 121.9	890 ± 17.0
Box 3	461	345 ± 111.4	387 ± 36.6	345 ± 15.8
Box 4	1002	796 ± 90.3	949 ± 44.0	811 ± 23.6

Table 5. Palletized Box Compression Strength on GMA with Tie-sheet.

	Control (Kg)	Interlocked (Kg)	Overhang (Kg)	Interlocked Overhang (Kg)
Box 1	1228.8	897.2 ± 89.3	1067.1 ± 93.9	820.2 ± 77.5
Box 2	1367.1	938.1 ± 26.2	1030.4 ± 79.7	859.5 ± 39.8
Box 3	584.2	492.6 ± 21.6	582.8 ± 32.1	520.2 ± 10.6
Box 4	927.1	801.1 ± 19.1	915.5 ± 107.7	754.1 ± 14.7

Table 6. Palletized Box Compression Strength on GMA with No Tie-sheet.

	Control (Kg)	Interlocked (Kg)	Overhang (Kg)	Interlocked Overhang (Kg)
Box 1	1055	762 ± 77.3	854 ± 31.5	692 ± 55.6
Box 2	932	714 ± 143.4	877 ± 61.4	704 ± 34.8
Box 3	549	467 ± 5.9	496 ± 39.2	396 ± 37.9
Box 4	965	623 ± 80.2	803 ± 68.7	636 ± 101.3

Table 7. Percent Loss of Palletized Box Compression Strength on CHEP® with Tie-Sheet.

	Interlocked (Kg)	Overhang (Kg)	Interlocked Overhang (Kg)
Box 1	17%	2%	24%
Box 2	14%	–	17%
Box 3	4%	6%	19%
Box 4	31%	3%	22%

Table 8. Percent Loss of Palletized Box Compression Strength on CHEP® with No Tie-Sheet.

	Interlocked (Kg)	Overhang (Kg)	Interlocked Overhang (Kg)
Box 1	26%	–	27%
Box 2	25%	–	19%
Box 3	25%	16%	25%
Box 4	21%	5%	19%

Table 9. Percent Loss of Palletized Box Compression Strength on GMA with Tie-Sheet.

	Interlocked (Kg)	Overhang (Kg)	Interlocked Overhang (Kg)
Box 1	27%	19%	34%
Box 2	31%	6%	24%
Box 3	14%	10%	28%
Box 4	14%	17%	34%

is larger when boxes were placed on a CHEP® pallet without tie-sheet on the top deck board.

A similar trend was not observed for the boxes palletized on a GMA pallet (Tables 9 and 10). It was observed that the palletized box compression strength for boxes placed on a GMA pallet with tie-sheet and without tie-sheet between layers was very similar for most of the stack configurations and type of boxes. However, comparing Table 5 and Table 6 it is evident that tie-sheet does provide a positive effect on the palletized box compression strength on GMA pallets.

4.0 CONCLUSIONS

This study evaluated the effect of pallet type, tie-sheet and stack configuration on compression strength of a palletized load of four sizes of boxes. The following conclusions were reached in this study:

1. The compression strength of empty stacked boxes in an inter-lock pattern is lower than that of column stacked boxes on a wood pallet.
2. The compression strength of palletized empty corrugated boxes on a CHEP® pallet is higher than compression strength of similar stacked boxes on a Grocery Manufacturers Association specified wood pallet.
3. The loss in compression strength with no tie-sheet between layers

Table 10. Percent Loss of Palletized Box Compression Strength on GMA with No Tie-Sheet.

	Interlocked (Kg)	Overhang (Kg)	Interlocked Overhang (Kg)
Box 1	28%	19%	34%
Box 2	23%	6%	24%
Box 3	15%	10%	28%
Box 4	35%	17%	34%

is more than with a tie-sheet when comparing stacked empty and palletized boxes.

4. The average loss in compression strength due to three-high palletization is 25% or boxes retain 75% of their original empty box compression strength.
5. The average loss in compression strength due to over-hang on a three high stacked boxes on a pallet is 13% or boxes retain 87% of their original empty box compression strength.
6. Loss of strength in stacked configurations affects the overall stability of stacked loads during warehousing and storage and can result in fatal results in the form of damage or injury.

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