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Effect of Pallet Overhang on Box Compression Strength

Final Report

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Executive Summary

Unit loads, consisting of pallets and corrugated boxes, are one of the primary forms of storage and distribution of packaged products. The corrugated box's compression strength can easily be affected by environmental parameters, such as pallet overhang, which reduce a box's effective compression strength. The effects of overhang on box compression strength have been investigated by multiple researchers, but each previous study used its own unique set of different sizes of boxes made from different materials, limiting the broad comparability of the results and challenging strong statistical analysis.

The study presented here, performed on behalf of the Fibre Box Association and ICPF, aimed to investigate the effects of pallet overhang on box compression strength using four different sizes of corrugated boxes, made from two different board combinations, in order to compare existing values in the Fibre Box Handbook, and potentially explore the possibility of developing a more universal model for predicting the effects of pallet overhang. The four sizes of boxes, for each nominal 32 ECT C-flute and nominal 48 ECT BC-flute corrugated materials, were examined in over a dozen single-side overhang configurations and five adjacent-side overhang scenarios. Compression tests were conducted in compliance with the TAPPI T804 standard, conducting 10 replicates for each statistical factor evaluated.

The research project was divided in two phases. The first, and main part of the study, consisted on the evaluation of the effect of the pallet overhang on the box compression strength on a single box. The second phase evaluated the effect of pallet overhang on the compression strength of a full layer of boxes on a simulated pallet.

After conducting the first phase of the study, it was identified that the effective BCT decreases as the degree of overhang increases, regardless of the overhanging side or the box size. Comparing the single-side scenarios showed that the effect of overhang is larger when the overhang exists on the longer side of the box regardless of box size, board grade, or number of walls. Although the number of unsupported corners is expected to affect effective BCT reduction, the amount of unsupported box perimeter also seems to be affecting the result. The effective BCT loss on 32 ECT C-flute boxes with the short side overhanging ranged from -0.98% to -29.40%. Long side overhang scenarios ranged from -6.43% to -32.21%. In cases of 48 ECT BC-flute boxes, short side overhang scenarios had effective BCT reduction between -0.22% and -33.36%. Long side overhang scenarios' reduction in effective BCT ranged from -4.18% to -27.49%. The 48 ECT BC-flute box scenarios followed the same

trend, except for cases where a very large overhang existed. The results are summarized in Table 1.

Table 1. Summary results for effective Box Compression Strength loss due to overhang.

	Effective BCT loss range	
	32 ECT C-flute	**48 ECT BC-flute**
Short side	-0.98% ~ -29.40%	-0.22% ~ -33.36%
Long side	-6.43% ~ -32.21%	-4.18% ~ -27.49%
Adjacent side	-13.70% ~ -40.70%	-15.13% ~ -40.39%

The magnitude of the adjacent side overhang effect cannot be explained solely by the summation of short and long overhang effects. It creates a noticeably unique effect when you lose three box corners of support (the adjacent side overhang in this study) as compared to losing only two box corners of support (the single side overhang in this study).

Estimated reduction in effective BCT from Fibre Box Handbook was between -20% and -40% while the measured BCT reduction for this study was between -2.05% and -40.39%. This is shown graphically in Figure 1 and Figure 2.

A range of multiple linear and nonlinear regression models based on these test results were developed for this study. These models provide the estimated change in a box's compression strength due to any overhang, compared to a no-overhang scenario, by percentage. These models found that the magnitude of the overhang on the box's short and/or long side, whether an adjacent overhang exists, the box perimeter, and board types all affect the effect of pallet overhang on BCT.

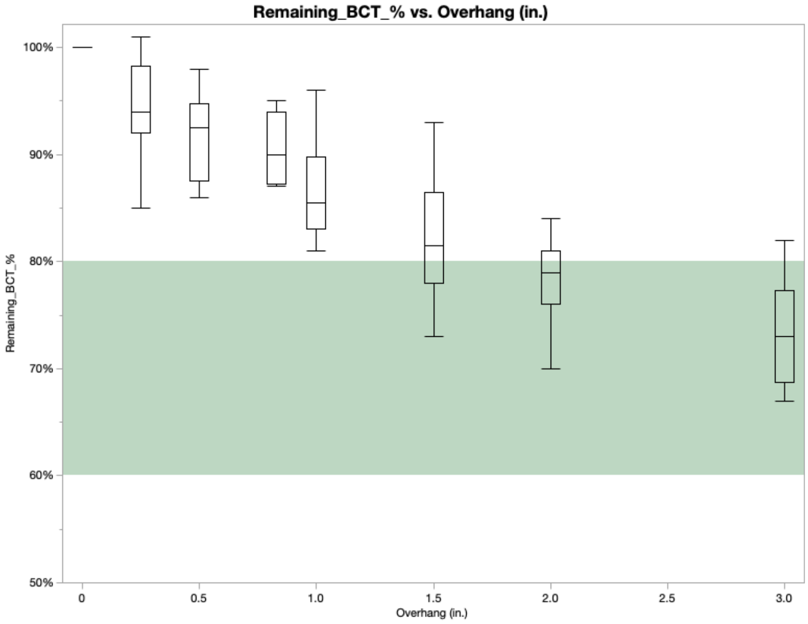

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Figure 1. Box-plot of the average remaining box compression strength for each of the single-side overhangs investigated. The recommended ranges by the FBA Handbook are shown in green.

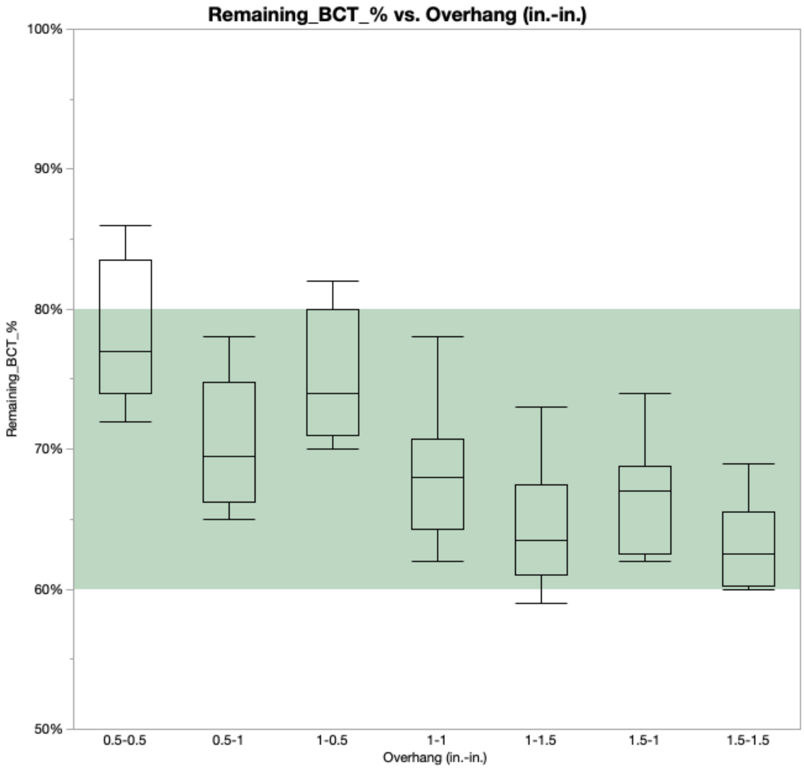

Figure 2. Box-plot of the average remaining box compression strength for each of the adjacent overhangs investigated. The recommended ranges by the FBA Handbook are shown in green.

When evaluating the compression resistance of a single-layer unit load of corrugated boxes there was a significant reduction when the boxes were not fully supported by the underlying simulated pallet along all sides. The layer of boxes showed a reduction in compression resistance that ranged from 13.78% up to 28.21%. The reduction in compression strength was within the expected reduction due to a 1 in. single-side overhang observed for a single box (3.79%-19.27%) and due to a 1-1 in. adjacent overhang (21.60%-37.85%). An explanation for the result could be that during a full layer test the measured compression strength is a combination of the strength of boxes that are fully supported and boxes that have a single-side 1 in. overhang and adjacent 1-1 in. overhang.

The limited testing conducted to evaluate the overall compression strength of a full layer of boxes on a simulated pallet provided significant agreement with the data obtained in the single-box compression testing.

Finally, it is concluded that as expected from previous work, the effective box compression strength decreases as the magnitude of the overhang increases. This work demonstrated the need for further research refining the prediction model and extending it to other materials, box sizes, box aspect ratios, and more granular overhang values.

The following reports presents a summary of the previous research published related to box overhangs on pallets followed by a detailed description of the materials, methods and main results and conclusions of the study conducted.

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1 Introduction

Unit loads, consisting of pallets, products, and load stabilizers, are the primary form of storage and distribution of packaged products in today's supply chain [1]. Approximately 80% of the products in the United States are distributed in unit load form [2]. Packaging materials used to unitize products on pallets can vary between pails, corrugated boxes, bags, and others. Among the myriad types of unitized products, corrugated boxes account for 72% of unit loads [3].

Due to the high demand for corrugated boxes for unit loads, accurate prediction of box compression strength (BCT) has become crucial in preventing package failure. Historically, packaging engineers measured BCT by conducting compression tests following standards, such as TAPPI T804 [4] and ASTM D642[5], or they predicted BCT using a simplified equation developed by McKee et al.[6]. Starting in the late 1960s, design/safety factors that account for environmental and unitizing conditions present within the box service environment were widely researched, and the results were applied to improve BCT prediction through empirical testing and mathematical calculations.

In practice, corrugated boxes are mostly stacked in several layers and unitized on an underlying pallet. This common package configuration leads the bottom boxes to experience the highest compression stresses, and they commonly fail first [7]. The pallet directly supports this highly stressed layer of corrugated boxes. Accordingly, various physical interactions exist between the pallet and bottom layer of corrugated boxes, and these interactions affect the predicted BCT for any unit load scenario. Therefore, several pallet-associated factors to BCT, such as pallet overhang [8–10], pallet deckboard gaps [8–11], and top deck stiffness [12–15], have been widely studied in the past.

Intended and unintended pallet overhang can easily be observed in unit loads. Packaging engineers might design pallet overhang to increase storage space efficiency through higher pallet surface utilization[10], or unintended pallet overhang could appear due to horizontal shocks during shipment, mishandling, and misalignment. Due to such frequent situations causing packages to overhang the pallet, the effect of pallet overhang on effective BCT has been studied by several researchers.

Ievans[8] was the first who endeavored to characterize the effect of pallet overhang on effective BCT. Ievans investigated the extent of compression strength loss using three different levels of overhang (0.5 inches (in.), 1 in., and 1.5 in.) on length, width, and two adjacent edges of 24 in. 15.5 in. x 12 in. (length x width x height) C-flute, single-wall corrugated boxes under an unknown type of platen. Double-wall boxes of the same size were also evaluated for all tested configurations, but only under the 1 in. overhang condition. This study showed that 1.5 in. overhangs on adjacent panels (largest overhanging box perimeter) created the most severe reduction in compression strength; this reduced effective BCT by 49% as compared to a single box on a solid surface. The least severe compression strength reduction was observed on the 0.5 in. overhang on the width panel (smallest overhanging box perimeter), and this showed a 14% reduction. Based on McKee's model, Ievans introduced a new concept called 'Overhang Loss Factor' (OLF), which was the ratio of the percent of compression strength loss to the percent of overhanging box perimeter. The OLF concept expected the percentage reduction of compression strength to be proportional to the percentage reduction of box perimeter, and the result would be mostly one (1). However, the OLF was found to be less than 1 in some cases of lesser overhang, meaning the overhang effect was not directly or uniquely governed by the percentage of unsupported box perimeter (overhung box perimeter in this case).

Later, Monaghan and Marcondes[9] conducted another study on the pallet overhang and gap effects on the compression strength of corrugated boxes. They tested the reduction of effective compression strength when nine different magnitudes of overhang (0 cm, 0.5 cm, 1 cm, 1.5 cm, 2 cm, 3 cm, 3.5 cm, 4 cm, and 5 cm) existed on lengths and widths of four different dimensions of C-flute, single-wall boxes (25 cm x 20 cm x 14.5 cm, 34 cm x 25.5 cm x 30.5 cm, 40 cm x 27 cm x 17 cm, and 40 cm x 25 cm x 25 cm) under the floating platen. Unlike work from Ievans[8], their study didn't investigate overhang on adjacent edges. They concluded that even a small pallet overhang (1 cm) caused a significant reduction of effective compression strength, and the level of effective compression strength reduction becomes more severe as the overhang increases. They also attempted to create a regression model of effective compression strength loss connecting it to overhanging box perimeter using the OLF developed by Ievans[8]. However, it was unsuccessful due to the high variation from the expected value of one; showing a maximum of 38% variation.

DiSalvo[10] investigated the effects of various palletizing factors, including pallet overhang, pallet gaps, and interlock stacking, on effective BCT. Preloaded 10 in. x 6 in. x 6 in. B-flute boxes were tested for four levels of pallet overhang (0%, 5%, 15%, and 25% of bottom perimeter) under the fixed platen. Hot glue was applied to close these boxes instead of packaging tape. The tests were conducted using a compression tester with a fixed platen. This study observed that the BCT reduction from pallet overhang ranged from 30.5% to 42.1%. DiSalvo also created a linear regression model to combine different palletizing factors investigated during his study. For example, linear regression lines were drawn for the combined effects of pallet gaps and overhang, the combined effects of pallet gaps and interlock stacking, the combined effects of pallet overhang and interlocked stacking, and the combined effects of all three investigated factors. DiSalvo concluded that pallet overhang is the most governing factor of effective BCT reduction amongst all investigated factors due to its highest linear correlation coefficient in any case of linear regression lines.

Previously mentioned studies have made it evident that pallet overhang certainly has a considerable effect on BCT. Nonetheless, the effect of pallet overhang on effective BCT has not been sufficiently characterized, since previous studies have shown a lack of statistical analysis and are missing important pieces of information which would allow the reproduction of their test results. All three studies provided a percentage reduction in compression strength under pallet overhang circumstances based on their empirical testing results, but they failed to report the standard deviation of their data. Without this standard deviation, it is impossible to statistically evaluate the data since that data might have huge variations. The Fibre Box Association[16] suggested reporting basic material descriptions of test samples such as board combination, furnish, and caliper for repeatability and comparability of work. Previous studies have not provided most of this essential information about their tested corrugated boxes. Moreover, a box closure method that restricts the movement of the minor flaps during testing is recommended. Unrestrained movement of these minor flaps can cause an increase in the measured BCT of 6% to 10%[17]. A closure method such as applying hot melt glue is preferred over the use of packaging tape due to this effect. Ievans[8] and Monaghan and Marcondes[9] did not list their methods resulting in the lesser reliability of their results. Furthermore, each study evaluated the pallet overhang effect using different sizes of boxes, different overhang magnitudes, and different types of platens (fixed or floating) making it hard to compare data from one study to the other. Using different types of platens may result in different measurements in box compression strength data since fixed platen could end up stressing more on the stronger parts of the box which could result in higher compression strength reading as compared to floating platen[17,18].

More recently, J. Singh et al.[19] and S. P. Singh et al.[20,21] investigated the changes in effective BCT due to lateral offsets in the middle layer of boxes and the overhang of corrugated boxes, stacked three high, on the pallet. The effect of a lateral offset closely relates to the pallet overhang effect, but it does not present a direct overhang relationship between the pallet and corrugated box. The effect on the three-high, stacked, corrugated boxes investigated in these studies could not be reported as the effect of pallet overhang since their experiments were done with a full unit load. This configuration may introduce other factors, such as the load bridging effect[22,23] and the deckboard stiffness effect[12,14,15]. Additionally, the effects from lateral offsets and overhangs could change depending on the box stack height during these experimental designs.

Pallet overhang environmental factors listed in Fibre Box Handbook[24] published by Fibre Box Association (FBA) are widely used in the corrugated industry to make sure boxes survive pallet overhang situations. However, these environmental factors do not successfully harmonize the different results across the studies cited above. Given the limitations of previous studies, the Technical Committee of the FBA raised the need for a more extensive study to understand the effect of pallet overhang on the BCT to help corrugated industry design their boxes with more accurate information. In response to this motivation, the FBA and International Corrugated Packaging Foundation (ICPF)funded the current study. Therefore, this study has aimed to investigate the effects of pallet overhang on the effective BCT using four different sizes of corrugated boxes made from two different board combinations, in order to explore the possibility of developing a more universal model for predicting the effects of pallet overhang.

The research project was divided in two phases. The first, and main part of the study, consisted on the evaluation of the effect of the pallet overhang on the box compression strength on a single box. The second phase evaluated the effect of pallet overhang on the compression strength of a full layer of boxes on a simulated pallet.

2 Phase 1 – Effect of Pallet Overhang on the Box Compression Strength

2.1 Materials

2.1.1 Corrugated Box

The samples used in this study were Regular Slotted Container (RSC) type corrugated boxes. Two types of corrugated boards were used for this study: nominal 32 Edge Crush Test (ECT) C-flute and nominal 48 ECT BC-flute. The nominal board grade for the two corrugated boards was 33-30C-33 pounds per thousand square feet (lb/MSF) and 33-23B-33-23B-33 lb/MSF, respectively. Four box sizes were used during the study. The inside dimensions of these boxes were 12 in. x 10 in. x 10 in., 16 in. x 13.3 in. x 10 in., 20 in. x 16 in. x 10 in., and 24 in. x 20 in. x 10 in. The single wall boxes were manufactured at WestRock Corp. in Richmond, Virginia and the double wall boxes at WestRock Winston-Salem, NC. The manufacturer's joint was sealed using adhesive by the manufacturer. The boxes were shipped knocked down in bundles on a pallet. Each unit load was secured using plastic straps. The top and bottom two layers of boxes on the pallets were removed and discarded in order to avoid testing boxes with potential damages due to the strapping.

Prior to erecting them, the flattened boxes were preconditioned for 24 hours in an environment that was between 10% and 30% relative humidity (RH) and between 22°C and 40°C. And, then the flattened boxes were conditioned at 23°C and 50% RH for another 72 hours. The boxes were erected using a squaring jig to ensure 90° corners. The top and bottom major flaps were sealed to the minor flaps by two parallel beads of 3M™ Hot Melt Adhesive 3762 (3M Corporation, Saint Paul, MN, US) on each section where the flaps met.

2.1.2 Wooden Plate

To simulate the edge of a pallet, glued laminated wooden plates were manufactured in two sizes: 25 in. x 20.5 in. x 1.5 in. and 20 in. x 15.25 in. x 2 in. The plates were planed down to ensure their faces were parallel to each other.

2.2 Methods

2.2.1 Compression Testing

The compression testing procedures followed the guidelines of the TAPPI 804 standard [4]. A fixed platen Lansmont Squeezer compression tester (Lansmont Corp., Monterrey, CA, USA) equipped with a 2,268 kg load cell was used to measure the compression strength of the boxes. The load was applied at a constant speed of 0.5 in./min. The parallelism between the top and bottom platens was maintained between 1:450 and 1:600. The wooden plate was centered on the bottom platen using guidelines that marked the center on both. The boxes were aligned on the wooden plate either with a single side overhanging the plate or with two adjacent box sides overhanging. The single-side overhang boxes were centered by aligning the center marks on the box with the center marks on the wooden plate. The adjacent side overhanging boxes were centered using the center marks on the box and the center marks on the top platen. In this case, the box was centered on the platens, but the wooden plate was not. 3D printed spacers were used to ensure an identical overhang for each replicate (Figure 3). The spacers were only used to position the boxes and were removed prior to starting the test. The compression test was conducted at 23 °C and 50% RH conditions. To ensure that all the tested boxes were properly conditioned, the moisture content of the boxes was measured intermittently. The moisture content of each box had to be between 6.5% and 7.5% to be included in the data. If the measured moisture content value was not within this range, then the data was omitted, and the boxes retested. Moisture content was measured using a Cole-Palmer MB-40 Moisture Balance (Antylia Scientific, Vernon Hills, IL, US) and by following the guidelines of the TAPPI 412 standard [25].

Ten replicate tests were conducted for each box size and board grade combination. The experimental design (DOE) can be seen in Table 2 and Table 3.

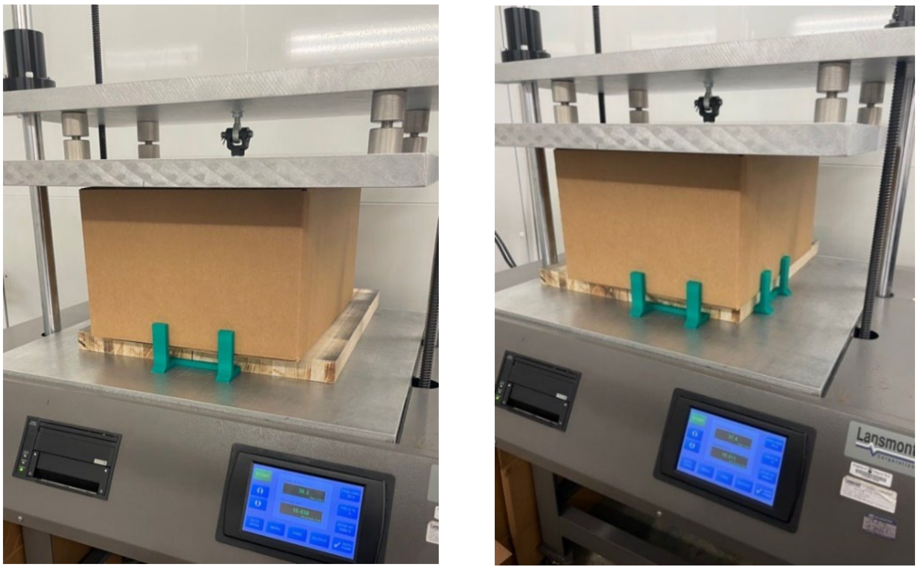

Figure 3. Experimental setup for the box compression test. Left: Single side overhang. Right: Adjacent side overhang.

Table 2. Experimental design for the single side overhang scenarios.

Edge overhanging	Board type	Box size	Box Overhang on Pallet (in.)							
			0	0.25	0.5	0.83	1	1.5	2	3
Short Side	32 ECT C-Flute	12 in. x 10 in. x 10 in.	10	10	10	10	10	10	10	10
		16 in. x 13.3 in. x 10 in.	10	10	10	10	10	10	10	-
		20 in. x 16 in. x 10 in.	10	10	10	10	10	10	10	-
		24 in. x 20 in. x 10in.	10	10	10	10	10	10	10	10
	48 ECT BC-Flute	12 in. x 10 in. x 10 in.	10	10	10	10	10	10	10	10
		16 in. x 13.3 in. x 10 in.	10	10	10	10	10	10	10	-
		20 in. x 16 in. x 10 in.	10	10	10	10	10	10	10	-
		24 in. x 20 in. x 10in.	10	10	10	10	10	10	10	10
Long Side	32 ECT C-Flute	12 in. x 10 in. x 10 in.	10	10	10	-	10	10	10	10
		16 in. x 13.3 in. x 10 in.	10	10	10	-	10	10	10	-
		20 in. x 16 in. x 10 in.	10	10	10	-	10	10	10	-
		24 in. x 20 in. x 10in.	10	10	10	-	10	10	10	10
	48 ECT BC-Flute	30 cm x 25 cm x 25 cm (12 in. x 10 in. x 10 in.)	10	10	10	-	10	10	10	10
		16 in. x 13.3 in. x 10 in.	10	10	10	-	10	10	10	-
		20 in. x 16 in. x 10 in.	10	10	10	-	10	10	10	-
		24 in. x 20 in. x 10in.	10	10	10	-	10	10	10	10

Table 3. Experimental design for the adjacent side overhang scenarios.

Edge overhanging	Board Type	Box size	Box Overhang on Pallet (in.)				
			0.5 - 0.5	0.5 - 1	1 - 1	1 - 1.5	1.5 - 1.5
Adjacent overhang (Short – Long)	32 ECT C-Flute	12 in. x 10 in. x 10 in.	10	10	10	10	10
		16 in. x 13.3 in. x 10 in.	10	10	10	10	10
		20 in. x 16 in. x 10 in.	10	10	10	10	10
		24 in. x 20 in. x 10in.	10	10	10	10	10
	48 ECT BC-Flute	12 in. x 10 in. x 10 in.	10	10	10	10	10
		16 in. x 13.3 in. x 10 in.	10	10	10	10	10
		20 in. x 16 in. x 10 in.	10	10	10	10	10
		24 in. x 20 in. x 10in.	10	10	10	10	10
Adjacent overhang (Long – Short)	32 ECT C-Flute	12 in. x 10 in. x 10 in.	-	10	-	10	-
		16 in. x 13.3 in. x 10 in.	-	10	-	10	-
		20 in. x 16 in. x 10 in.	-	10	-	10	-
		24 in. x 20 in. x 10in.	-	10	-	10	-
	48 ECT BC-Flute	12 in. x 10 in. x 10 in.	-	10	-	10	-
		16 in. x 13.3 in. x 10 in.	-	10	-	10	-
		20 in. x 16 in. x 10 in.	-	10	-	10	-
		24 in. x 20 in. x 10in.	-	10	-	10	-

2.2.2 Data Analysis

The data was analyzed using SAS JMP Pro 16 software (SAS Enterprises, Raleigh, NC). Multiple linear regression models and a nonlinear regression model with a significance level of 0.05 were developed to estimate the effect of overhang on effective BCT using several variables.

2.3 Results and discussion

The average reduction in effective BCT as a function of box overhang is presented for 32 ECT C-flute boxes (Table 4) and 48 ECT BC-flute boxes (Table 5). The effective BCT decreases as the degree of overhang increases, regardless of the overhanging side or the box size. Comparing the single-side scenarios showed that the effect of overhang is larger when the overhang exists on the longer side of the box regardless of box size, board grade, or number of walls. Although the number of unsupported corners is expected to affect effective BCT reduction, the amount of unsupported box perimeter also seems to be affecting the result. The effective BCT loss on 32 ECT C-flute boxes with the short side overhanging ranged from -0.98% to -29.40%. Long side overhang scenarios ranged from -6.43% to -32.21%. In cases of 48 ECT BC-flute boxes, short side overhang scenarios had effective BCT reduction between -0.22% and -33.36%. Long side overhang scenarios' reduction in effective BCT ranged from -4.18% to -27.49%. The 48 ECT BC-flute box scenarios followed the same trend, except for cases where a very large overhang existed. The averaged Coefficient of Variation (COV) of the effective compression strength measured in this study was 5.22%, which was well in line with typical variation in the industry (4.8% - 11.5%)[26]. This variation was due to the natural variation in corrugated boxes.

The magnitude of the adjacent side overhang effect cannot be explained solely by the summation of short and long overhang effects. It creates a noticeably unique effect when you lose three box corners of support (the adjacent side overhang in this study) as compared to losing only two box corners of support (the single side overhang in this study).

The trend observed by Ievans[8] was that the degree of effective BCT reduction varies based on box geometry, and the trend found in this current study matched Ievans findings. However, we weren't able to compare degree of effective BCT reduction as a function of pallet overhang found from Ievans study to current study's results due to different tested box sizes, board grades, and unclear flap closing methods, joint adhesives, and platen type.

The Fibre Box Handbook[24] also provides pallet overhang environmental factors for retention analysis. These factors are widely used in the industry to design corrugated boxes when pallet overhang exists. Although environmental factors usually focus on worst-case scenarios in order to ensure that the corrugated boxes survive distribution, there is a large gap between these safety factors and tested values for single-side overhang scenarios in this study. Estimated reduction in effective BCT from Fibre Box Handbook was between -20% and -40% while the measured BCT reduction for this study was between -2.05% and -40.39%.

Table 4. Average box compression loss as a function of various magnitudes of overhang for 32 ECT C-flute box scenarios.

	Overhang level (in.)	32 ECT C -flute boxes							
		12 in. x 10 in. x 10 in.		16 in. x 13.3 in. x 10 in.		20 in. x 16 in. x 10 in.		24 in. x 20 in. x 10in.	
		Comp. Str. (lbf) (COV)	Comp. Str. Red.	Comp. Str. (lbf) (COV)	Comp. Str. Red.	Comp. Str. (lbf) (COV)	Comp. Str. Red.	Comp. Str. (lbf) (COV)	Comp. Str. Red.
Short side overhang	0	526.94 (6.57%)	0%	596.42 (3.66%)	0%	589.88 (5.20%)	0%	658.08 (9.57%)	0%
	0.25	506.79 (7.31%)	-3.82%	547.98 (4.14%)	-8.12%	584.08 (3.86%)	-0.98%	633.98 (5.38%)	-3.66%
	0.5	479.59 (5.62%)	-8.99%	533.33 (3.98%)	-10.58%	576.17 (2.92%)	-2.32%	622.77 (4.75%)	-5.37%
	0.83	458.78 (7.19%)	-12.94%	516.09 (4.13%)	-13.47%	559.55 (2.91%)	-5.14%	593.25 (4.65%)	-9.85%
	1	463 (5.90%)	-12.13%	511.46 (3.74%)	-14.24%	543.46 (4.81%)	-7.87%	611.45 (4.64%)	-7.09%
	1.5	441.26 (4.38%)	-16.26%	487.04 (4.14%)	-18.34%	510.85 (5.12%)	-13.40%	572.92 (9.13%)	-12.94%
	2	399.09 (8.62%)	-24.26%	473 (2.34%)	-20.69%	495.43 (1.61%)	-16.01%	546.58 (4.1%)	-16.94%
	3	372.02 (5.32%)	-29.40%	-	-	-	-	514.77 (6.97%)	-21.78
Long side overhang	0	526.94 (6.57%)	0%	596.42 (3.66%)	0%	589.88 (5.20%)	0%	658.08 (9.57%)	0%
	0.25	450.16 (6.25%)	-14.57%	532.61 (4.31%)	-10.7%	547.23 (3.03%)	-7.23%	606.85 (4.63%)	-7.78%
	0.5	454.51 (8.99%)	-13.75%	513.66 (2.21%)	-13.88%	550.86 (3.70%)	-6.61%	615.77 (6.00%)	-6.43%
	0.83	-	-	-	-	-	-	-	-
	1	442.7 (5.67%)	-15.99%	489.41 (3.65%)	-17.94%	498.82 (4.37%)	-15.44%	542 (4.39%)	-17.64%
	1.5	385.4 (7.24%)	-26.86%	463.55 (4.80%)	-22.28%	480.33 (3.73%)	-18.57%	500.93 (3.85%)	-23.88%
	2	370.51 (7.89%)	-29.69%	450.04 (3.61%)	-24.54%	475.64 (5.71%)	-19.37%	498.98 (4.31%)	-24.18%
	3	357.2 (5.76%)	-32.21%	-	-	-	-	493.13 (6.34%)	-25.07%
Adjacent overhang (Short – Long)	0.5 – 0.5	396.1 (7.85%)	-24.83%	432.08 (4.63%)	-27.55%	468.66 (3.92%)	-20.51%	567.94 (3.46%)	-13.70%
	0.5 -1	342.35 (8.21%)	-35.03%	394.45 (3.31%)	-33.86%	415.83 (3.16%)	-29.51%	493.37 (3.38%)	-25.03%
	1 – 0.5	392.61 (7.48%)	-25.49%	416.17 (2.83%)	-30.22%	456.48 (5.47%)	-22.61%	533.97 (2.79%)	-18.86%
	1 – 1	340.61 (8.20%)	-35.36%	382.02 (3.79%)	-35.95%	409.51 (5.15%)	-30.58%	464.49 (4.07%)	-29.42%
	1 – 1.5	312.48 (5.04%)	-40.70%	364.9 (5.34%)	-38.82%	390.12 (5.33%)	-33.86%	447.73 (4.69%)	-31.96%
	1.5 – 1	337.95 (5.50%)	-35.87%	368.04 (1.53%)	-38.29%	400.87 (4.89%)	-32.04%	456.62 (4.16%)	-30.61%
	1.5 – 1.5	319.22 (6.53%)	-39.42%	359.02 (5.70%)	-39.80%	377.00 (5.39%)	-36.09%	434.18 (3.34%)	-34.02%

* Comp. Str.: box compression strength (BCT), COV: coefficient of variation, and Comp. Str. Red: BCT reduction.

Table 5. Average box compression loss as a function of various magnitudes of overhang for 48 ECT BC-flute box scenarios.

	Overhang level (in.)	48 ECT BC -flute boxes							
		12 in. x 10 in. x 10 in.		16 in. x 13.3 in. x 10 in.		20 in. x 16 in. x 10 in.		24 in. x 20 in. x 10in.	
		Comp. Str. (lbf) (COV)	Comp. Str. Red.	Comp. Str. (lbf) (COV)	Comp. Str. Red.	Comp. Str. (lbf) (COV)	Comp. Str. Red.	Comp. Str. (lbf) (COV)	Comp. Str. Red.
Short side overhang	0	874.73 (6.22%)	0%	1139.92 (3.55%)	0%	1423.96 (6.12%)	0%	1488.05 (5.43%)	0%
	0.25	884.46 (4.72%)	1.11%	1082.26 (5.61%)	-5.06%	1406.9 (3.26%)	-1.20%	1484.79 (5.87%)	-0.22%
	0.5	844.21 (4.16%)	-3.49%	1050.02 (4.39%)	-7.89%	1329.42 (5.27%)	-6.64%	1457.6 (2.50%)	-2.05%
	0.83	792.78 (9.01%)	-9.37%	1000.97 (6.55%)	-12.19%	1288.67 (4.40%)	-9.50%	1418.67 (3.03%)	-4.66%
	1	774.46 (6.33%)	-11.46%	970.80 (4.65%)	-14.84%	1227.44 (5.95%)	-13.80%	1431.64 (5.97%)	-3.79%
	1.5	741.69 (4.16%)	-15.21%	937.63 (6.92%)	-17.75%	1263.4 (4.81%)	-11.28%	1383.54 (2.61%)	-7.02%
	2	690.47 (4.50%)	-21.06%	922.27 (6.27%)	-19.09%	1120.64 (8.99%)	-21.30%	1336.02 (3.32%)	-10.22%
	3	582.9 (7.61%)	-33.36%	-	-	-	-	1224.01 (3.24%)	-17.74%
Long side overhang	0	874.73 (6.22%)	0%	1139.92 (3.55%)	0%	1423.96 (6.12%)	0%	1488.05 (5.43%)	0%
	0.25	809.67 (6.10%)	-7.44%	1053.64 (4.67%)	-7.57%	1311.98 (5.84%)	-7.86%	1425.81 (4.61%)	-4.18%
	0.5	763.93 (4.98%)	-12.67%	986.87 (2.35%)	-13.43%	1279.34 (5.67%)	-10.16%	1393.01 (2.15%)	-6.39%
	0.83	-	-	-	-	-	-	-	-
	1	706.16 (6.07%)	-19.27%	950.42 (5.38%)	-16.62%	1182.98 (7.97%)	-16.92%	1333.77 (4.89%)	-10.37%
	1.5	700.52 (5.27%)	-19.92%	887.28 (4.47%)	-22.16%	1097.78 (4.57%)	-22.91%	1193.16 (4.11%)	-19.82%
	2	696.62 (5.70%)	-20.36%	886.73 (8.11%)	-22.21%	1046.69 (6.14%)	-26.49%	1161.28 (4.29%)	-21.96%
	3	642.49 (9.54%)	-26.55%	-	-	-	-	1078.92 (3.28%)	-27.49%
Adjacent overhang (Short – Long)	0.5 – 0.5	642.94 (4.11%)	-26.50%	848.85 (6.79%)	-25.53%	1126.55 (6.67%)	-20.89%	1262.9 (4.27%)	-15.13%
	0.5 -1	582.99 (4.08%)	-33.35%	781.32 (6.97%)	-31.46%	1055.65 (3.31%)	-25.87%	1160.83 (3.49%)	-21.99%
	1 – 0.5	618.95 (10.43%)	-29.24%	808.53 (5.01%)	-29.07%	1034.73 (5.01%)	-27.33%	1217.17 (3.43%)	-18.20%
	1 – 1	543.63 (3.23%)	-37.85%	760.10 (6.06%)	-33.32%	997.65 (5.68%)	-29.94%	1066.62 (6.34%)	-21.60%
	1 – 1.5	535.14 (9.13%)	-38.82%	698.82 (7.53%)	-38.70%	938.78 (2.94%)	-34.07%	1091.48 (8.78%)	-26.65%
	1.5 – 1	539.84 (6.46%)	-38.28%	760.18 (4.34%)	-33.31%	955.42 (4.05%)	-32.90%	1099.57 (5.75%)	-26.11%
	1.5 – 1.5	521.4 (8.36%)	-40.39%	693.60 (5.56%)	-39.15%	915.59 (7.78%)	-35.70%	1030.63 (6.06%)	-30.74%

* Comp. Str.: box compression strength (BCT), COV: coefficient of variation, and Comp. Str. Red: BCT reduction.

2.3.1 Regression Analyses

In this study, three equations were derived through regression analyses, but the authors caution the reader from widely adopting these models to predict the decrease in effective BCT as a function of pallet overhang as our data and analysis on the overhang effect is still limited to the box sizes, styles, and board types tested in this study and requires further research. However, the models allow us to identify statistically significant factors that affect BCT losses from overhang and provide a pathway on what factors need to be further investigated to make these models more robust.

Multiple linear regression analysis was conducted using individual values from each test to examine the reduction in effective BCT in response to pallet overhang. Table 6 summarizes the descriptive statistics and analyzed data. The first multiple linear regression model (MLR 1) defined the remaining effective BCT compared to the no overhang scenario by percentage, as the dependent variable. Working with the average values helped eliminate underlying noise from the data. The magnitude of overhang, whether on the short and/or long side of the box, whether an adjacent overhang exists (categorical variable), the box perimeter, and the board type (categorical variable for whether 32 ECT C-flute or 48 ECT BC-flute was used) were all set as independent variables. The remaining effective BCT by percentage was selected as the dependent variable in order to help eliminate the effect of box size on boxes' compression strength values. This model was statistically significant ($F(5, 1674) = 1504.730$, $p < 0.001$, adj $R^2 = 0.82$), resulting in Equation 1:

$$y = 0.823 - 0.072\alpha_{os} - 0.101\alpha_{ol} - 0.051\alpha_{oa} + 0.001\mu + 0.006\vartheta \qquad \textbf{[1]}$$

where:

y = is the remaining effective BCT compared to a no overhang scenario by percentage;

α_{os} = is the magnitude of overhang on the short side (in);

α_{ol} = is the magnitude of overhang on the long side (in);

α_{oa} = is whether overhang exists on a single side (0) or adjacent side (1) (categorical);

μ = is box perimeter (in);

ϑ = is board type – 32 ECT C-flute (0) or 48 ECT BC-flute (1) (categorical).

Table 6. First multiple regression model (MLR 1) results for the prediction of BCT reduction in response to pallet overhang.

MLR 1	**Unstandardized Coefficient**		**Standardized Coefficient**		
Variable	**B**	**Std. Error**	β	**t**	**p**
Constant	0.823	0.006		137.63	<.001
Overhang on the short side (in.)	-0.072	0.002	-0.401	-34.68	<.001
Overhang on the long side (in.)	-0.101	0.002	-0.581	-49.52	<.001
Adjacent overhang	-0.051	0.002	-0.370	-30.68	<.001
Box perimeter (in.)	0.001	7.98×10^{-5}	0.188	18.03	<.001
Board type	0.006	0.001	0.046	4.38	<.001

Table 7. Lack of fit test of first multiple linear regression model (MLR 1).

Source	DF	Sum of Squares	Mean Square	F ratio	P value
Lack of fit	154	1.823	0.012	5.809	<.001
Pure Error	1520	3.097	0.002		
Total Error	1674	4.920			

As can be seen in Table 6, overhangs on the short side, the long side, and adjacent sides have significant negative regression weights, indicating that any overhang experienced by the corrugated box would reduce the effective BCT as compared to a compression scenario without overhang. It was also observed that long-side overhang has a greater negative regression than short-side overhang. The adjacent overhang scenario adds even more reduction to effective BCT than any single side overhang, confirming the findings above.

This model further indicates that box perimeter and board grade have a significant positive regression impact. A significant positive regression for the box perimeter means that the effect of pallet overhang on the effective BCT is less noticeable for larger boxes. This model also shows that having different board types could affect the impact level of the overhang on the effective BCT. However, because the two investigated board types had different ECT values (32 ECT and 48 ECT) and flutes (C-flute and BC-flute), it is impossible to determine whether the changes in effective BCT reduction were due to changes in ECT values or changes in flute type.

Although MLR 1 provides insights into which variables are important factors to consider, this model still has a room to be improved. We would expect the model to predict a value of 1 (no loss) in the case of no overhang, but it does not. As well, the lack of fit parameter was significant in the modeling (Table 7). The lack of fit test is important for deciding whether a model can be used as an appropriate predictor of a dependent variable. If a lack of fit error is found to be significantly higher than pure error, it implies that a more appropriate model exists to remove these remaining issues from the residuals (such as a model with higher terms). We explored a nonlinear regression model (NLR 1) to further investigate what could be possible causes for significant lack of fit issue, using the same dependent and independent variables. Among the multiple models tried, adding quadratic terms to the magnitude of overhang on the long side and box perimeter solved the lack of fit problem (Table 8). This indicates that the effect of overhang may not be linear in relation to the reduction in effective BCT (Equation 2):

$$y = 0.831 - 0.031\alpha_{os} - 0.052\alpha_{ol} + 0.005\alpha_{ol}^2 - 0.034\alpha_{oa} + 0.001\mu + 0.000004\mu^2 + 0.006\vartheta \quad \textbf{[2]}$$

Table 8. Lack of fit test of the nonlinear regression model (NLR 1).

Source	DF	Sum of Squares	Mean Square	F ratio	P value
Lack of fit	152	0.134	0.0009	2.273	0.105
Pure Error	8	0.003	0.0004		
Total Error	160	0.137			

However, it was also observed that all of the data points for the 8 cm (3 in.) overhang scenario had excessive leverage in the modeling. The current DOE had only a few select 8 cm (3 in.) overhang scenarios tested, which led each data point for an 8 cm (3 in.) overhang to impact the resulting model more significantly than the other data points. In response to this information, 8 cm (3 in.) overhang data points were removed from the list and additional regression analysis was conducted. Eliminating these data points with high leverage brought the model back to a linear model (MLR 2) with no lack of fit problem (Table 9). MLR 2 continued to use the average remaining effective BCT values by the percentage to conduct the regression analysis. Adding additional data points with significant overhang into future investigation may be helpful to fully understand the physics, but it might be unnecessary for the purpose of practical use of model since overhang over 5 cm (2 in.) would most likely create an overall stability issue of unit load before a box would get damaged by the loss of compression strength during distribution. The fitted regression model MLR 2 is presented in Equation 3.

$$y = 0.831 - 0.071\alpha_{os} - 0.113\alpha_{ol} - 0.045\alpha_{oa} + 0.001\mu + 0.006\vartheta \quad \textbf{[3]}$$

Table 9. Lack of fit test of the second multiple linear regression model (MLR 2).

Source	DF	Sum of Squares	Mean Square	F ratio	P value
Lack of fit	146	0.153	0.0011	2.705	0.065
Pure Error	8	0.003	0.0004		
Total Error	154	0.156			

Besides described learning outcomes and limitations of regression models, additional limitations that are common for all introduced models exist. All investigated boxes in the current DOE had the same height and base aspect ratio; therefore, how other box heights and base aspect ratios could affect the future model is unknown. Moreover, only two types of corrugated boards were investigated for this model.

Despite the limitations described above, multivariate regression modeling could have a great potential to predict the effect of overhang on box compression strength instead of using fixed adjustment factors, such as the ones listed in the Fiber Box Handbook, to describe the overhang effect. However, an expanded study using box sizes with different aspect ratios, ECT values, and board types and more granular overhang values is needed to create a more robust model before this approach can be adopted by the corrugated industry.

3 Phase 2 – Effect of Pallet Overhang on Box Compression Strength using a Full Layer of Corrugated Boxes

3.1 Materials

3.1.1 Corrugated Box

The samples used in this study were Regular Slotted Container (RSC) type corrugated boxes. Two types of corrugated boards were used for this study: nominal 32 Edge Crush Test (ECT) C-flute and nominal 48 ECT BC-flute. The nominal board grade for the two corrugated boards was 33-30C-33 pounds per thousand square feet (lb/MSF) 33-23B-33-23B-33 lb/MSF, respectively. Four box sizes were used during the study. The inside dimensions of these boxes were 12 in. x 10 in. x 10 in, 16 in. x 13.3 in. x 10 in.), 20 in. x 16 in. x 10 in., and 24 in. x 20 in. x 10 in. The single wall boxes were manufactured at WestRock Corp. in Richmond, Virginia and the double wall boxes at WestRock Winston-Salem, NC. The manufacturer's joint was sealed using adhesive by the manufacturer. The boxes were shipped knocked down in bundles on a pallet. Each unit load was secured using plastic straps. The top and bottom two layers of boxes on the pallets were removed and discarded in order to avoid testing boxes with potential damages due to the strapping.

Prior to erecting them, the flattened boxes were preconditioned for 24 hours in an environment that was between 10% and 30% relative humidity (RH) and between 22°C and 40°C. And, then the flattened boxes were conditioned at 23°C and 50% RH for another 72 hours. The boxes were erected using a squaring jig to ensure 90° corners. The top and bottom major flaps were sealed to the minor flaps by two parallel beads of 3M™ Hot Melt Adhesive 3762 (3M Corporation, Saint Paul, MN, US) on each section where the flaps met.

3.1.2 Wooden Plates

To simulate the different overhangs of a full layer of boxes on a pallet, two flat platens were manufactured, accounting for the actual outside dimensions of the erected boxes. The plates were built by placing two layers of ¾ in plywood board oriented crosswise and glued together. The flat rigid plates were initially made 52 in x 44 in. to fully support the array of boxes with no overhang. Subsequently, the plates were trimmed to match the outside dimensions of each corresponding box arrangement minus the 1 in. overhang on each edge.

3.2 Methods

Compression testing for a full layer of corrugated boxes on a simulated solid deck 48 in. x 40 in. pallet was conducted following a modified TAPPI T804 standard (TAPPI, 2020). A solid deck pallet was simulated to eliminate the effect of pallet gaps. A fixed platen Tinius Olsen compression tester (Tinius Olsen TMC - United States., Horsham, PA, USA) equipped with a four 10,000 lb. load cell was used to measure the compression strength of the layer of boxes. The load was applied at a constant speed of 0.5 in./min. The parallelism between the top and bottom platens was between 1:200 and 1:800. The plywood plate was centered on the bottom of the testing equipment, with its center of gravity equidistant from the four load cells. The boxes were placed on the plywood board and centered. For conditions with overhang, 3D-printed spacers were used to ensure identical overhang for each of the four sides of the simulated pallet. The spacers were only used to position the boxes and were removed prior to starting the test. The experimental setup is presented in Figure 4.

Samples were pre-conditioned and conditioned according to TAPPI T412. The compression tests were conducted at laboratory conditions, which ranged from 22 C to 24 C and 18% to 26% relative humidity during testing. Boxes were exposed to non-standard conditions for a brief period for test setup and conducting compression testing. The moisture content of the samples decreased by an average of 0.20%, going from a moisture content of 6.55% prior to being removed from conditioning to a moisture content of 6.38% immediately after testing. Table 10 shows the tests conducted for each box size and pallet overhang. Figures 5 show the placement for each of the pallet overhanging scenarios and include identification of all the unsupported corner locations.

Table 10. Experimental design for the full layer compression testing.

Board Grade (lb/in.)	Box size (in.)	Number of Replicates	
		No Overhang	1 in. Overhang
32 ECT C-Flute	12x10x10	2	2
	16x13.3x10	2	2
48 ECT BC-Flute	12x10x10	1	1
	16x13.3x10	1	1
	20x16x10	1	1
	24x20x10	1	2

Figure 4. Experimental setup for the box layer compression test. Left: No overhang. Right: 1 in. overhang.

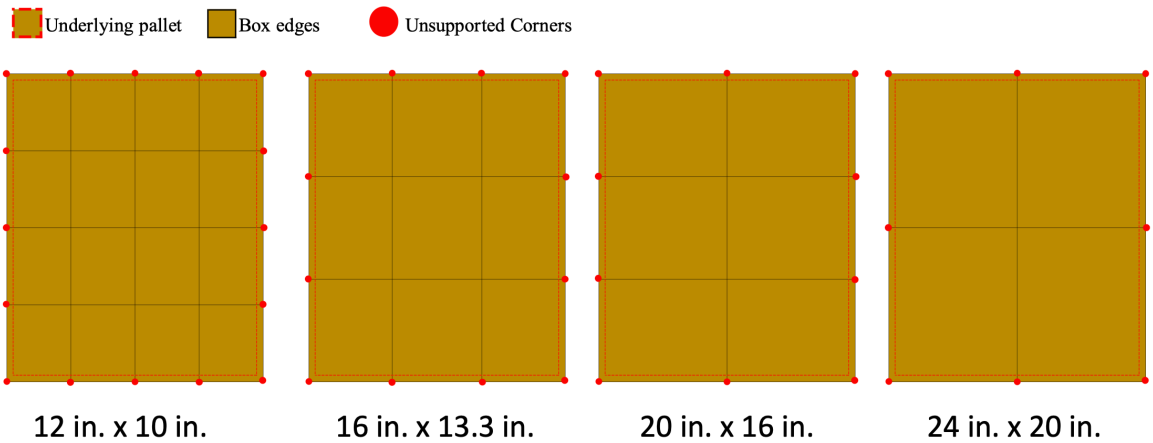

Figure 5. Top view diagram of the array of the investigated box sizes with the 1 in. overhang across the pallet edges.

3.3 Results and discussion

The compression resistance of a single-layer unit load of corrugated boxes was significantly reduced when the boxes were not fully supported by the underlying simulated pallet along all sides. The peak loads and displacement at these load levels are presented in Table 11. The layer of boxes showed a reduction in compression resistance that ranged from 13.78% for the 12 in. x 10 in. x 10 in. BC-flute box up to 28.21% for the 24 in. x 20 in. x 10 in. box. The reduction in compression strength for the full layer of boxes with a 1 in. overhang was within the expected reduction due to a 1 in. single-side overhang observed for a single box (3.79%-19.27%) and due to a 1-1 in. adjacent overhang (21.60%-37.85%). An explanation for the result could be that during a full layer test, the measured compression strength is a combination of the strength of boxes that are fully supported and boxes that have a single-side 1 in. overhang and adjacent 1-1 in. overhang. The limited testing conducted to evaluate the overall compression strength of a full layer of boxes on a simulated pallet provided significant agreement with the data obtained in the single-box compression testing.

Table 11. Compression resistance of a single layer unit load of corrugated boxes and compression loss as a function of overhang.

		Box Overhang on Pallet (in.)				
		0		1		
Board Grade	**Box size (in.)**	**Average Peak Load (lbf)**	**Average Displacement at Peak Load (in.)**	**Average Peak Load (lbf)**	**Average Displacement at Peak Load (in.)**	**Average Compression Reduction**
32 ECT C-Flute	12x10x10	9,559.28	0.65	7,090.69	0.74	25.82%
	16x13.3x10	5,798.12	0.61	4,249.90	0.72	26.70%
48 ECT BC-Flute	12x10x10	17,002.12	0.92	14,658.92	0.91	13.78%
	16x13.3x10	10,436.69	0.84	7,790.01	0.91	25.36%
	20x16x10	9,542.60	0.84	7,286.28	0.94	23.64%
	24x20x10	6,867.50	0.78	4,930.35	0.91	28.21%

A general observed trend was not only the reduction in overall compression strength, but also the stiffness reduction of the unit load. That is when looking into the peak displacements for all scenarios, the peak load of the layer of boxes with a 1 in. overhang was lower and the peak displacement was higher. Boxes compressed further before reaching that peak load. A higher peak displacement can generate a higher risk of damage to the products inside since the box overhead space will be reduced more. Further investigation into this effect is required for more clear conclusions.

Table 12 shows the individual box compression strength when dividing the total peak force of the full layer compression test by the number of boxes in each configuration evaluated. When comparing the load supported by each box, the peak load is 1.7-21.5% higher than the measured BCT (no overhang, single box tests). This increased force resistance is due to the interacting effects of contiguous boxes, where panels are prevented from bulging freely as when testing individual boxes.

Table 12. Comparison of the measured and estimated single box compression strength value for the no overhang scenario.

No Overhang					
Board Grade (lb/in.)	**Box size (in.)**	**Boxes per Layer**	**Measured Single Box BCT (lbf)**	**Estimated Single Box BCT from Full Layer (lbf)**	**Difference between single box and full layer BCT**
32 ECT C-Flute	12x10x10	16	526.94	597.45	13.4%
	16x13.3x10	9	596.42	644.24	8.0%
48 ECT BC-Flute	12x10x10	16	874.73	1,062.63	21.5%
	16x13.3x10	9	1,139.92	1,159.63	1.7%
	20x16x10	6	1,423.96	1,590.43	11.7%
	24x20x10	4	1,488.05	1,716.88	15.4%

4 Conclusions

In this study, the results of box compression tests and a range of regression models were analyzed to examine the effect of pallet overhang on effective BCT reduction. The following conclusions were made:

- There is a significant negative correlation between the amount of overhang and the effective support provided by the corrugated box at the bottom of a unit load. Transporting boxes with high overhang on a single side could reduce the effective BCT of the box was much as 33%.
- The magnitude of the overhang on the short and/or long side of the box, whether an adjacent overhang exists, the box perimeter, and board types are all statistically significant factors that affect the effective BCT reduction as a function of pallet overhang.
- Overhang present on the long-side of the box causes more reduction in effective BCT than overhang on the short-side due to more unsupported box perimeter.
- Adjacent side overhang adds an additional, unique effect as compared to just the combination of short and long side overhang effects in effective BCT reduction due to the loss of more box corners. We saw BCT reduction as high as 40% across this study.
- The percent reduction of BCT for a single box observed was a similar percent reduction for a full layer of boxes on a simulated pallet, confirming that the single box study provides reliable data as a representative study of the full effect.
- Safety factors from the Fibre Box Handbook potentially overestimate the effect of pallet overhang on effective BCT reduction. At minimum, the Fibre Box Handbook would benefit from additional clarity as to the structure and impact of the number of sides overhanging when providing guidance on effective impact on BCT.
- The potential impact of box height, different aspect ratios, board grade, ECT, and the number of walls were not outlined in this study.
- Multiple models were created for this study, but all of these models have limitations and indicated additional work is necessary to build a closed-form model describing the impact of overhang on effective BCT.

Further investigation into the effect of pallet overhang on effective BCT is needed to characterize the effect of box height, aspect ratio, and board types not investigated in this study. In addition, an increased number of scenarios for 8 cm (3 in.) overhang are needed to solve the lack of fit and leverage challenges in the current study.

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<u>Appendix A</u> – Additional regression analyses results.

Table A-1. Nonlinear regression model (NLR 1) results for the prediction of BCT reduction in response to pallet overhang (Imperial units).

NLR 1	**Unstandardized Coefficient**		**Standardized Coefficient**		
Variable	**B**	**Std. Error**	β	**t**	**p**
Constant	0.831	0.012		78.69	<.001
Overhang on the short side (in.)	-0.078	0.004	-0.464	-21.49	<.001
Overhang on the long side (in.)	-0.132	0.006	-0.801	-23.60	<.001
Adjacent overhang	-0.034	0.004	-0.272	-9.79	<.001
Box perimeter (in.)	0.001	0.0001	0.196	10.36	<.001
Board type	0.006	0.002	0.048	2.56	0.011
Overhang on the long side^2	0.029	0.004	0.212	6.78	<.001
Box perimeter^2	2.64×10^{-5}	1.04×10^{-5}	0.048	2.52	0.013

* $F(7, 160) = 376.540$, $p < 0.001$, adj $R^2 = 0.94$

Table A-2. Second multiple linear regression model (MLR 2) results for the prediction of BCT reduction in response to pallet overhang (Imperial units).

MLR 2	**Unstandardized Coefficient**		**Standardized Coefficient**		
Variable	**B**	**Std. Error**	β	**t**	**p**
Constant	0.831	0.012		70.36	<.001
Overhang on the short side (in.)	-0.071	0.005	-0.368	-15.29	<.001
Overhang on the long side (in.)	-0.113	0.005	-0.598	-24.32	<.001
Adjacent overhang	-0.045	0.003	-0.359	-13.36	<.001
Box perimeter (in.)	0.001	0.0002	0.191	9.13	<.001
Board type	0.006	0.003	0.049	2.33	0.021

* $F(5, 154) = 425.727$, $p < 0.001$, adj $R^2 = 0.93$