Effect of Horizontal Offset on Vertical Compression Strength of Stacked Corrugated Fiberboard Boxes

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ABSTRACT: The purpose of this study was to evaluate the effect of horizontal offset on the compression strength of stacked box configurations. Four different boxes of varying sizes and similar board combinations, made from similar flute but different manufacturers were studied. The single box compression strength for each type of box was determined to represent as the control for this study. The compression strength of control boxes were compared to overall strength of a three-high stack and in three different offset configurations. In addition, a set of perfectly aligned boxes stacked three high were compression tested for comparison with control and mis-aligned stacked boxes. The stack configurations were offset either in the length, width or diagonally (both length and width) with an offset distance of 12.7 mm, 25.4 mm or 38.1 mm (0.5, 1, and 1.5 inches).

1.0 INTRODUCTION

THE compression strength of a corrugated fiberboard shipping container is affected by various factors including but not limited to dimensions, flute size, basis weight of linerboards/medium, exposure to temperature and humidity, creep, stacking configuration, as well as shipping and handling. Some of these climatic and physical factors can contribute towards the natural variation and degradation in the fiberboard and box compression strength or the box's ability to stack and support other filled and loaded boxes during storage and shipping. Over the past four decades the industry has developed various methods to un-

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derstand the performance of a box after it is filled and supports a load to survive the various elements of the distribution environment [1–3]. The most common method to evaluate the strength of an “empty” box and then predict it’s degradation due to each individual factor is to perform compression strength tests in the vertical orientation using a fixed rate compression tester. The information from this type of test helps package designers and engineers to predict performance and compensate for strength reducing factors that are associated with a given customer’s distribution environment.

The test methods [4] that have been widely accepted and used globally to test empty box compression strength for over forty years is ASTM D642 “Standard Test Method for Determining Compressive Resistance of Shipping Containers, Components and Unit Loads” or its International Standards Organization (ISO) equivalent ISO 12048 “Packaging-Complete, Filled Transport Packages-Compression and stacking test using a compression tester”. For the last forty years paper fiberboard boxes are tested with no contents (empty) or filled with actual product. This information is used to compare their expected performance in actual conditions after they are filled and stacked in warehouses. The test method was originally developed by the paper industry through the Technical Association of Pulp and Paper Industries (TAPPI). TAPPI standard T804 was the original standard for “Compression Testing of Fiberboard Containers”. 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 will have a significantly different performance. Bulk liquids and bulk granular products when filled in a fiberboard box will cause it to bulge and most likely reduce strength of the box, whereas semi-rigid and rigid contents will enhance overall package (combined box and contents) strength.

Box compression strength can be measured by either a floating platen or a fixed platen on a compression testing machine (ASTM D642) [4]. A research study [5] showed that there was no significant difference in box compression strength between the two methods, comparing several types of boxes. The conclusions found that there is more variation associated with the compression strength performance between identical boxes as opposed to the difference between fixed and floating platen methods [4]. However, both paper and corrugated fiberboard, and box manufacturing processes have improved considerably over the past few decades in order to reduce the natural varia-

tion in box compression strength, by increased refining and calendaring towards making mechanical properties of containerboard more uniform.

Additional studies have also shown that overall vertical compression strength of stacked boxes is lower than that of individually tested boxes [1]. Results show that in a three-high column stack of perfectly aligned boxes, strength reduction of 6–15% was observed in regular-slotted-container (RSC) style boxes, when compared to strength of a single box [1]. These effects are further magnified if the stack is misaligned [1,7]. A study performed previously investigated the reduction in box compression strength where a stack was deliberately offset by 12.7 mm, 25.4 mm or 38.1 mm (0.5, 1.0 and 1.5 inches) in the lateral and diagonally offset boxes [8]. The findings of this study show strength reductions of 59% in misaligned stacks as compared to individual box vertical compression strength [8]. Since, shipping containers are stacked on a pallet during transportation and warehousing, it is critical to minimize offsets during stacking to maintain a stable unitized load over long periods of storage.

Twede and Selke [9] have discussed the effects of humidity and creep on box performance based on earlier studies done by the Institute of Paper Chemistry. The study also cites factors for interlocking and column stacking of boxes on a pallet. The authors [9] state that column stacked aligned boxes on a pallet retain 85% of the box compression strength, whereas an interlock stack pattern that indicates an offset loading, will reduce strength of the stack by 50%.

During palletization of boxes on a pallet it is likely that misalignment among stacked layers may occur. Since, it has been established that vertical edges of a box contribute 2/3 (66.7%) of the total box compression strength [1], significant strength reductions in stacked boxes will occur if they get misaligned during stacking [7]. A study was performed to compare loss of strength in stacked boxes due to increase in relative humidity and misalignment [6]. It was found that misaligned stacks with lateral or diagonal offset showed greater reduction in compression strength than changes due to humidity [6]. Results showed that stacked boxes lost 24% of strength due to exposure to high humidity of 90%, whereas misalignment in lateral and diagonally offset stacks showed a 52% reduction. It was noted that the combined effect of both high humidity and misalignment of "tested" boxes was 64%. This study found a very interesting conclusion that combined effects of several factors (such as misalignment and humidity) do not show a cumulative effect based on the worse case of individual factors.

Table 1. Sample Box Specifications.

Box 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

2.0 MATERIALS AND METHODS

Four regular slotted fiber board boxes of varying dimensions made from same board grade with an ECT of 5.71 Kgf/cm were selected for this study (Table 1). The test samples were obtained from three different box suppliers in Michigan. These boxes were erected, hot glued, and pre-conditioned at 23°C (73°F) and 50% RH in accordance with "standard" conditions described in ASTM D4332 [10], for at least 72 hours prior to compression testing in accordance with ASTM D642 [4] (Figure 1). Thirty samples of each box type were tested for individual box compression strength using a compression tester (Lansmont Corporation, Monterey, CA). The vertical compression strength of individual

Figure 1. *Boxes pre-conditioned at standard conditions for at least 72 hours.*

Figure 2. *Test set up for single box compression strength.*

boxes for each type as seen in Table 1 was represented as the "control" (Figure 2). Data measured with three-high stacking and misalignment was compared to these "control" strength values (Figure 2).

The second phase of this study compared the box compression strength of the three-high stack, with three different types of offsets (Length, Width and Diagonal or Both Side) as shown in Figure 2. The offset amounts used were 12.7, 25.4 and 38.1 mm (0.5, 1.0 and 1.5 inches). A set of perfectly aligned boxes stacked three-high were compression tested for comparison with control and a misaligned stack. Ten replicates of compression testing were performed for each test set up, and the experimental design is shown in Table 2. All tests were performed under "standard" conditions.

Table 2. Experimental Design for Different Test Treatments.

	Number of Replicates			
Stack Offset	**12.7 mm**	**25.4 mm**	**38.1 mm**	**Perfectly Aligned**
Length Panel	10	10	10	
Width Panel	10	10	10	10
Two Adjacent Panel	10	10	10	

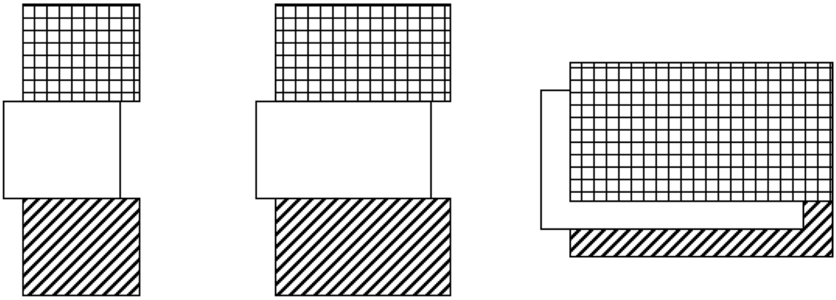

Figure 3. *Illustration of misaligned three-high stacks of boxes.*

3.0 RESULTS AND DISCUSSION

The data representing the average single box compression strength and that of a perfectly aligned three-high stack of boxes is shown in Table 3 and Table 4. The loss of strength in corrugated boxes as a function of lateral and diagonal offset was also studied (Figures 4–6). The average compression strength of three-high stack of boxes with the three different levels of misalignment was also measured and is shown in Table 5.

The single box measured compression strength was the highest for Box 2 followed by Box 1, Box 4 and Box 3 (Table 3). It was observed that the standard deviation in compression strength of identical boxes ranged between 6 to 8% for all types of boxes. A similar trend was observed for the box compression strength for perfectly aligned stack of boxes, where Box 2 was recorded to have the highest box compression strength followed by Box 1, Box 4 and Box 3. However, the standard deviation in compression strength of identically stacked boxes with no misalignment was between 4 to 10% for all types of boxes. This shows that the natural variation in single box compression strength further contributes to further variation in the stack of perfectly aligned boxes.

Table 3. Single Box Compression Strength.

Box Type	Compression Strength (lbs)	Max	Min
Box 1	227.7 ± 14.7	261.9	196.5
Box 2	280.8 ± 20.8	317.0	230.6
Box 3	138.1 ± 15.1	160.4	102.4
Box 4	191.2 ± 16.2	233.4	164.7

Table 4. Box Compression Strength of Aligned Stack.

Box Type	Compression Strength (Kg) Control
Box 1	212.9 ± 16.2
Box 2	227.5 ± 11.5
Box 3	127.0 ± 16.5
Box 4	176.4 ± 19.4

Data for this is shown Tables 3 and 4. The percent loss in compression strength of a perfectly aligned stack of boxes ranged from 6.5% to 19% (Table 6). This finding agrees with a study done earlier, where the percent reduction of compression strength of three-high stacked boxes ranged from 6–15% [3].

Similar trends were observed when comparing box compression strength of single boxes to the various misaligned stacks of boxes (Table 6). The percent loss in compression strength was observed to be the highest for misaligned stacks with an offset distance of 38.1 mm (1.5 in) followed by the 25.4 mm (1.0 in) and 12.7 mm (0.5 in) offset in the lateral directions along the length and the width (Table 7) for all four box types. However, the effect of offset direction on box compression strength was the highest when a stack of box was diagonally offset by

Figure 4. *Test setup for misaligned three-high stacks of boxes along the long edge.*

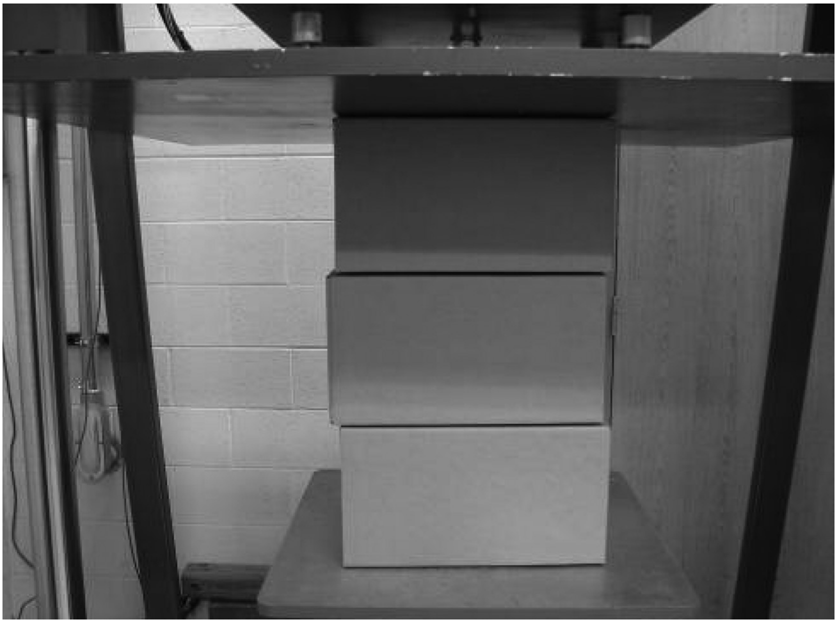

Figure 5. *Test setup for misaligned three-high stacks of boxes along the wide edge.*

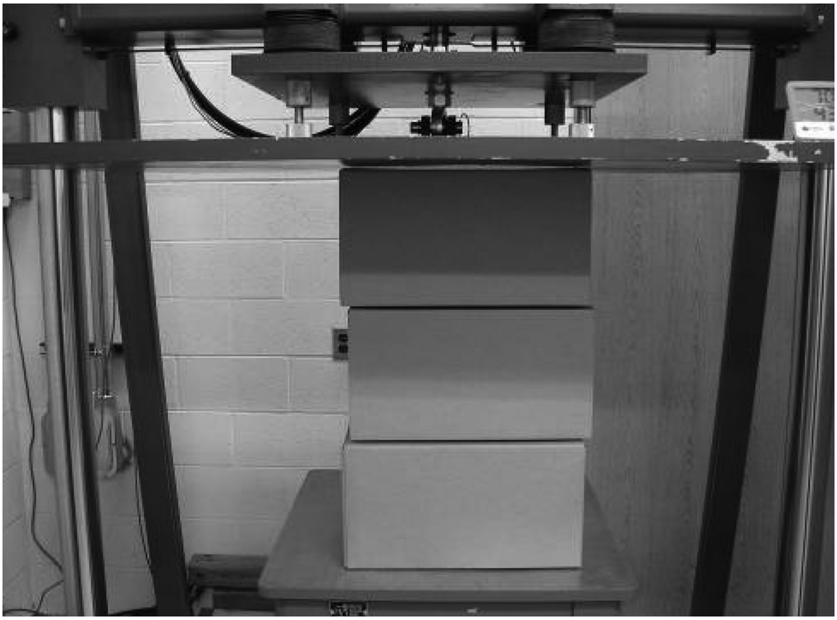

Figure 6. *Test setup for misaligned three-high stacks of boxes along the adjacent edges.*

Table 5. Box Compression Strength of Mis-aligned Stack.

	Compression Strength (Kg)		
Box Type	**Offset 12.7 mm**	**Offset 25.4 mm**	**Offset 38.1 mm**
		Length Panel	
Box 1	202.6 ± 8.3	154.7 ± 19.1	137.7 ± 35.6
Box 2	196.6 ± 11.8	168.6 ± 24.2	149.5 ± 12.1
Box 3	94.4 ± 4.7	84.3 ± 8.3	80.6 ± 6.5
Box 4	145.3 ± 8.6	113.7 ± 16.3	103.0 ± 9.7
		Width Panel	
Box 1	185.7 ± 10.9	169.6 ± 10.1	164.3 ± 9.7
Box 2	206.7 ± 16.1	193.0 ± 24.2	171.0 ± 13.8
Box 3	91.9 ± 11.1	80.6 ± 8.2	76.1 ± 6.5
Box 4	149.6 ± 14.4	130.7 ± 7.1	115.9 ± 14.2
		Adjacent Panels	
Box 1	186.2 ± 9.2	147.2 ± 5.2	109.1 ± 8.3
Box 2	188.2 ± 8.9	152.8 ± 5.3	113.3 ± 10.8
Box 3	95.7 ± 6.1	76.7 ± 5.4	54.5 ± 0.6
Box 4	136.8 ± 17.0	105.0 ± 13.2	89.1 ± 19.9

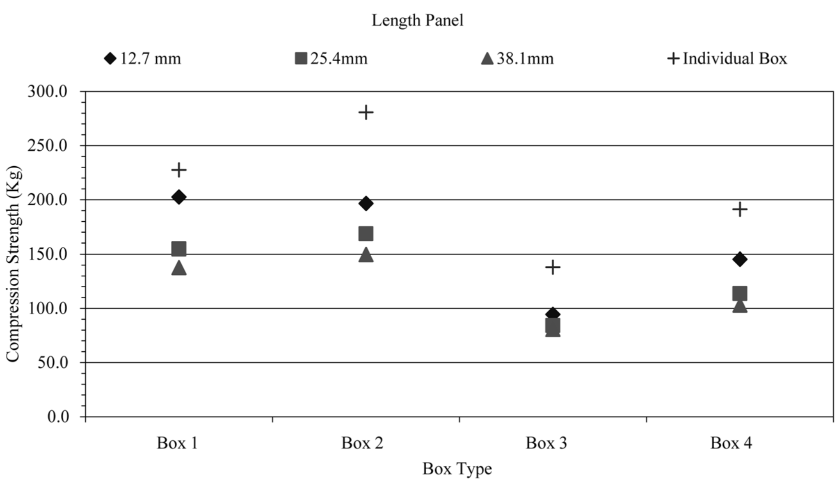

Figure 7. *Compression strength results as a function of offset on the long edge.*

Table 6. Percent Loss in Box Compression Strength of Aligned Stack.

Box Type	Percent Loss Compression Strength
Box 1	6.5%
Box 2	19.0%
Box 3	8.0%
Box 4	7.8%

38.1 mm (1.5 inches). Table 7 shows the data for boxes stacked with an offset. It is clear that even the smallest offset of 12.7 mm or 0.5 inch produces a large reduction in compression strength. This can be seen in Figures 7–12. Additional offset amounts continued to show additional reduction in strength.

4.0 CONCLUSIONS

The following conclusions were reached in this study:

1. A perfectly aligned stack of boxes shows a 6–15% reduction in compression strength when compared to the individual compression strength of a box, irrespective of the box specification.
2. Stack misalignment contributed towards the reduction of box compression strength.
3. Compression strength of stacked boxes with an offset of 12.7 in either of the 3 directions showed similar reduction in box compression strength for all sizes of tested for this study.

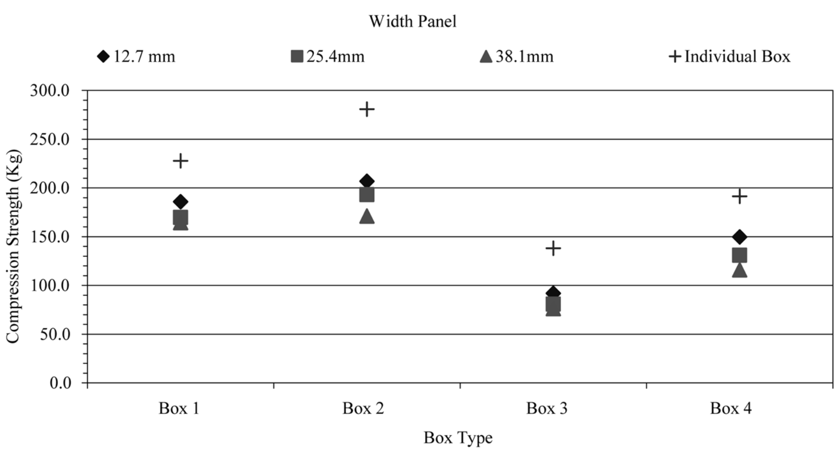

Figure 8. Compression strength results as a function of offset on the wide edge.

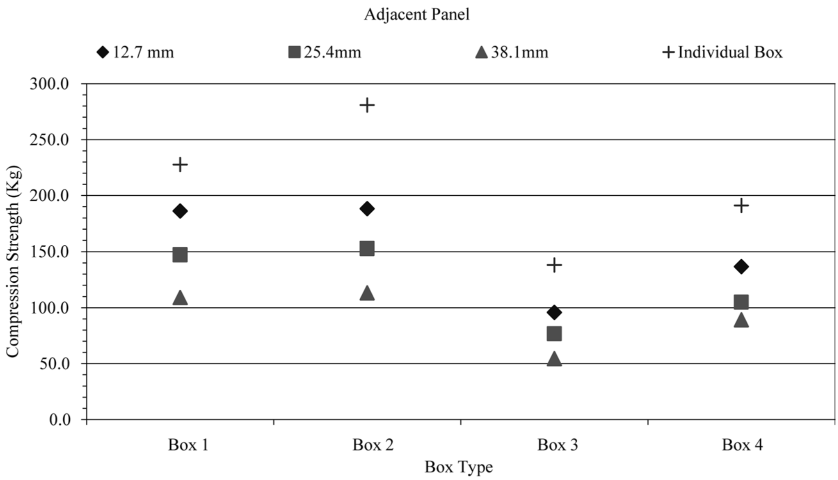

Figure 9. *Compression strength results as a function of offset on 2 adjacent edges.*

4. The reduction of box compression strength of a misaligned stack as an effect of offset distance and direction was more pronounced for 25.4 mm and 38.1 mm offset along the length, width and adjacent panels.
5. Reduction in box compression strength was the highest for stack offset along the adjacent panels followed by length and width panel.

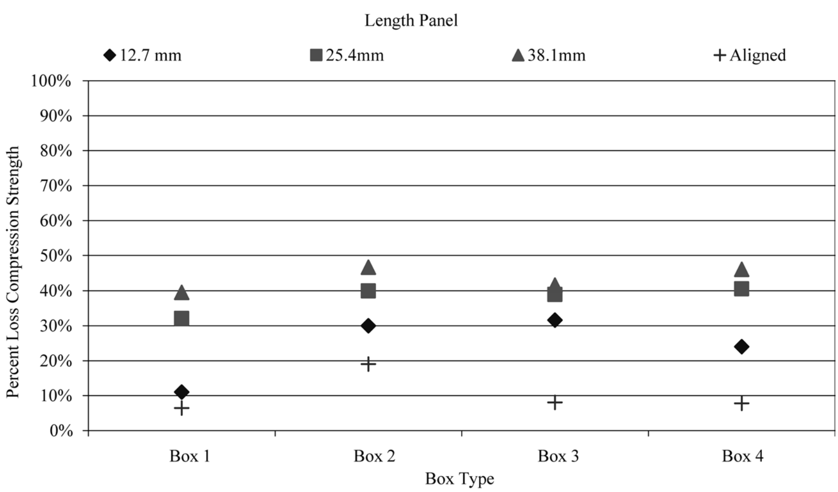

Figure 10. *Percent Loss in box compression strength of mis-aligned stack along the long edge.*

Table 7. Percent Loss in Box Compression Strength of Mis-aligned Stack of Corrugated Box.

	Percent Loss in Box Compression Strength		
Box Type	**Offset 12.7 mm**	**Offset 25.4 mm**	**Offset 38.1 mm**
		Length Panel	
Box 1	11%	32%	40%
Box 2	30%	40%	47%
Box 3	32%	39%	42%
Box 4	24%	41%	46%
		Width Panel	
Box 1	18%	26%	28%
Box 2	26%	31%	39%
Box 3	33%	42%	45%
Box 4	22%	32%	39%
		Adjacent Panels	
Box 1	18%	35%	52%
Box 2	33%	46%	60%
Box 3	31%	44%	61%
Box 4	28%	45%	53%

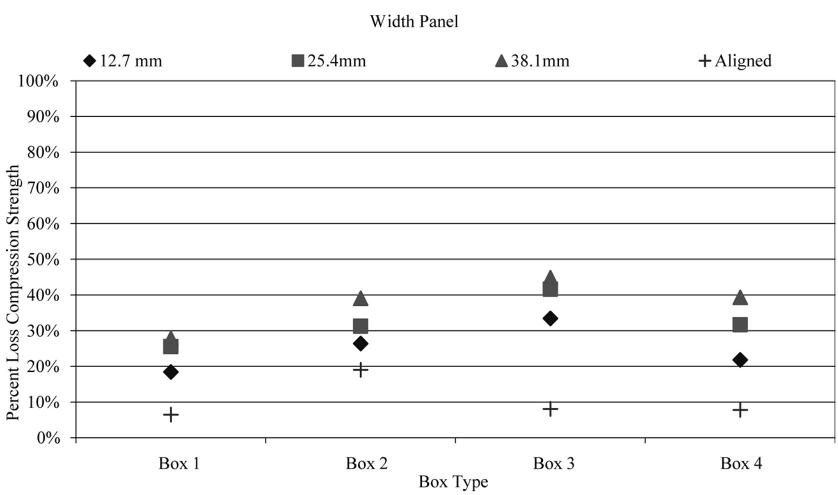

Figure 11. *Percent Loss in box compression strength of mis-aligned stack along the wide edge.*

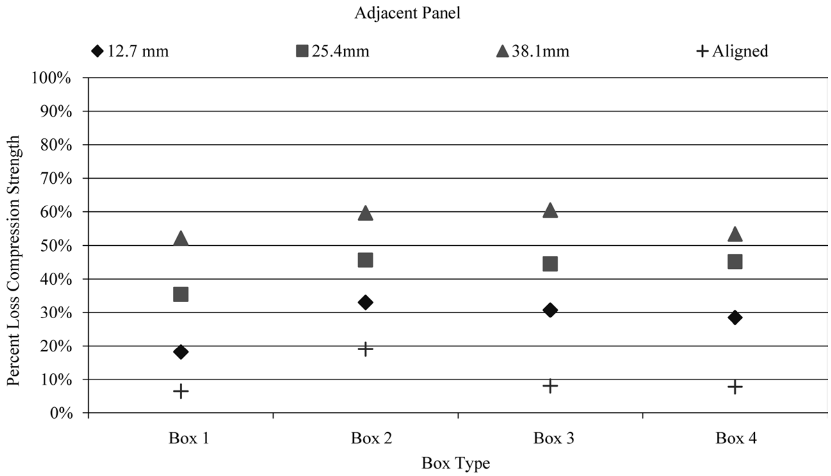

Figure 12. *Percent Loss in box compression strength of mis-aligned stack along the adjacent edges.*

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